

GRDC Grains Research Update



GOONDIWINDI

Tuesday, 1st & Wednesday, 2nd
March 2016

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GRDC Grains Research Update

Day 1 – Tuesday 1st March, 2016

Time	Topic	Speaker (s)
10:00 AM	Welcome	GRDC
10:15 AM	Characterising soils for plant available water capacity - methods, tools, accuracy & drivers of fallow efficiency	Brett Cocks & Jeremy Whish (CSIRO)
10:55 AM	Driving the new soil water app	David Freebairn
11:15 AM	Estimating water use efficiency in the northern region - Should evaporation losses be deducted?	David Freebairn
11:35 AM	Field ready frost research <ul style="list-style-type: none"> • Genetic susceptibility • Management • Predicting impact & mapping events 	Tim March (University of Adelaide)
12:00 PM	NGA - key outcomes & engagement	Richard Daniel (NGA)
12:10 PM	<i>Lunch</i>	
1:10 PM	Concurrent session 1 (<i>See concurrent sessions for details</i>)	
2:55 PM	<i>Afternoon tea</i>	
3:25 PM	Concurrent session 2 (<i>See concurrent sessions for details</i>)	
5:10 PM	Close	
6:40 PM	Pre-dinner drinks (Supported by Nufarm)	
7:30 PM	Dinner, Royal Hotel, Marshall Street	

Day 2 – Wednesday 2 March, 2016

Time	Topic	Speaker (s)
7:30 AM	Early risers - informal time with key speakers (Back room of main venue)	Nick Poole (Far Aust.), Steve Simpfendorfer (NSWDPI), Greg Platz & Lisle Snyman (DAFQ)
8:30 AM	Concurrent session 3 (<i>See concurrent sessions for details</i>)	
10:15 AM	<i>Morning tea</i>	
10:45 AM	Concurrent session 4 (<i>See concurrent sessions for details</i>)	
12:30 PM	<i>Lunch</i>	
1:30 PM	Weeds & crop stubble as pathogen hosts. A PhD presentation	Sue Thompson (USQ)
1:40 PM	Improvements in biomass partitioning & transpiration efficiency in wheat. A PhD presentation	Andrew Fletcher (UQ)

1:50 PM	Understanding & managing N loss pathways <ul style="list-style-type: none"> How big are the losses, what are the drivers The impact of N source Urease & denitrification inhibitors Local case studies 	Mike Bell (QAAFI) & Graeme Schwenke (NSW DPI)
2:25 PM	Applying N months ahead of sowing <ul style="list-style-type: none"> Mineralisation, loss & crop impact compared with at sowing applications 	Richard Daniel (NGA)
2:45 PM	Developments in microwave technology to clean up fallow weed escapes	Graham Brodie (Univ. Melb.)
3:10 PM	Close	

Location of concurrent sessions

	Main auditorium	River room	Goondiwindi Training Centre	Goondiwindi Training Centre computer lab
Day 1				
Sessions 1 & 2	Disease	Weeds & Herbicides	Nutrition & barley fungicides	On-farm research workshop with Alison Kelly (DAF Qld) (1hr, session 2 only)
Day 2				
Session 3 & 4	Cereals & varieties	Nematodes & soil health	Bits	Soil water workshop

Concurrent sessions – Day 1

Disease

Barley disease update <ul style="list-style-type: none"> Pathotype surveys of powdery mildew & net form net blotch - implications for management Barley leaf rust 	Greg Platz & Lisle Snyman (DAF Qld)
Chickpea disease update <ul style="list-style-type: none"> Canola interactions with Sclerotinia in chickpeas Phytophthora & Botrytis grey mould - management in 2016 How variable is the Ascochyta population? 	Kevin Moore (NSW DPI)
Managing wheat residue in wide & narrow row chickpeas <ul style="list-style-type: none"> Implications for crown rot 	Steven Simpfendorfer (NSW DPI)
Rust & crown-rot - what's new & what it means for management	Steven Simpfendorfer (NSW DPI)

Weeds & Herbicides

The impact of herbicides on soil biology A multi-state & multi-year study & literature review	Lukas Van Zwieten (NSW DPI)
Sowthistle - glyphosate resistance survey, resistance testing options, costs & management options	Annie Van der Meulen (DAF Qld)
Feathertop Rhodes grass management – can winter crop herbicide choice make a difference?	Richard Daniel (NGA)
The genetics of glyphosate resistance - mechanisms & levels in key northern weeds.	James Hereward (UQ)

Nutrition & barley fungicides

pH effects on P availability in alkaline soils <ul style="list-style-type: none"> • Implications for rhizosphere acidification - A PhD presentation 	Karl Andersson (UNE)
Varietal variation in northern wheat & barley responses to nutrients	Chris Guppy (UNE)
Phosphorous & potassium nutrition <ul style="list-style-type: none"> • Critical test values & P & K interactions • Tradeoff between rate, when & how it's applied? • Seasonal response patterns • Chickpeas as a 'canary crop' for K deficiency • On-farm trials, test strips & 'best bet' options 	Mike Bell (QAAFI) & David Lester (DAF Qld)
New & emerging disease management options in barley	Nick Poole (FAR)

Concurrent sessions – Day 2

Cereals & varieties

Durum agronomy & variety update <ul style="list-style-type: none"> • New varieties - performance, quality & agronomic management • Fit in early sowing windows • Crown-rot responses 	Rick Graham (NSW DPI)
Wheat varietal tolerance to heat stress in northern region varieties - scope for improvement & implications for varietal selection	Richard Trethowan (University of Sydney PBI)
High yield cereals <ul style="list-style-type: none"> • New varieties • Key determinants of yield • Getting N & P right • Time of sowing • Crown-rot & population interactions 	Rick Graham (NSW DPI) & Allan Peake (CSIRO)

Nematodes & soil health

Managing grain crops in nematode-infested fields to minimise loss/optimize profit <ul style="list-style-type: none"> • Updated crop tolerance & resistance ratings • Crop sequence • Water use in affected crops • Sowing date impacts • Weeds as hosts • Rules of thumb to estimate decline rates in nematode numbers 	Brendan Burton (NGA), Kirsty Owen (USQ) & Jeremy Whish (CSIRO)
Biological suppression of root lesion nematode & encouraging soil biology	Nikki Seymour (DAF Qld)
Soil health, biology, diseases & sustainable agriculture - links between soil properties & plant health	Graham Stirling (Biological Crop Protection)

Bits

<p>Tactical agronomy of safflower & linseed - rotations, yield, time of sowing, row spacing, plant growth & marketing</p>	<p>Kathi Hertel (NSW DPI)</p>
<p>Pushing pulse crop yield</p> <ul style="list-style-type: none"> • Time of sowing, nutrition, varieties, plant population & row spacing • Chickpea podding patterns in 2015 • Frost risk in chickpeas & stubble • PBA Nasma^b fababeans - can we keep smaller seed for sowing? • Fababean agronomy 	<p>Bec Raymond & Kerry McKenzie (DAF Qld)</p>
<p>Aphids, scarabs & new research on insect pests</p> <ul style="list-style-type: none"> • Scarabs: impacts on sorghum, tillage effects & at sowing treatments • Thresholds for Heliiothis & mirids in fababean • Aphids in canola - direct feeding damage vs viral transmission & scouting beneficials • Managing Rutherglen bug populations after canola 	<p>Melina Miles (DAF Qld)</p>

Soil water workshop

<p>Profit from better soil water decisions</p> <ul style="list-style-type: none"> • Soil water, yield, gross margins, pillar crops & rotations • Optimising soil moisture • Yield projections, WUE & benchmarks & harvest index impact • Fallow length & opportunity crop impact on gross margin • Planting time, WUE & moisture seeking capability impact on wheat margins • Risk management & resilient farming systems - diversification of crops, sowing times & inclusion of fallow • Monitoring moisture & analysing data on yield, WUE & profit 	<p>Simon Fritsch & Peter Wylie (AgriPath)</p>
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Compiled by Independent Consultants Australia Network (ICAN) Pty Ltd.
PO Box 718, Hornsby NSW 1630
Ph: (02) 9482 4930, Fx: (02) 9482 4931, E-mail: northernupdates@icanrural.com.au
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General plenary session day 1

Drivers of fallow efficiency: Effect of soil properties and rainfall patterns on evaporation and the effectiveness of stubble cover

Kirsten Verburg¹, Jeremy Whish²

CSIRO Agriculture Canberra¹ and Toowoomba²

Key words

Plant Available Water (PAW), Plant Available Water Capacity (PAWC), fallow management, stubble retention

GRDC code

CSP00170 and past projects CSA00013 and ERM00002.

Take home message

- Soil properties (bulk soil and surface conditions) affect fallow efficiency through their effects on the different water balance terms.
- Rainfall patterns affect fallow efficiency as well as the effectiveness of stubble cover to reduce evaporation losses.
- The more limited effect of stubble retention on evaporation does not take away the benefits stubble cover provides in protecting the soil surface, increasing infiltration and reducing runoff and erosion.

Plant available water at sowing and fallow efficiency

Plant available water (PAW) at sowing will depend on water left behind by a previous crop, rainfall amount during the fallow and its distribution, efficiency of water infiltration (versus runoff), evaporation, water use (transpiration) by weeds, drainage beyond the root zone and in some cases subsurface lateral flow. Fallow efficiency, defined as the proportion of rain falling during the fallow period that becomes PAW, is similarly affected by these water balance terms (Figure 1).

Fallow management like stubble retention or weed control can change the magnitude of some of these water balance terms. In this paper we discuss how soil properties and rainfall patterns affect evaporation and the effectiveness of stubble cover.

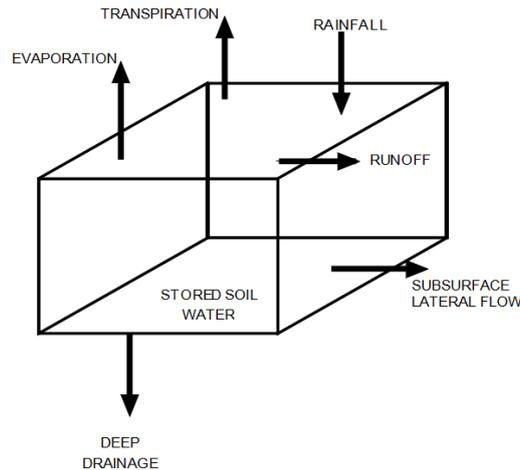


Figure 1. The relative magnitude of the different water balance terms determines the balance of inputs and losses and hence the fallow efficiency.

Impact of soil properties on evaporation

Just like soil properties affect the Plant Available Water Capacity (PAWC; see Verburg et al. paper in these proceedings), they also influence the magnitude of the different fallow water balance terms and hence PAW and fallow efficiency. The smaller particle size of clay soils allows them to hold larger quantities of water than sandy soils (i.e. lower drainage losses), but also causes the pore space (space between particles) to be finer. This reduces the water infiltration rate and can increase runoff losses, particularly in high intensity rainfall events and following prolonged rainfall. Soil surface conditions can, however, dramatically change this picture: open cracks in shrink-swell soils will aid infiltration, whereas surface sealing will increase runoff.

The higher PAWC of clay soils also means that water from small events is stored close to the soil surface where it will often be lost to evaporation if no follow up rain occurs. In sandy soils the water will infiltrate deeper into the profile.

Evaporation can dry the soil to below the crop lower limit in the surface layer. While this is a slow process in clay soils, the amount of rainfall needed to replenish this unavailable 'bucket' following a prolonged dry period will be larger in a clay soil than in a sandy soil. This is illustrated in Figure 2 where a sandy clay loam soil can hold 11.9 mm of water between the air-dry value and drained upper limit, but with only 8.7 mm available to the plant and an unavailable water capacity (UWC) of 3.2 mm. If evaporation had dried the soil to air dry and we had a 10mm rainfall event only 6.8 mm would be available for plant growth.

In contrast the heavy clay soil in Figure 2 holds 42mm between air dry and drained upper limit of which 20 mm is available for plant growth. In the same scenario as before, if the soil was dry and we had a 10 mm rainfall event there would be no water available for plant growth, unless it went down a deep crack into deeper and less dry soil. Over 22mm of rain needs to fall to fill the unavailable bucket in the surface of this soil. Fortunately, the fine structure of the heavy clay soil also means the unavailable bucket will take a long time to dry out, so that on many occasions only the upper layers of the soil will need to be refilled.

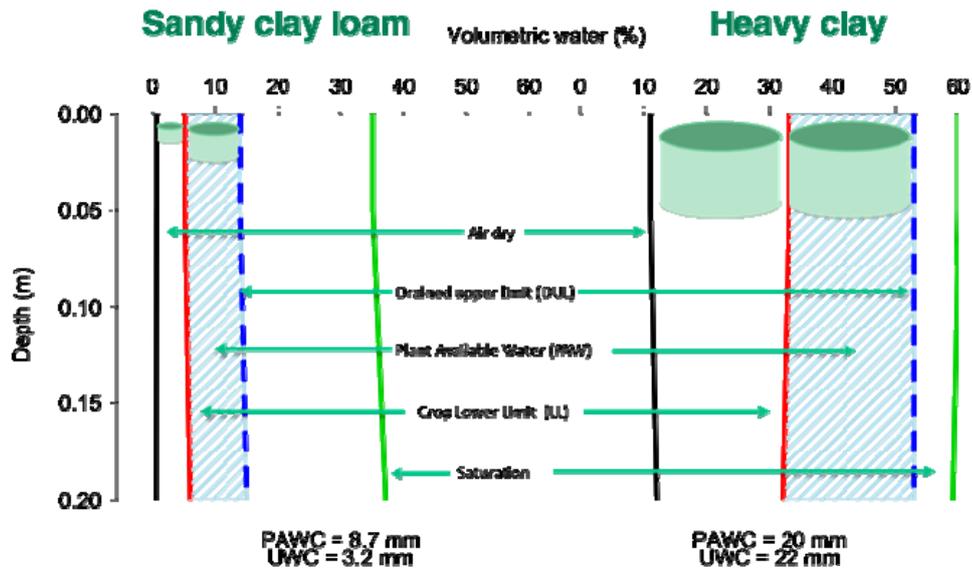


Figure 2. Conceptual diagram of the difference in unavailable water bucket size (UWC) in the surface 20 cm of a sandy clay loam and a heavy clay soil

Impact of rainfall pattern

The interaction between depth of infiltration and susceptibility to evaporation loss also plays a role in determining the effectiveness with which rainfall is turned into PAW for the subsequent crop. Unless runoff is an issue, large rainfall events will infiltrate deeper than small events, allowing some of the water to be pushed below the evaporation zone and contribute to PAW at sowing. Single, isolated rainfall events have, however, typically a lower efficiency than more frequent events. When two or more rainfall events occur closely together, the resulting soil water 'pulses' can build on each other (Figure 3). The amount of water needed to refill the unavailable bucket in the surface layer (following evaporation) is reduced, thereby allowing the water to move deeper into the profile.

The amount of overlap between soil water 'pulses' is affected by a balance between pulse frequency and pulse duration. Rainfall frequency is the driver behind pulse frequency, whereas pulse duration is affected by the amount of infiltrated rainfall, evaporative demand, stubble cover and soil type.

The above illustrates why the same amount of rainfall can result in different fallow efficiencies. Surface conditions can, however, complicate the picture. Surface sealing following multiple or prolonged rainfall events can reduce the infiltration rate and increase runoff. Conversely, a single large storm on a dry cracking clay soil can infiltrate deeper via the open cracks.

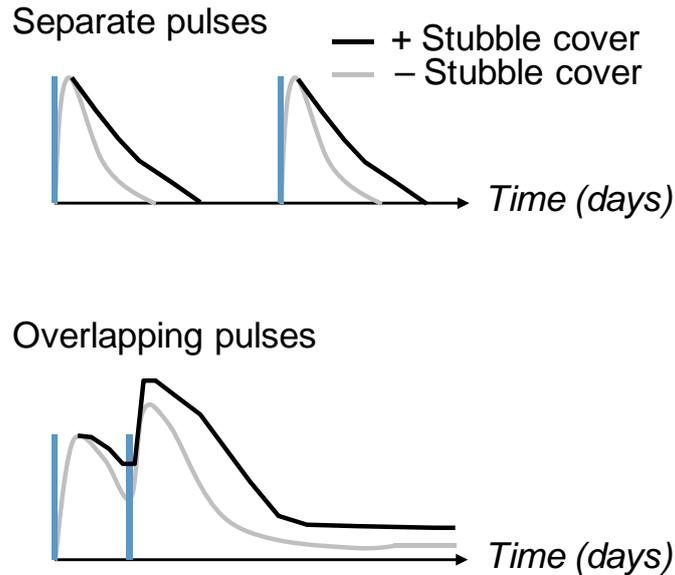


Figure 3. Rainfall events (vertical blue bars) cause pulses of soil water that last for different amounts of time in the presence (black lines) or absence (grey lines) of stubble. When pulses overlap, more water infiltrates beyond the evaporation zone in the presence of stubble cover and this will increase fallow efficiency. (Adapted from Verburg et al. 2010)

Impact of rainfall pattern on the effectiveness of stubble to reduce evaporation

While rainfall pattern effects are beyond our control, fallow efficiency can be maximised by reducing the losses. Several trials in recent years have demonstrated that weed control dramatically reduces transpiration losses (e.g. Hunt et al. 2011; Routley 2010) and that stubble retention increases infiltration and hence reduces runoff losses (Whish et al. 2009; Hunt et al. 2011). The effect of stubble and stubble management (e.g. standing vs. flattened stubble) on reducing evaporation losses has, however, often disappointed people with many trials returning no significant treatment effects (e.g. Scott et al. 2010; Hunt et al. 2011; Hunt 2013). The exception is when large amounts of stubble are concentrated on a smaller area to create high loads (Hunt et al. 2011).

The observed limited effectiveness of stubble cover to reduce evaporation losses can be explained using the same concept of soil water pulses. The high evaporative demand experienced during summer in Australia limits the duration of the soil water pulses. In the case of sparse rainfall events this allows the system with stubble cover to 'catch up', despite the initial reduction in evaporation. Freebairn et al. (1987) showed this experimentally in soil evaporation studies using shallow weighing lysimeters. Stubble cover slowed evaporation for around 3 weeks following rainfall, but there was no longer term benefit to soil moisture levels. If the next rainfall event occurs prior to the system catching up, soil water will move deeper in the system with stubble cover and may store (more) water beyond the nominal evaporation zone. A higher level of stubble cover (as in experiments by Northern Grower Alliance, 2015) will prolong the duration of the soil water pulse, increasing the chance of events overlapping and of causing a lasting increase in PAW. In the event of small, isolated rainfall events, high loads of stubble may be detrimental to overall PAW with the water captured in the stubble layer and prone to evaporation.

As shown in Figure 3, evaporative demand plays a role too. A lower evaporative demand will lengthen the duration of soil water pulses and hence increase the chance of pulses to overlap. Indeed simulations as well as data from lysimeter experiments near Wagga Wagga by Verburg et al. (2012) showed that stubble cover later in autumn and early winter (when evaporative demand was lower and rainfall frequency higher) did cause a significant reduction in evaporation (10-15 mm over

an 8-week period following sowing into a stubble load of 4 t/ha while differences over the preceding 4 months during summer were only 3-4 mm).

Final remarks

Understanding the drivers of fallow efficiency and awareness of the particular conditions experienced during the fallow will assist in explaining observed PAWs and predict which fallow seasons may have higher or lower fallow efficiency. When using PAW to inform management decisions, it is, however, recommended to confirm actual PAW levels through measurement (soil core, push probe).

While this paper specifically discussed the evaporation loss term of the water balance, it should be noted that the more limited effect of stubble retention on evaporation does not take away the benefits stubble cover provides in protecting the soil surface, increasing infiltration and reducing runoff and erosion.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. The concepts and findings presented in this paper were developed as part of GRDC projects CSP00170, CSP00111, CSA00013 and ERM00002.

References

- Freebairn, D.M., Hancock, N.H. and Lott, S.C. (1987), Soil evaporation studies using shallow weighing lysimeters: Techniques and preliminary results, *Trans. Mech. Engn., Inst. Engn. Australia*, Vol. ME12. pp 67-72.
- Hunt J et al. (2011) Summer fallow management. GRDC Update paper. <https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/02/Summer-fallow-management>
- Hunt J (2013) Control summer weeds to reap yield benefits. *Ground Cover Supplement-Water Use Efficiency*, edited by J Paterson. Grains Research and Development Corporation, Canberra. March-April 2013. ISBN 1039-6217.
- Northern Grower Alliance (2015) Stubble impact on fallow water efficiency in western zones 2014/15. Project report – Results in a nutshell. <http://www.nga.org.au/results-and-publications/download/356/project-reports-general/results-in-a-nutshell/stubble-impact-on-fallow-water-efficiency-2014-15.pdf>
- Routley R (2010) Water use efficiency – Optimizing farming systems performance and balancing fallow length and sowing decisions. GRDC Update paper. <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/water-use-efficiency-optimizing-farming-systems-performance-and-balancing-fallow-length-and-sowing-decisions>
- Scott BJ, Eberbach PL, Evans J and Wade LJ (2010) Stubble Retention in Cropping Systems in Southern Australia: Benefits and Challenges. *EH Graham Centre Monograph Series Monograph No. 1* (<http://www.csu.edu.au/research/grahamcentre/research/publications/stubble-retention-SA.htm>)
- Verburg K, Bond WJ, Hunt JR (2010) Variable soil water accumulation under fallow management: Explanation using a pulse paradigm. In "Food Security from Sustainable Agriculture" Edited by H. Dove and R. A. Culvenor *Proceedings of 15th Agronomy Conference 2010, 15-18 November 2010, Lincoln, New Zealand.*
- Verburg K, Bond WJ, Hunt JR (2012). Fallow management in dryland agriculture: Explaining soil water accumulation using a pulse paradigm. *Field Crops Research* 130, 68-79.

Whish, J.P.M., Price, L., Castor, P.A., 2009. Do spring cover crops rob water and so reduce wheat yields in the northern grain zone of eastern Australia? *Crop Pasture Science* 60, 517–525.

Contact details

Kirsten Verburg
CSIRO Agriculture
Ph: (02) 6246 5954
Email: kirsten.verburg@csiro.au

Jeremy Whish
CSIRO Agriculture
Ph: (07) 4688 1419
Email: Jeremy.whish@csiro.au

Methods and tools to characterise soils for plant available water capacity

Kirsten Verburg¹, Brett Cocks², Tony Webster³, Jeremy Whish²

CSIRO Agriculture Canberra¹, Toowoomba², and Cairns³

Key words

Soil characterisation, Plant Available Water Capacity (PAWC), Plant Available Water (PAW), APSoil, soil-landscape, fallow management, APSIM.

GRDC code

CSP00170

Take home messages

- Information regarding the plant available water (PAW) at a point in time, particularly at planting, can be useful in a range of crop management decisions. Estimating PAW, whether through use of a soil water monitoring device or a push probe, requires knowledge of the plant available water capacity (PAWC) and/or the Crop Lower Limit (CLL).
- A wide variety of soils in the northern region have been characterised for PAWC and the characterisations are publicly available in the APSoil database, which can be viewed in Google Earth and in the 'SoilMapp' application for iPad.
- The field-based method for characterising PAWC has been tried and tested across Australia, but users need to be mindful of common pitfalls that can cause characterisation errors.
- Knowledge of physical and chemical soil properties like texture or particle size distribution and (sub) soil constraints helps interpret the size and shape of the PAWC profiles of different soils. It can also assist in choosing a similar soil from the APSoil database.
- Extrapolating from the point-based dataset to predict PAWC at other locations of interest is a challenge that needs further research. Preliminary analyses drawing on soil landscape mapping (NSW) and land resource area (LRA) mapping (Queensland) suggest that an understanding of position in the landscape and the story of its development may assist with extrapolation. This is because in many landscapes the soil properties determining PAWC are tightly linked to a soil's development and position in the landscape and these same aspects underpin soil and land resource surveys.
- While the concept of using soil-landscape information to inform land management is not new (e.g. Queensland land management manuals draw on the same concept), the availability of these maps on-line makes them more accessible and assists with visualising a location's position in the landscape. Combining these maps with the geo-referenced APSoil PAWC characterisations will increase the value that both resources can provide to farmers and advisors.
- Uncertainty of PAWC estimates translates into uncertainty in PAW. The extent to which this affects potential decision making depends on the question asked, but also needs to be viewed in terms of the spatial variability in PAW and the accuracy of the method to convert this water into a yield forecast.

Plant available water and crop management decisions

A key determinant of potential yield in dryland agriculture is the amount of water available to the crop, either from rainfall or stored soil water. In the northern region the contribution of stored soil water to crop productivity for both winter and summer cropping has long been recognized. The

amount of stored soil water influences decisions to crop or wait (for the next opportunity or long fallow), to sow earlier or later (and associated variety choice) and the input level of resources such as nitrogen fertiliser.

The amount of stored soil water available to a crop - Plant Available Water (PAW) – is affected by pre-season and in-season rainfall, infiltration, evaporation and transpiration. It also strongly depends on a soil's Plant Available Water Capacity (PAWC), which is the total amount of water a soil can store and release to different crops. The PAWC, or 'bucket size', depends on the soil's physical and chemical characteristics as well as the crop being grown.

Over the past 20 years, CSIRO in collaboration with state agencies, catchment management organisations, consultants and farmers has characterised more than 1000 sites around Australia for PAWC. The data are publicly available in the APSoil database, including via a Google Earth file and in the 'SoilMapp' application for iPad (see Resources section).

A number of farmers and advisers, especially in the southern Australia, are using the PAWC data in conjunction with Yield Prophet® to assist with crop management decisions. Yield Prophet® is a tool that interprets the predictions of the APSIM cropping systems model. It uses the information on PAWC along with information on pre-season soil moisture and mineral nitrogen, agronomic inputs and local climate data to forecast, at any time during the growing season, the possible yield outcomes. Yield Prophet® first simulates soil water and nitrogen dynamics as well as crop growth with the weather conditions experienced to date and then uses long term historical weather record to simulate what would have happened from this date onwards in each year of the climate record. The resulting range of expected yield outcomes can be compared with the expected outcomes of alternative varieties, time of sowing, topdressing, etc. to inform management decisions.

Others use the PAWC data more informally in conjunction with assessments of soil water (soil core, soil water monitoring device or depth of wet soil with a push probe) to estimate the amount of plant available water. Local rules of thumb are then used to inform the management decisions.

The APSoil database provides geo-referenced data (i.e. located on a map), but the PAWC characterisations are for points in the landscape. To use this information one needs to find a similar soil. This is not a straight forward process and subject of ongoing research, but a number of data and information sources are available that can assist. If suitable PAWC data are not found, local measurement of PAWC is required. This will often also provide a more accurate estimate although spatial variability may still be an issue.

This paper describes the measurement of PAWC, including practical tips and pitfalls, and outlines where to find existing information on PAWC. It discusses the principles behind extrapolation from known soil profiles and illustrates this with examples of PAWC data for local soils.

Plant Available Water Capacity (PAWC)

To characterise a soil's PAWC, or 'bucket size', we need to determine (Figure 1a):

- drained upper limit (DUL) or field capacity – the amount of water a soil can hold against gravity;
- crop lower limit (CLL) – the amount of water remaining after a particular crop has extracted all the water available to it from the soil; and
- bulk density (BD) – the density of the soil, which is required to convert measurements of gravimetric water content to volumetric water content

In addition, soil chemical data are obtained to provide an indication whether subsoil constraints (e.g. salinity, sodicity, boron and aluminium) may affect a soil's ability to store water, or the plant's ability to extract water from the soil.

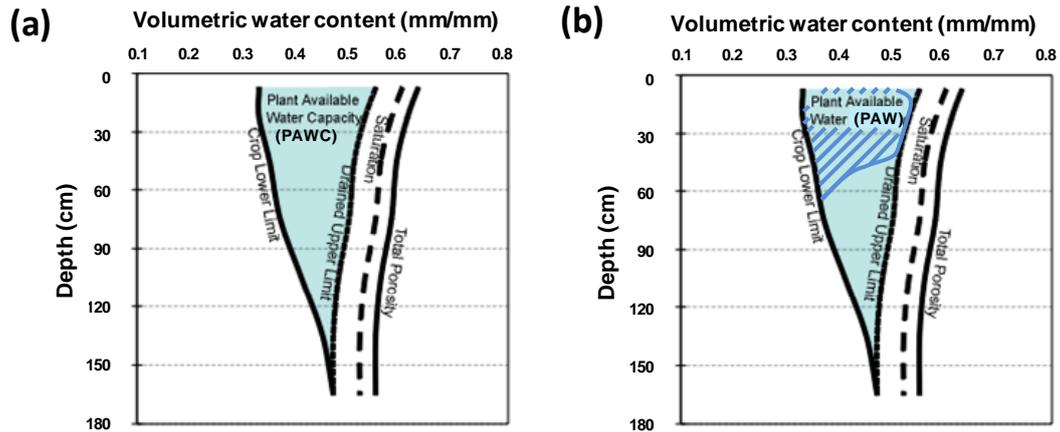


Figure 1. (a) The Plant Available Water Capacity (PAWC) is the total amount of water that each soil type can store and release to different crops and is defined by its Drained Upper Limit (DUL) and its crop specific crop lower limit (CLL); (b) Plant Available Water (PAW) represents the volume of water stored within the soil available to the plant at a point in time. It is defined by the difference between the current volumetric soil water content (blue line) and the CLL.

Plant Available Water (PAW)

Plant available water is the difference between the CLL and the volumetric soil water content (mm water / mm of soil) (Figure 1b). The latter can be assessed by soil coring (gravimetric moisture which is converted into a volumetric water content using the bulk density of the soil) or the use of soil water monitoring devices (requiring calibration in order to quantitatively report soil water content).

An approximate estimate of PAW can be obtained from knowledge of the PAWC (mm of available water/cm of soil depth down the profile) and the depth of wet soil (push probe or based on a feel of wet and dry limits using an uncalibrated soil water monitoring device).

Knowledge of PAW can inform management decisions and many in the northern region have, formally or informally, adopted this. Several papers at recent GRDC Updates have illustrated the impact of PAW at sowing on crop yield in the context of management decisions (see e.g. Routley 2010, Whish 2014, Dalgliesh 2014 and Fritsch and Wylie 2015).

Field Measurement of PAWC

Field measurement of DUL, CLL and BD are described in detail in the GRDC PAWC Booklet 'Estimating plant available water capacity' (see Resources section). Briefly, to determine the DUL an area of approximately 4 m x 4m is slowly wet up using drip tubing that has been laid out in spiral (see Figure 2). The area is covered with plastic to prevent evaporation and after the slow wetting up it is allowed to drain (see GRDC PAWC booklet for indicative rates of wetting up and drainage times). The soil is then sampled for soil moisture and bulk density.

The CLL is measured either opportunistically at the end of a very dry season or in an area protected by a rainout shelter between anthesis/flowering and time of sampling (Figure 2). This method assumes the crop will have explored all available soil water to the maximum extent and it accounts for any subsoil constraints that affect the plant's ability to extract water from the soil.



Figure 2. Wetting up for DUL determination and rainout shelter used for CLL determination

Pitfalls and common mischaracterization issues

While the concept of PAWC is simple and the measurement methods for DUL and CLL were developed to be straightforward and not require any sophisticated equipment, it is important to keep an eye out for possible sampling errors. The list below summarises some of the key pitfalls and common mischaracterization issues that we have come across in our collective experience of PAWC characterisations across Australia.

To allow interpretation and use of the data by others, PAWC characterisations should be accompanied by as much extra information as possible, including descriptions of the landscape position, surface condition (e.g. cracking, waterlogging), colour, texture (ideally with a full particle size analysis), Australian soil classification and any local classification soil name.

DUL

- Weeds are often seen growing on the side of the plastic cover. It is important that these are strictly controlled throughout the wetting up process until sampling.
- In sandy-textured soils the concentric rings of dripper line must be laid sufficiently close to each other to ensure consistent wetting across the whole area.
- Allowing insufficient time for drainage may lead to overestimation of DUL, especially at depth. Heavier soils can take 1-2 months to drain.
- Insufficient water application or application at too high a rate leads to underestimation of DUL at depth. This is particularly an issue with heavy clay soils, dispersive sodic soils and strong duplex (texture contrast) soils where water may move sideways. Both the GRDC *PAWC booklet* and the *Soil Matters* book provide indicative rates and amounts for different soils. The wetting and drainage processes may be monitored (e.g. using NMM or a moisture probe), but this is not often done due to cost constraints (time, money).
- Bulk density sampling, which is often done in conjunction with DUL sampling, requires a relatively high level of precision as any error in bulk density values will propagate when used to convert gravimetric water contents (including DUL, CLL and PAW) into mm of water. The procedure is described and illustrated in detail in the GRDC *PAWC booklet*.
- Snakes like to hide under the plastic, so take care when wetting and sampling the plot.

CLL

- The CLL method as described above relies on crop roots exploring the soil to the fullest extent. If the crop had insufficient moisture to establish its root system prior to anthesis, the CLL may not reflect maximum soil water extraction. Roots will not grow through a dry layer even if there is moisture underneath. It is, therefore, important to perform CLL

measurement in paddocks with a well established and healthy crop. Wetting up of the CLL site prior to the growing season may help, but requires close attention to weeds and to supplying the right amount of nitrogen fertiliser.

- In wetter climates and years with rainfall in the weeks just prior to the erection of rainout shelters at anthesis may refill the PAWC 'bucket'. If the PAWC is large, this may prevent the crop from using all soil water and result in an overestimate of CLL (too wet). Ideally CLL is measured over multiple seasons, but this is rarely done in practice. Calibrated moisture probes can be an effective tool to assess a crop's ability to extract moisture over a range of different seasons.
- The CLL measured for one crop type may not apply to a different crop type, especially where growing season length or susceptibility to subsoil constraints differs. It is possible that long-season varieties may extract water from a greater depth than short season varieties because of more extensive root development, and hence result in different CLL.
- If sampling is not deep enough to capture the full root zone, PAWC will be underestimated. In this case the CLL and DUL do not reach the same value at the bottom of the profile.
- If there is insufficient wetting of the profile prior or during the growing season, the measured CLL may reflect the CLL of a previous crop. If the current crop has a shallower root system this could cause the PAWC to be overestimated. Wetting up of the CLL site prior to the season may help. Taking a soil core when the rainout shelter is installed and comparing values against those determined at the time of final sampling can assist with interpretation of the data.
- Rainout shelters have blown loose or away on occasions, so it is important to secure the sides firmly into the soil.
- For duplex soils located on hills slopes > 3-5% or soils at the break of slope, subsurface lateral flow can cause soil wetting despite the presence of a well constructed rain-out shelter. Keep an eye on late season rainfall and note any unusual wetness in samples collected.
- Sampling after harvest when the soils are dry and hard, or have hard layers can be tricky. Digging a soil pit can be a better alternative than soil coring from the surface in these situations.

General

- Soil variability may mean there is more than one PAWC profile within the paddock. Variability in depth of layers, e.g. texture contrast in duplex soils, can occur over small distances. This makes mixing replicates and selecting a "representative soil" difficult.
- High soil variability can cause the DUL and CLL measurements to effectively be on different soils (even though they are usually only 2-3 m apart). It is essential to measure DUL and CLL on the same soil type. Yield or soil maps may assist in deciding where to sample.

Where to find existing information on PAWC

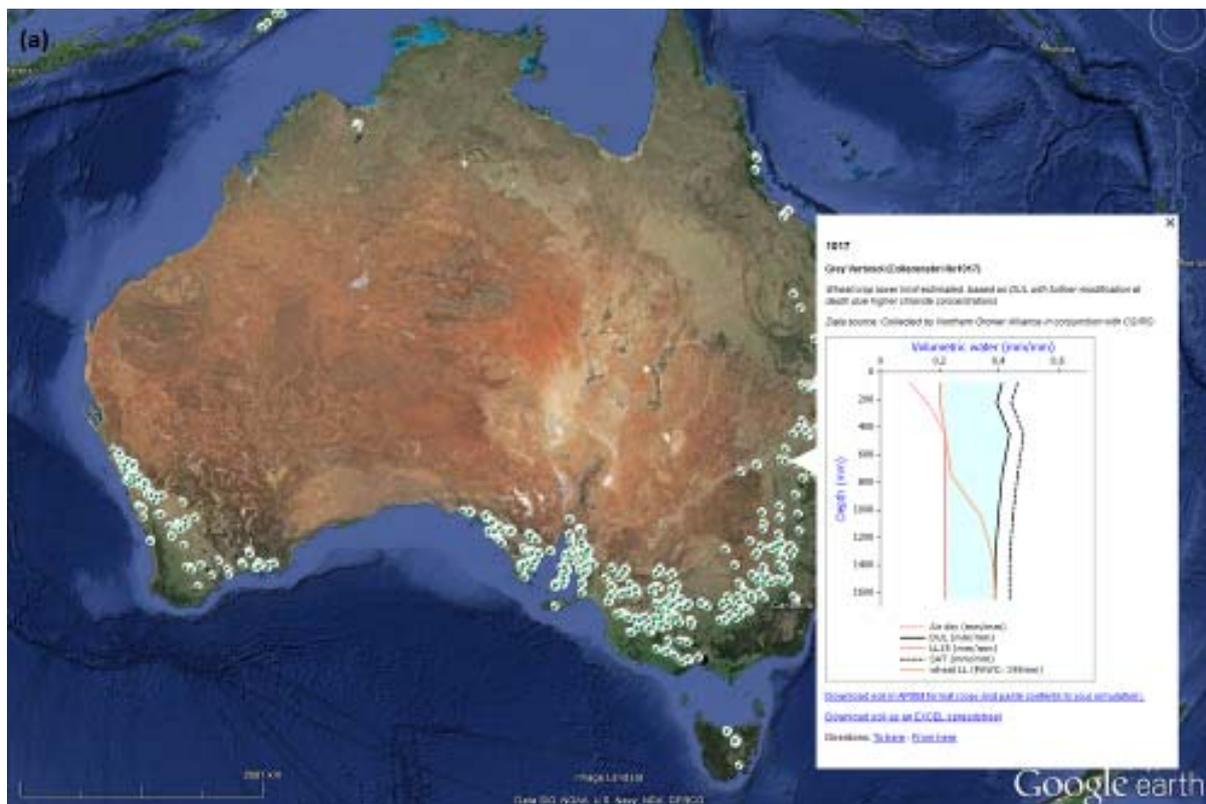
Characterisations of PAWC for more than 1000 soils across Australia have been collated in the APSoil database and are freely available to farmers, advisors and researchers. The database software and data can be downloaded from <https://www.apsim.info/Products/APSoil.aspx>. The characterisations can also be accessed via Google Earth (KML file from APSoil website) and in SoilMapp, an application for the iPad available from the App store. The yield forecasting tool Yield Prophet® also draws on this database.

In Google Earth the APSoil characterisation sites are marked by a shovel symbol (see Figure 3a), with information about the PAWC profile appearing in a pop-up box if one clicks on the site. The pop-up box also provides links to download the data in APSoil database or spreadsheet format.

In SoilMapp the APSoil sites are represented by green dots (see Figure 3b). Tapping on the map results in a pop-up that allows one to 'discover' nearby APSoil sites (tap green arrow) or other soil (survey) characterisations. The discovery screen then shows the PAWC characterisation as well as any other soil physical or chemical analysis data and available descriptive information.

Most of the PAWC data included in the APSoil database has been obtained through the field methodology outlined above, although for some soils estimates have been used for DUL or CLL. Some generic, estimated profiles are also available. While field measured profiles are mostly geo-referenced to the site of measurement (+/- accuracy of GPS unit), generic soils are identified with the nearest, or regional town.

The report *PROFILE descriptions – District guidelines for managing soils in north-west NSW* by Daniells et al. (2002) provides PAWC characterisations for 17 soils in the region drawing on the same methodology. In addition this report provides valuable soil descriptions for areas around Coonabarabran, Coonamble, Wyallda, Moree, Pilliga, and Walgett.



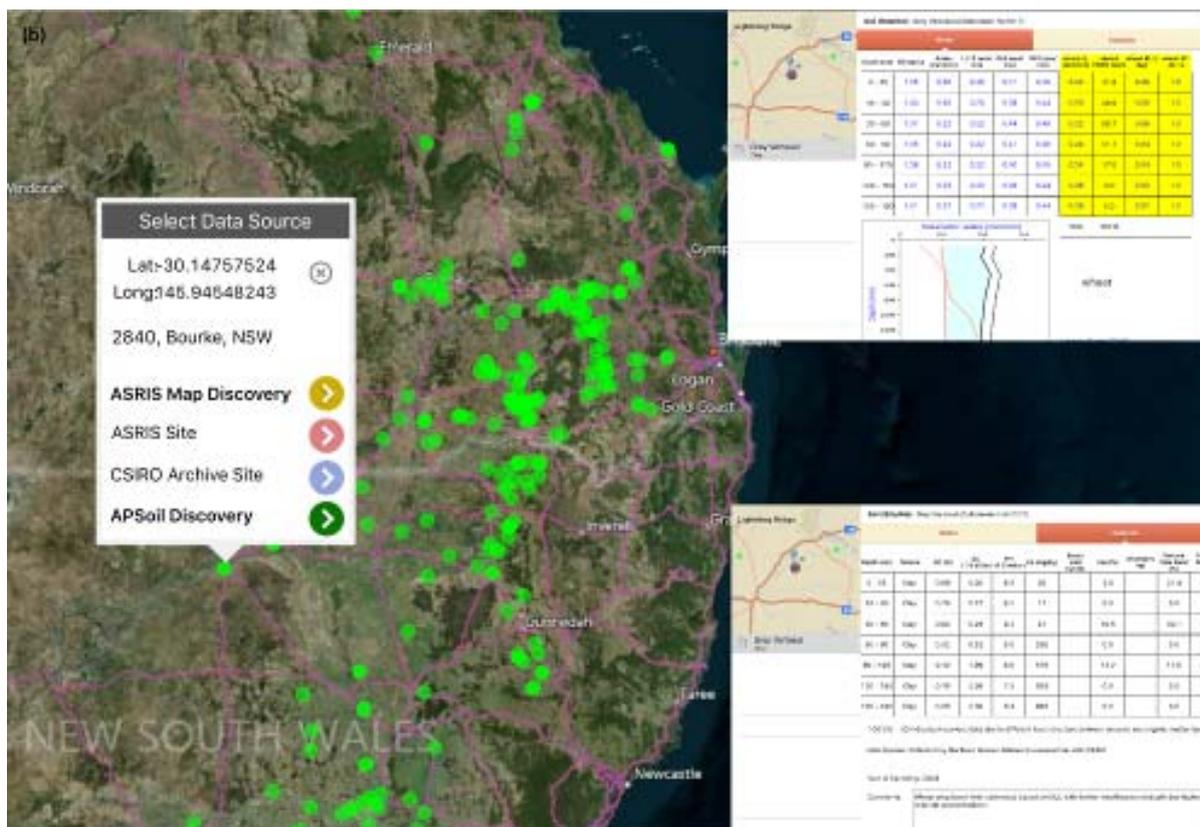


Figure 3. Access to geo-referenced soil PAWC characterisations of the APSOil database via (top) Google Earth and (bottom) SoilMapp (APSOil discovery screens as inserts)

Factors that influence PAWC

An important determinant of the PAWC is the soil's texture. The particle size distribution of sand, silt and clay determines how much water and how tightly it is held. Clay particles are small (< 2 microns in size), but collectively have a larger surface area than sand particles occupying the same volume. This is important because water is held on the surface of soil particles which results in clay soils having the ability to hold more water than a sand. Because the spaces between the soil particles tend to be smaller in clays than in sands, plant roots have more difficulty accessing the space and the more tightly held water. This affects the amount of water a soil can hold against drainage (DUL) as well as how much of the water can be extracted by the crop (CLL).

The effect of texture on PAWC can be seen by comparing some of the APSOil characterisations from the northern region, as illustrated below (Figures 4-11). The soil's structure and its chemistry and mineralogy affect PAWC as well. For example, subsoil sodicity may impede internal drainage and subsoil constraints such as salinity, sodicity, toxicity from aluminium or boron and extremely high density subsoil may limit root exploration, sometimes reducing the PAWC bucket significantly.

The CLL may differ for different crops due to differences in root density, root depth, crop demand and duration of crop growth. Some APSOil characterisations only determined the CLL for a single crop. The CLL for wheat, barley and oats are often considered the same and that of canola can be found to be similar as well, but care needs to be taken with such extrapolations as different tolerances for subsoil constraints can cause variation between crops.

A detailed explanation of the factors influencing PAWC is included in the 'Soil Matters – Monitoring soil water and nutrients in dryland farming' book, a pdf of which is available for free online (see Resources section).

Walgett – Collarenebri - Pilliga

The 'Profile Descriptions - District guidelines for managing soils in north-west NSW' report (Daniells et al. 2002) provides descriptions of the soils in the Walgett, Pilliga, Warialda, Moree, Coonamble and Coonabarabran areas, including PAWC data for select soils. This is a valuable resource that complements the existing APSoil characterisations and used the same methodology for the PAWC characterisations.

The report describes characterised soils in the Walgett area as being dominated by Grey and Brown Vertosols, which are all strongly sodic (and dispersive) below 15 or 60 cm and alkaline. Most are also saline in the deeper subsoil. PAWC for wheat is usually high and frequently in the 200-220 mm range, but some of the APSoil characterisations confirm that smaller and bigger buckets do occur depending on texture and subsoil constraints in particular (see e.g. Figure 4).

Soils included in the Profile Descriptions report for the area between Collarenebri, Mungindi and Moree are described as black and grey vertosols "which have lower PAWC than the 'true black earths' east of Moree" (PAWC 160-205 mm). The soils are strongly sodic (and dispersive) below 30 or 45 cm, which explains their reduced PAWC. Crops respond differently to subsoil constraints, resulting in different PAWC (Figure 5). Where the differences are small, they could also be due to measurement error (including due to seasonal variation).

We have included two lighter textured soils from the Profile Descriptions report from the Pilliga area to illustrate the effect that their lighter texture has on PAWC (Figure 6b,c).

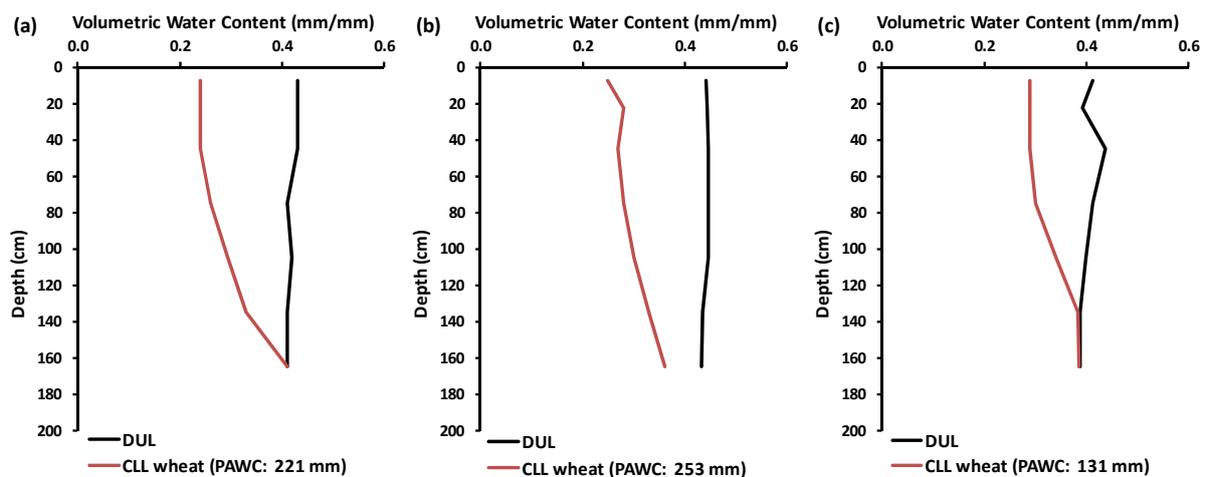


Figure 4. Select soils west of Walgett (see (a), (b) and (c) below):

(a) Grey Vertosol (APSoil 1013) (also W79 in Profile Descriptions report). Strongly sodic subsoil below 90 cm. Rotten Plain land system unit (low-lying back plains of Quaternary alluvium, periodically partially inundated by local run-off or floodwaters; depressed to 4m; land systems unit report via ESspade).

(b) Grey Vertosol (APSoil 1015) near Angledool Lake with a deeper and hence larger PAWC profile not limited by subsoil constraints.

(c) Grey Vertosol (APSoil 1016) between Walgett and Cumborah in alluvial deposits. Particle size and chemistry data not available, but shape suggests subsoil constraints limit the PAWC.

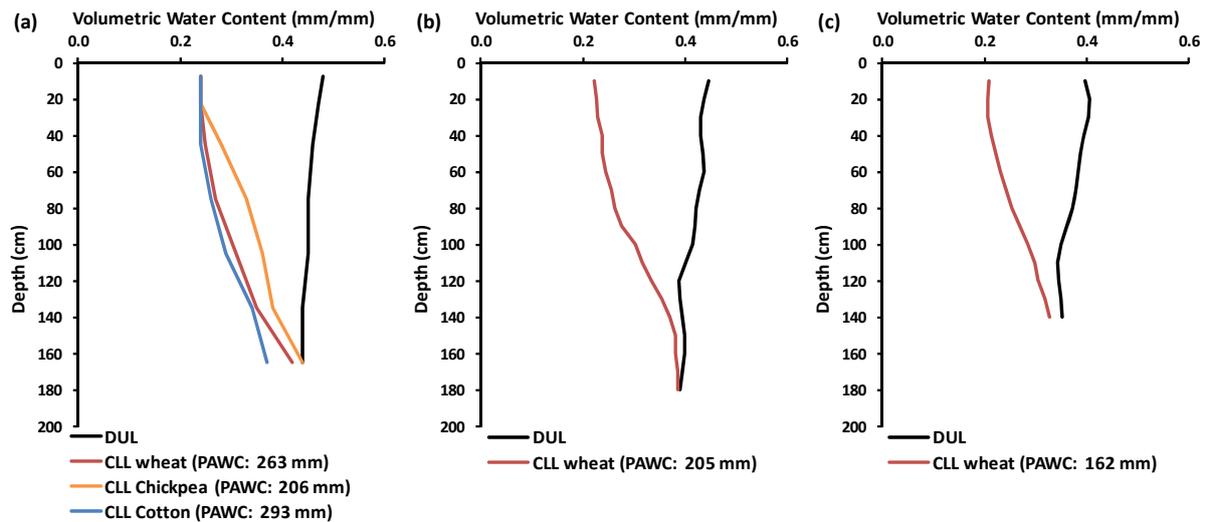


Figure 5. Select soils near Collarenbri (see (a), (b) and (c) below):

(a) Grey Vertosol (APSoil 126) near Merrywinebone in alluvial deposits. The high clay content (~60%) contributes to the high PAWC although the subsoil below 90 cm is affected by chloride and sodicity.

(b) Grey Vertosol MW51 near Collarenbri from the Profile Descriptions report. It has a strongly sodic subsoil although the report notes rooting to 175 cm.

(c) Grey Vertosol MW52 near Bullarah from the Profile Descriptions report. The report notes that dispersive subsoil may limit the penetration of water and reduce the effective rooting depth, but the PAWC of 162 mm may be an underestimate as characterisation was only down to 140 cm. (Data (b) and (c) from Profile Descriptions report)

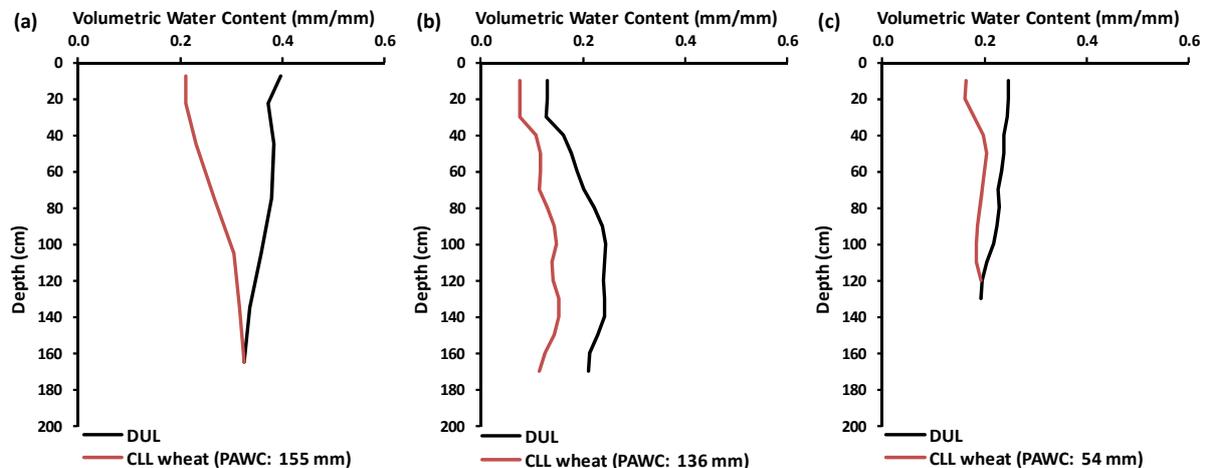


Figure 6. Select soils near Pilliga (see (a), (b) and (c) below):

(a) Grey Vertosol (APSoil 1014) just north of Pilliga and (judged by location in Google Earth) on alluvial deposits. The high clay content (58%) results in the higher PAWC compared with (b,c), but subsoil constraints (chloride and sodicity) reduce the PAWC from what it may have been based on texture alone.

(b) Red Chromosol (texture change (duplex) soil) North of Gwabegar (P56 from the Profile Descriptions report). The abrupt increase in clay % causes the shift and widening of the PAWC profile between 20 and 40 cm depth.

(c) Brown kandosol (structure less soil) north-east of Gwabegar (P57 from the Profile Descriptions report). Described in the report as being dispersive and poorly structured below 15 cm, the soil has a very low PAWC despite having a clay texture throughout.

North Star

The available APSoil PAWC characterisations in the region around North Star NSW fall roughly into two groups: lighter, texture contrast soils with smaller PAWC (Figure 7a) and vertosols characterised by larger PAWC, although dependent on texture (Figure 7c,d) and presence of subsoil constraints (Figure 7 b,c,d). The PAWC differed depending on crop type due to differing responses to soil chemical conditions and growing season length (Figure 7b,c,d), although where differences are small they could be due to measurement error, including seasonal differences. Soil depth will impact on rooting depth and may also be an important factor determining the magnitude of PAWC, especially on the non-cracking clay soils.

The Profile Descriptions report provides descriptions and PAWC information for soils a bit further south in a region labelled in the report as ‘Moree East’ around Warialda. It describes the black vertosols that are non-sodic and non-saline as having PAWC up to 265 mm. The non-cracking soils (red and brown) in this area have PAWC between 100 and 215 mm, depending on texture and soil depth.

There are a number of APSoil characterisations to the east of this around the Newell Highway, which show varying PAWC. Factors like soil texture, depth of soil and subsoil constraints would play a role in determining the PAWC profiles, much like the examples shown in Figure 7.

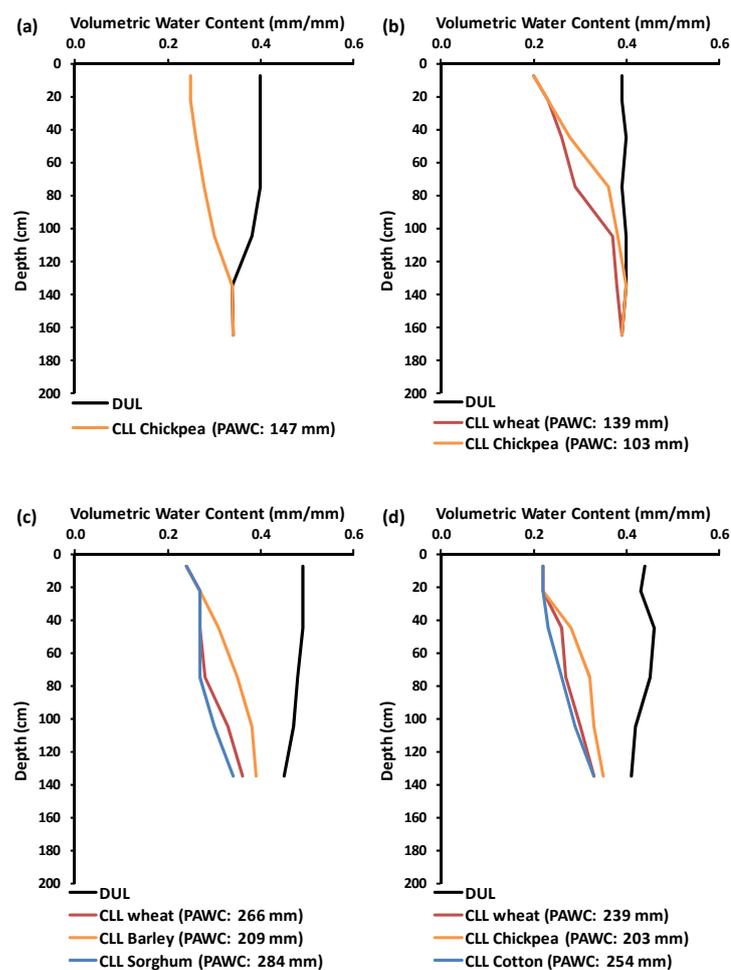


Figure 7. Soils near North Star (see (a), (b), (c) and (d) below):

(a) Red chromosol (texture contrast soil) (APSoil 240) near North Star. The PAWC in the surface soil seems a bit high for a chromosol, which would normally show a shift and widening of the PAWC bucket. It could be that the texture change was not picked up if it was too shallow. Unfortunately particle size information was not available. Depth of texture change and subsoil chemistry will affect PAWC of the texture change soils.

(b) Black Vertosol (APSoil 237) near North Star with subsoil constraints limiting the PAWC (narrowing of the PAWC profile from 60 or 80 cm. Different crops respond differently to the constraints. (c),(d) Clay content affects the PAWC of the vertosols as illustrated by

(c) a Grey Vertosol - heavy Brigalow (APsoil 101) near Tullooona) and

(d) Grey Vertosol – Light Brigalow (APSoil 102) near Tullooona. These two soils were located within the same paddock and descriptions ‘heavy’ and ‘light’ may have had local relevance describing a texture difference, but particle size analysis is not available so this could not be confirmed.

Central Darling Downs

The features and characteristics of soils in the Central Darling Downs are described in detail in the *Central Darling Downs Land Management Manual* (Harris et al. 1999). The soils are presented within Land Resource Areas (LRA), a concept which is discussed in a subsequent section. Soils are described within a ‘local’ soil classification distinguishing the various black and grey vertosols through observable features. This includes estimates of the PAWC (total mm) range. APSoil includes a lot of PAWC (profile) characterisations in this area, a selection of which is shown in Figure 8.

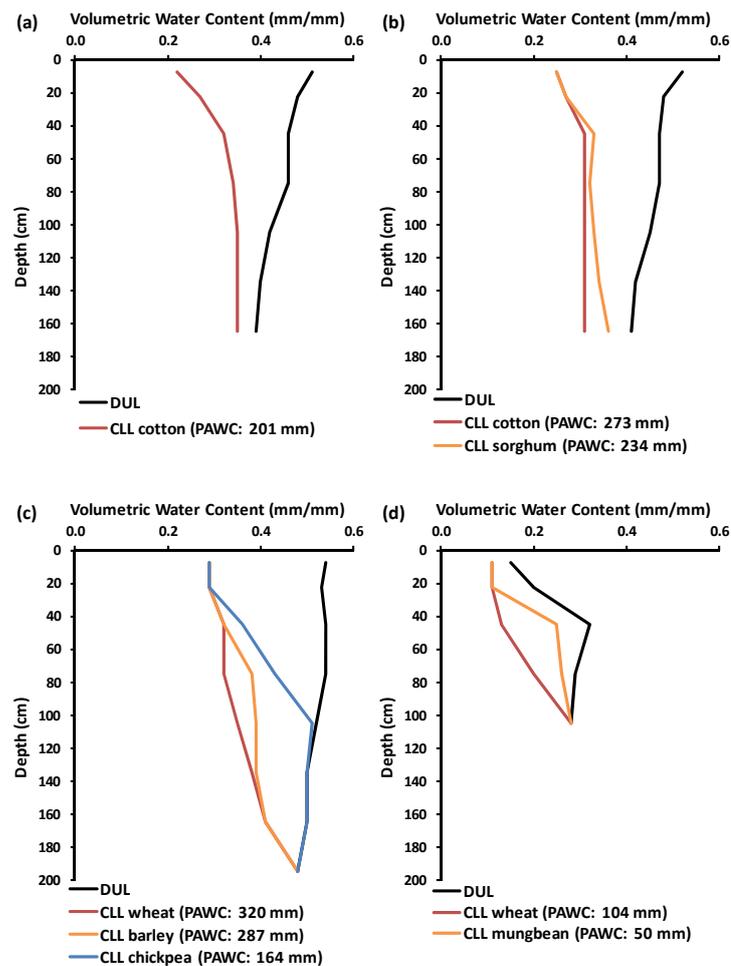


Figure 8. Select soil PAWC characterisations from the Central Darling Downs (see (a), (b), (c) and (d) below):

(a,b) Variation within the broad level recent alluvial plains (LRA unit 1a) stems from the mixed basaltic and sandstone origin of the alluvium and from particle size of the sediments in response to position within the plains. The Condamine soil is a deep, coarse structured black cracking clay adjacent to the Condamine River. It has coarse sand and gravel throughout and moderate to high subsoil salinity, both of which limit PAWC to about 150-200 mm, as seen in the example of APSoil 8 from near Yandilla, Qld (a). The Anchorfield black cracking clay has a finer structure which is reflected in its larger PAWC (typically >250 mm) as illustrated by APSoil 6 from near Brookstead (b).

(c) The Waco soil is more common in the broad level older alluvial plains of basaltic alluvium. The high clay content of these soils along with the smectite clay minerals contributed by the basaltic origin are responsible for the severe cracking and self-mulching nature of these soils and their large PAWC (APsoil site 16 near Jimbour, Qld).

(d) The undulating to steep, low hills and rises of Walloon sandstone of the Brigalow Uplands (LRA unit 6b) are characterised by grey-brown cracking clays with brown sands over brown clays. The Diamondy soil of APSoil site 88 near Jinghi, Qld is a texture contrast soil with a hardsetting surface and impermeable subsoil. The lower PAWC (50-100 mm) is in response to the limited depth, lower water holding capacity of the sandy surface layer and sodicity and salinity at depth.

Roma-Murra-Tara-Chinchilla

Two land management manuals (Macnish 1987; Maher 1996) describe the soils in this area and are, like the Central Darling Downs and a number of other areas, described within a mapping of LRA's. The APSoil characterisations in the area, unfortunately usually lack this local soil classification, which makes it a bit harder to cross-reference between resources. A few example PAWC profiles from the area (Figure 9) illustrate effects of texture, crop and subsoil constraints and the impact of landscape position.

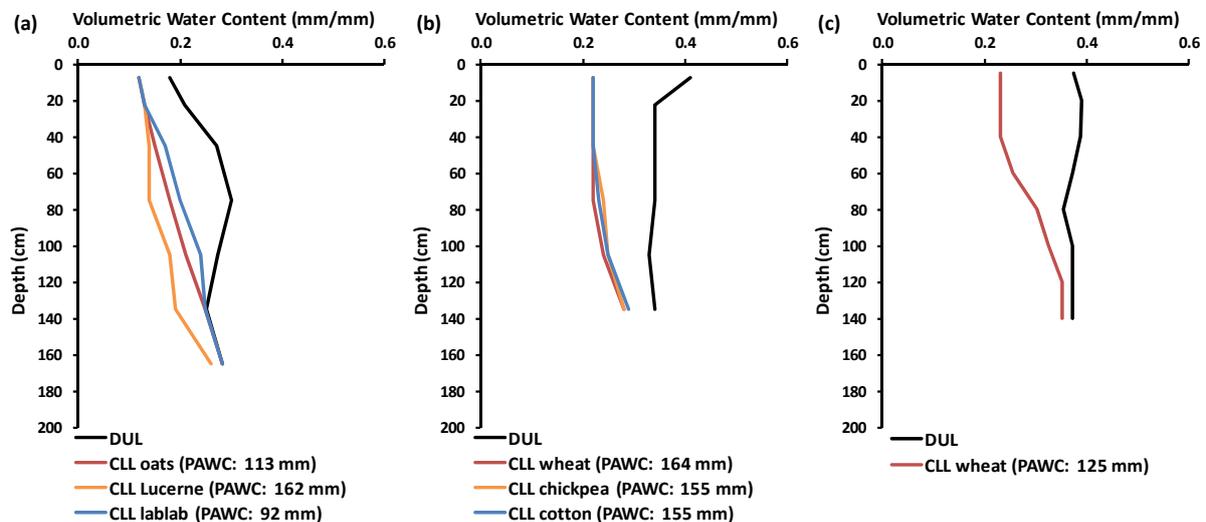


Figure 9. Select soil PAWC characterisations from the Roma-Murra-Tara-Chinchilla region (see (a), (b), and (c) below):

(a) Brown Vertosol east of Wakon (APSoil 1024). While classified as a vertosol, the description does not a sandy surface texture. This is reflected in the narrow PAWC 'bucket' near the top of the profile. The different CLL for oats, lucerne and laplap illustrate crop rooting (depth and duration) effects.

(b) Grey Vertosol (Kupunn) near Condamine (APSoil 105). Murra-Tara-Chinchilla Land Resource Area map Brigalow plains unit 4a where Kupunn is the most common soil (Field Manual, reference). The soil is described as having sodic to strongly sodic subsoils, which are medium to very highly saline. Estimated PAWC range is from low (50-100 mm) to medium (100-150 mm). This soil is on upper end of that, likely because subsoil constraints are not limiting PAWC within the depth of measurement.

Note that in this soil the crop effects on CLL appear to be much smaller, although it is not known if the characterisations were done in the same year.

(c) Grey Vertosol near Wallumbilla (APSoil 843). Subsoil constraints affect PAWC from a shallower depth and reduce the total PAWC relative to the profile in (b). The site is downslope from a Queensland key reference site, which is classified as a Brown Vertosol and has a higher PAWC (182 mm) due to subsoil constraints affecting PAWC at a deeper depth. This illustrates that within paddock variation can be significant, but may be explained through soil type and landscape position.

Central Queensland

Soils in the Central Highlands are described in the Land Management *Manual Understanding and Managing Soils in the Central Highlands* (Bourne and Tuck 1993). The area around Jambin is not covered by this LRA map, but has a separate 'Soils of the Banana Area, Central Queensland' map with a local classification that can be viewed in Google Earth via the Queensland Globe.

The greater part of the cropping landscape for the Central Qld area consists of grey and black Vertosols. Depth of soil to underlying weathering basalts affects the magnitude of the PAWC with within paddock variability noted but not always correlated with yield (Lynch and Dougall, 2007). The weathering basalts limit the depth of the PAWC characterisations, although it is unsure if crop roots can still find water between the cracks of the decaying basalt. As with similar soils of southern Queensland these soils can suffer chemical constraints in the form of salinity and sodicity at depth.

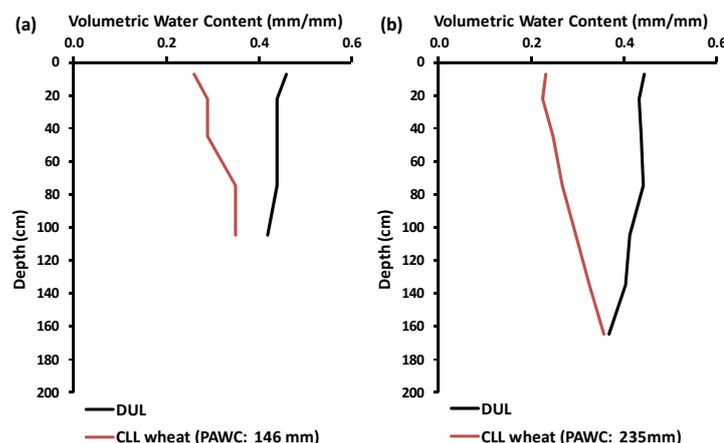


Figure 10. Select soil PAWC characterisations from Central Queensland (see (a) and (b) below):

(a) (Black Epicalcareous-Endohypersodic Vertosol lower slopes alluvial plain with >2% micro relief and 0% slope derived from basalts a similar soil to (b) but with exchangeable sodium increasing with depth, the decaying basalts are impeding measurement of PAWC at 105 to 135 cm restricting the PAWC to 146 mm.

(b) Black Epicalcareous Vertosol lower slopes alluvial plain with >2% micro relief and 0% slope derived from basalts; similar looking soil to (a) but it is physically and chemically unconstrained with a PAWC of 235 mm.

Choosing an APSoil characterisation

As shown above, the soil PAWC can vary significantly. How do we choose the most appropriate APSoil characterisation, if we are not in the position to do a local field PAWC characterisation? This is still research in progress, but some guidance can already be provided.

- The nearest APSoil may not be the most appropriate as its soil, parent material and landscape position could be quite different (cf. Figure 5)

- Compare soil with descriptions of the APSoil sites (texture, colour, soil classification, chemical analysis). More recently collected APSoil characterisations include chemical analysis and particle size. As illustrated in Figures 4-11 both particle size and subsoil constraints strongly affect the PAWC.
- Dig a hole (soil auger, soil core, backhoe trench, roadside bank or cutting); note surface features (cracking, hard setting), subsoil issues (salinity, sodicity, etc), rooting depth. This can assist with APSoil selection as well as adapting an APSoil profile to local conditions (e.g. if depth of texture change or rooting depth is different).
- A measured sowing soil water profile (convert to volumetric) needs to 'fit' between CLL and DUL and can assist with APSoil selection (Figure 1b). If the measured (volumetric) water content profile is below CLL or above DUL then the texture of the soil does not match that of the chosen APSoil.
- Opportunistic CLL (e.g. soil core following a dry finish; convert to volumetric) can be compared with CLL of APSoil characterisations.
- Check for nearby soil survey characterisations (SoilMapp, Espade, Queensland Globe (see Resources section) and local soil reports) to help describe soils.
- Draw on soil-landscape mapping (where available) to find APSoil sites in similar landscape positions (see below).
- Native vegetation is often a useful indicator of soil type too and is indeed often included in information about soil-landscape, land resource area and land systems units.

Using soil –landscape information

In many landscapes the soil properties are tightly linked to a soil's development and position in the landscape and these same aspects underpin the many soil and land resource surveys that have been carried out over the years and that are increasingly becoming available on-line. Many of these present a mapping of so-called soil-landscape units that are based on a combination of geology, landscape features like slope and relief, vegetation and groups of soils. Effectively the distribution of soil types described by these maps and their mapping units descriptions are based on a landscape model or story. These descriptions, where available, can be used to interpret and potentially extrapolate APSoil characterisations.

In parts of NSW these soil-landscape units can be accessed through the ESfade tool (see Resources section), which delineates the units and provides a description and typical soil profiles for each unit (see Figure 11). In parts of Queensland, similar land resource area (LRA) mappings are used as part of land management manuals (see Figure 12). Where this information is available, it may be possible to use it to find an APSoil site in a similar landscape position as a first approximation of PAWC.

The concept of using soil-landscape information to classify and inform soil properties is not new. The Queensland land management manuals accompanying the LRA maps draw on the same concept as do the 'Glovebox Guide to Soil of the Macquarie-Bogan Flood Plain' by Hulme (2003) and several 'Soil Specific Management Guidelines for Sugarcane Production' in different sugarcane growing areas from northern NSW to northern Queensland (e.g. Wood et al 2003). The availability of these maps on-line makes them more accessible and assists with visualising a location's position in the landscape. Combining these maps with the geo-referenced APSoil PAWC characterisations will increase the value that both resources can provide to farmers and advisors.

Using these resources to inform or even predict PAWC profiles is, however, still research in progress. In particular its predictive power and spatial accuracy still needs to be assessed as well as the required level of soil and landscape information. Not all areas within the northern region are covered by these soil-landscape maps and knowledge of (hydraulic properties of) soils within these

areas varies too. Another resource that may prove useful in the future but requires further testing for its use in predicting PAWC profiles, is the new Soil and Landscape Grid of Australia (see Resources section) which provides digital soil and landscape attribute predictions at a spatial resolution of 90 m x 90 m).

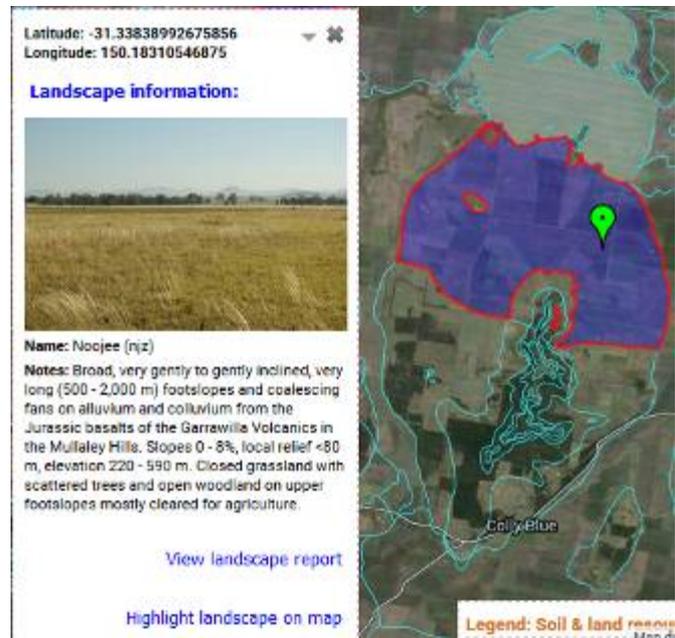


Figure 11. Example of soil-landscape mapping available for parts of NSW through ESspade showing the location of the characterisation of Figure 10a. Mapping unit description is available through a pdf report.



Figure 12. Section of Central Darling Downs with Land Resource Areas (LRA) delineated on Google Earth map with APSoil sites indicated. The accompanying description assisted in describing the differentiation between APSoil 6 and 8 of Figure 11a,b.

Local soil and landscape mapping information

Walgett – Collarenbri – Pilliga

ESpade does not provide on-line access to soil-landscape mapping in this area and a draft map based on the 1:250,000 Walgett geology map only covers the south-western part of this region (south of Walgett and west of Come By Chance). A pdf copy of this draft can be found on http://archive.ils.nsw.gov.au/__data/assets/pdf_file/0004/495886/archive-walgett_map.pdf.

ESpade does provide higher-level land systems mapping for the western part of this region (north of Kamilaroi Highway and west of the Gwydir Highway). The pdf descriptions of the different land systems can provide some insights in typical floodplain components and their soil types.

Useful information about soils in the region is contained in the Profile Descriptions report by Daniells et al. (2002).

North Star

ESpade does not provide on-line access to soil-landscape mapping in this area and neither is land systems mapping available online. Soilmapp provides a broad distinction of where the heavier vertosols and lighter texture change soils may be, but within these there will be local exceptions and variations.

The Profile Descriptions report provides descriptions and PAWC information for soils a bit further south in a region labelled in the report as 'Moree East'.

Queensland

The Central Darling Downs is covered by a LRA map, of which Google Earth files can be obtained (see Resources section). This allows simultaneous viewing of the LRA units and APSoil characterisations. Descriptions of the LRA units as well as the various soils identified in a local classification and their typical positions within the various LRA units are provided in the accompanying Land Management Manual (see Resources section). Estimated PAWC ranges (in 50 mm intervals) are provided for each local soil type.

Other areas covered by LRA maps and Land Management Manuals include Crow's Nest District, Roma District, Central Highlands, Inglewood, Moreton, Murrumbidgee-Chinchilla Shires, Stanthorpe-Rosenthal, Taroom Shire and Waggamba Shire. In addition there are other areas with just LRA mapping: Sandstone Walloons and Lockyer Catchment.

The maps are available in Google Earth (see Resources section for links) and through the Queensland Globe, which also includes other soil maps and soil survey points and associated reports.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. We also gratefully acknowledge the contributions of CSIRO colleagues and many collaborators and farmers to the field PAWC characterisations. Their feedback also helped prepare the list of 'tips and tricks'. The information on PAWC presented in this paper heavily draws on the work over many years by Neal Dalgliesh. Discussions with him and others, including with those involved with soil-landscape mapping in NSW (Neil McKenzie, Rob Banks, Brian Murphy and Neroli Brennan) were invaluable for the development of concepts and ideas presented in this paper. We thank Sean Murphy for access to the Profile Descriptions report for north-west NSW and its authors for the work involved with the PAWC characterisations and soil descriptions. Claire Yung provided assistance with the preparation of graphs.

Resources

APSoil, PAWC methodology and national information:

APSoil database: <http://www.apsim.info/Products/APSoil.aspx> (includes link to Google Earth file)

SoilMapp (soil maps, soil characterisation, archive and APSoil sites): Apple iPad app available from App store; documentation: <https://confluence.csiro.au/display/soilmappdoc/SoilMapp+Home>

GRDC PAWC booklet: <http://www.grdc.com.au/GRDC-Booklet-PlantAvailableWater>

Soil Matters book: <http://www.apsim.info/Portals/0/APSoil/SoilMatters/pdf/Default.htm>

Soil and Landscape Grid of Australia: <http://www.csiro.au/soil-and-landscape-grid>

Yield Prophet®: <http://www.yieldprophet.com.au>

NSW:

ESpade (soil-landscape and land systems mapping and reports, reports on soil characterisation sites from various surveys): <http://www.environment.nsw.gov.au/eSpadeWebApp/>

Unpublished soil-landscape maps exist for: Nyngan, Walgett, Narromine, Narrabri, Gilgandra

Soil Profile Descriptions - District guidelines for managing soils in north-west NSW (Daniells et al. 2002)

Queensland:

Land Management Manuals: <https://publications.qld.gov.au/dataset?q=land+management+manual>

Land Resource Area (LRA) maps: Google Earth files: <https://data.qld.gov.au/dataset/land-resource-areas-series> or via the Queensland Globe

Queensland Globe has a variety of soil maps and survey points in its Soils Globe; Queensland Globe Google Earth kml file can be obtained from: <https://www.business.qld.gov.au/business/support-tools-grants/services/mapping-data-imagery/queensland-globe>

References

- Bourne GF and Tuck GA (1993) Field Manual. In R.N. Thwaites and J.M. Maher (eds.) Understanding and Managing Soils in the Central Highlands, Department of Primary Industries Training Series QE93002, Brisbane.
- Dalgliesh N (2014) Practical processes for better soil water management. GRDC Update paper. <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Practical-processes-for-better-soil-water-management>
- Daniels I, Manning B, Pearce L (2002) Profile descriptions. District guidelines for managing soils in north-west NSW. NSW Agriculture.
- Fritsch S, Wylie P (2015) Managing the yield gap to achieve your yield potential on the western Downs. GRDC Update paper. <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Managing-the-yield-gap-to-achieve-your-yield-potential-on-the-western-Downs>
- Harris, P.S., Biggs, A.J.W. and Stone, B.J. (eds). (1999). Central Darling Downs Land Management Manual. Department of Natural Resources, Queensland. DNRQ990102
- Hulme P (2003) Glove-box guide to the soils of the Macquarie – Bogan floodplain, Sustainable Soils Management, Warren.
- Lynch BC and Dougall CP (2007) Yield Maps - More than just Pretty Pictures? Does soil depth explain spatial variability of yield on a Central Queensland Black Vertisol? p.103-109 Controlled Traffic and Precision Agriculture Conference 5th Australian Controlled Traffic and Precision

Agriculture Conference, University of Western Australia, July 16-18, 2007.
<http://actfa.net/wp-content/uploads/2014/02/Yield-Maps-More-than-just-Pretty-Pictures.-Does-Soil-Depth-Explain-Spatial-Variability-of-Yield-on-a-Central-Queensland-Black-Vertisol.pdf>

Macnish SE (1987) Land management Field Manual Roma District. Queensland Department of Primary Industries Brisbane.

Maher J.M. (ed.) 1996, Understanding and Managing Soils in the Murilla, Tara and Chinchilla Shires, Department of Primary Industries Training Series QE96001, Brisbane

Routley R (2010) Water use efficiency – Optimizing farming systems performance and balancing fallow length and sowing decisions. GRDC Update paper. <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/water-use-efficiency-optimizing-farming-systems-performance-and-balancing-fallow-length-and-sowing-decisions>

Whish J (2014) Sorghum yield risk vs starting soil moisture. GRDC Update paper. <http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Sorghum-yield-risk-vs-starting-soil-moisture>

Wood A, Schroeder B, Stewart B (2003) Soil Specific Management Guidelines for Sugarcane Production. CRC for Sustainable Sugar Production, Townsville.

Contact details

Kirsten Verburg
CSIRO Agriculture
Ph: (02) 6246 5954
Email: kirsten.verburg@csiro.au

Brett Cocks
CSIRO Agriculture
Ph: (07) 4688 1580
Email: brett.cocks@csiro.au

Tony Webster
CSIRO Agriculture
Ph: (07) 4059 5002
Email: tony.webster@csiro.au

SoilWaterApp – a new tool to measure and monitor soil water

David Freebairn, University of Southern Queensland

Key words

Soil water, PAWC, soil type, decision making

GRDC code

USQ00014

Take home message

SoilWaterApp (SWApp) provides farmers and advisers with a ready estimate of plant available water in the soil (PAW) during fallows and early crop growth.

SWApp uses weather data from the Bureau of Meteorology that can be localised with manual entry of rainfall or a newly-developed “wireless” rain gauge. Soil types and crops are selected for each paddock.

SWApp is for iPhone and iPad (iOS) devices. Visit www.soilwaterapp.net.au for details.

Background

Grain production in Australia is limited in most seasons by water supply. Soil water stored during the fallow and early season maintains crop water supply leading up to the critical time around anthesis. SWApp has been designed to give grain growers and advisers a simple tool to efficiently and reliably estimate soil water content during a fallow and early crop phases.

The App

The first thing SWApp asks the new user for is a property and paddock name, then by selecting a relevant climate station. Since you are using smart device, it will present you with the 5 nearest available climate stations but you have a choice of 4,500 stations across Australia! SWApp uses long-term records for your site to estimate upcoming rainfall.

A soil type that best represents your soil is then selected from a comprehensive list covering the major soil types in your state. If you want to use more locally relevant rainfall data than the BoM, you have an option to replace the BOM data with records from your rain gauge.

When you “update the site” with the selections listed above, the next screen (below) allows you to: (1) set a start date and soil water distribution; (2) select the soil cover conditions for fallow or crop, and set crop plant and maturity dates; and (3) make additions to a local rain gauge if previously added.

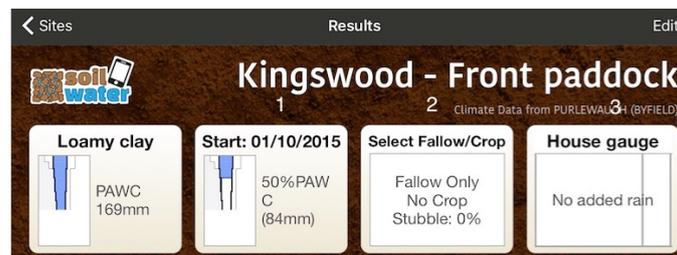


Figure 1. Screen allowing user to (1) set a start date and soil water distribution; (2) select the soil cover conditions for fallow or crop, and set crop plant and maturity dates; and (3) make additions to a local rain gauge if previously added.

Results are shown as text and graphics. Percentage of PAWC and mm water available take centre stage with the water balance and where the water is in the soil profile on either side. The graphic at the bottom of the screen shows the pattern of water accumulation, soil and crop cover. Accumulated rain can be compared with historical patterns as an option.

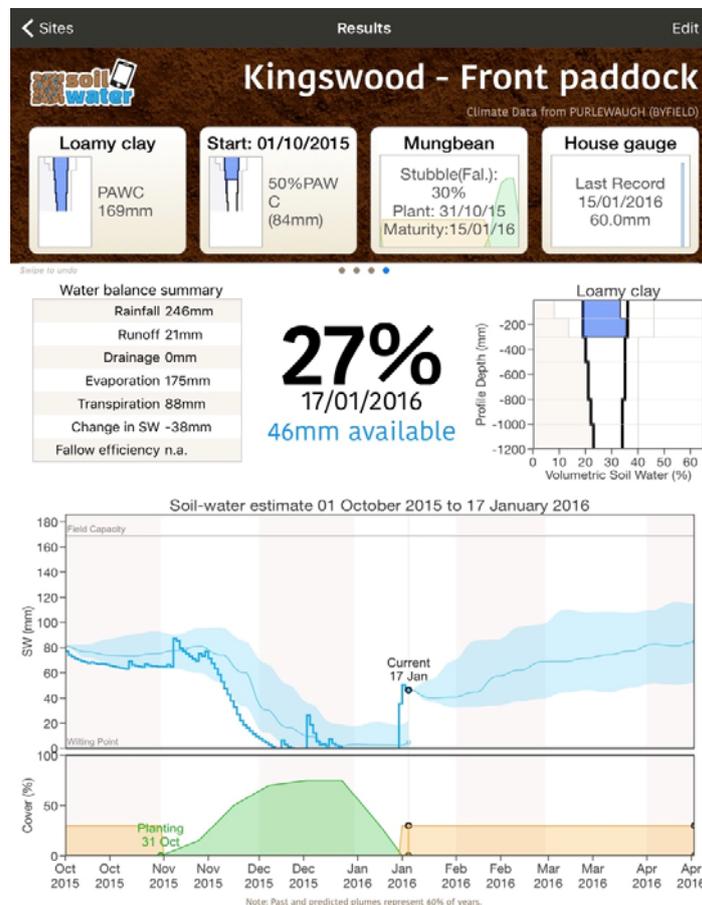


Figure 2. Results screen showing both text and graphics. Percentage of PAWC and mm water available take centre stage with the water balance and where the water is in the soil profile on either side. The graphic at the bottom of the screen shows the pattern of water accumulation, soil and crop cover.

The blue line looking forward from today's date (17 Jan in this example) is based on previous years weather for the specified conditions while the shaded "plume" envelops 60% of likely outcomes.

Data is securely stored and available to multiple devices (other iPhones and iPads). We are currently testing a wireless Bluetooth rain gauge and soil water sensors that SWApp detects and collects data from when your device is nearby (10 metres). Additional facilities such as report generation, a Push Probe data entry and an irrigation module are to be added during 2016.

Acknowledgements

SoilwaterApp was developed for the Grain Research and Development Corporation project "New tools to measure and monitor soil water" (USQ 00014) by the University of Southern Queensland. The project team includes: Prof. Steve Raine, Erik Schmidt, Brett Robinson, Jochen Eberhard, Victor Skowronski, Jasim Uddin and Shree Kodur from USQ and David McClymont from DHM Environmental Software Engineering.

The App's development has benefited from the significant contributions of grain growers and research scientists across Australia who contributed data for model testing. Valuable feedback from

“beta testers” over the last 12 months has improved the App. We look forward to further constructive comments from users.

Contact details

David Freebairn
University of Southern Queensland
West St, Toowoomba Q 4350
Ph: 040 887 6904
Email: david.freebairn@usq.edu.au

Improving fallow efficiency

David Freebairn, University of Southern Queensland

Key words

Soil water, fallow efficiency, conservation tillage, soil monitoring, Australian CliMate, Soil water App

GRDC code

USQ00014

Take home message

- While ~20% of rain is stored during fallows, small changes in soil management can improve this apparent low efficiency and have large impacts on profit.
- Water stored can be improved through longer fallow, weed control, soil cover and reduced compaction. This can be achieved through reduced tillage, controlled traffic and planting crops before the soil fills.
- Stubble retention combined with reduced or zero tillage almost universally results in better water storage.
- Better water storage results in better yields, especially in dry years.
- Soil water and N mineralisation can be tracked using a number of decision support tools (e.g. Australian CliMate, Soil Water App, Yield Prophet).

Getting water into the soil

Storing soil water is a challenge in our environment where evaporation potential is higher than rainfall in all months. Typically, we have 2-3 times the evaporation potential compared to rainfall. High clay content soils, which hold so much water in the surface, make the value of small falls of rain less useful than we might hope for. High intensity rainfall, a feature of summer rainfall in the northern grain region, can result in valuable water being lost as runoff and resultant erosion.

The starting point for improving rainfall capture is to minimise runoff. Soil cover is a crucial factor determining infiltration (*Table 1*). Cover, either as crop residue or a crop canopy, reduces surface sealing. A puddled crust of 1-2 mm thickness is enough to slow infiltration. On average, a soil cover greater than 40 per cent over the summer can reduce annual runoff by 15-30mm compared to bare fallows.

Table 1. Influence of tillage and soil cover on runoff and water storage on a grey brigalow clay (Greenwood 1978-83).

Tillage management (fallow cover)	Bare fallow (<5%)	Disc tillage (25%)	Blade tillage (45%)	Min/no till (>65%)
Fallow efficiency (%)	21	25	26	32
Range of FE	9-29	8-38	17-36	12-32
Reduced runoff (mm)	-	24	32	15
Extra soil water (mm)	-	13	16	36

Soil cracks also offer a pathway for rapid uptake of rainfall, with intense storms putting some water at depth through cracks, out of evaporations harm's way. Avoid cultivation if soil cover is low and soil is cracked (*Figure 1*).

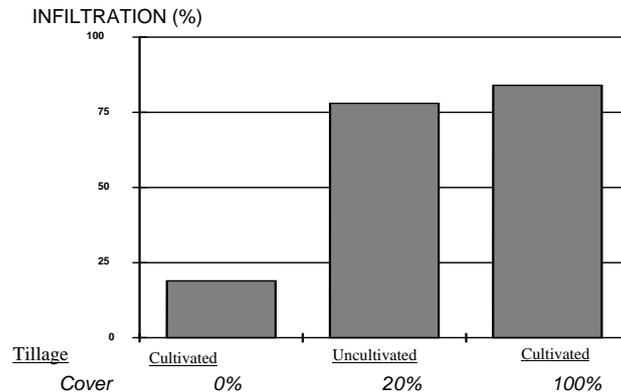


Figure 1. Infiltration of simulated rainfall (40 mm at 100 mm h-1) on a brown clay near Wallumbilla where the soil was cultivated with no soil cover after cultivation, left uncultivated with low cover and cracks, or cultivated with good cover.

Soil water content (How wet?) is important in determining the rate of infiltration. When a soil is full, further rain will either runoff or evaporate. Crop sequences need to be flexible to capitalise on wetter than average conditions and likewise be prudent when soil water is low. As a general rule, fallows longer than one summer are wasteful in terms of storing water. If the soil profile is greater than 50-75 per cent full, planting another crop should be considered.

Keeping it in?

Once rainfall is captured in the soil, the next major challenge is to keep it there for crop use. This is not as easy as it might first seem. During fallows, an average of 65 per cent of rainfall is lost as evaporation - this high loss is largely a result of the high water holding capacity of our clay soils, infrequent rainfall and high evaporation conditions. Many small falls of rain are 'captured' in the top 10 cm, only to be lost to evaporation before the next rainfall.

Stubble can reduce evaporation by increasing the reflectance of the soil surface and reducing the velocity of air movement at the soil surface, but these differences are not long lived. If it stays dry for a few weeks, any gains associated with stubble can be lost. Surface cover and good soil structure allow water to move below the "hot" zone where it will be relatively safe from evaporation "pull". Improvements in water storage have mostly been explained by reductions in runoff losses although evaporation reduction can be important in extending planting dates.

Weeds can be a serious cause of water loss within a crop and fallow - up to 5 mm/day. It is essential that weeds be controlled while they are small to avoid use of soil water and seed setting.

Money in the bank?

Extra water safely stored in the soil through best management can be worth up to 500 kg/ha, especially in dry years. *Figure 2* shows a comparison of grain yields from all tillage trails in southern and central Queensland over a 30-year period. Minimum/no-tillage results in superior yields except in wetter years. In order to make use of available water, nutrition and disease management are equally important, with good rotations a key part of the better water management game. It would be fair to say that farmers have got better at agronomy (compared to researchers) with time than the results in *Figure 2* suggest.

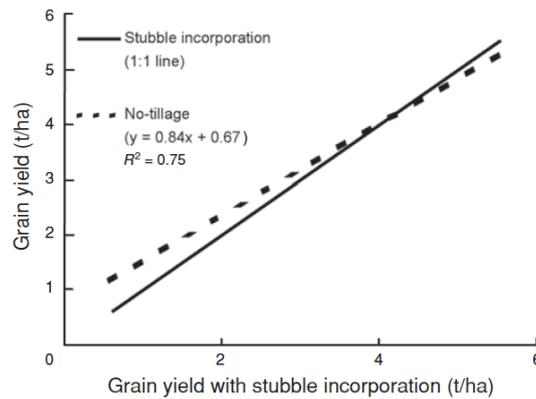


Figure 2. Comparison of grain yields from 120 experiment years from tillage trails in southern and central Queensland in the 1970's to 2007 (Thomas et. al 2007).

Soils are different

While it seems obvious, soils vary greatly, even in the one paddock, so are there any general rules? Much is talked about regarding tillage or no-tillage. Recent research by Dang et al (2014) has shown that an occasional tillage does not appear to undo hard-won gains in soil structure. Some common principles can be summarised as:

- soil cover from stubble or crops is good, and generally the more the better;
- when no soil cover occurs, tillage may be the best option;
- water storage and use is best when crops are growing – provide cover and keep soil drier;
- compaction can only be a bad thing for roots and infiltration; and
- weeds will always be robbers of moisture and nutrients, but may be tolerated at times if small and don't seed.

But each soil needs to be managed differently, and good observation with contrasting management is the best way to learn about your soil. For example, the following observations from a simple rainfall simulation demonstration raised many questions and much discussion (*Figure 3*).

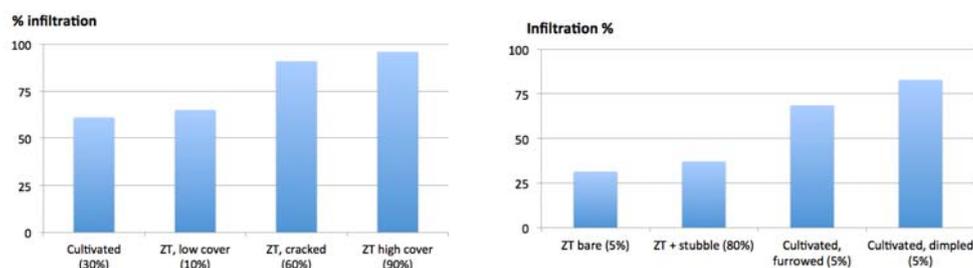


Figure 3. Infiltration of simulated rain on two soil types: a Brigalow-belah clay near Wallumbilla (left) and a red brown earth near Goondiwindi (right) (Cawley et. al 1992).

An example fallow decision pathway

A possible decision pathway for deciding what tillage strategy to follow after harvest.

How long to fallow?

If good rain occurred before harvest, and the soil profile is greater than 3/4 full, extending a fallow is a waste of time, water and money. Remember that on average, only one mm in every 4-5 mm of

rain (20-25 per cent) is stored in the soil. Push probes, soil cores and SoilWaterApp should be useful here.

Are weeds a problem?

If no, best option is to do nothing. If weed control is necessary, either spray, or cultivate to maximise stubble cover.

Is soil cracked?

- If yes, cracks indicate moisture is gone. Do not cultivate until cracks close.
- Once cracks are closed, either a) maintain stubble cover or b) if little cover, create a rough surface
- Roughness can be created with tillage, but don't use harrows. Extra cover (stubble) cannot be created after harvest so look after it.

What happens if no stubble is available?

Once cracks are closed, tillage is needed to maintain roughness and break crusts. Hard setting soils especially need tillage and roughness (some of these soils may need a pasture phase to improve soil structure).

What happens if the soil is fine and no stubble is available?

An unenviable position - hope for gentle rain and plant a crop as soon as possible.

References

Cawley ST, Hamilton NA, Freebairn DM, Markey LJ, Wockner GH. 1992. Evaluating fallow management options by using rainfall simulation - action learning approach with farmers. QDPI Proj. Rept. SQA 91012. 27 pp.

Dang YP, Seymour NP, Walker SR, Bell MJ, Freebairn DM. 2015. Strategic tillage in no-till farming systems in Australia's northern grains-growing regions: I. Drivers and implementation, Soil Tillage Res.

Thomas GA, Titmarsh GW, Freebairn DM, Radford BJ. 2007. No-tillage and conservation farming practices in grain growing areas of Queensland –a review of 40 years of development. Aust. J. Experimental Agric. 47:887-898.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

David Freebairn
Ph: 040 887 6904
Email: david.freebairn@usq.edu.au

Commonly asked questions about soil water and soil management

Graeme Wockner and David Freebairn

Key words

Soil water, soil management, stubble, evaporation, organic matter, infiltration, burning, no till

Stubble factors

Does stubble reduce evaporation?

Yes, in the short term because of reduced soil temperatures but any long-term benefits are negated if we have any hot dry weather after rain. Evaporation is the great equaliser (e.g. 8-12mm free water evaporation a day in summer) which can quickly vaporise any moisture in the surface 0-10cm layer. Stubble is still necessary however, to maintain an open surface structure that reduces the formation of a surface seal and promotes the infiltration of rain.

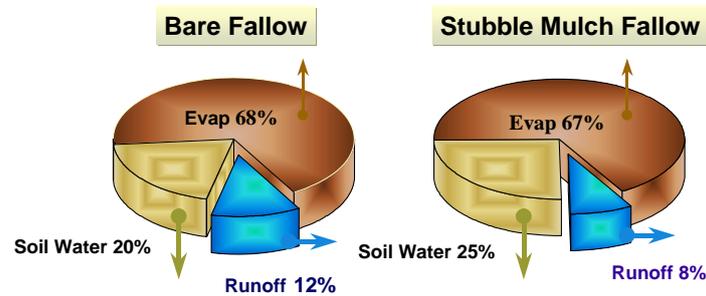


Figure 1. Comparison of two surface management treatments that show only small differences in evaporation but significant differences in soil water infiltration between a bare and a stubble mulch fallow.

Does burying stubble get organic matter into the soil?

Not anymore than leaving it standing. Buried stubble ties up nitrogen in the short term as soil microbes use nitrate for energy to break down the stubble. Above ground, stubble is broken down more slowly by fungi because it is dryer. Eventually the organic matter returns to the ground but in the breakdown process 70% is converted to carbon dioxide.

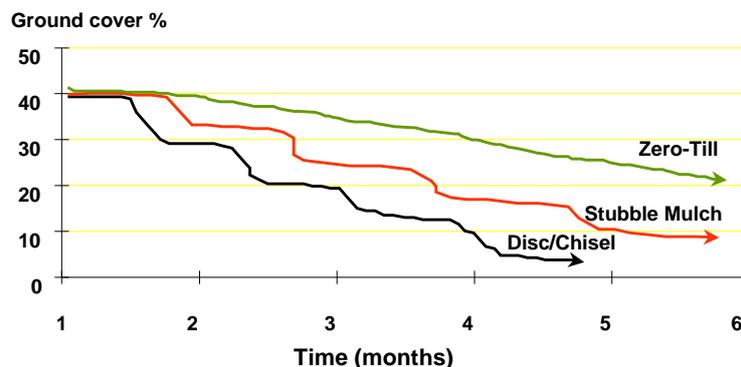


Figure 2. Relationship between time and surface cover breakdown using different tillage instruments

Does burying stubble get more water into the soil than leaving it on the surface?

No, because unless the straw protrudes through the surface infiltration will actually be inhibited. Soil absorbs water like a sponge. You won't improve a sponge by pushing pieces of straw in it! Straw works best by absorbing the energy of raindrops and preventing the surface of the soil from sealing.

Is it better to leave stubble standing or slash it or knock it over?

A catch 22 question because they both have advantages and disadvantages but it is generally accepted that standing stubble is more effective in erosion control. Stubble laying flat increases the overall cover percentage but most high intensity summer storm rainfall falls at an acute angle so standing stubble absorbs a lot of the rainfall energy. Standing stubble is also rooted in the soil and less likely to be washed downhill. Standing stubble is less likely to clog planters in a no-till farming system than slashed or flattened stubble.

Does organic matter improve soil structure and infiltration?

Yes, but we need a lot of organic matter to make a difference. All soils benefit from increased organic matter but unfortunately this is a slow process. It can take less than 20 years to run soils down but much longer to rebuild good soil structure. Organic matter encourages soil fauna; eg: beetles, ants and worms which effectively improve infiltration.

What is the best way to improve organic matter?

Maintaining or improving soil organic fertility through management practices is an important basis for sustainable farming. A decline in organic carbon is accompanied by degradation of a range of properties important for soil fertility. A pasture phase incorporated into your rotation is probably the best way to build organic matter. No-till farming is also beneficial but takes time to substantially raise levels.

Is a late stubble burn OK with regards to soil erosion?

Yes; with the proviso that we delay it as long as possible (e.g. late April). March traditionally has the highest runoff but not the highest rain. This is because the soil moisture profile at this time is nearly filled to capacity and "when a bucket is full", water can only run off. If the rain is intense it will take soil with it. The downside of this is that burning is often a more difficult procedure later in the season. If a clean burn is not possible then the use of fire harrows to substantially reduce stubble levels is recommended. Modern no-till machinery is capable of handling large amounts of stubble that don't require burning.

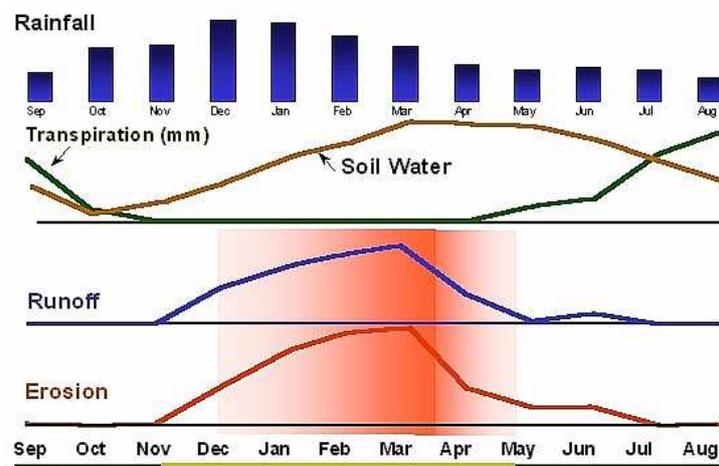


Figure 3. Water dynamics of a summer fallow

Stubble burning is an option available for farmers to control diseases such as yellow spot, minimise nitrogen tie-up in crop residues, and make planting easier with conventional equipment after heavy crops. The 1998 winter wheat crop was severely affected by leaf diseases, and burning was an option for reducing potential carry over of disease. However, in many cases, there is sufficient disease inoculum in the environment to reinfect crops if weather conditions are favourable. Burning a paddock will not remove spores that are present in adjacent grassland for instance.

Bare ground left after burning greatly increases the chance of erosion while reducing the efficiency of water storage during the fallow. If stubble must be burnt, the risk of extreme erosion can be reduced if burning is carried out at an appropriate time. While it is not a prescribed management practice, burning may be practiced from time to time. The key is to understand the risks of runoff and consequent soil erosion.

Other considerations

Will a delay in burning mean it gets too wet to burn!

The risk that a season will turn wet, thus losing an opportunity for a clean burn, needs to be weighed against improved water storage and erosion control. Typically there are many opportunities for a burn through March - April. As a compromise, it may be worth considering burning fewer acres initially.

What if a crop is planted soon after a burn?

If another crop is established quickly, it will provide soil cover, and use soil water (water deficit is the best guarantee for minimising runoff and erosion) thereby minimising the risk of soil erosion.

Will a stubble burn result in less nitrogen tie up?

Generally there is initial less plant available nitrogen when stubble is retained. Over the longer term, losses of organic carbon and nitrogen associated with burning, increased erosion and faster declines in total nitrogen and organic matter in soil eliminate the difference between the two practices.

Will stubble burning reduce disease in other crops?

The main reason to burn is to reduce carry over of yellow spot. Yellow spot mainly affects wheat, so the best strategy to avoid yellow spot is to plant an alternative winter or summer crop in rotation.

Does No-Till promote diseases and pests?

Although some disease organisms grow or survive on stubble, there are strategies to overcome most problems. Rotation of crops is the key. Mice thrive on grain, not stubble - it has too low a feed value, just as it is not preferred by stock. Stubble does provide some protection for mice, but avoiding spilt grain and good farm hygiene are major preventative measures. Complete removal of winter grains can be a challenge in seasons where cereal grains are small or crops lodge.

What can we do when there is no stubble?

Roughness is an option as the increased micro-relief acts as a physical barrier to water movement and increases the entry points for water because of the larger surface area. Results from research work at Wallumbilla show that rough tillage with a chisel plough decreased runoff by 10mm over a summer fallow when compared with smooth scarified tillage.

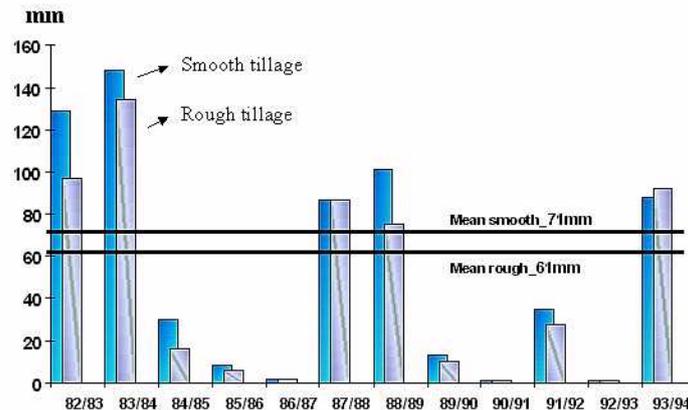


Figure 4. Runoff from smooth and rough tillage treatments at Wallumbilla; Queensland showing the mean 10mm increase in runoff between smooth and rough tillage.

Tillage factors

In controlled traffic can I plough up and down the slope?

Most work in Controlled traffic, which has shown a benefit of up and down working, has been done on fairly low slopes. More work is needed to show the effects on steeper slopes. However, controlled traffic is only successful in reducing erosion in no-till farming systems. In the end, cover is the key to reducing runoff and erosion.

No-till promotes waterlogging and runoff in wet years. Is that so?

Yes and No. Untilled soil with good soil cover increases infiltration and therefore the “bucket” (soil profile) fills sooner. In a wet year because our bucket fills quicker any further rain can only run off or remain on the surface if there is insufficient drainage. Trial work at Greenmount in south-east Queensland has recorded relatively high runoff from no-till treatments sooner in the season than other treatments because the no-till profile filled the quickest. Conversely, in dry years this rapid filling of the bucket gives no-till its big yield advantage.

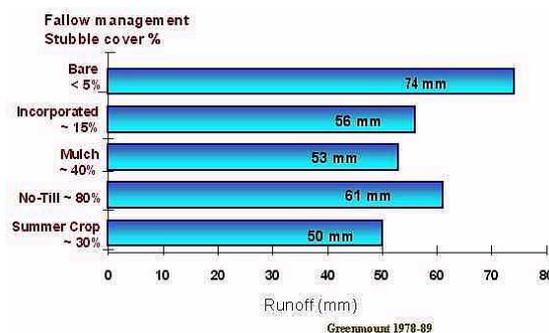


Figure 5. Mean runoff data from Greenmount showing the relatively high runoff from no-till when compared to other treatments.

What effect does herbicide have on worms?

Herbicides (plant killers) should not be confused with insecticides which are sometimes deadly for non-targeted species. The most common herbicides used in no-till systems have no effect on worm populations. Populations of worms in tilled paddocks are usually quite small. Worms and steel ploughs don't mix.

Is opportunity cropping worth it ?

Generally, Yes, in Queensland's variable climate. Since the 1970's the best farmers have been saying "Use it or lose it" when talking about soil water. However, opportunity cropping means your farming system must be very flexible. E.g. machinery, seed and long or short crop varieties must be available.

How soon do weeds start having a negative effect on stored moisture?

As a rule of thumb if weeds (e.g. summer grasses) have 8 days to establish, they can then grow at 2-3 centimetres a day. Therefore they are depleting our stored reserves (below 10cm) after 12 days.

Rainfall factors

Are weather forecasts based on the SOI too late to make winter cropping decisions?

The SOI forecast for winter is most accurate after late May. Weather experts have to be conservative in their predictions until they know for sure that the pattern has stabilised. If you keep your own records you can observe weather trends, which allow individuals to make earlier decisions. Weather forecast systems are constantly improving and researchers are confident that earlier, more accurate long-term predictions will eventually be possible.

Is rainfall amount a useful measure of how much soil moisture is stored in the fallow?

Not necessarily, it depends on how much rain fell. Steady rain over several days fills the soil bucket. Sporadic light rain (<15mm in a day) will mostly evaporate if dry days follow. Heavy rain (>50mm in a single storm) will produce runoff. Flood rains may only wet a hard setting soil to a few centimetres.

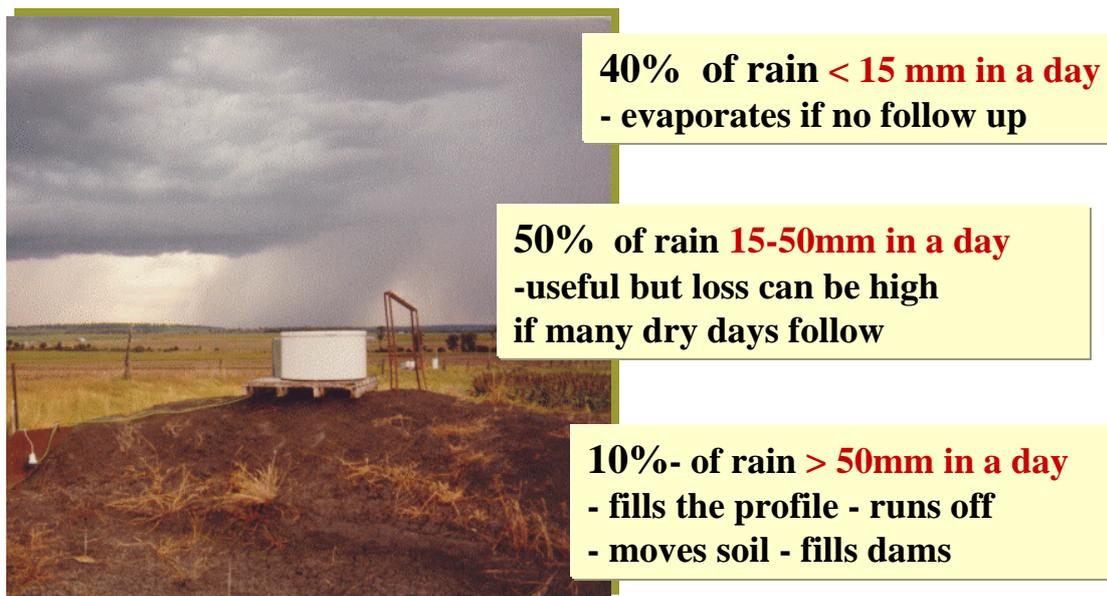


Figure 6. Rainfall fits into different categories

Soil factors

Should nitrogen be applied early or late?

No firm answers because it depends on the season. If we don't have any rain after we apply early we can have losses. (This may be compensated if nitrogen is cheaper earlier in the season.) Early application means one less job at planting but we might just end up fertilising the early weeds! Nitrogen is extremely mobile and a wet fallow can move it deeper into the profile so a small starter application at planting may be necessary. Some experts feel that banding is best as the growing crop

has a better chance of competing for the available N. Top dressing before the flag stage is important because the efficiency of N use drops off dramatically.

Do cracks promote evaporation from the sub soil?

Only in negligible amounts. A soil cracks when it is dry so if a soil is cracked the water has already gone. The crack is more likely to be a net receptor of any storm runoff than a net loser through evaporation. There is little sunlight or air movement in a crack and these are the main causes of evaporation.

Why does my lighter country do better than my heavy country sometimes?

Rainfall on lighter soils infiltrates deeper and more evenly than into a heavy clay but a clay soil holds a lot of water in a small volume of soil. A black earth may hold 18mm of rain per 100mm depth of soil. By contrast, a red earth may only hold 10mm per 100mm or 80% less. Therefore a light fall of rain will only wet a shallow depth of a clay soil but will soak down to a greater depth in a lighter textured soil. This means that light falls of rain on clay soils may evaporate more easily because the water is held close to the surface.

Lighter soils hold water less tightly than a clay soil. Plants can more easily soak up water in a light soil whereas some water in clay soils is not available to plants. Clay soils, then, require more rainfall before plants can extract water from them. This means that plants will respond to light falls of rain better in a light soil. Because clay soils store a greater amount of water, they can supply plants with water longer than light soils when droughty conditions follow good soaking rains.

Can cultivation seal in the moisture?

No. Cultivation turns soil over and exposes moist soil underneath to evaporation. Sometimes a cultivated layer "dust mulch" feels dry while the subsoil feels damp. The surface soil is not sealing in the moisture; it is just evaporating to dryness faster than the sub-soil. At night, when evaporation is less, the dust mulch, too will feel moist as water diffuses from the wetter subsurface to the dry surface.

Contact details

Graeme Wockner and David Freebairn,
Previously Queensland Department of Primary Industries, Natural Resources and many other
departmental names, First prepared in 2005

David Freebairn
University of Southern Queensland
West St, Toowoomba Q 4350
Ph: 040 887 6904
Email: david.freebairn@usq.edu.au

Ranking cereal varieties for frost susceptibility using frost values

Tim March¹, Michael Laws¹, Paul Eckermann¹, Paul McGowan², Simon Diffey³, Brian Cullis⁴, Richard Maccallum⁵, Brenton Leske⁶, Ben Biddulph⁶, Jason Eglinton¹

¹ School of Agriculture, Food & Wine, The University of Adelaide

² Innovative Food Technologies, Agri-Science Queensland, Department of Agriculture and Fisheries

³ Statistics for the Australian Grains Industry (SAGI), Centre for Crop and Disease Management, Curtin University

⁴ Statistics for the Australian Grains Industry (SAGI), National Institute for Applied Statistics Research Australia (NIASRA), University of Wollongong

⁵ NSW Department of Primary Industries

⁶ Department of Agriculture and Food Western Australia

Keywords

Frost, wheat, barley, grain sterility, frost induced sterility, flowering

GRDC project code

UA00136, DAW00234, UW00005

Take home message

- Wheat and barley varieties differ in susceptibility to reproductive frost damage during booting and flowering.
- Barley is less susceptible to reproductive frost damage than wheat. No varieties are frost tolerant. Under severe frost (for example -8°C) or multiple minor frosts (several nights of -2° to -4°C) all varieties tested to date are equally susceptible, resulting in up to 100 percent sterility in flowering heads.
- Variation in reproductive frost susceptibility has not been linked to variation in susceptibility to stem frosts experienced in 2014 across Southern Australia or to later frosts during grain filling.
- Frost Values have been developed for cereal varieties to rank their relative susceptibility to reproductive frost. This information will be available through the use of an interactive tool on the National Variety Trial website and can be used to manage frost risk and fine tune variety selection after first selecting for local adaptation, yield, flowering time, and other key target traits.

Background

Frost has been estimated to cost Australian growers around \$360 million in direct and indirect yield losses every year.

Breeding new cereal varieties with improved frost tolerance is one solution to minimise financial losses due to frost. Historically little has been known about variation for frost tolerance in Australian varieties, leading to the assumption that little variation exists. The limited knowledge about frost tolerance is also due to the practical difficulties in measuring frost damage under field conditions due to the sporadic and dynamic nature of frost events. However, successive GRDC funded projects have enabled dedicated frost screening nurseries to be developed in SA, WA and NSW. These nurseries have enabled the measurement of susceptibility to reproductive frost under minor frosts with greater accuracy and repeatability than previously. This research is part of the GRDC's multidisciplinary National Frost Initiative.

Methodology

The frost susceptibility data is generated from research trials grown in frost prone parts of the commercial production environment near Loxton SA, Merredin and Wickepin WA and Narrabri NSW in 2012, 2013 and 2014. To improve the predictions for these environments, similar trials grown in Loxton SA in 2010 and 2011 were also included in the analysis.

At each site, between 6 and 11 times of sowing (TOS) are planted as separate blocks at approximate equidistant thermal time from around April 15 to June 15 at each site to increase the probability that the test lines are at the flowering stage when a natural frost event occurs. On site weather stations monitor the temperature at the crop canopy. Following a frost event, 30 flowering heads are tagged and then assessed for frost induced sterility (FIS) during grain fill 4-6 weeks later. FIS is assessed on the outside grains of every spikelet excluding the terminal and basal spikelets. This approach minimises confounding effects due to maturity and enables repeatable results over successive seasons and sites. Different research agencies conducted the trials in each state, although the same protocols were used. Table 1 gives a summary of the trials.

The genotypes that were grown included a selection of the most commonly grown wheat and barley varieties in the three states, genotypes which had been well characterised previously for frost tolerance and other genotypes of particular interest to breeding companies.

Table 1. Summary of wheat experiments used in analysis, replications =2.

State	Location	Year	Number of Sowing dates	Number of Varieties
SA	Loxton	2010	6	35
		2011	6	36
		2012	11	65
		2013	10	65
		2014	10	72
WA	Merredin	2012	7	48
	Wickepin	2013	6	54
	Wickepin	2014	8	72
NSW	Narrabri	2012	7	30
		2013	7	32
		2014	7	32

Results and discussion

When cereal varieties are flowering on the same day and a frost occurs, there is a wide range in frost susceptibility within commercial varieties under mild reproductive frost conditions (minimum temperature -1° to -3°C) (Figure 1). Under very severe frost (for example -8°C) or multiple minor frosts (several nights of -2° to -4°C) all varieties are equally susceptible, resulting in up to 100 per cent sterility. It should be noted that the relationship between canopy temperature and FIS is complex and can be confounded by TOS, variety and environmental factors. Understanding this relationship will be the focus of ongoing research.

Frost values

The relative ranking of the frost susceptibility has been expressed as a frost value (FV) for each variety in each environment. FVs are presented as positive or negative differences relative to the average frost induced sterility (FIS) of all varieties in the current data-set for a given year and site. Low FVs are more desirable than high FVs. The units of measurement for FVs relate to the transformed FIS data and therefore do not directly correspond to a particular level of frost damage. Therefore the comparative ranking between a subset of varieties of interested should be considered when making variety decisions as it is the difference between FVs that is critical.

When using FVs for selection decisions, it is recommended that growers and advisors consider not just a single environment/year, but a number of relevant environments. This allows examination of stability of variety performance over a range of environments which are prone to frosts.

FVs can be displayed graphically for a set of either wheat or barley varieties of interest using the interactive tool that is available from NVT Online (<http://www.nvtonline.com.au/>) an example of this is shown in Figure 2.

The rankings are currently based on the variation in wheat and barley variety's ability to maintain grain number under minor reproductive frosts. Under reproductive/floret or head frosts, grain number is the main yield component affected. Yield is a function of grain size multiplied by grain number and hence grain number normally corresponds to yield. However, this may not be the case if there is variation in the length of season and the ability of varieties to compensate with late tillers, synchronisation of flowering time or plasticity of grain number. Therefore, it is critical that varieties are selected on local adaptation and yield first and FVs are only used to identify and manage frost risk.

Further research is ongoing to validate the yield relationship with FIS (DAW00234) and also compensation ability (CSP00180) as part of the GRDC's multidisciplinary National Frost Initiative.

In addition it is important to note that research to date has not conclusively assessed if the variation in reproductive frost susceptibility is related to susceptibility to frost during stem elongation and grain filling.

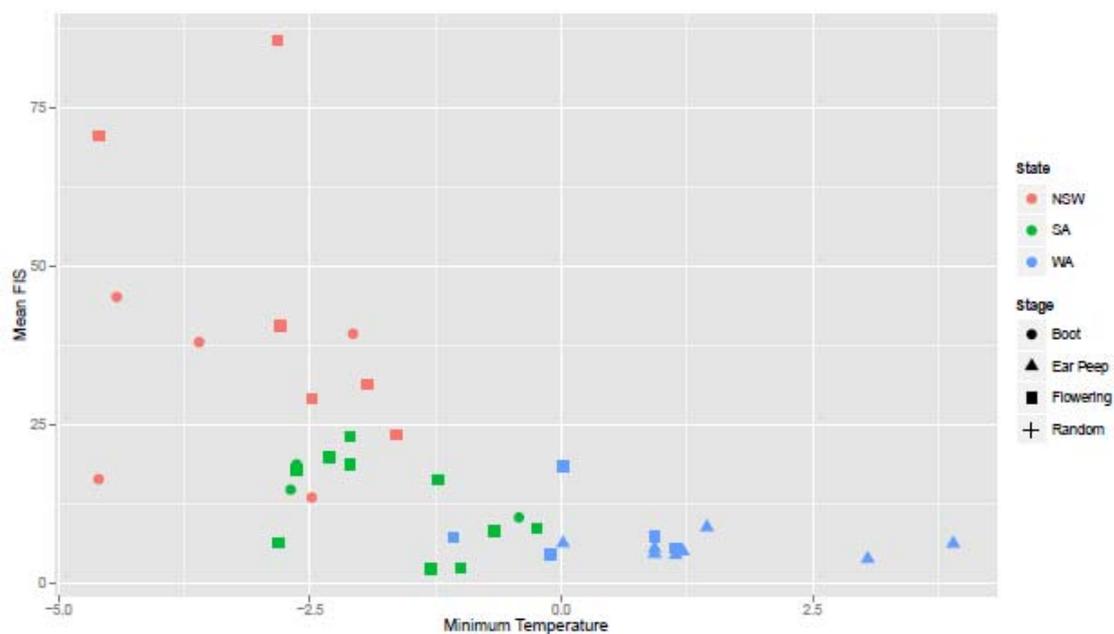


Figure 1. Relationship between minimum temperature in 3 environments and raw FIS data for each wheat tagging event, at different development stages in 2012-2013.

FV-PLUS performance over experiments

(the dashed line represents an average variety for that trial)

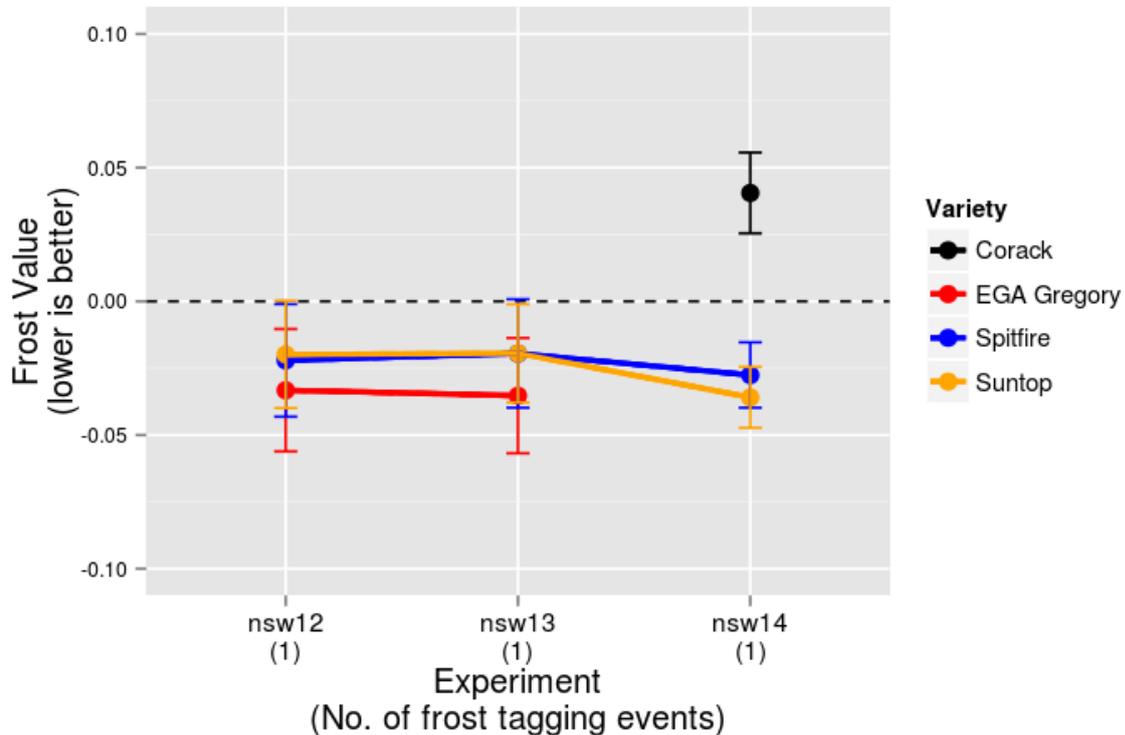


Figure 2. Frost Value graph for five wheat varieties tested at Narrabri NSW. Each FV for each variety is presented along with prediction standard error bars. The number of tagging events is indicated in brackets for each site/year. Lower FVs are better.

(¹) EGA Gregory, Spitfire, Suntop & Corack are all varieties protected under the Plant Breeders Rights Act 1994)

Conclusion

As frost exerts a complex production constraint in cropping systems, it requires a package of risk management strategies. These strategies should include pre-season, in-crop and post frost management tactics. These tactics should be regularly reviewed and updated as part of annual farm management planning and as new ideas and research findings are uncovered.

Variation in cereal varieties for reproductive frost susceptibility is just one component of a management strategy and may be used to fine-tune variety selection to manage the risk of frost damage.

Acknowledgements

The authors acknowledge Mr Nathan Height and Mike Baker DAFWA for Technical support. Trials in Narrabri were sown and managed by Kalyx and by Living Farm in Wickepin. This research was funded by the GRDC and is part of the National Frost Initiative.

Contact details

Richard Maccallum
NSW Department of Primary Industries
Ph: 02 6895 1025
Email: richard.maccallum@dpi.nsw.gov.au

Tim March
University of Adelaide
Ph: 08 8313 6700
Email: tim.march@adelaide.edu.au

Jason Eglinton
University of Adelaide
Ph: 08 8303 6553
Email: jason.eglinton@adelaide.edu.au

Ben Biddulph
DAFWA, South Perth
Ph: 08 9368 3431
Email: ben.biddulph@agric.wa.gov.au

Ⓢ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994

NGA project overview 2010-2015

Richard Daniel, Northern Grower Alliance

Key words

NGA, grower solutions group, agronomy

GRDC code

NGA00003: GRDC Grower Solutions for Northern NSW and Southern Qld

Take home message

1. NGA continues to perform a key role in conducting responsive, regionally prioritised project activity in the northern grains region
2. In excess of 400 trials conducted during NGA00003 with an average of 10 project themes per season
3. Weed and disease management were the major areas of activity
4. Key project themes: feathertop Rhodes grass and awnless barnyard grass control, *Pratylenchus thornei* impact and management, nitrogen strategies in wheat
5. Nutrition and other agronomy issues are increasing in importance in recent years

The process

NGA has been actively involved in regional R,D&E in the northern grains region since early 2006. The approach or model of operation has essentially remained unchanged during that period. In its simplest form the process is:

1. Local Research Groups (LRGs) are set up to provide a broad regional coverage
2. Members of the LRGs (regional consultants, agronomists and growers) determine and prioritise the issues of agronomic concern
3. NGA develops project activity to respond to these issues after discussion with key researchers (agency and private) to fine-tune direction and avoid duplication of effort
4. Project results are communicated via a range of methods, including GRDC Updates and our website (www.nga.org.au), but with a primary pathway being directly via the LRG network of advisers
5. Feedback is obtained to complete or further refine project direction

One of the key components that has helped to ensure the value of NGA activity is the flexibility to rapidly respond to issues raised by industry. This is a significant challenge in management due to the very short time frames between issue generation and project initiation, however it ensures that activity is focussed on the highest priority issues in the timeliest fashion. This does however mean it is difficult to predict future research areas.

Project activity

During the 5 year period, NGA were involved in conducting or sampling in excess of 425 individual trials. Trial activity was conducted on ~10 different project themes in each winter or summer season. The majority of these themes were evaluated for 2-3 years with Table 1 detailing the broad breakdown of the key segment of activity.

Table 1. Breakdown of NGA trial activity by segment 2010-15

Segment	% of total trials
Weeds	48
Diseases	28
Nutrition	11
Other agronomy	13

Weeds

- Weed management has been the major segment with summer fallow weed control the primary area of attention
- Key weed targets were fleabane (particularly 2010-2012), feathertop Rhodes grass (2010-2015), awnless barnyard grass (particularly 2013-2015) and more recently, common sowthistle
- The dominant issue has been the evaluation of management strategies for glyphosate resistant/tolerant weed populations

Diseases

- A major segment of activity particularly from a winter crop perspective
- Key disease targets included crown rot (particularly 2010-2012), yellow spot (2011-2013), *Fusarium* in sorghum (2010-2012) and *Pratylenchus thornei* (2010-2015)

Nutrition

- Increasing number of priority issues in this segment in recent years
- Nitrogen management in wheat continues to be a major issue involving aspects of canopy management, application timing and issues of low protein achievement in key varieties
- Canola nutrition was also a focus (2012-2014) along with chickpea nutrient responses

Other agronomy

- Another segment with an increasing amount of project activity in recent years
- Important areas of trial activity have been fallow monitoring to improve our understanding of N mineralisation rates and fallow soil water efficiency together with evaluations of crop safety from fallow or previous crop herbicide use
- Minor areas of activity have evaluated harvest aid strategies in a range of crops

Key outcomes

Feathertop Rhodes grass (FTR) management

- FTR started to become a major issue in northern NSW and southern Qld from ~2009 onwards
- An excellent example of the benefits from having an approach enabling a rapid response in evaluation of management options together with important input from CQ learnings and the northern weeds team
- NGA heavily involved in evaluating effective double-knock strategies and obtaining a permit (PER12941) to enable the use of a haloxyfop followed by paraquat for improved knockdown control

- NGA also heavily involved in evaluating residual chemistry for activity against FTR, particularly when used as registered in the winter crop phase. This approach can assist reducing the seedbank and decreasing the reliance on knockdown control in the summer fallow
- NGA efficacy results also helped to fast track the addition of FTR on product registrations
- Surveys on the management of summer grass weeds conducted to measure the impact of project activity on knowledge levels, adoption and uptake

Pratylenchus thornei (Pt)

- Major theme throughout entire project
- NGA played a key role in raising awareness of the importance and impact of this disease, particularly in northern NSW and central to western Darling Downs
- Conducted three 'multiple season/multiple individual trial' sites (at Weemelah and Yallaroi, NSW and Macalister, Qld) evaluating the performance of a range of crops for actual *Pt* impact
- Heavily involved in variety and crop evaluation for *Pt* resistance which has highlighted the commercial implications of variety choice but also validated a new technique to improve evaluation of new varieties
- Identified the agronomic and economic importance of variety choice in situations where both *Pt* and crown rot are primary disease risks
- Collaborated with seed companies, breeders and NVT co-ordinators to obtain valuable extra *Pt* resistance data from existing trials
- Surveys conducted to measure the impact of activity of project activity on knowledge levels, adoption and uptake

Nitrogen management in wheat

- Heavily involved in determining the direction of N volatilisation activity conducted by NSW DPI
- Evaluated the potential of late N application for protein achievement in wheat under northern conditions
- Validated N volatilisation results under regional trial conditions for mechanically incorporated v spread urea
- Evaluated the fit of alternative urea formulations and treatments and their potential for use in canopy management
- Investigated the impact of timing of N application on canopy management and economic outcomes

Communication

- The NGA website (www.nga.org.au) has operated since 2011
- Finalised project reports, GRDC Update papers, survey results, maps of trial locations by project theme and year together with other communications are available. NB some projects involving off label evaluation, can't be published.
- Annually ~1,500-2,000 visitors to the site with >10,000 page views
- Since 2011, a total of >60,000 downloads of project reports and GRDC Update papers

- A new role to focus on improving the speed and timeliness of NGA communications has been recently created

Extra engagement

- An *eNewsletter* is sent to >500 subscribers twice per annum to detail project plans and highlight other topics of importance. Project results are sent directly to the same subscribers as available. Newsletter signup is available on the website to anyone interested
- New growers interested in being involved in the LRGs are always welcome. For more information please contact Glenn Milne - Darling Downs, Stuart Thorn - Goondiwindi, Andrew Earle - Mungindi, Tim Poole - Moree, Brad Coleman - Walgett and Greg Giblett -Liverpool Plains. Contact details are listed on our website under *Key Contacts*
- Agronomist involvement must be partly structured to ensure a broad regional coverage, representation from both private and agribusiness organisations and to ensure meeting size is still practical and effective. For more information again see our *Key Contacts*
- For those unable to attend meetings but keen to propose an issue for consideration, a *Raise a Research Issue* opportunity is also available on our website or contact other LRG members
- NGA has started to evaluate Twitter as another communication medium (@NthGwrAlliance)

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Richard Daniel
Northern Grower Alliance
Ph: 07 4639 5344
Email: richard.daniel@nga.org.au

Day 1 concurrent sessions

Disease concurrent session

Barley diseases update - Pathotype surveys of powdery mildew and net form net blotch - implications for management.

Greg Platz, Ryan Fowler, DAF Queensland

Key words

Pathotype, virulence, differential, fungicides, survey

GRDC code

DAQ00187 – Barley Foliar Pathogens Variety Improvement Program

DAQ00189 - National Variety Trials - Increasing grower management of crop disease through resistance knowledge.

Take home message

Disease populations are in a constant state of change – change that is often directed by resistance genes in commercial varieties.

Annual pathotype surveys are the best means of monitoring the presence of existing virulences and detecting the evolution of new virulences in disease populations.

Keep abreast of significant changes in disease populations that may alter the resistance ratings of commercial varieties to plan appropriate management strategies.

Introduction

Powdery mildew (*Blumeria graminis* f. sp. *hordei*) and net form of net blotch (*Pyrenophora teres* f. *teres*) of barley (*Hordeum vulgare*) are omnipresent throughout the Northern Region. In susceptible varieties, losses of up to 13% and 47% respectively have been recorded. Varietal resistance remains the best means of control; however few Australian varieties have maintained their resistance to either disease for extended periods.

One of the best examples of applied pathology in overcoming a major disease problem is our own Australian Cereal Rust Control Program and its predecessors in combatting the stem rust (*Puccinia graminis* f.sp. *tritici*) scourge in northern Australia. Over the past 50 years, wheat stem rust has declined from a major disease to the point where it is difficult to find in the region. This has been achieved by:

- **Widespread adoption of resistant varieties** - Resistant varieties deny the disease a host and inoculum levels plummet.
- **Reduction in inoculum levels** - Whether through elimination of the green bridge or removal of susceptible varieties from the cropping system, inoculum survival and increase is greatly reduced.
- **The use of combinations of resistance genes** - Most fungal diseases will mutate or recombine to develop new virulences. It is much easier for a fungus to overcome a single resistance gene than several genes in combination and
- **Annual pathotype surveys** - By knowing what virulences are present in a disease population we are able to target resistances effective against those virulences and alert industry as to what resistances may be at risk.

If this strategy worked for wheat stem rust – one of the most voracious and damaging crop diseases - why then should it not prevail for other crop diseases?

Pathotype surveys

Pathotype surveys involve appropriate sampling of a disease population by the collection of individual isolates and then determining the virulence combinations of those isolates, by inoculating them onto a range of varieties or lines with known and /or different resistances (differential varieties). For example, the varieties Beecher, Prior, Skiff and Shepherd[Ⓛ] are key differentials in identifying pathotypes of net form net blotch (NFNB) in Australia. If any of these varieties are shown to be susceptible to an isolate collected in a survey, then we know the isolate has virulence for the resistance in that variety. It may be virulent on one or several varieties which not only defines pathotype but also tells us how virulent that particular isolate is.

Both powdery mildew (PM) and NFNB reproduce sexually on crop stubble, resulting in rearrangement of their genetic material and the potential for new virulences to evolve. It is therefore imperative that surveys are conducted annually and that differential varieties are reviewed regularly to reflect their relevance to commercial production.

Results of pathotype surveys

There have been a number of state based surveys of PM and NFNB in the past; but these now have a national focus as integral components of the GRDC funded Barley Foliar Pathogens Project. Researchers at Hermitage Research Facility conduct surveys for both PM and NFNB.

The initial PM survey (Dreiseitl *et al.* 2013), conducted in 2010 and 2011, identified 27 pathotypes with virulence on just eight PM resistance genes – a relatively simple population. Since then, virulences on Shepherd[Ⓛ] (*Mla3* 2012), Grout[Ⓛ] (*Mla9* 2012), Navigator[Ⓛ] (*Mla12* 2012) and Hindmarsh[Ⓛ] (*MILa* 2014) have been detected in eastern Australia. The resistance gene *MILa* contributes to PM resistance in several popular varieties. The changes in resistance ratings of some of those varieties to the “new” virulence are given in Table 1.

Table 1. Comparison of resistance ratings of varieties carrying *MILa* resistance before and after detection of *MILa* virulence.

	Postulated resistance gene(s)	Field 2013 <i>MILa</i> avirulent	Field 2014 <i>MILa</i> virulent	Field 2015 <i>MILa</i> virulent	
				Tillering	Adult
			Mid-elongation		
Baudin [Ⓛ]	<i>Mla8</i>	VS	VS	VS	SVS
Commander [Ⓛ]	<i>Mlg, MILa</i>	MRMS	MSS	MSS	MS
Compass [Ⓛ]	<i>Mlg, MILa</i>	MS	S	MSS	MRMS
Hindmarsh [Ⓛ]	<i>Mla8, MILa</i>	MRMS	SVS	MSS	MSS
La Trobe [Ⓛ]	<i>Mla8, MILa</i>	MS	S	MSS	S
Mackay	<i>Mlg, MILa, +</i>	MR	MR	MR	R
Oxford	<i>Ml(St)</i>	R	R	R	R

Pathotype determinations are usually made using seedlings. It is important to highlight that virulence on seedling resistances does not automatically imply that a variety carrying that resistance will be susceptible at adult stages. Our program now screens lines at both the vegetative and adult stages to determine resistance status at both growth stages.

The NFNB survey identified at least 15 significant pathotypes which grouped into families aligned to virulence on the varieties Beecher, Prior or Skiff. Skiff virulence is dominant in the Northern region; yet virulence on Shepherd[Ⓛ] and Prior is frequently detected. Virulence on Beecher has not been detected in this region; but is common in Western Australia.

Implications for management

Both diseases are best managed through an integrated approach of sowing resistant varieties; adopting rotations that avoid sowing barley on barley and the use of fungicides if resistance is not available.

Powdery mildew

PM is mostly a disease of the vegetative stage occurring between early tillering and mid elongation. Few varieties appear susceptible after flowering. This suggests that yield should not be seriously impacted by the disease and we have been unable to demonstrate yield losses in excess of 13.4%; yet in high yielding crops this can be significant. It also warns that powdery mildew control should be implemented early in crop development.

Fungicides can be applied up-front as seed treatments or on fertilizer in furrow. This will provide up to 8 weeks protection around which time crops should be breaking into head.

Foliar fungicides are very effective; but need to be applied early in epidemic development as PM can increase rapidly. In most cases a single application should be sufficient; but in favourable conditions a second spray may be warranted.

Net form net blotch

Both PM and NFNB are airborne diseases but PM is much more mobile and a more prolific sporulator than NFNB; therefore PM can spread farther, quicker than NFNB. However, NFNB can be seed-borne which has major implications for disease management.

Skiff virulent pathotypes dominate in the northern region and have done so since the late 1990's. The cultivation of varieties susceptible to these pathotypes allows them to survive and increase. Varieties resistant to the Skiff virulence have been released in recent years; yet some of these are susceptible to other virulences that are already present in the population.

One such variety is Shepherd^(D) which is resistant to the dominant Skiff pathotype but very susceptible to pathotypes with the Shepherd virulence. In a recent survey, Shepherd^(D) virulence was present in about 10% of isolates; but it is an increasing component of the NFNB population. In 2015, we detected two crops of Shepherd^(D) on the Darling Downs that had severe NFNB and the disease was present at much lower levels in many other crops of this variety.

Why were these crops heavily infected? It would appear that grower retained seed infected with the disease was sown early providing conditions very favourable for disease development.

This example is not a recommendation NOT to sow Shepherd^(D). Shepherd^(D) can continue to be grown successfully with appropriate management.

1. Use clean seed
If in doubt treat seed with registered seed treatment.
2. Do not sow Shepherd^(D) on Shepherd^(D)
3. Monitor crops at risk
4. Apply fungicides before the epidemic is well established.

Similarly, our most popular malting variety Commander^(D) is resistant to the Skiff pathotypes, but susceptible to the Prior virulence. If these and similar varieties remain in our cropping system for an extended period it is likely that the minor pathotypes will increase and the current dominant pathotypes will decrease.

Conclusion

Pathotype surveys provide the intelligence necessary to make reliable varietal recommendations, to select effective resistances in breeding new varieties, to choose disease isolates appropriate for effective screening and to assess risk in the management of plant disease.

Surveys must be at least regionally based and ongoing to keep abreast of changes in disease populations as the evolution of new virulences can render resistant varieties susceptible and recent information obsolete.

Reference

Dreiseitl A, Fowler RA and Platz GJ (2013) Pathogenicity of *Blumeria graminis* f. sp. *hordei* in Australia in 2010 and 2011. Australasian Plant Pathol. 42:713–721.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support.

Contact details

Greg Platz
Department of Agriculture and Fisheries Queensland
Hermitage Research Facility
604 Yangan Road, Warwick Qld 4370
Ph: 07 4660 3633
Fx: 07 4660 3600
Email: Greg.Platz@daf.qld.gov.au

Ryan Fowler
Department of Agriculture and Fisheries Queensland
Hermitage Research Facility
604 Yangan Road, Warwick Qld 4370
Ph: 07 4660 3665
Fx: 07 4660 3600
Email: Ryan.Fowler@daf.qld.gov.au

Barley leaf rust 2016 – what lies ahead?

Lislé Snyman, Clayton Forknall, DAF Queensland

Key words

Barley, leaf rust, resistance, fungicide

GRDC code

DAW00245 – Yield loss response curves for host resistance to leaf, crown and root diseases in wheat and barley.

Take home message

Resistant varieties are the most practical way of controlling barley leaf rust. Yields of S and VS varieties are impacted most by the disease and increase the amount of inoculum exerting pressure on available resistance genes. If using S and VS varieties, be pro-active in terms of removing the green bridge, monitor crops regularly and apply fungicides early.

Introduction

Barley leaf rust is caused by the obligate parasite (*Puccinia hordei*) and spread by means of airborne spores that can travel long distances. The pathogen has the ability to spread rapidly when conditions are favourable and large areas planted to susceptible varieties create the perfect scenario for epidemic development. In the presence of a green bridge, the pathogen can survive over summer and be present at high levels early in the growing season. High inoculum levels put pressure on major resistance genes and can lead to the development of new pathotypes with increased virulence.

Leaf rust is considered one of the five major barley diseases in Australia and can cause significant yield loss up to 60% (\$25/ha) and a reduction in grain quality (Murray & Brennon, 2009). Despite varying greatly between production areas, it is widely distributed and occurs regularly in some regions.

What have we learned so far?

In 2010 a barley leaf rust epidemic occurred in Queensland with major contributing factors being susceptible varieties sown over large areas, producing ample inoculum combined with favourable conditions for disease development. Favourable conditions during the previous summer provided inoculum for early sown crops. Foliar fungicide applications provided mixed results that could be contributed to many factors, including high inoculum pressure and late application of fungicides.

The identification of new pathotypes virulent to the single, major *Rph3* gene has rendered some varieties susceptible, including Bass[Ⓛ] and Compass[Ⓛ]. This virulence has been identified in all major production areas.

In looking at the resistance levels of barley varieties to leaf rust it is evident that over 50% of current commercial varieties carry no or very little resistance to leaf rust. The distribution of leaf rust resistance levels in northern region barley varieties is indicated in Figure 1.

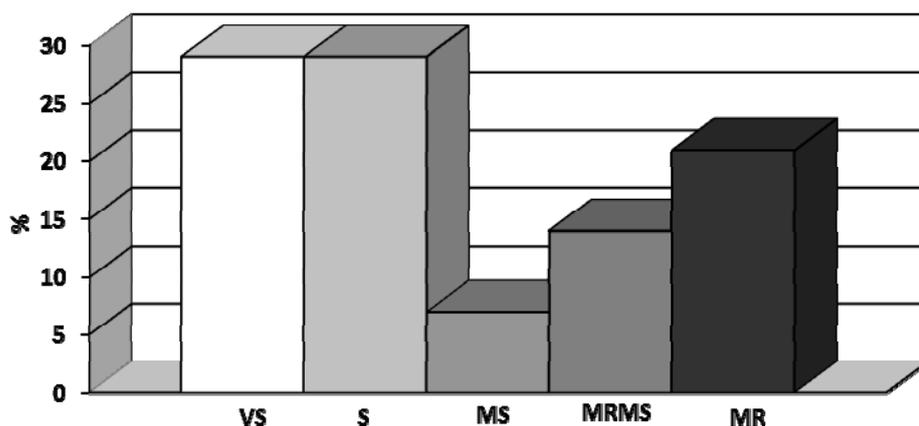


Figure 1. The distribution of resistance levels to leaf rust in barley varieties in the northern region. Currently large areas are sown to varieties in the S or VS categories. The area sown to Compass[®] (VS) is expected to increase Australia wide in the 2016 season, increasing the risk of epidemics caused by high inoculum levels and will put additional pressure on the currently effective resistance genes available.

Some varieties carry adult plant resistance (APR) genes such as *Rph20* and *Rph23*. Unless combined with major resistance genes, varieties carrying APR can be quite susceptible during tillering and may require fungicide protection during early growth stages. Regular monitoring of crops can reveal the need for early intervention with fungicides, particularly in susceptible varieties.

Yield loss response trials

A significant amount of research has been done in an effort to quantify losses caused by barley leaf rust. A pilot study by DAF QLD in 2013 identified the need for fungicide application on susceptible varieties.

The study included the barley varieties Shepherd[®] (MR), Flagship[®] (MS), Commander[®] (MSS) and Grout[®] (VS). A single fungicide application on Shepherd[®] (GS72-74) increased yield by 314 kg/ha compared to the untreated plot. There was however no significant difference between a single spray and two sprays. Two sprays in both Flagship[®] and Grout[®] resulted in a significantly higher yield than a single spray and both single and double sprays had an increased yield advantage over the nil treatment. In Commander[®] a single and double spray resulted in similar yields, which were significantly better than the nil treatment. In addition, both spray treatments resulted in test weights acceptable for malt quality, in comparison to the seed treatment and nil application where test weights were below 65 kg/hl. The seed treatment did not seem to have any advantage over the nil treatment in any of the varieties. Results (Table 1) indicated that the more susceptible a variety, the more benefit can be gained by foliar fungicide application.

Table 1. Yield advantage in barley varieties of a single spray compared to nil fungicide treatment

Variety	1 spray (kg/ha)	Nil treatment (kg/ha)	Yield advantage (kg/ha)
Shepherd [®]	4566.80	4252.63	314.17
Flagship [®]	4166.92	3790.20	376.72
Commander [®]	4606.95	3851.45	755.49
Grout [®]	3947.08	3059.68	887.40

Following the 2013 trials, more detailed trials were performed in 2014 and 2015. Yield and quality loss were calculated in 6 varieties, ranging from MR to VS. Plots were inoculated with leaf rust to represent infection levels ranging from nil disease (fungicide treated) to high.

Yield responses (Figure 2) in all varieties, except Shepherd[®] (MR), indicated a significant yield loss for the high disease plot compared to nil disease. All treatments had significantly higher yields than the high disease treatments in the susceptible varieties Grout[®] and Compass[®], with the biggest yield loss observed in Compass[®]. Yield loss in the susceptible variety Scope[®] was lower than expected. Test weights and protein for all treatments in La Trobe[®] were acceptable for malt quality, whereas none of the Scope[®] treatments, including the nil disease, had test weights or protein acceptable for malt quality. Only the Nil treatment of Compass[®] (not yet malt accredited) was above 65 kg/hl.

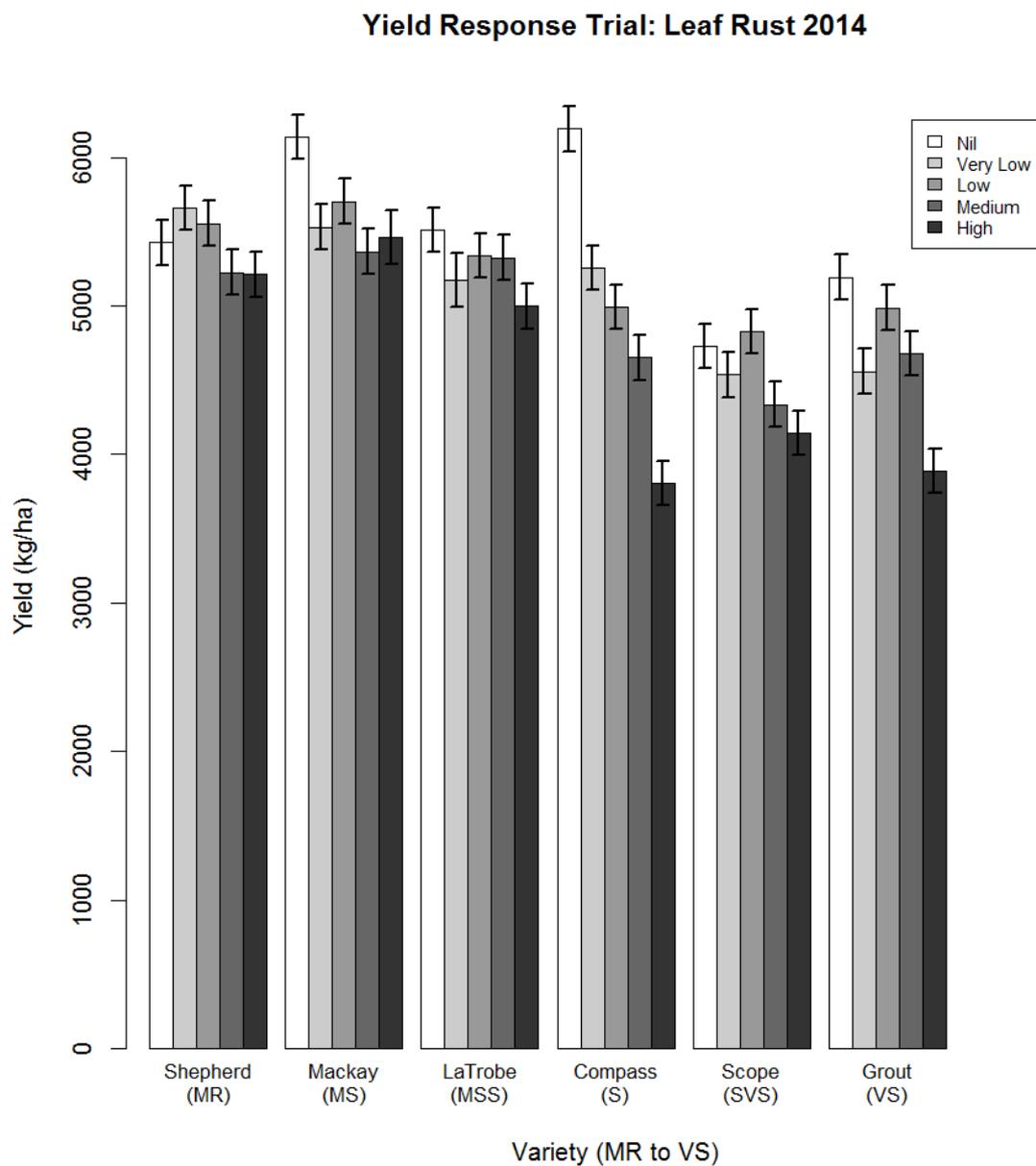


Figure 2. Yield response of barley varieties at different disease levels in 2014

Results from 2014 led to variety changes in 2015 with Mackay replaced by malt variety Commander and Fathom included as a MS type. Compass replaced Grout as a VS type.

Results from 2015 confirmed observations from 2014. In all varieties (Figure 3) the nil disease treatment had significantly higher yield than the high disease treatment and in all varieties, except Shepherd and Commander, all treatments were significantly better than the high disease treatment. Similar to 2014, the biggest yield loss was observed in Compass.

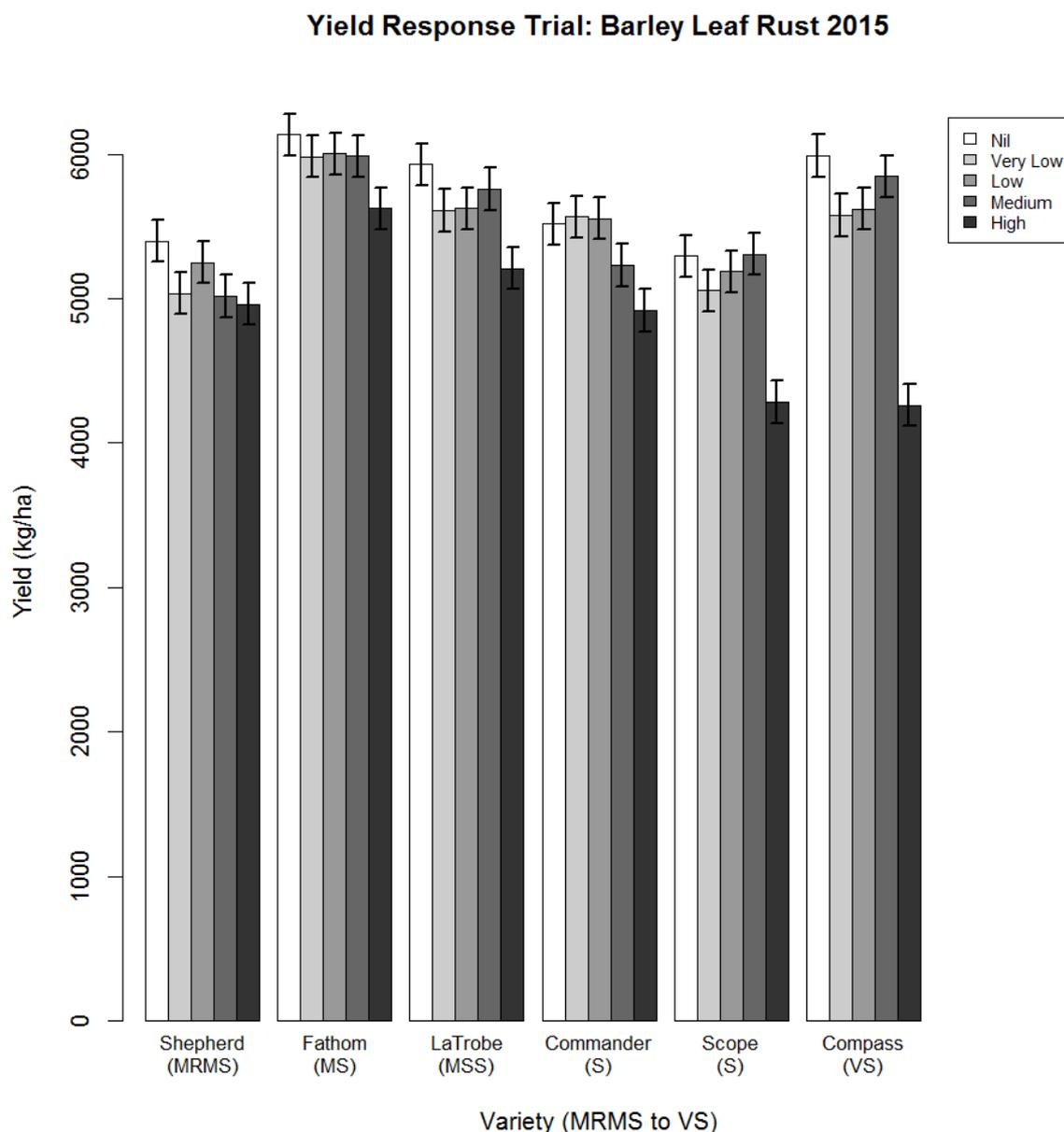


Figure 3. Yield response of barley varieties at different disease levels in 2015

Conclusions

Trials conducted in 2014 and 2015 confirmed observations made in 2013 that the more susceptible a variety, the bigger the yield and quality losses due to leaf rust. Using resistant varieties is the most

practical means of disease control. In avoiding S and VS varieties, the amount of inoculum can be reduced.

According to the Bureau of Meteorology above average rainfall is expected for most of southern Queensland and parts of northern NSW for the first three months of 2016, providing ideal conditions for the over summering of rust on volunteers. Leaf rust was observed in the 2015 season with some crops requiring fungicide spraying. Regular crop monitoring, particularly in susceptible varieties is essential for timely intervention with fungicide. Keep in mind that rust diseases are difficult to control once established. In some instances more than one fungicide application may be needed for rust control.

Even though barley leaf rust can cause significant yield and quality losses, data indicated that by being pro-active it is possible to manage the disease. We however need to be able to adapt to ever changing pathogens and climatic conditions.

Reference

Murray, GM & Brennan GP, 2009. Estimating disease losses to the Australian barley industry. *Australasian Plant Pathology* 39, 85-96.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

The author would like to thank Greg Platz for guidance and the technical - and farm staff at Hermitage Research Facility for their assistance.

Contact details

Lislé Snyman
DAF QLD
Hermitage Research Facility, 604 Yangan Rd, Warwick, Qld
Ph: 07 4660-3661
Fx: 07 4660-3600
Email: lisle.snyman@daf.qld.gov.au

Greg Platz
Ph: 07 4660-3633
Email: greg.platz@daf.qld.gov.au

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Chickpeas – what we learnt in 2015 and recommendations for 2016

*Kevin Moore, Leigh Jenkins, Paul Nash, Gail Chiplin and Sean Bithell,
Department of Primary Industries, NSW*

Key words

chickpea, Ascochyta, Phytophthora, management

GRDC code

DAN00176 Northern NSW Integrated Disease Management

Take home message

- Plant seed of known identity and purity and of high quality that has been properly treated with a registered seed dressing.
- Localities where Ascochyta was found on any variety in 2015 are considered high risk for 2016 crops and growers are advised to apply a preventative fungicide before the first post-emergent rain event to PBA HatTrick[®].
- Mild temperatures, long cloudy periods and frequent rainfall events during Jun/Jul across the Northern region as occurred in 2015, are ideal for early season outbreaks of Ascochyta blight in chickpea crops.
- In wet seasons the management of Ascochyta can be hindered by getting ground rigs into wet paddocks and shortage of fungicides.
- Follow the disease management recommendations in this article and associated links – they will maximise your chance of a profitable chickpea crop in 2016.

The 2015 northern NSW/southern QLD chickpea season

Unprecedented high prices (peaking at \$900 in Jun) led to a record planting of chickpeas in the region. The 2015 winter crop season in northern NSW/southern QLD followed a wet Jan, dry Feb/Mar, wet Apr (except Dalby) and wet May (except Roma, Table 1).

In most centres in northern NSW, mild, wet to very wet conditions in Jun/Jul were followed by average or below average Aug, a very dry Sep, below average Oct rain and a wet Nov harvest. On the Downs conditions were much drier. Rainfall totals and long term averages for the Jun-Nov period were: Dubbo 292mm (LTA 279mm), Gilgandra 301mm (LTA 261mm), Trangie 251mm (LTA 225mm), Nyngan 204mm (LTA 190mm), Coonamble 158mm (LTA 231mm), Walgett 236mm (LTA 201mm), Moree 204mm (LTA 258mm), Tamworth 341mm (LTA 315mm), Roma 173 (LTA 226mm), Dalby 124mm (LTA 261mm) with monthly figures in Table 2.

With the exception of the Downs and western areas, these conditions, together with early sowing resulted in high biomass crops which used a lot of water. Cold, dry weather from late August to late September led to flower and pod abortion. This was not helped by considerable temperature fluctuations in the last 10-14 days of September (up to 20°C in a 24hr period). Hot, dry conditions in early October put crops under further stress (as most had run out of water). Thus, in many parts of northern NSW, seasonal conditions conspired to produce big canopies that ran out of water during the major pod filling period. Coupled with frosts, low and fluctuating temperatures, this resulted in missing pods, ghost pods or single-seed pods.

Table 1. Jan – May 2015 rain (mm) at selected locations in NSW/QLD

Location	Jan	Feb	Mar	Apr	May
Roma	86	31	33	46	12
Dalby	107	49	13	11	86
Dubbo	131	32	8	82	48
Gilgandra	103	21	3	99	73
Trangie	59	1	11	114	48
Nyngan	91	5	13	44	44
Coonamble	74	11	6	76	51
Walgett	34	0	6	24	30
Moree	105	4	60	63	33
Tamworth	90	23	52	86	38

Table 2. Jun – Nov 2015 rain (mm) at selected locations in NSW/QLD

Location	Jun	Jul	Aug	Sep	Oct	Nov
Roma	64	12	24	16	16	41
Dalby	10	18	24	15	47	9
Dubbo	72	60	39	8	46	67
Gilgandra	87	59	31	1	32	92
Trangie	44	44	33	3	28	99
Nyngan	51	35	29	7	13	70
Coonamble	39	27	13	4	29	35
Walgett	58	44	27	1	34	72
Moree	62	36	11	4	10	83
Tamworth	109	34	54	24	50	71

Nevertheless, in NSW yields east of the Castlereagh and Newell highways were generally good with the better crops going 2.5 – 3.0t/ha. However, farmers west of these highways were disappointed with some crops yielding less than 0.2t/ha.

In QLD, some crops on the Downs planted on wide rows went >3.0 t/ha with at least one Kyabra[Ⓛ] crop going 3.6 t/ha. The Downs crops were sown on a full profile but with in-crop rainfall well below average, they did not have a lot of biomass. This, coupled with wide rows which allowed the soil to warm up, is believed to account for the large yield differences between crops at say Dalby and those at Moree.

Chickpea diseases in 2015

In 2015, 243 crop inspections were conducted as part of DAN00176. *Ascochyta* blight, AB (*Phoma rabiei* formerly called *Ascochyta rabiei*) was detected in 60 crops. High chickpea prices tempted some growers to break rules, eg plant back to back chickpeas and they paid the price, in terms of AB infection and AB management costs in 2015 chickpea crops that followed 2014 chickpeas. Some growers reported more AB in PBA HatTrick[Ⓛ] than they ever saw in Jimbour, but many of these crops had been inundated in Jun/Jul and we know that AB resistance of waterlogged chickpeas is compromised. Further the genetic purity of the variety could not be determined. Generally, however, good management and dry conditions through Aug – Oct kept AB under control and no major yield losses were reported.

Phytophthora root rot, PRR (*Phytophthora medicaginis*, 23 cases) caused light to moderate losses but only in paddocks with a history of medics or where the susceptible variety PBA Boundary[Ⓛ] was planted.

The mild wet winter also favoured *Sclerotinia* (24 cases) especially in paddocks with a canola history, with both basal and aerial infections detected. Where canola was involved, the species was always

S. sclerotiorum. One crop in the wetter areas east of Narrabri had aerial infection from ascospores of *S. minor* instead of the typical infection of roots and stem base by mycelia from sclerotia. This was the first record in this region for infection from windborne ascospores from sclerotia (due to carpogenic germination of sclerotia) leading to infection of chickpea by of *S. minor*. If such windborne infection is common, greater *S. minor* infection may result.

Botrytis Grey Mould, BGM (*Botrytis cinerea*) threatened to be a problem in high biomass crops and some of these were sprayed with carbendazim in early spring. This together with the hot dry finish, diminished the risk of BGM and no damage was reported.

Across the region, viruses were uncommon only reaching damaging levels in crops with poor, patchy stands (often the result of early season waterlogging) or where weeds had not been controlled.

Herbicide injury (Groups B, C, & I) was detected in most crops during Jun/Jul inspections including one striking example of damage predisposing a crop of PBA HatTrick[®] at Billa Billa to PRR. Overall, herbicides caused no serious yield loss.

Disease management recommendations for 2016

Seed treatment and seed purity: Seed borne Botrytis, seed borne Ascochyta and several soil borne fungi can cause pre- and post-emergence seedling death. Irrespective of source of seed and year of production all chickpea planting seed should be treated with a registered seed dressing (Table 3). Proper coverage of the seed with an adequate rate of product is essential. Be confident of the identity and purity of your planting seed. If unsure acquire certified seed from a reputable seed merchant.

Table 3. Chickpea seed treatments

Active ingredient	Example Product	Rate	Target disease
thiabendazole 200 g/L+ thiram 360 g/L	P-Pickel T [®]	200 mL/100 kg seed	Seed-borne Ascochyta, Botrytis, Damping off, Fusarium
thiram 600 g/L	Thiram 600	200 mL/100 kg seed	Seed-borne Botrytis and Ascochyta, Damping off
thiram 800 g/kg	Thiragranz [®]	150 g/100 kg seed	Seed-borne Botrytis and Ascochyta, Damping off
metalaxyl 350 g/L	Apron [®] XL 350 ES	75 mL/100 kg seed	Phytophthora root rot

Ascochyta Blight

The following strategy should reduce losses from Ascochyta in 2016:

- In areas where AB was detected in 2015, spray all varieties, including PBA HatTrick[®] and PBA Boundary[®] with a registered Ascochyta fungicide prior to the first rain event after crop emergence, three weeks after emergence, or at the 3 branch stage of crop development, whichever occurs first.
- In areas where AB was NOT detected in 2015, spray all varieties with AB resistance lower than PBA HatTrick[®] with a registered Ascochyta fungicide prior to the first rain event after crop emergence, three weeks after emergence, or at the 3 branch stage of crop development, whichever occurs first.
- 2-3 weeks after each rain event, monitor all crops irrespective of variety and spray if Ascochyta is detected in the crop or is found in the district on any variety.

- Ground application of fungicides is preferred. Select a nozzle such as a DG TwinJet or Turbo TwinJet that will produce no smaller than medium droplets (ASAE) and deliver the equivalent of 80–100 litres water/hectare at the desired speed.
- Where aerial application is the only option (e.g. wet weather delays) ensure the aircraft is set up properly and that contractors have had their spray patterns tested.

Botrytis grey mould, BGM

In areas outside Central Queensland, spraying for BGM is not needed in most years. However, if conditions favour the disease it will develop even though BGM was not a problem in 2015. Thus, in situations favourable to the disease (high biomass, average daily temperature 15C or higher, overhead irrigation in spring), a preventative spray of a registered fungicide before canopy closure, followed by another application 2 weeks later will assist in minimising BGM development in most years. If BGM is detected in a district or in an individual crop particularly during flowering or pod fill, a fungicide spray should be applied before the next rain event. None of the fungicides currently registered or under permit for the management of BGM on chickpea have eradicant activity, so their application will not eradicate established infections. Consequently, timely and thorough applications are critical.

Phytophthora root rot

Phytophthora root rot is a soil and water-borne disease, the inoculum can become established in some paddocks. Alternative Phytophthora hosts such as pasture legumes, particularly medics and lucerne must be managed to provide a clean break between chickpea crops. Damage is greatest in seasons with above average rainfall but only a single saturating rain event is needed for infection. Avoid high-risk paddocks such as those with a history of Phytophthora in chickpea, water logging or pasture legumes, particularly medics and lucerne. If considerations other than Phytophthora warrant sowing in a high-risk paddock, choose PBA HatTrick[®] or Yorker[®] and treat seed with metalaxyl. Metalaxyl can be applied in the same operation as other seed dressings providing all conditions of permits and labels are met. Metalaxyl only provides protection for about 8 weeks; crops can still become infected and die later in the season.

Further information on chickpea disease management can be found at the following

<http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management>
www.pulseaus.com.au

- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/northern-guide#Diseasemanagement>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/idm-strategies>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/sclerotinia>
- <http://www.pulseaus.com.au/growing-pulses/publications/manage-viruses>

and in the NSW DPI 2016 Winter Crop Variety Sowing Guide

Acknowledgements

This research is made possible by the significant contributions of growers through both trial cooperation, paddocks access and the support of the GRDC, the authors would like to thank them for their continued support.

Contact details

Kevin Moore

Department of Primary Industries, Tamworth, NSW

Ph: 02 6763 1133

Mb: 0488 251 866

Fx: 02 6763 1100

Email: kevin.moore@dpi.nsw.gov.au

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Chickpea on chickpea – is it worth it?

Kevin Moore, Kristy Hobson and Sean Bithell, Department of Industry, NSW, Tamworth

Key words

chickpea, Ascochyta, Phytophthora, Sclerotinia, management

GRDC codes

DAN00176, DAN00151

Take home message:

Planting your 2016 chickpea crop into paddocks that had chickpeas in 2015, or earlier, is risky and you could lose money.

Further, it puts current disease management practices under pressure and could lead to reduced life of chickpea varieties, development of fungicide resistance and problems with weeds and insects.

Growers are urged to follow recommendations for current best practice especially with regard to crop rotation.

Background

Tempting as they are, current chickpea prices should not lure growers into thinking back to back chickpea is a viable option. Why not? For growers, the biggest risk is you stand to lose money – a lot of money. For the chickpea industry, the concern is that current best practices will become redundant prematurely or will fail completely.

What are the risks of back to back chickpea?

The main risks are seed borne, stubble borne and soil borne diseases. Successful disease management in chickpeas relies heavily on an integrated management package involving paddock selection (crop sequencing), variety choice, seed treatment, strategic fungicide use and hygiene.

Back to back chickpea - which diseases are of concern? There are four major chickpea diseases that will be favoured by planting chickpea on chickpea, ie:

- Ascochyta blight (AB, *Phoma rabiei* – previously called *Ascochyta rabiei*)
- Phytophthora root rot (PRR; *Phytophthora medicaginis*)
- Sclerotinia rot (“Sclero” *Sclerotinia sclerotiorum* and *S. minor*)
- Root lesion nematode (RLN, *Pratylenchus* spp)

Of these, Ascochyta, Phytophthora and Sclerotinia have the potential to cause 100% loss if conditions are conducive.

The risks of Botrytis grey mould (BGM, *Botrytis cinerea*), Botrytis seedling disease (BSD, *B. cinerea*) and viruses (several species) are unlikely to increase with chickpea on chickpea UNLESS some consequence of back to back chickpea favours these diseases eg patchy, uneven stands caused by Ascochyta, Sclerotinia or Phytophthora will increase the risk of virus.

If I did not find any disease in my 2015 crop, is it safe to plant chickpea on chickpea in 2016?

The short answer is NO. Severe disease can occur even if disease was not detected in the 2015 crop or even in earlier chickpea crops. This was demonstrated clearly in 2015 in north western NSW/southern QLD.

Case 1: The bulk of one paddock had been planted in 2013 to PBA HatTrick[®] but a narrow strip was sown with the new variety PBA Boundary[®]. The soil was a clay grey vertosol conducive to Phytophthora root rot when wet. PBA HatTrick[®] has some resistance to Phytophthora (rated MR) but PBA Boundary[®] is susceptible. In 2013, no Phytophthora was observed in either variety. The entire paddock grew wheat in 2014 and in 2015 was sown to PBA HatTrick[®]. On 2 September 2015, Phytophthora (confirmed by lab test) was obvious in the area sown to PBA Boundary[®] in 2013 but was not detected in the bulk of the paddock sown to PBA HatTrick[®] in 2013. The 2015 Phytophthora was so severe in the 2013 PBA Boundary[®] strip that it was not harvested whereas the 2013 PBA HatTrick[®] area went over 2t/ha.

Case 2: In 2014 several paddocks on one farm were planted to Kyabra[®] (susceptible to Ascochyta blight). Ascochyta was not detected in 2014 either on the farm or in the district. This, together with the prediction of an El Nino kicking in towards the end of July 2015, led to a decision to plant Kyabra[®] in the paddocks that had Kyabra[®] in 2014. It was reasoned that if Ascochyta did occur in 2015, it could be controlled with fungicides. What was not considered would be how to manage Ascochyta if it was too wet to spray – which unfortunately is what happened in early winter. Even though no Ascochyta was detected in 2014, the pathogen was clearly on farm and infected plants in late autumn/early winter. The first fungicide was not applied until 14 July by which time the disease was well established. When inspected on 29 July 2015, Ascochyta was rampant in all paddocks and was especially severe in those that had chickpeas in 2014, with many areas of dead and stunted plants. Although no rain fell after end July, these “bad” areas only went 0.6 – 0.8 t/ha compared with Kyabra[®] planted into wheat stubble that went 1.0 – 1.5 t/ha.

What are the impacts of back to back chickpea on a grower?

The main short term one is losing money both from lost yield and quality and, for those diseases that can be controlled in-crop eg Ascochyta, increased production costs. Longer term consequences include increasing inoculum loads in paddocks, rendering them less productive and less flexible. For example with *Sclerotinia* spp, which have wide host ranges (including cotton), the survival structures (sclerotia) remain viable in soil for many years. Thus any practice that increases the sclerotial load reduces the potential of the paddock for host crops such as faba bean, canola, lupin, field pea, cotton (and future chickpea crops).

What are the impacts of back to back chickpea on the industry?

There are three:

1. Increased risk of changes in the pathogen ie it becomes more virulent and aggressive
2. Reduced commercial life of varieties ie back to back chickpea increases the risk of the pathogen establishing in the crop early which increases the potential for more disease cycles throughout the growing season which means resistance genes are subjected to more challenges by the pathogen. Resistance genes are limited; the loss of any gene will severely hinder the development of new chickpea varieties.
3. Increased risk of pathogens developing resistance to fungicides ie reduced life of fungicide. For diseases that can be managed with in-crop fungicides eg Ascochyta, the earlier the disease establishes, the more likely is the need for repeated applications of fungicides. If you wanted to find resistance to chlorothalonil in the Ascochyta pathogen, a good place to look would be in early sown back to back Kyabra[®]. The problem here is that any isolate that is resistant to chlorothalonil is unlikely to be confined to the paddock (or farm) in which that resistance developed. Thus an Ascochyta isolate with resistance to chlorothalonil on a single farm in say Moree could become established in the Darling Downs and elsewhere in northern and north central NSW within a few seasons. This would be the end of chlorothalonil as a disease management tool for chickpeas.

Planting 2016 chickpeas into 2015 chickpea paddocks – is it worth it?

Definitely NOT. Besides it doesn't make sense. As well as increased risk of disease, weed and insect management will also be more challenging. At \$800/t, surely growers should be doing everything to reduce risk and maximise yield and quality.

Further information on chickpea disease management can be found at the following:

<http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management>

www.pulseaus.com.au

- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/northern-guide#Diseasemanagement>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/idm-strategies>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/sclerotinia>
- <http://www.pulseaus.com.au/growing-pulses/publications/manage-viruses>

and in the NSW DPI 2016 Winter Crop Variety Sowing Guide

Acknowledgements

This research is made possible by the significant contributions of growers through both trial cooperation, field access and the support of the GRDC; the authors most gratefully thank them and the GRDC. We also thank agronomists for help with the crop inspections and submitting specimens, Gordon Cumming, Pulse Australia for industry liaison and chemical companies who provide products for research purposes and trial management.

Contact details

Kevin Moore
Ph: 02 6763 1133
Mb: 0488 251 866
Fx: 02 6763 1100
Email: kevin.moore@dpi.nsw.gov.au

Kristy Hobson
Ph: 02 6763 1174
Mb: 0400 955 476
Fx: 02 6763 1100
Email: kristy.hobson@dpi.nsw.gov.au

Sean Bithell
Ph: 02 6763 1117
Mb: 0429 201 863
Fx: 02 6763 1100
Email: sean.bithell@dpi.nsw.gov.au

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Chickpea Ascochyta – latest research on variability and implications for management

Kevin Moore¹, Kristy Hobson¹, Nicole Dron¹, Prabhakaran Sambasivam², Rebecca For³, Steve Harden¹, Yasir Mehmood³, Jenny Davidson⁴, Shimna Sudheesh⁵,
Bithell¹ and Sean⁵

¹Department of Primary Industries NSW, ²University of Melbourne VIC, ³Griffith University, QLD, ⁴SARDI, SA, ⁵Agribio DEDJTR, VIC

Key words

chickpea, Ascochyta, pathogenicity, latent period

GRDC code

DAN00176, UM00052, DAN00151, DAV00126, DAN00151, DAV00098

Take home message

- In 2015, Ascochyta blight occurred in a higher proportion of chickpea crops (60 of 243 crop inspections) than in 2014 (62 of 332 crop inspections). Most infected crops were PBA HatTrick[®] which was also the most commonly grown variety.
- Work to determine if the Ascochyta pathogen is changing started in 2013, where a number of projects are working together to provide an integrated approach to chickpea Ascochyta blight to improve variety resistance and best management practices.
- Initial results show that the population varies in time for spore germination, germ tube length, ability to cause disease (pathogenicity), and time to develop fruiting bodies (latent period).
- Significant differences in the reaction of some varieties and advanced breeding lines to two aggressive isolates of the AB pathogen have been found
- It is essential that growers adhere to best management practices, such as sustainable rotations, to minimise selection pressure on the pathogen and maximise the longevity of variety resistance.
- While research into variability of the AB pathogen continues, it seems prudent to adopt a conservative approach to AB management

Ascochyta blight in 2015 chickpea crops

In 2015, 243 chickpea crop inspections were conducted as part of DAN00176. Ascochyta blight (AB) (*Phoma rabiei* formerly called *Ascochyta rabiei*) was detected in 60 crops. Inoculum had carried over from the 2014 season and wet conditions during Jun/Jul favoured infection and disease development. High chickpea prices tempted some growers to break best practice eg plant back to back chickpeas resulting in severe disease. Some growers reported more AB in PBA HatTrick[®] than they ever saw in Jimbour but many of these crops had been inundated in Jun/Jul and we know that AB resistance of waterlogged chickpeas is compromised. Further the genetic purity of the variety could not be determined. Generally, however, good management and dry conditions through Aug – Oct kept AB under control and no major yield losses were reported.

Details of chickpea diseases and a review of the 2015 chickpea season are in another paper in these Proceedings (Chickpeas – what we learnt in 2015 and recommendations for 2016).

Latest research on variability in the *Ascochyta* pathogen

Is the pathogen changing? Yes, and as a population of living individuals (isolates), we should expect it to change.

Has the pathogen changed in response to selection pressure such as the widespread cultivation of varieties with improved resistance or other factors? We don't yet know. To know if something has changed, you need to track it over a suitable time period. Detailed studies on molecular variability in the AB fungus commenced in 2008 and have shown that the overall population variation hasn't changed much. However, pathogenicity studies that began in 2013 indicate that there are differences in pathogenicity among isolates and that highly pathogenic isolates are causing disease on PBA HatTrick[®]. This paper provides key results from a range of research groups working on this combined project to better understand the chickpea AB population and its threat to the resistance sources through potential adaptation and selection.

Latent period

The incubation period is the time from infection to the appearance of symptoms. The latent period (LP) is the time from infection to the development of pycnidia (the small dark fruiting bodies that develop in the leaf and stem lesions), the LP is important because it determines how fast the disease can cycle in a crop. Determining these characteristics is thus another way of measuring variability in the pathogen population.

Three experiments were conducted in 2015. In each experiment, five isolates representing a sub-set of the pathogen population in Eastern Australia plus a 6th control isolate (obtained in 2014 from PBA HatTrick[®] at Yallaroi, TR6415) were evaluated in a growth cabinet (20°C/15°C 12h day/12h night) on four chickpea genotypes. There were eight replicates (pots) for each of the 24 genotype by isolate combinations. At the 3 leaf stage plants were grouped by isolate and inoculated with a conidial suspension of 100,000 conidia/mL (sprayed to run-off). Plants were examined daily for symptoms and pycnidia. The mean LP was estimated by survival analysis with the status of a pot based on whether pycnidia had or had not developed. For each genotype-isolate, the data is the last day that pycnidia had not developed.

The four genotypes, their AB rating and abbreviation are: 1) ICC3996 (rated R, coded ICC), 2) Genesis[™] 090 (rated R, coded GEN), 3) PBA HatTrick[®] (rated MR, coded HAT), 4) Kyabra[®] (rated S, coded KYB).

For each experiment, LP varied significantly between some isolates and genotypes (LP range 6-8 days). Furthermore, all isolates had the shortest LP on the most susceptible entry, KYB and the longest LP on the most resistant entry, ICC or the second most resistant entry, GEN (see example findings, Figure 1). Within an experiment, no single isolate had the shortest LPs on all genotypes, we interpret this as indicating there are no clear differences among isolates in the contribution of LP to isolate aggressiveness.

These experiments complement the pathogenicity work and confirm variability does exist in the pathogen population

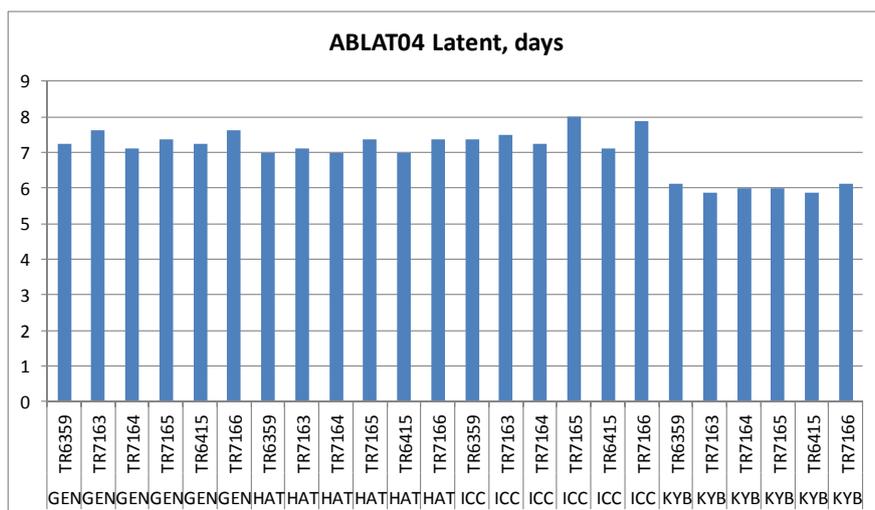


Figure1. Latent period results for experiment ABLAT04 grouped by genotype (ICC3996 (ICC), Genesis 090 (GEN), PBA HatTrick[®] (HAT), Kyabra[®] (KYB)) for inoculation with six isolates listed by isolate no, source and variety: TR6359 2014 North Star NSW, Flipper[®]; TR7165 2014 Horsham VIC; Genesis425, TR7163 2014 Donald VIC; Slasher[®]; TR6415 2014 Yallaroi NSW, HatTrick[®]; TR7164 2014 Donald VIC, Slasher[®]; TR7166 2014 Salter Springs SA, Monarch[®].

Histopathology experiments

A range of preliminary histopathology experiments have been completed, see Figure 2 for summary spore germination and germ tube length results. Key findings from a range of work in this area are that:

- Spore germination begins much faster on the susceptible Kyabra[®] and on PBA HatTrick[®] than on the resistant Genesis090
- Spore germination is consistently slower and lower on the resistance source ICC3996 than on any other chickpea genotype tested
- There is significant variation in germination time among different isolates and this correlates with their level of pathogenicity
- After germination, germ tube length prior to invasion is significantly shorter on ICC3996 than any other chickpea genotype tested

These differential fungal responses may be indicative of host recognition and defence strategies, which are being further investigated.

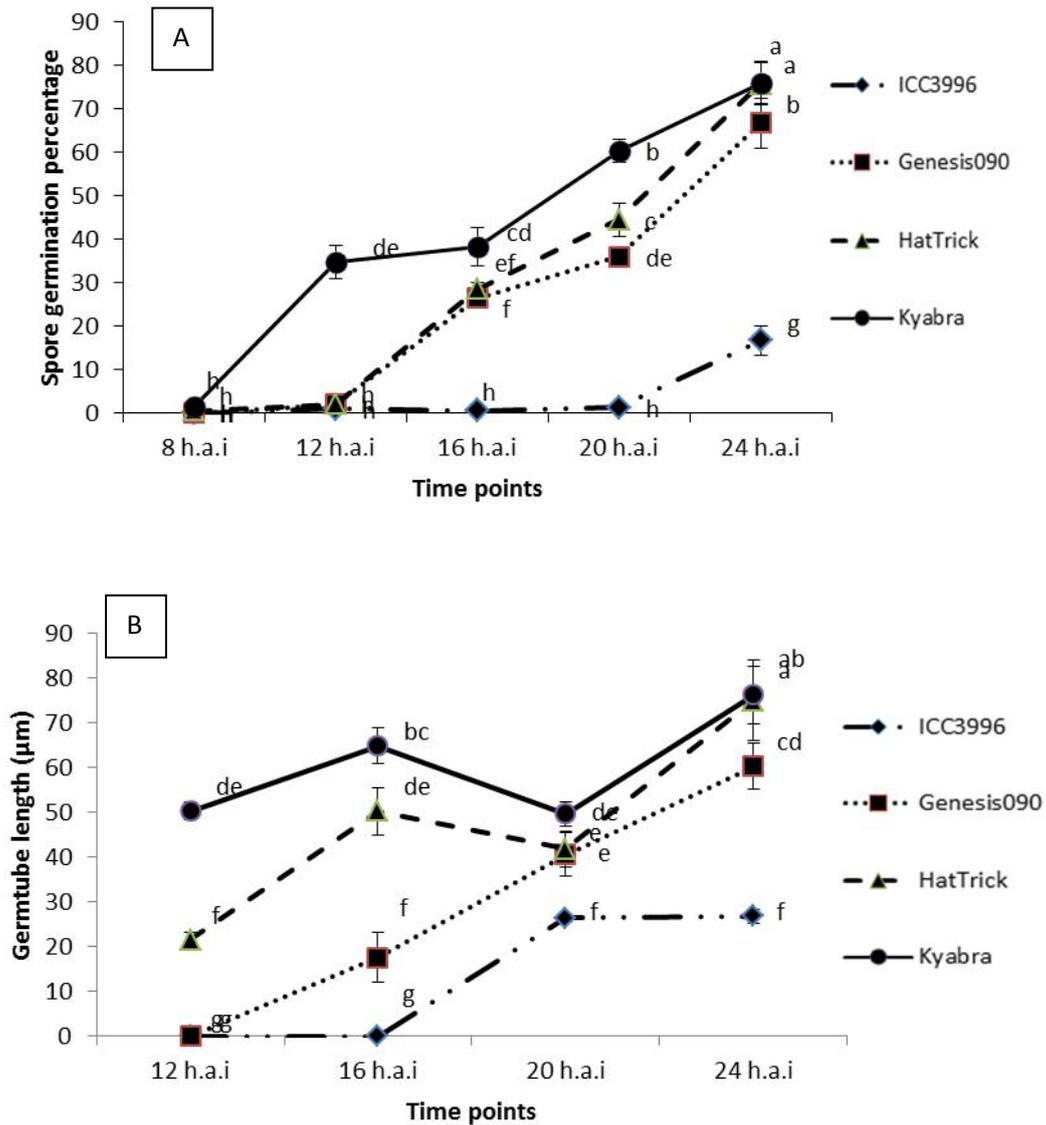


Figure 2. Significant differences were observed among the physiological traits of a highly pathogenic isolate FT13092-1 from Kingsford, SA when inoculated onto chickpea genotypes that are resistant (ICC3996 and Genesis090), moderately resistant (PBA HatTrick) or susceptible (Kyabra). Where A = the percentage of germinated spores and B = the germ tube length over time after inoculation.

How is this information used by the PBA Chickpea program?

In 2014 and 2015 two aggressive isolates identified by the pathogen variability project were screened on the national Stage 3 desi and kabuli entries in a controlled environment by SARDI. In 2015 the two isolates tested were collected in 2013; FT13092-1 from South Australia on Genesis 090 and TR5919 from northern NSW (Tooraweenah) on PBA HatTrick. Of the 154 entries tested, 62 breeding lines significantly differed in their resistance (% of main stem broken) to the two isolates (subset of lines presented in Table 1). The northern isolate was found to be more aggressive than the South Australian isolate. There was no significant difference in the response of PBA HatTrick to the two isolates, but PBA Boundary, CICA0912 and CICA1007 had significantly higher disease with TR5919. Conversely, the kabuli variety Genesis Kalkee had significantly lower disease with the TR5919 isolate compared to the SA isolate. The desi CICA1521 and kabuli CICA1156 had very low levels of disease from both isolates. The 2014 research examined two isolates collected in 2010 and

a much smaller number of entries 8 (out of 137) had a significantly different response to the two isolates.

To complement this information, molecular markers have been screened across the 154 entries. A total of 5 flanking molecular markers (3 SNPs and 2 SSRs) for AB resistance (resistance sources S95362 (kabuli) and ICC3996 (desi)) were identified within “DAV00098 - Molecular markers for the pulse breeding programs” led by DEDJTR, Victoria. These markers have been validated across a diverse set of chickpea lines as part of DAV00126 program. By combining the phenotypic and genotypic information, the breeding program will gain a greater understanding of the genetic resistance in each breeding line. The wider implementation of AB molecular markers across the PBA Chickpea program has identified breeding material which may contain alternative resistance genes. Research into alternative genetic resistance genes is continuing in DAV00126. The use of alternative resistance genes in the breeding program will be essential to ensure new chickpea varieties have adequate levels of AB resistance.

Table 1. Ascochyta blight ratings, response of varieties and breeding lines (% main stems broken, Isd 29.2) to two *Phoma rabiei* isolates in a controlled environment and presence/absence (+/-) of molecular marker and source of resistance.

Name	AB Field rating	% of main stems broken		Marker genotype
		Isolate FT13092-1	Isolate TR5919	
Kyabra ^(D)	S	100	100	-
PBA HatTrick ^(D)	MR	0	20	+, desi
PBA Boundary ^(D)	MR	35	75	+, desi
Genesis 836	MS	8	28	Not conclusive
CICA0912	R*	0	42	+, desi
CICA1007	MR*	0	50	+, desi
CICA1521	R*	0	8	+, desi
Almaz ^(D)	MS	8	8	-, suggests other genes
Genesis 090	R	0	8	+, kabuli
Genesis 425	R	8	17	+, kabuli
Genesis Kalkee	MS	50	20	--, suggests other genes
PBA Monarch ^(D)	MS	3	42	+, kabuli plus others
CICA1156	R*	0	0	+, kabuli

*Advanced breeding lines, putative AB rating

While research into variability of the AB pathogen continues, it seems prudent to adopt a conservative approach to AB management

Further information

<http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management>

www.pulseaus.com.au

- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/northern-guide#Diseasemanagement>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/idm-strategies>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould>
- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot>

- <http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/sclerotinia>
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and in the NSW DPI 2016 Winter Crop Variety Sowing Guide

Acknowledgements

This research would not be possible without the considerable and ongoing support from growers and the GRDC for which we are most grateful. Thanks to Paul Nash and Gail Chiplin for technical support. Thanks also to agronomists for help with the crop inspections and submitting specimens.

Contact details

Kevin Moore
NSW DPI
Ph: 02 6763 1133
Mb: 0488 251 866
Fx: 02 6763 1100
Email: kevin.moore@dpi.nsw.gov.au

Kristy Hobson
Ph: 02 6763 1174
Mb: 0400 955 476
Fx: 02 6763 1100
Email: kristy.hobson@dpi.nsw.gov.au

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Effect of chickpea ascochyta on yield of current varieties and advanced breeding lines – the 2015 Tamworth trial VMP15

*Kevin Moore, Kristy Hobson, Steve Harden, Paul Nash, Gail Chiplin and Sean Bithell,
Department of Primary Industries, Tamworth, NSW*

Key words

Ascochyta, variety, management

GRDC code

DAN00176, DAN00151

Take home message

- Under extreme disease pressure, Ascochyta can be successfully and economically managed on susceptible varieties such as Kyabra[®] and Jimbour.
- However, Ascochyta management is easier and more cost effective on varieties with improved resistance eg PBA HatTrick[®] and PBA Boundary[®]
- The 2015 Ascochyta trial, VMP15, confirmed the next variety planned for release (CICA0912) has excellent resistance to Ascochyta

2015 Tamworth Ascochyta management trial, VMP15

VMP15 sought to evaluate Ascochyta blight (AB) management using ten varieties/advanced breeding lines with a range of Ascochyta resistance ratings: seven desis Kyabra[®] (S, susceptible), PBA HatTrick[®] (MR, moderately resistant), PBA Boundary[®] (MR), CICA0912 (putatively R, resistant), CICA1007 (putatively MR), CICA1302 (for CQ, putatively MR) and CICA1303 (for CQ, putatively MR) plus the kabulis Genesis Kalkee[™] (rated MS), PBA Monarch[®] (MS, moderately susceptible) and Genesis 425[™] (rated R).

There were three treatments: a regular fungicide application with regular applications of 1.0L/ha chlorothalonil (720g/L active), an alternative application variety management package (VMP) treatment with a low and off label rate of chlorothalonil; and a nil application; irrespective of treatment, all fungicides were applied before rain. Data for full rate and nil fungicide treatments only, are reported here because of restrictions on publishing off label results.

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®

The first Group S VMP spray for Kyabra[®] was applied before inoculation. The first Group MS VMP spray for Genesis Kalkee[™], PBA Monarch[®], CICA1302 and CICA1303 was applied after three

infection events (6 rain days, 67 mm rain since inoculation), for Group MR VMP spray (PBA HatTrick[®] and PBA Boundary[®], CICA1007) and R (CICA0912, Genesis 425[™]) the first spray occurred after four infection events (14 rain days, 79 mm rain since inoculation). The number of rain days, rainfall and spray applications are summarised in Table 1.

Key findings of VMP15 (see Table 2) were:

- Under extreme disease pressure, Ascochyta can be successfully managed on susceptible varieties with frequent applications of registered rates of chlorothalonil
- Well managed Kyabra[®] yielded 1862 kg/ha with a GM of \$954/ha
- Under extreme disease pressure, unsprayed PBA HatTrick[®] yielded only 417 kg/ha (GM -\$4/ha)
- The new line CICA0912 performed well, yielding 1568 kg/ha (GM \$844/ha) with no foliar fungicide

The performance of PBA HatTrick[®] in VMP15 was both a surprise and a disappointment. In all previous VMP trials at Tamworth, unsprayed (Nil treatment) PBA HatTrick[®] has produced substantial and profitable yields. For example in the 2010 trial, VMP10, it produced 1707 kg/ha (Table 3). 2010 also had above average rain in Jun/Jul that persisted throughout the season, so was in fact more conducive to Ascochyta than 2015 (although 2015 had more rain days in Jun/Jul than 2010).

VMP10 was sown 19 May 2010 using disc openers on 38cm row spacing in plots 4m wide by 10m long. There were four replicates (Table 3). On 17 Jun, when plants were at the 3 leaf stage, the trial was inoculated during a rainfall event with a cocktail of nine isolates of Ascochyta collected from commercial chickpea crops in 2008 and 2009 at a rate of 1 million spores per mL in 200L/ha water. From inoculation to desiccation (28 Nov), the trial received 430mm rain in 67 rain days (46 days >1.0mm) ie wetter than VMP15 both in total mm and number of rain days. Both VMP15 and VMP10 were in seasons that had regular rainfall and so supported the Ascochyta development consistently over the season and so provide a strong evaluation of current varieties and advanced breeding lines. A number of the key findings of VMP10 were similar to VMP15:

- Under extreme disease pressure, Ascochyta can be successfully managed on susceptible varieties with registered rates of chlorothalonil
- Well managed Jimbour[®] yielded nearly 3t/ha with a GM of \$750/ha
- The performance of varieties and advanced breeding lines with improved resistance to Ascochyta provided the best gross margins

The findings below contrasted between the two VMP experiments

- in 2010 PBA Boundary[®] performed exceptionally well, yielding over 2t/ha without any foliar fungicide, a minimal yield loss (4%), compared with 53 % in 2015.
- Under extreme disease pressure in 2010 unsprayed HatTrick[®] still gave a profitable yield, but unsprayed HatTrick[®] yields were lower in 2015 and was not profitable

Table 1. VMP15 2015 dates, number of rain days (>1 mm rain), mm of rain and dates and number of 1 L/ha chlorothalonil applications, trial sown 18-19 May. *trial was AB inoculated on 16 June

Date	No. days	mm Rain	1L spray
28-31 May	4	31	
12 Jun			1 st All genotypes
16*-19 Jun	4	61	
22 Jun	1	1	
30 Jun-01 Jul	2	4	
9 Jul			2 nd All genotypes
10-17 Jul	8	12	
21 Jul			3 rd All genotypes
24-27 Jul	4	13	
21 Aug			4 th All genotypes
23-24 Aug	2	40	
1 Sep			5 th All genotypes
3 Sep	1	11	
4 Sep	1	6	
16 Sep	1	4	
11 Oct			6 th All genotypes
14 Oct	1	16	
22 Oct	1	18	
23 Oct	1	12	
26 Oct	1	10	7 th All genotypes

The following factors in VMP15 may have contributed to the nil PBA HatTrick^(b) treatments having poorer yields than in prior VMP trials:

- (a) parts of VMP15 were waterlogged during Jun/Jul; we know from past experience and commercial crops that any stress including waterlogging compromises PBA HatTrick's^(b) moderate resistance to Ascochyta.
- (b) interaction between herbicide damage and Ascochyta resistance – VMP15 sustained minor herbicide injury in August. This may have also compromised PBA HatTrick's^(b) moderate resistance to Ascochyta.
- (c) Change in the pathogen; the isolates used in VMP10 were collected from crops in 2008 and 2009 compared to the isolates used in VMP15 which were collected from 1999 to 2014. Recently collected isolates have shown a higher level of aggressiveness on PBA HatTrick. See Ascochyta Variability GRDC Update paper for further information.

Table 2. Number and rate/ha of chlorothalonil sprays, cost of spraying, grain yield, and gross margin for seven desi and three kabuli chickpea varieties on red soil in the Tamworth VMP15 trial. (GMs also take into account other production costs estimated at \$300/ha; chickpea price desi \$730/t; kabuli \$1000/t) Yield P<0.001, lsd 417kg/ha; GM P<0.001, lsd \$354/ha

Variety and treatment		No. Sprays	Cost \$/ha	Yield kg/ha	GM \$/ha
CICA0912	1.0L	7	105	1853	984
Genesis425	1.0L	7	105	1875	1470
CICA1007	1.0L	7	105	1846	982
PBA Boundary ^(b)	1.0L	7	105	1755	876
PBA Monarch ^(b)	1.0L	7	105	1274	869
PBA HatTrick ^(b)	1.0L	7	105	1722	852
CICA1302	1.0L	7	105	1864	954
CICA1303	1.0L	7	105	1949	1018
Kyabra ^(b)	1.0L	7	105	1862	954
Kalkee	1.0L	7	105	1659	1254
CICA0912	Nil	0	0	1568	844
Genesis425	Nil	0	0	1144	844
CICA1007	Nil	0	0	1083	491
PBA Boundary ^(b)	Nil	0	0	1233	600
PBA Monarch ^(b)	Nil	0	0	887	587
PBA HatTrick ^(b)	Nil	0	0	417	4
CICA1302	Nil	0	0	0	-300
CICA1303	Nil	0	0	0	-300
Kyabra ^(b)	Nil	0	0	0	-300
Kalkee	Nil	0	0	1589	1289

Table 3. Number and rate/ha of chlorothalonil sprays, cost of spraying, grain yield, and gross margin for four desi chickpea varieties in the Tamworth VMP10 trial. (GMs also take into account other production costs estimated at \$300/ha; chickpea price \$450/t))

Variety and treatment	No. Sprays	Cost \$/ha	Yield kg/ha	GM \$/ha
Jimbour 1.0L	14	294	2988	750
^a Kyabra [Ⓟ] 1.0L	14	294	2549	553
PBA HatTrick [Ⓟ] 1.0L	14	294	2604	578
PBA Boundary [Ⓟ] 1.0L	14	294	2410	491
Jimbour Nil	0	0	0	-300
Kyabra [Ⓟ] Nil	0	0	0	-300
PBA HatTrick [Ⓟ] Nil	0	0	1707	468
PBA Boundary [Ⓟ] Nil	0	0	2320	744

^aKyabra[Ⓟ] 1.0L one of the four reps was severely affected by water logging which (i) compromised Ascochyta control and (ii) impacted on yield

Acknowledgements

This research is made possible by the significant contributions of growers through both trial cooperation, field access and the support of the GRDC; the authors most gratefully thank them and the GRDC. Thanks to Woods Grains, Goondiwindi and Glen Coughran, “Beefwood”, Moree for providing seed for the trials. We also thank agronomists for help with the crop inspections and submitting specimens, Gordon Cumming, Pulse Australia for industry liaison and chemical companies who provide products for research purposes and trial management.

Contact details

Kevin Moore
 NSW DPI
 Ph: 02 6763 1133
 Mb: 0488 251 866
 Fx: 02 6763 1100
 Email: kevin.moore@dpi.nsw.gov.au

Kristy Hobson
 NSW DPI
 Ph: 02 6763 1174
 Mb: 0400 955 476
 Fx: 02 6763 1100
 Email: kristy.hobson@dpi.nsw.gov.au

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A new DNA tool to determine risk of chickpea *Phytophthora* root rot

Sean Bithell¹, Kevin Moore¹, Kristy Hobson¹, Steve Harden¹, Willy Martin² and Alan McKay³

¹NSWDPI, Tamworth, NSW; ²DAFQ Warwick, ³SARDI, Adelaide, SA

Key words

Phytophthora root rot, risk management, inoculum measurement, PreDicta B[®]

GRDC code

DAS00137, DAN0172, DAN0176

Take home message

- Increasing level of inoculum (oospores/plant) of *Phytophthora medicaginis* (Pm) was strongly correlated with decreasing yield of the moderately resistant variety Yorker
- An inoculum level of 660 oospores/plant (PreDicta B[®] > 5000 Pm copies/g soil) at sowing significantly reduced yields compared with lower inoculum levels under both dryland and irrigated conditions
- Testing soil samples from growers' 2015 paddocks confirmed the results of testing 2014 samples that the PreDicta B[®] soil Pm test can identify Pm in growers paddocks in NSW and QLD
- These findings provide further evidence that the PreDicta B[®] Pm test will be a useful tool for growers to determine their risk of *Phytophthora* root rot

Note: the SARDI PreDicta B[®] test for *Phytophthora medicaginis* is under development and is not yet available commercially

Phytophthora medicaginis detection in soil

Phytophthora medicaginis (Pm), the cause of chickpea *Phytophthora* root rot (PRR) is endemic and widespread in southern QLD and northern and north central NSW. Under conducive conditions, PRR can cause 100% loss. The pathogen survives from season to season on chickpea volunteers, lucerne, native medics, sulla and as resistant structures (oospores) in roots and soil.

A PreDicta B[®] soil DNA test has been developed by the South Australian Research and Development Institute (SARDI) to quantify the amount of Pm DNA in soil samples and so provide a measure of the amount of Pm inoculum (infected root tissue and oospores) in paddocks. We report on the second season of studies to assess the capability of this test to:

1. detect Pm inoculum in soil from commercial paddocks
2. predict the risk of PRR disease and potential yield losses in chickpea

Pm inoculum level, PRR disease and yield

It would be useful if the Pm DNA test could predict the amount of PRR disease and potential losses. For example, would paddocks with nil, low and high Pm inoculum levels have nil, low and high PRR disease and yield losses? Our 2014 Pm inoculum concentration field trial (Tamworth) using the PRR susceptible variety Sonali (rating S) showed that yield losses were greatest at the highest soil Pm concentrations but that even at low soil concentrations (100 oospores/plant) substantial yield loss occurred. Pm is able to multiply quickly under high soil water conditions. The 2014 trial showed that following a saturating rain event, the amount of disease and extent of yield loss with medium

levels of inoculum (500 and 1000 oospores/plant) caught up with those of higher levels of inoculum (2000 and 4000 oospores/plant)

The aim of the 2015 field trial (DAF Qld Hermitage Research Station, Warwick, QLD) was to relate the Predicta B[®] Pm test to PRR level and yield loss for low inoculum levels (<1000 oospores/plant) using the most PRR resistant variety Yorker^ϕ (rating MR), under dryland and irrigated conditions. Irrigation was included to specifically test if low inoculum treatments would have similar effects on disease and yield loss to those of high inoculum treatments under disease conducive conditions. On 10 June 2015, a range of Pm inoculum levels was established by applying, at sowing, different rates of oospores in-furrow. On 10-11 Jun, thirty soil samples (150 mm depth cores) per plot (5 reps) were pooled and tested for soil Pm concentration by PreDicta B[®]. The trial was also sampled for end-season DNA Pm concentrations on 15 December (data not available at time of writing).

Irrigation was applied on 10-11 Sep and on 16-17 Oct following 2 weeks with low rainfall (< 3mm). Winter rainfall was similar to long term average values for July (22mm) and August (25mm) but September and October both had below average rainfall totals. November was wet with 97mm of rain.

Soil Pm DNA values at sowing differed significantly among oospore treatments but not between irrigation treatment (Table 1). Three of ten Nil (0) oospore plots had positive but low Pm DNA results, indicating background *Phytophthora* in some plots.

On 13 Oct (end of flowering), the irrigated 130 and 660 oospores/plant treatments had significantly more PRR than the dryland 130 and 660 oospores/plant treatments (Table 1). By 12 Nov (dryland treatments senescing), the irrigated 40, 130 and 660 oospores/plant treatments had significantly more PRR than the dryland 40, 130 and 660 oospores/plant treatments.

The interaction of irrigation and oospore treatments on grain yield was complex as indicated by (Table 1, Figure 1):

- (i) at low inoculum levels (zero and 40 oospores/plant), irrigation increased yield compared with dryland
- (ii) for medium inoculum (130 oospores/plant), irrigation had no significant effect on yield
- (iii) for the highest inoculum level (660 oospores/plant) irrigation reduced yield compared with the dryland treatment.

These interactions suggest that at low PRR levels, the primary effect of irrigation is on yield, but at high PRR levels the primary effect is on disease. However, the shape of these relationships are likely to vary from season to season due to differences in seasonal rainfall (Figure 1).

Furthermore multiple processes will affect outcomes. For example, although yields did not differ between the irrigated and dryland 130 oospores/plant treatments (~3000 P.med DNA seq no/g soil) there was more disease in the irrigated treatment. In this 2015 trial, the uninfected irrigated plants in a plot will have had grain yield benefits from irrigation and so probably compensated for the yield loss of infected plants. However, for seasons with above average early-season rainfall there may be greater early-season disease development and hence greater impacts on yield at this same 3000 P.med DNA seq no/g soil inoculum level.

Under PRR conducive conditions, can low initial levels of inoculum catch up to high initial levels with regard to disease severity and yield loss? This is not clear from the current experiment and further research is required.

Can the Pm DNA soil test predict risk of *Phytophthora*? Based on the results of this trial with Yorker^ϕ (MR) and the 2014 Tamworth one with Sonali (S), the answer is YES. For Yorker^ϕ significant yield loss can be expected with starting (pre-sow sampling) inoculum levels above ca 3000 Pm DNA sequences/g soil (ca 130 oospores/plant).

However, these values may need to be interpreted with some caution as seasonal conditions will modify outcomes, for instance in a dry season less disease may develop from the same amount of inoculum.

Table 1. Irrigation-oospore treatment, soil Pm DNA concentration, PRR assessment and yield of Yorker in 2015 Pm inoculum trial at Warwick, QLD (Soil Pm concentration: $P < 0.001$; LSD 1092.6; 13 Oct PRR rating: $P = 0.038$; LSD = 0.58; 12 Nov row cm of PRR stunted plants: $P = 0.035$; LSD 46.4; Grain yield: $P < 0.001$; LSD = 480.7)

Treatment, dryland (D), irrigated (I), no. oospores per plant	Soil Pm DNA concentration at sowing no. Pm sequences/g soil	13 Oct PRR rating (1= no disease, 9 = all plants dead)	12 Nov. cm of row of PRR stunted plants	Grain yield, kg/ha
D-0	342	1.1	16	3198
D-40	1986	1.7	18	2961
D-130	3051	2.0	88	3038
D-660	5357	3.1	203	2402
I-0	169	1.2	6	3914
I-40	1765	1.8	78	3631
I-130	2996	2.8	185	2966
I-660	5925	4.2	395	1764

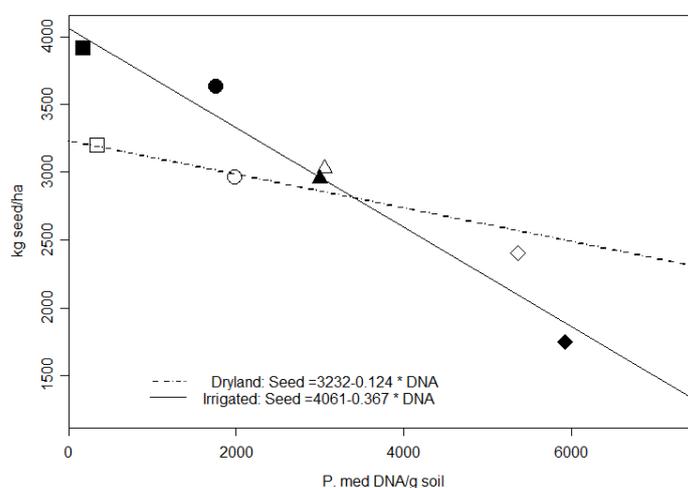


Figure 1. Multiple regression for plot soil Pm concentrations at sowing vs. grain yield for dryland (black symbols) and irrigated (white symbols) treatments (model $R^2 = 0.745$), treatment means presented.

Pm DNA detection in soil samples from commercial paddocks

We evaluated the ability of the Pm DNA test to detect Pm in soil samples from growers' paddocks.

Over the winter-spring period of 2014, soil samples were collected from fields in central (16) and south-western Queensland (10), and Victoria (7). Most paddocks included chickpeas in the rotation but not all had chickpeas in 2014. There were eight perimeter sample sites per paddock, one near

each corner and one near the midpoint of each side. At each of the eight sample sites, a W collection pattern was walked towards the centre of the paddocks and 10 soil cores (150 mm depth PreDicta B® soil corer) collected every 20 – 25 paces along the sample path (total distance 200 – 250 m per sample site), giving a total of 80 soil cores.

Samples (9) were also collected from southern NSW, in this case most paddocks included either lucerne or lupins in the rotation. For these sites a diagonal collection pattern across low lying and weedy areas of paddocks was used and 80 150mm PreDicta B® cores collected per site.

Soil samples were stored in sealed plastic bags at 5°C. Samples were homogenised by cutting up cores and mixing, following which a 400g sub sample was sent to SARDI for DNA analysis. The remainder of each sample was then restored at 5°C until the baiting experiment was setup.

Samples from 43 paddocks were prepared for DNA analysis and a Pm baiting experiment. Subsamples of soil were dried at 105°C for 24h to determine soil moisture content, then non-dried soil was mixed with sand (dry weight basis, 55g soil + 154g sand), placed in a plastic cup (70mm width, 75mm height). There were five reps; soil from a Pm inoculated field trial (MET14) served as a control. Three Sonali seeds were sown in each cup, the cups placed in a glasshouse (RCB design). The cups were watered to 21% soil moisture content three times a week. After 18 days the cups were flooded for 48h then drained. Seedlings were assessed for disease (chlorosis, stem cankers, death) three times a week. Stem canker tissues were plated to isolate Pm. Cultures with Phytophthora like growth on cornmeal agar were plated on low strength V8 agar and colony morphology, oospore production and oospore size used to identify Pm like cultures. The isolation of Pm was attempted from all treatments that produced chlorosis followed by the appearance of Pm like stem cankers, in addition, the isolation of Pm was also attempted from any treatments where there were disease symptoms or seedlings with poor growth. After eight weeks the experiment was terminated.

Ten of the 43 paddock soil treatments produced PRR like cankers on plants, Pm like cultures were isolated from eight samples from growers paddocks; Pm like cultures were also isolated from the MET14 control soil, giving a total of nine Pm isolates. One of the samples (NIE1) produced cankers that were not caused by Pm.

Of the 43 paddock soil treatments (including the MET14 control soil), 9 had positive Pm DNA results. Comparing the DNA results to the isolation results showed that most (8/9, 89%) samples which had positive DNA results also yielded Pm cultures and that most (33/34, 97%) samples which had negative DNA results also did not yield Pm cultures (Table 2).

Notably, one sample (LOU2) which yielded a Pm culture was negative for Pm DNA.

One sample (A) was positive for Pm DNA but did not yield Pm cultures, seedlings in all 5 cups remained healthy. This sample that did not produce any PRR symptoms had a lower Pm DNA value (1,234 Pm copies/g soil) than other samples (range 2,443-813,436 Pm copies/g soil). Possible explanations for this result is: (i) more time may be required for symptoms to develop, or (ii) that the pathogen had died but some DNA had been detected.

Table 2. Comparison of *Phytophthora medicaginis* (Pm) DNA detection in 43 paddock soil samples and isolation success of Pm from Sonali chickpeas grown in these samples

		43 samples analysed for Pm DNA	
		9/43 + Pm DNA	34/43 nil Pm DNA
43 soil samples baited with chickpeas for Pm	9/43 + Pm isolates	8/9 (positives)	1/34 (false negatives)
	34/43 nil Pm isolates	1/9 (false positives)	33/34 (negatives)

These second season of results for the capability of the soil Pm DNA test are again generally promising, with most samples with positive and negative Pm DNA results corresponding to expected Pm isolation results. However, results for some samples indicate that further work is required to a) identify what factors may contribute to false negative results and b) determine if false positives are due to the presence of dead or inactive Pm DNA.

Pm DNA sampling in paddocks and disease risk determination

The DNA result for a soil sample from a paddock can only provide an indication of inoculum concentration and disease risk for the areas of the paddock which were sampled. Therefore, the spread and locations of sampling across a paddock will affect how representative DNA results are for a paddock. Because of the risk of rapid PRR disease build up following wet conditions it may be appropriate to treat a negative Predicta B[®] test result as indicating a low risk rather than a nil risk, as the pathogen could still be in areas of the paddock that were not sampled and so still cause PRR and reduce yield.

To maximise the probability of determining the PRR risk of a paddock, target those areas of the paddock where Pm is more likely to occur. The pathogen thrives in high soil moisture contents and so often occurs in low lying regions of paddocks where pooling following rain may occur. The pathogen also carries over from season to season on infected chickpea volunteers, lucerne and, native medics. Including low lying areas and weedy areas of paddocks during PreDicta B[®] soil sampling may provide the best strategy to identifying a paddocks disease risk of PRR in chickpea.

Detailed information on control of PRR in chickpea is available at:

<http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot>

Acknowledgements

This research is made possible by the significant contributions of growers through both trial cooperation, paddocks access and the support of the GRDC, the authors would like to thank them for their continued support. Kurt Lindbeck (NSW DPI), Frank Henry () and Peter Keys (DAFQ) kindly located sample sites. Thanks to Gail Chiplin and Kris King for technical support

Contact details

Sean Bithell & Kevin Moore

NSW Department Primary Industries

Ph: 0429 201 863 & 0488 251 866

Fx: 02 6763 1100

Emails: sean.bithell@dpi.nsw.gov.au & kevin.moore@dpi.nsw.gov.au

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Phytophthora in chickpea varieties HER15 trial –resistance and yield loss

Kevin Moore¹, Lisa Kelly², Kristy Hobson¹, Steve Harden¹, Willy Martin³, Kris King³, Gail Chiplin¹ and Sean Bithell¹

¹ NSW DPI Tamworth; ² DAFQ Toowoomba; ³ DAFQ Warwick

Key words

Phytophthora root rot, variety, risk management

GRDC code

DAN00176, DAN00151, DAQ00186, DAS00137

Take home message

- In a wet season, substantial (94%) yield losses from PRR occur in susceptible varieties such as PBA Boundary[Ⓟ]. Do not grow PBA Boundary[Ⓟ] if you suspect a PRR risk
- Varieties with improved resistance to PRR (PBA HatTrick[Ⓟ] and Yorker[Ⓟ]) can also have large yield losses (68-79%) in a very heavy PRR season
- Although yield losses will occur in very heavy PRR seasons, crosses between chickpea and wild *Cicer* species such as the breeding line CICA1328 offer the best resistance to PRR
- Avoid paddocks with a history of lucerne, medics or chickpea PRR

Varietal resistance to phytophthora root rot

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

Detailed information on control of PRR in chickpea is available at:

<http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot>

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

From 2007 to 2015 PRR resistance trials at the DAF Qld Hermitage research Facility, Warwick QLD have evaluated a range of varieties and advanced PBA breeding lines. Each year the trial is inoculated with *P. medicaginis* at planting. There are two treatments, (i) seed treatment with thiram + thiabendazole and metalaxyl and regular soil drenches with metalaxyl (Note: soil drenches with metalaxyl not currently registered) and (ii) seed treatment with thiram + thiabendazole only with no soil drenches. The first treatment has prevented infection by the PRR pathogen in all of these trials. The difference in yield between the metalaxyl-treated plots and untreated plots are used to calculate the yield loss caused by PRR i.e. % loss = 100*(Average yield of metalaxyl-treated plots – Average yield of nil metalaxyl plots)/ Average yield of metalaxyl-treated plots.

Yields in metalaxyl-treated plots were close to seasonal averages for the 2015 season with the lowest yielding breeding lines and varieties (CICA1328, Yorker[Ⓛ] and PBA HatTrick[Ⓛ]) yielding close to 2.5 t/ha (Table 1).

In 2015 the level of PRR in the trial was considerably higher than those previous seasons such as 2014 (Table 2). For example yield losses were greater than 40% for CICA1328 in 2015 but only 1.8% in 2014 and yield losses for PBA Boundary[Ⓛ] were 94% in 2015 and 74% in 2014. However, the 2015 trial again confirmed that Yorker[Ⓛ] and PBA HatTrick[Ⓛ] had better resistance than PBA Boundary[Ⓛ] (Table 1), which has been consistent across previous trials.

Results for the high PRR disease season of 2015 showed that susceptible varieties sustain substantial yield loss from PRR and that varieties with moderate resistance have reduced losses. The 2015 trial again confirmed the superior PRR resistance of the PBA breeding line CICA1328 which is a cross between a chickpea (*Cicer arietinum*) line and a wild *Cicer* species.

CICA1007 was included in the 2015 trial because it has high yield and large seed size in a Yorker[Ⓛ] background. In the absence of PRR it was the second highest yielder in the trial (2.93t/ha) and its yield loss to PRR was similar to Yorker[Ⓛ].

Table 1. Yields of commercial chickpea varieties and breeding lines protected from Phytophthora root rot, and % yield losses from PRR in a 2015 trial at Warwick QLD. (P Yield<0.001; lsd Yield = 0.46)

Variety/line ^A	Yield (t/ha) in absence of <i>Phytophthora</i> infection	Yield (t/ha) in presence of <i>Phytophthora</i> infection	% yield loss due to <i>Phytophthora</i> infection
CICA1328 ^A	2.64	1.54	41.7
D06344>F3BREE2AB027 ^A	2.52	1.05	58.4
PBA HatTrick [Ⓛ]	2.50	0.81	67.7
Yorker [Ⓛ]	2.61	0.57	78.7
CICA1007	2.93	0.71	75.9
CICA0912	2.76	0.37	86.6
PBA Boundary [Ⓛ]	2.88	0.17	94.0

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

Table 2. Yields of commercial chickpea varieties and breeding lines protected from Phytophthora root rot, and % yield losses from PRR in a 2014 trial at Warwick QLD. (P Yield<0.05; lsd Yield = 0.80)

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

^A These lines are 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.

This research is made possible by the significant contributions of growers through both trial cooperation, field access and the support of the GRDC, the authors would like to thank them for their continued support.

Contact details

Kevin Moore
NSW Department Primary Industries
Mb: 0488 251 866
Fax: 02 6763 1100
Email: kevin.moore@dpi.nsw.gov.au

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Integrated management of crown rot in a chickpea – wheat sequence

Andrew Verrell, NSW Department of Primary Industries, Tamworth

Key words

row placement, row spacing, wheat, stubble, chickpea

GRDC code

DAN00171 - Winter pulse agronomy project

Take home message

- Sow chickpea crops between standing wheat rows
- Sow the following wheat crop *directly* over the row of the previous year chickpea crop
- Keep wheat stubble intact and do not spread it across the surface

Introduction

Crown rot, caused by the stubble-borne fungus *Fusarium pseudograminearum* (*Fp*), remains a major limitation to winter cereal production across the northern grains region of Australia. Crop sequencing with non-host crops, has proven to be one of the best means of reducing the impact of crown rot (CR) infection (by 3.4-41.3%) and increasing wheat yield (by 0.24-0.89 t/ha) compared to a cereal-wheat sequence (Kirkegaard *et al.* 2004, Verrell *et al.* 2005). While inter-row sowing has been shown to reduce the impact of CR and increase yield, by up to 9%, in a wheat-wheat sequence (Verrell *et al.* 2009). Verrell *et al.* (2014) showed that using mustard-wheat and chickpea-wheat crop sequencing resulted in a 40-44% increase in wheat yield over a continuous wheat system under zero-tillage and adding inter-row sowing increased wheat yield by a further 11-16% depending on the row placement sequences.

Chickpea are the most prevalent break crop grown in sequence with wheat in the northern NSW region. Chickpea crops are reliant on the use of post-sow pre-emergent residual herbicides (Group C and H) for broadleaf weed control and a common commercial practice is to level the seeding furrow after sowing, usually with Kelly chains, to avoid the risk of herbicide residue concentrating in the furrows and causing damage. The consequence of leveling the seed furrow to avoid possible herbicide damage is that any standing wheat residue, under a zero-tillage system, is shattered and spread across the entire soil surface. If this wheat residue is infected with *Fp* then CR inoculum is no longer confined to the standing wheat rows.

There was a need to examine whether integrating row placement, stubble management, chickpea row spacing and ground engaging tool would affect the incidence of *Fp* and grain yield in wheat in a chickpea– wheat sequence grown under a zero-tillage system.

What did we do?

A three year crop sequence experiment (wheat-chickpea-wheat) was established at Tamworth in 2012 to examine the effect of ground engaging tool, chickpea row spacing, row placement and wheat residue management on the incidence of *Fp* and grain yield of a wheat crop.

In 2012, durum wheat (EGA Bellaroi¹) was sown into a cultivated paddock using a Trimble® RTK auto-steer system fitted to a New Holland TL80A tractor with narrow row crop tyres. The crop was sown with a disc seeder on 40 cm row spacing and bulk harvested with the residue cut at a uniform height of 24 cm.

In 2013, chickpea (cv. PBA HatTrick[®]) was sown at 80 kg/ha and treatments consisted of; main-plot was row placement; (between or on 2012 wheat rows), sub-plot was stubble management; (standing or slashed and spread), sub-sub plot was row spacing; (narrow 40 cm or wide 80 cm) and sub-sub-sub plots were ground engaging tool; (Barton[®] single disc opener or Janke[®] coultter-tyne-press wheel parallelogram). The stubble management treatments was applied after the plots were sown.

In 2014, wheat (cv. EGA Gregory[®]) was sown over the chickpea plots and treatments consisted of; sub-sub plots as row placement; (between or on 2012 wheat rows) and sub-sub-sub plots were ground engaging tool; (Barton single disc opener or Janke coultter-tyne-press wheel parallelogram).

What did we find?

Chickpea grain yield increased when sown with a disc opener (by 6%), on narrow rows (by 22%) and sown between the 2012 wheat rows (by 7%) but stubble management did not have a main effect on chickpea yield. However, stubble management had a significant interaction with row spacing where sowing chickpeas on narrow rows (40 cm) into standing residue out yielded narrow rows where the residue had been slashed (by 6%) (see Figure 1). There was no significant yield effects with chickpeas sown on wide rows (80 cm) whether the wheat residue was left standing or slashed.

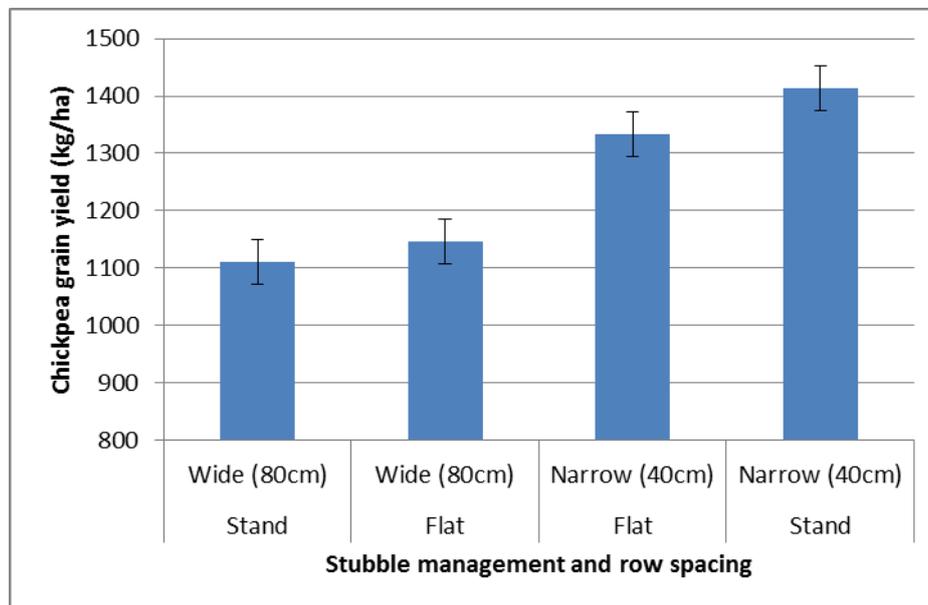


Figure 1. Effect of row spacing and wheat stubble management on chickpea grain yield (kg/ha)

In the 2014 wheat crop, sowing with a coultter-tyne-press wheel out yielded the disc opener (by 6.3%). Row placement of the wheat (relative to the 2012 wheat crop) had a significant interaction with the stubble treatment in the 2013 chickpea crop. Where wheat was sown into the space between the old wheat rows (2012) and the stubble was left standing in the 2013 chickpea crop resulted in the highest grain yield (3718 kg/ha) (see Fig. 2). This was significantly higher than the other row x stubble combinations; on-row x flat, on-row x standing and between-row x flat which yielded, 3585, 3515 and 3487 kg/ha, respectively, which were not significantly different from one another.

The incidence of *Fp* at harvest, as main effects, was lower where chickpeas had been sown between wheat rows (6.6%) compared to on the row (10.0%) and lower when stubble was left standing (6.4%) compared to spreading (9.9%). The type of ground engaging tool, row spacing in the previous chickpea crop or row placement of the 2014 wheat crop had no significant main effect on the incidence of *Fp* at harvest. For the narrow row (40 cm) chickpea system; sowing on the old wheat

row led to a significant increase in the incidence of *Fp* at harvest in the following wheat crop (11.8%) compared to sowing between the old wheat rows (5.8%).

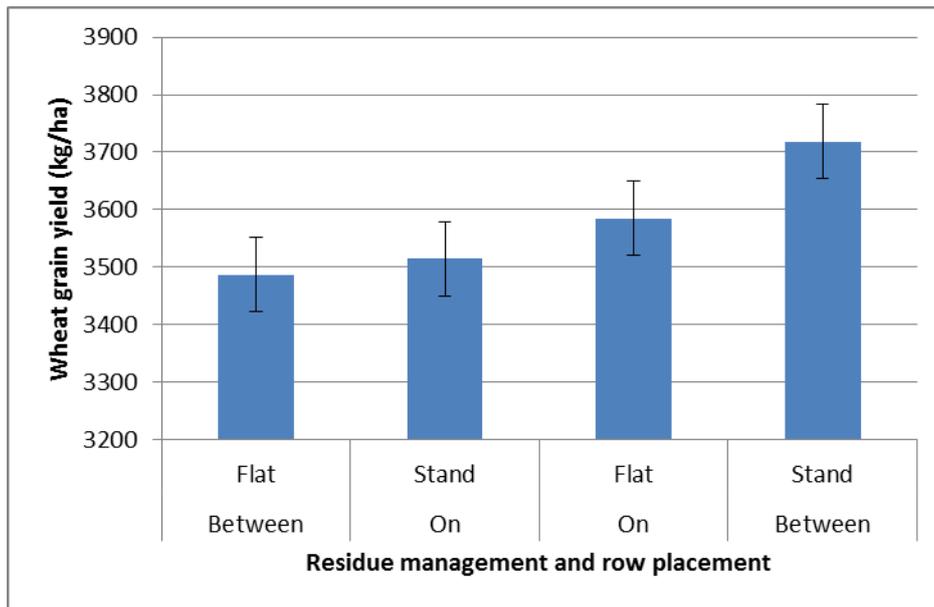


Figure 2. Effect of row placement (relative to the 2012 wheat crop) and stubble management in the 2013 chickpea crop on grain yield (kg/ha) in the 2014 wheat crop

Under the wide row (80 cm) chickpea system; row placement had no effect on the incidence of *Fp* (mean 7.5%). Sowing the 2013 chickpea crop between standing wheat rows and the following wheat crop directly over the previous chickpea row and between the old wheat rows resulted in the lowest incidence of *Fp* (4.6%) (see Fig. 3).

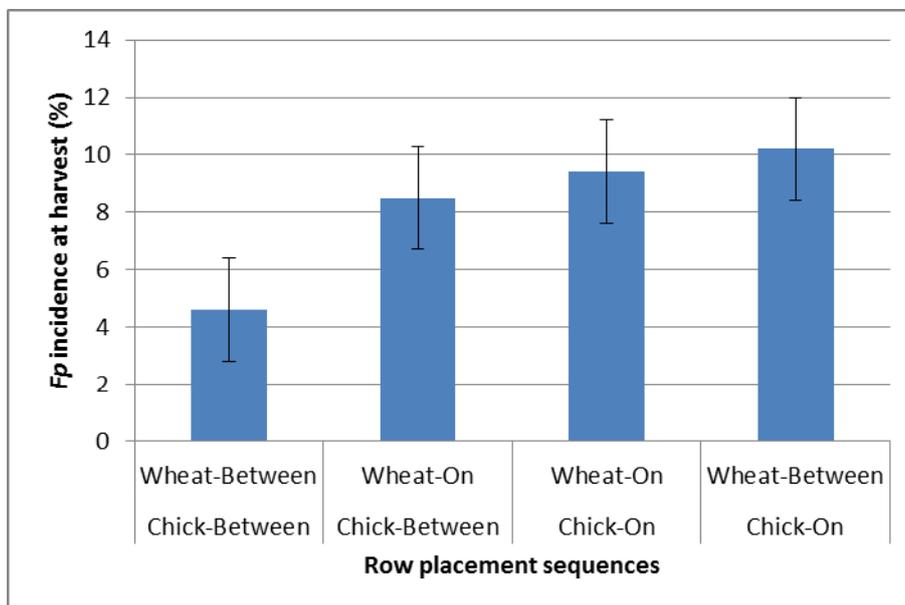


Figure 3. The interaction of chickpea row placement (2013) and wheat row placement (2014) on the incidence of *Fp* in wheat

Other row placement combinations; chickpea between wheat rows x wheat on-rows, chickpea on wheat rows x wheat on-rows, and chickpea on-rows x wheat between wheat rows resulted in *Fp* levels of 8.5, 9.4 and 10.2%, respectively.

Conclusion

At Tamworth in 2013, sowing chickpea on narrow rows (40 cm) realised a 22% yield advantage over wide rows (80 cm). Also sowing chickpeas between standing wheat rows resulted in a higher yield (by 6%) compared to sowing the crop then slashing the wheat stubble and spreading it across the surface. Growing chickpeas between standing wheat stubble has been shown to provide a yield advantage in previous studies largely by reducing the incidence of aphid transmitted viruses (Verrell and Moore 2015).

The highest wheat yield (3718 kg/ha) came from sowing the wheat into the inter row space of the old wheat crop (2 years old) and keeping the stubble standing. Using a tyne also resulted in a yield advantage over a disc opener. When stubble was left standing the incidence of *Fp* was lower (6.4%) compared to spreading stubble across the surface (9.9%). Sowing the 2013 chickpea crop between standing wheat rows and the following wheat crop directly over the previous chickpea row and between the old wheat rows resulted in the lowest incidence of *Fp* (4.6%). Any stubble management practice which spreads residues into the inter row space is likely to undo row placement benefits associated with reducing the incidence of crown rot infection, as *Fp* inoculum is no longer confined to the standing wheat rows. The perceived crop safety benefits of leveling the seeding furrow after applying post-sow pre-emergent residual herbicides (Group C and H) in chickpeas needs to be balanced against potential impacts on chickpea yield and increased incidence of crown rot infection in the following winter cereal crop.

Acknowledgements

The research undertaken as part of project DAN00171 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. Thanks to Michael Nowland and Paul Nash (NSW DPI) for their assistance in the trial program. *Fp* levels were kindly determined through laboratory plating by the NSW DPI Cereal Pathology Group based at Tamworth.

References

- Verrell, A.G., Simpfendorfer S., Nash P. and Moore K. (2009) Can inter-row sowing be used in continuous wheat systems to control crown rot and increase yield? 13th Annual Symposium on Precision Agriculture in Australasia (2009), UNE, Armidale.
- Verrell, A.G., Simpfendorfer S., Nash P. and Moore K. (2005) Crop rotation and its effect on crown rot, common root rot, soil water extraction and water use efficiency in wheat. Proceedings 2005 GRDC Grains Research Update, Goondiwindi.
- Verrell A (2014) Managing crown rot through crop sequencing and row placement. GRDC. Available at: <http://grdc.com.au/Research-and-Development/GRDC-Update%20Papers/2014/07/Managing-crown-rot-through-crop-sequencing-and-row-placement>
- Verrell A and Moore KJ (2015). Managing viral diseases in chickpeas through agronomic practices Australian Agronomy Conference, Hobart.

Contact details

Dr Andrew Verrell
NSW Department Primary Industries
Ph: 0429 422 150
Email: andrew.verrell@dpi.nsw.gov.au

Reviewed by Dr Steven Simpfendorfer

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Crown rot – does cereal crop or variety choice matter?

Steven Simpfendorfer, NSW DPI Tamworth

Key words

Yield benefit, inoculum load, resistance, crown rot, variety

GRDC codes

DAN00175 – National crown rot epidemiology and management program

Take home message

- Barley and bread wheat varieties do vary in their yield response to crown rot infection.
- Variety choice can provide a 20-50% yield benefit over growing the susceptible variety EGA Gregory[Ⓛ] in the presence of high levels of crown rot infection.
- However, all varieties are **susceptible** to crown rot infection and will **not** significantly reduce inoculum levels for subsequent crops. Variety choice is **NOT** a sole solution to crown rot.
- Crown rot tolerance should not be the only consideration in variety choice, impacts on other pathogen populations, especially *Pratylenchus thornei*, resistance to other pathogens, grain quality and delivery should all be considered along with relative grain prices.

Background

Crown rot, caused predominantly by the fungus *Fusarium pseudograminearum* is a significant disease of winter cereal crops in the northern NSW and southern Qld. All winter cereal crops host the crown rot fungus. Yield loss varies between crops and the approximate order of increasing loss is oats, barley, triticale, bread wheat and durum. Barley is very susceptible to crown rot infection and will build up inoculum but tends to suffer reduced yield loss through its earlier maturity relative to wheat. Late planted barley can still suffer significant yield loss especially when early stress occurs within the growing season.

Yield loss trials conducted across 11 sites in northern NSW in 2007, in collaboration with the Northern Grower Alliance (NGA), found that the average yield loss from crown rot was 20% in barley (4 varieties), 25% in bread wheat (5 varieties) and 58% in one durum (EGA Bellaroi[Ⓛ]). In 2007, a yield benefit of only around 5-10% could be demonstrated in bread wheat varieties between choosing the best and the worst entries in the presence of high levels of crown rot infection. However, recent research highlights that some newer bread wheat varieties appear to differ significantly in their level of yield loss to crown rot with some in the northern region (Sunguard[Ⓛ], Suntop[Ⓛ], LRPB Spitfire[Ⓛ], LRPB Lancer[Ⓛ] and Mitch[Ⓛ]) appearing to suffer less yield impacts compared to the widely grown EGA Gregory[Ⓛ]. NSW DPI trials from a total of 23 sites conducted across the northern region in 2013 and 2014 indicate that this can represent a yield benefit of around 0.50 t/ha in the presence of high levels of crown rot infection. In a relatively short period of time the yield benefit associated with bread wheat variety choice in the presence of high crown rot infection has grown to around 20-30% with some of these newer varieties.

Continued research in 2015

A further 12 replicated crown rot yield loss trials were conducted across northern NSW and southern Qld in 2015 with sites spread from Wongarbron in the south to Macalister in the north (Figure 1). There were two barley, 13 bread wheat and one durum entry evaluated across the trials in 2015 (Figure 2). The trials used an inoculated versus uninoculated trial design to evaluate the relative yield response of varieties to crown rot infection at each site. Each site was soil cored at sowing (separate bulk samples across each range) to determine background pathogen levels using the DNA based soil

test PreDicta B®. Post-harvest soil cores were also collected from all plots at Wongarbron and Macalister in December and analysed by PreDicta B to determine the impact of varieties on the build-up of populations of the root lesion nematode, *Pratylenchus thornei* (Pt) and crown rot inoculum over the 2015 season. These two sites were targeted for post-harvest assessment based on PreDicta B analysis of all 12 sites at sowing.

Yield impact – site effects

Background crown rot inoculum levels existed at half of the 12 sites with medium background crown rot levels at Mullaley, Macalister and Merriwa while high background levels were measured at Coonamble, Wongarbron and Mungindi. All trials were conducted in grower paddocks and generally co-located with GRDC funded National Variety Trials (NVT). One criterion for selecting sites is that they are generally paddocks with a good crop rotation, with all 12 sites having a non-winter cereal break (chickpea, canola or sorghum) as the previous crop within the rotation sequence. The medium to high background crown rot inoculum levels still evident at half of the sites highlights the continuing difficulty of managing stubble-borne inoculum levels of the crown rot fungus across the region. Background crown rot levels potentially underestimate the yield impact associated with crown rot infection as varying levels of infection would have occurred in the no added crown rot (CR) treatment plots at these sites.

Yield varied across the sites which, when averaged across the 16 winter cereal entries, ranged from 4.60 t/ha at Mullaley down to 2.87 t/ha at Mungindi in the no added CR treatments (Figure 1). The addition of crown rot inoculum at sowing (added CR) significantly reduced yield at all 12 sites in 2015 when averaged across entries. Average yield loss (difference between no added CR and added CR treatments) ranged from 7% (0.29 t/ha) at Trangie up to 43% (1.22 t/ha) at Mungindi (Figure 1).

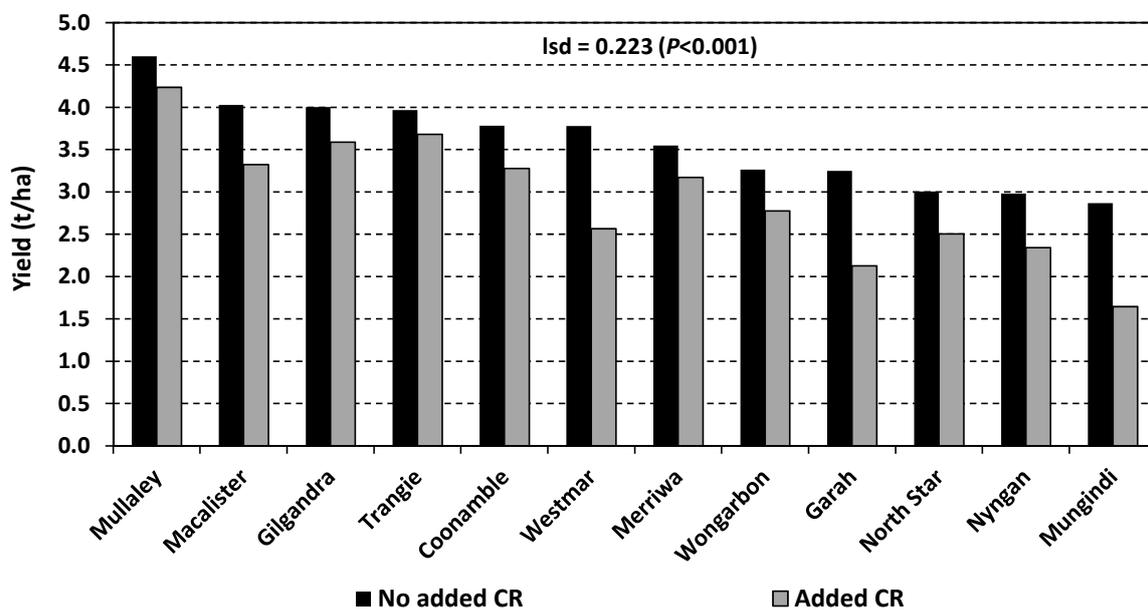


Figure 1. Average yield of 16 winter cereal entries in the absence and presence of added crown rot (CR) inoculum at 12 trial sites in 2015

Did cereal crop type and/or variety make a difference?

An across site analysis was conducted to assist in summarising the general trends in varietal performance across the 12 sites in 2015. Only yield results from the barley variety Commander[®] at Mungindi were excluded from the analysis due to severe damage from the herbicide Topik[®] which was applied across the predominantly wheat trial site. Significant lodging of both barley varieties

occurred at North Star due to delayed harvest of the trial site waiting for some of the bread wheat entries to mature. Unfortunately a significant rain event occurred during this period which severely lodged the barley and caused some sprouting which differentially impacted on barley yield at this site with La Trobe[Ⓛ] appearing to be more disadvantaged than Commander[Ⓛ]. Barley yellow dwarf virus (BYDV) was evident in the Merriwa trial site with the yield impact appearing to be greater in La Trobe[Ⓛ] (2.78 t/ha) than in Commander[Ⓛ] (3.44 t/ha). Based on Western Australian data Commander[Ⓛ] is rated MR-MS to BYDV while La Trobe[Ⓛ] has a provisional rating of S. The impact of BYDV on yield is generally greater in barley than in wheat, but as appears to have occurred at Merriwa, varieties can differ significantly in their levels of resistance. It is notable that the NVT trial conducted at this site was all treated with the seed treatment Hombre which contains a fungicide and the insecticide imidicloprid. Imidicloprid has been shown to provide early season control of aphids which transmit BYDV. No BYDV symptoms were evident in the NVT trial while interveinal yellowing/reddening of leaves characteristic of BYDV infection was obvious throughout the crown rot trial which was all treated with the same fungicide as a seed treatment (Dividend[®] M). However, yield results from the two barley varieties at both North Star and Merriwa were still included in the across site analysis.

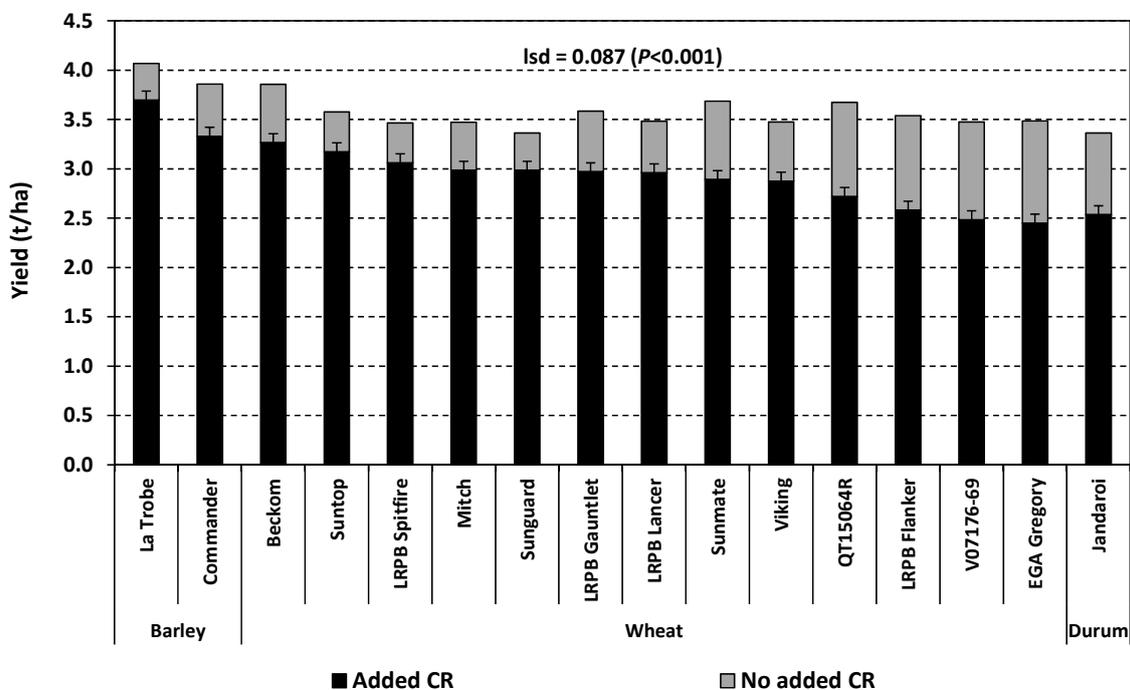


Figure 2. Impact of crown rot on the yield of two barley, 13 bread wheat and one durum entry averaged across 12 trial sites in 2015

Averaged across sites, yield in the no added CR treatments (grey bars) ranged in the barley from 4.07 t/ha (La Trobe[Ⓛ]) to 3.86 t/ha (Commander[Ⓛ]), in the bread wheat from 3.86 t/ha (Beckom[Ⓛ]) to 3.36 t/ha (EGA Gregory[Ⓛ]) and was 3.36 t/ha with Jandaroi[Ⓛ], the only durum variety included in the trial series (Figure 2). Remember, yield in the no added CR treatments was potentially impacted by background crown rot inoculum levels at half of the sites. The addition of crown rot inoculum at sowing (black bars) significantly reduced the yield of all entries compared to the no added CR treatments (grey bars). Yield loss associated with high levels of crown rot infection when averaged across the sites was 9% (0.37 t/ha) in La Trobe[Ⓛ] and 14% (0.53 t/ha) in Commander[Ⓛ]. In bread wheat, yield loss ranged from 11% (0.38 t/ha) in Sunguard[Ⓛ] up to 30% (1.04 t/ha) in EGA Gregory[Ⓛ] (Figure 2). Yield loss averaged 25% (0.83 t/ha) in the durum variety Jandaroi[Ⓛ].

Another way of comparing the relative impact of crown rot on the yield of varieties, which is not complicated by differential background inoculum levels present at the different sites, is to concentrate on the absolute yield achieved under high disease pressure in the added CR treatments (black bars; Figure 2). Under high crown rot pressure average yield ranged from 3.70 t/ha in the barley variety La Trobe down to 2.45 t/ha in the widely grown bread wheat variety EGA Gregory. Only the advanced bread wheat line V07176-69 and the durum variety Jandaroi were not significantly higher yielding than EGA Gregory when averaged across the 12 sites. The average yield benefit over growing EGA Gregory under high crown rot infection ranged from 1.25 t/ha (51%) with the barley variety La Trobe down to 0.13 t/ha (5%) with the recently released bread wheat variety LRPB Flanker. However, the relative yield benefit compared to EGA Gregory was considerably greater with other bread wheat varieties such as LRPB Lancer (0.51 t/ha; 21%), LRPB Gauntlet (0.52 t/ha), Sunguard (0.54 t/ha), Mitch (0.54 t/ha), LRPB Spitfire (0.61 t/ha), Suntop (0.72 t/ha) and Beckom (0.82 t/ha; 33%). Commander, the second barley variety in the trials, averaged a 0.88 t/ha (36%) yield benefit over EGA Gregory under high levels of crown rot infection across the 12 sites in 2015 (Figure 2).

Varietal impact on final soil populations of *Pratylenchus thornei*

The root lesion nematode, *Pratylenchus thornei* (*Pt*), has been demonstrated in repeated studies to be widespread across the northern region and at moderate to high populations it appears to interact with the expression of crown rot which can exacerbate yield loss from both pathogens. While consideration needs to be given to the relative yield of cereal type and variety in the presence of crown rot infection in the current season, potential consequences of these choices on the build-up of *Pt* for subsequent crops within the rotation should not be overlooked. Final *Pt* populations developed by the 16 different winter cereal entries was determined after harvest at two sites (Wongarbron and Macalister) in 2015 to determine potential residual impacts on the differential build-up of *Pt* populations within a rotational sequence.

Both sites had similar average starting *Pt* populations across the trial area at sowing of around 5.5-5.6 *Pt*/g soil in the 0-30 cm soil layer. This level is generally considered a medium risk for yield loss in intolerant wheat varieties (low = <2.0, medium = 2-15 and high =>15 *Pt*/g soil). Final populations established by the varieties during the 2015 season varied markedly between the two sites but significant differences between varieties were evident. Final *Pt* populations varied from 0.9 *Pt*/g soil after Suntop, up to 19.8 *Pt*/g soil after Mitch at Wongarbron. At Macalister populations varied from 11.8 *Pt*/g soil after Commander up to 105.0 *Pt*/g soil after Mitch (Table 1). There was generally a fair consistency between the ranking of varieties between the two sites with Mitch clearly being at the more susceptible end and Suntop at the more resistant. Both barley varieties and the durum variety Jandaroi were generally towards the mid to lower end of final *Pt* populations relative to the bread wheat entries. The two barley varieties appear to vary in their resistance to *Pt* with La Trobe leaving approximately double the *Pt* population of Commander at Macalister. The difference between the barley varieties at Wongarbron was not significant even though La Trobe similarly trended towards a higher final *Pt* population than Commander (Table 1).

Further research across sites is required to confirm differences in resistance of barley and wheat varieties to *Pt* as this can have significant implications for the build-up of *Pt* populations within a paddock and hence following rotational choices. For instance, while it appears that Mitch has a useful level of tolerance to crown rot (average 0.54 t/ha higher yielding than EGA Gregory in 2015), its increased susceptibility to *Pt* resulted in it taking nematode populations from a medium risk level at sowing to a high risk level (arguably extreme at Macalister) by harvest at both Wongarbron and Macalister in 2015 (Table 1). Hence, Mitch should only be considered for production in paddocks known to be free of *Pt* as its increased susceptibility to *Pt* is likely to override the yield gain in the presence of crown rot when considering the whole rotational sequence.

Table 1. Impact of selected barley, bread wheat and durum entries on final post-harvest soil populations of the root lesion nematode, *Pratylenchus thornei* (Pt/g soil) at two sites in 2015

Crop	Variety	Wongarbon		Macalister	
Barley	Commander ^(b)	2.7	cde	11.8	a
	La Trobe ^(b)	4.5	efg	24.5	cde
Wheat	Suntop ^(b)	0.9	a	13.7	ab
	Sunmate	4.6	fg	17.9	bc
	LRPB Viking ^(b)	3.2	cdef	22.1	cd
	LRPB Gauntlet ^(b)	1.0	ab	31.9	def
	LRPB Lancer ^(b)	1.9	bc	34.4	efg
	Beckom ^(b)	3.8	defg	38.0	fgh
	Sunguard ^(b)	5.3	g	43.4	fghi
	QT15064R	5.0	fg	45.9	fghi
	V07176-69	2.4	cd	48.4	ghi
	LRPB Spitfire ^(b)	4.6	fg	52.0	hi
	LRPB Flanker ^(b)	4.4	efg	52.5	hi
	EGA Gregory ^(b)	4.4	efg	59.6	i
	Mitch ^(b)	19.8	h	105.0	j
Durum	Jandaroi ^(b)	3.2	cdef	21.0	c

Values within sites followed by the same letter are not significantly different ($P=0.05$) based on transformed data ($\ln(x+1)$). Back transformed values presented in table. Sowing *Pt* soil populations averaged across ranges were 5.6 *Pt/g* soil at Wongarbon and 5.5 *Pt/g* soil at Macalister at 0-30 cm. Final *Pt* numbers post-harvest were from 0-30 cm at Wongarbon and due to drier soil conditions 0-15 cm at Macalister.

What about the build-up of crown rot inoculum?

Post-harvest soil cores collected from all plots at Wongarbon and Macalister were also analysed using PreDicta B for residual crown rot inoculum levels established by the different varieties. Crown rot risk is a sum of the DNA levels of all three *Fusarium* species known to cause crown rot expressed on a log scale where <0.6 is below detection, 0.6-1.4 is low, 1.4-2.0 is medium and >2.0 is high risk. At Wongarbon all entries left low inoculum levels (0.6 to 1.4) in the uninoculated plots and high levels (2.0 to 3.0) in the inoculated plots with no significant difference between entries. A similar outcome occurred at Macalister with crown rot inoculum levels across entries in uninoculated plots lower (0.5 to 1.8) but a high risk (2.0 to 3.0) remained with all inoculated plots with no significant difference between entries. Although varieties appear to significantly differ in their yield in the presence of crown rot infection, differences in the levels of partial resistance, which limits the rate of spread of the crown rot fungus through the plant during the season, do not appear to result in significant variation in inoculum levels at harvest. Partial resistance does not actually prevent the plant from being infected but rather slows the rate of fungal growth in the plant arguably delaying expression of the disease which can translate into a yield and grain quality (reduced screenings) benefit. However, the crown rot fungus, while being a pathogen when the winter cereal plant is alive, is also an effective saprophyte once the plant matures and dies. This saprophytic colonisation

of infected tillers late in the season as the crop matures is the likely reason why limited practical differences in residual inoculum levels are created between varieties and winter cereal crop types.

Barley is **very** susceptible to infection by the crown rot fungus. It **does not** have improved resistance to crown rot infection. Barley tends to yield better in the presence of crown rot infection due to its earlier maturity relative to bread wheat, providing an escape mechanism which reduces its exposure to moisture stress during the critical grain filling stage. This is often referred to as tolerance. It is **CRITICAL** that growers **do not** continue to confuse tolerance with resistance when considering crown rot. Barley is likely to provide a yield advantage over wheat in the presence of high crown rot infection but it **will not** reduce inoculum levels for subsequent crops. This is similarly true with any bread wheat variety choice. Variety selection can improve yield in the presence of crown rot, though all varieties still suffer yield loss, which can maximise profit in the current season but this **will not** reduce inoculum levels for subsequent crops.

Implications

Interestingly, the better options across sites in 2015 appeared to be the reduced biomass plant types La Trobe[®] barley and the new bread wheat variety Beckom[®]. These reduced growth habits may provide a yield advantage under lower yielding situations in the northern region as they potentially conserve soil water usage for grain-fill. This may also reduce the expression of crown rot and the impact of this disease on yield. Variety maturity and consequently sowing date can also have a large impact on the expression and therefore yield loss associated with crown rot infection. Earlier sowing or quicker maturity can result in grain-fill occurring under reduced evapotranspiration stress relative to delayed sowing or longer season varieties sown on the same date. This interacts with the expression of crown rot which is strongly influenced by moisture/heat stress during grain filling.

The barley variety La Trobe[®] appeared quite promising for maximising yield in the presence of high crown rot infection across the 12 sites conducted in 2015. La Trobe[®] on average had a significant yield benefit over Commander[®] barley (0.37 t/ha) and the best bread wheat varieties Beckom[®] (0.43 t/ha) and Suntop[®] (0.53 t/ha) in the presence of high crown rot infection in 2015. La Trobe[®] is malt accredited but relative grain price (malt vs feed barley; wheat vs barley), the increased susceptibility of La Trobe[®] to BYDV, impact on *Pt* populations, segregation by grain accumulators and performance of other barley and bread wheat varieties not included in these trials (www.nvt.online.com.au) should be considered as part of potential variety choices. Unfortunately, grain quality data was not available at the time of writing this update paper which should also be a consideration in variety choice.

If forced into planting a cereal crop in a high crown rot risk situation then some barley varieties may provide a yield advantage over bread wheat in that season, as long as early stress does not occur. Some of the newer bread wheat varieties do appear to be closing this gap to some extent. However, a key message is that this decision is only potentially maximising profit in the current season. Growing barley over bread wheat will **not** assist with the reduction of crown rot inoculum levels as barley is **very susceptible** to infection. Significant yield loss is still occurring in the best of the barley and bread wheat varieties in the presence of high crown rot infection. Crop and variety choice is therefore **not** the sole solution to crown rot but rather just one element of an integrated management strategy to limit losses from this disease.

Acknowledgments

The research undertaken as part of project DAN00175 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. The project is co-funded by the NSW state government through the NSW DPI who are also thanked for their support in fully funding my position and laboratory and other infrastructure costs. Technical assistance provided by Robyn

Shapland, Tim O'Brien, Finn Fensbo, Patrick Mortell, Carla Lombardo, Chrystal Fensbo, Kay Warren, Karen Cassin and Rachael Bannister is gratefully acknowledged. Soil-borne pathogen levels were determined using the DNA based soil test service PreDicta B provided by the South Australian Research and Development Institute. We are also extremely thankful to NVT operators Peter Matthews (NSW DPI), Douglas Lush (DAF Qld) and Research Agronomist Rick Graham (NSW DPI) and their staff for sowing, managing and harvesting the trials and co-operating growers for use of their paddocks.

Contact details

Dr Steven Simpfendorfer

NSW DPI

Mb: 0439 581 672

Email: steven.simpfendorfer@dpi.nsw.gov.au

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Reviewed by: Dr Guy McMullen, NSW DPI

Crown rot – do seed treatments have a place?

Steven Simpfendorfer, NSW DPI Tamworth

Key words

Establishment, yield, Rancona® Dimension, crown rot

GRDC codes

DAN00175 – National crown rot epidemiology and management program

Take home message

- Treating EGA Gregory seed with Rancona® Dimension reduced establishment losses associated with the addition of crown rot inoculum to 6% compared to 23% when no seed treatment was used.
- In this instance, Rancona Dimension did not provide a significant or consistent yield benefit in the presence of high levels of crown rot infection across the 12 trial sites in 2015.
- Growers should not expect Rancona Dimension to provide a significant and consistent reduction in yield loss from crown rot infection when used as a standalone management strategy.
- Growers considering the use of Rancona Dimension should follow the manufacturer's advice and only consider it as part of an integrated management strategy against crown rot.

Background

Crown rot, caused predominantly by the fungus *Fusarium pseudograminearum* is a significant disease of winter cereal crops in the northern NSW and southern Qld. Rancona® Dimension (ipconazole + metalaxyl) was recently registered in Australia as a fungicidal seed treatment with good activity against cereal bunts and smuts, pythium and suppression of rhizoctonia. Rancona Dimension is also the first seed treatment to be registered (at 320 mL/100 kg seed) for the suppression of crown rot. Suppression by definition indicates that the seed treatment reduces growth of the pathogen for a set period of time early in the season. This is distinct from control which Rancona Dimension and other seed treatments provide against bunts and smuts of wheat and barley in that they prevent infection throughout the season. It is recommended by the manufacturer that Rancona Dimension is used as part of an integrated disease management strategy for crown rot and not as a standalone option. However, growers may still be tempted to try and use Rancona Dimension under medium to high crown rot risk situations where other management strategies have not sufficiently reduced inoculum levels. This is not uncommon following seasons with low in-crop rainfall which limits the effectiveness of break crops such as chickpea, faba bean, canola and sorghum in decomposing cereal stubble which harbours the crown rot fungus. Under this scenario growers are often forced into sowing another winter cereal within the rotation sequence and may be tempted to resort to a seed treatment as their main option in trying to reduce yield loss associated with crown rot infection. Replicated research therefore appears warranted to determine the impact of Rancona Dimension on yield loss from crown rot infection across sites in the northern region. This will hopefully ensure that growers have a realistic expectation of what this seed treatment can achieve if used in isolation of other management strategies.

Research in 2015

Twelve replicated trials were conducted across northern NSW and southern Qld in 2015 with sites spread from Wongarboon in the south to Macalister in the north. Background crown rot inoculum levels existed at half of the 12 sites with medium background crown rot levels at Mullaley,

Macalister and Merriwa while high background levels were measured at Coonamble, Wongarbone and Mungindi in PreDicta B soil cores collected across the sites at sowing. All trials were conducted in grower paddocks and generally co-located with GRDC funded National Variety Trials (NVT). One criterion for selecting sites is that they are generally paddocks with a good crop rotation, with all 12 sites having a non-winter cereal break (chickpea, canola or sorghum) as the previous crop within the rotation sequence. The medium to high background crown rot inoculum levels still evident at half of the sites highlights the continuing difficulty of managing stubble-borne inoculum levels of the crown rot fungus across the region. The trials used an inoculated versus uninoculated trial design to evaluate the relative impact of seed treatments on the yield impact associated with crown rot infection at each site. High levels of crown rot infection were induced in inoculated plots (added CR) by incorporating non-viable durum seed colonised by at least five different isolates of *Fp* into the seeding furrow (2.0 g/m of row) at sowing. The crown rot susceptible bread wheat variety EGA Gregory[®] was used across all sites at a target plant population of 100 plants/m² with seed treatments evaluated being:

1. Nil seed treatment
2. Rancona[®] Dimension (ipconazole 25 g/L + metalaxyl 20 g/L) at 320 mL/100 kg seed
3. Dividend[®] M (difenoconazole 92 g/L + metalaxyl-M 23 g/L) at 260 mL/100 kg seed
4. Jockey[®] Stayer[®] (fluquinconazole 167 g/L) at 450 mL/100 kg seed

Dividend M and Jockey Stayer are NOT registered for suppression of crown rot but were included to represent a commonly used wheat seed treatments for bunt and smut control or early control of the leaf disease stripe rust, respectively. Inclusion of four treatments across each site ensured statistical rigour of yield outcomes.

Impact on crop establishment

An across site analysis was conducted to assist in summarising the general trends in the performance of Rancona Dimension across the 12 sites in 2015. In the no added crown rot (CR) treatments, Rancona Dimension and Dividend M had no significant impact on plant establishment compared to the nil fungicide treatment (Figure 1). However, establishment was slightly reduced with Jockey Stayer compared to the Rancona Dimension and nil treatments.

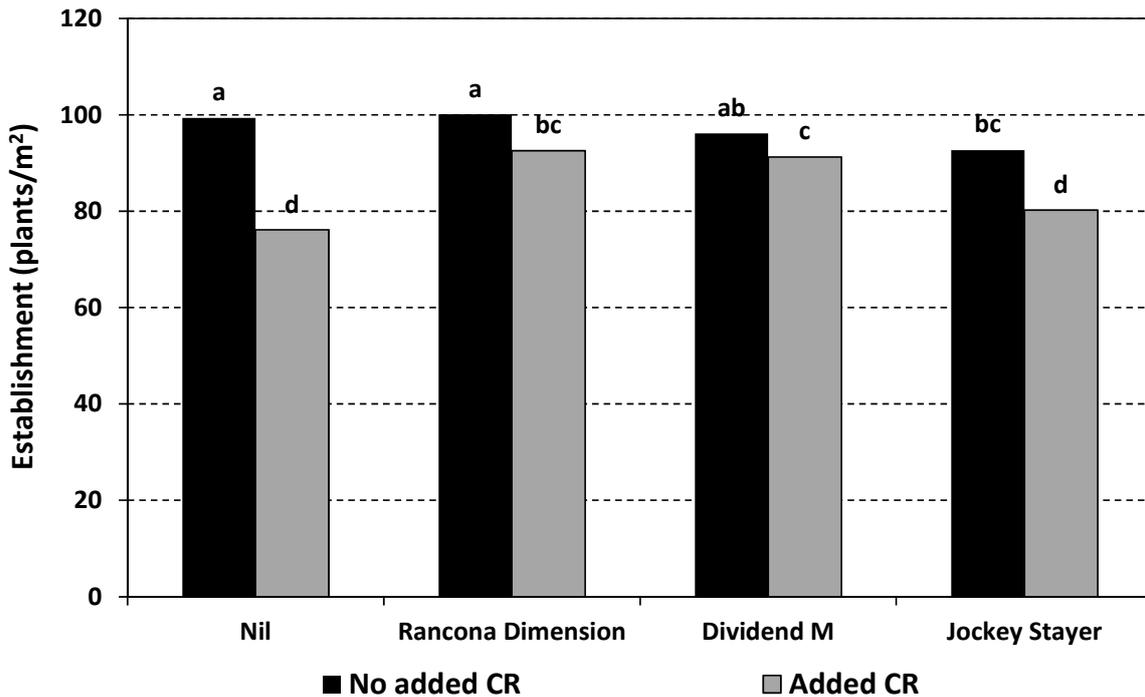


Figure 1. Impact of fungicide seed treatments on establishment of EGA Gregory^d in the absence and presence of added crown rot inoculum – average 12 sites in 2015

The addition of CR inoculum at sowing significantly reduced the establishment of EGA Gregory^d by 23% averaged across sites when no seed treatment was applied (Nil; Figure 1). Rancona Dimension and Dividend M significantly improved establishment in the presence of added CR with losses reduced to only 6% and 8%, respectively compared to the Nil – No added CR treatment. Jockey Stayer did not significantly improve establishment in the presence of added CR. Severe early infection from crown rot, as can occur with the addition of CR inoculum in the furrow at sowing, may result in seedling blight which reduces crop establishment. Rancona Dimension may provide a useful level of protection against seedling blight associated with severe early *Fusarium* infections but further research is required to prove this.

What does it mean in terms of yield?

An across site analysis of the 12 trials conducted in 2015 found that Dividend M had a minor yield reduction (0.07 t/ha) compared to using no seed treatment (Nil) in the no added CR treatment (Figure 2). Rancona Dimension did not have a significant impact on yield in the absence of added CR over the Nil treatment but was only slightly (0.09 t/ha) higher yielding than Dividend M. Across sites, yield loss in the added CR treatment was 28% with Dividend M, 31% with Rancona Dimension and 32% with Jockey Stayer. The extent of yield loss was unaffected by the seed treatments with none significantly different from what was measured in the Nil treatment (31%; Figure 2). Rancona Dimension[®] unfortunately did not provide a consistent yield benefit in the presence of high levels of crown rot infection across the 12 trial sites in 2015.

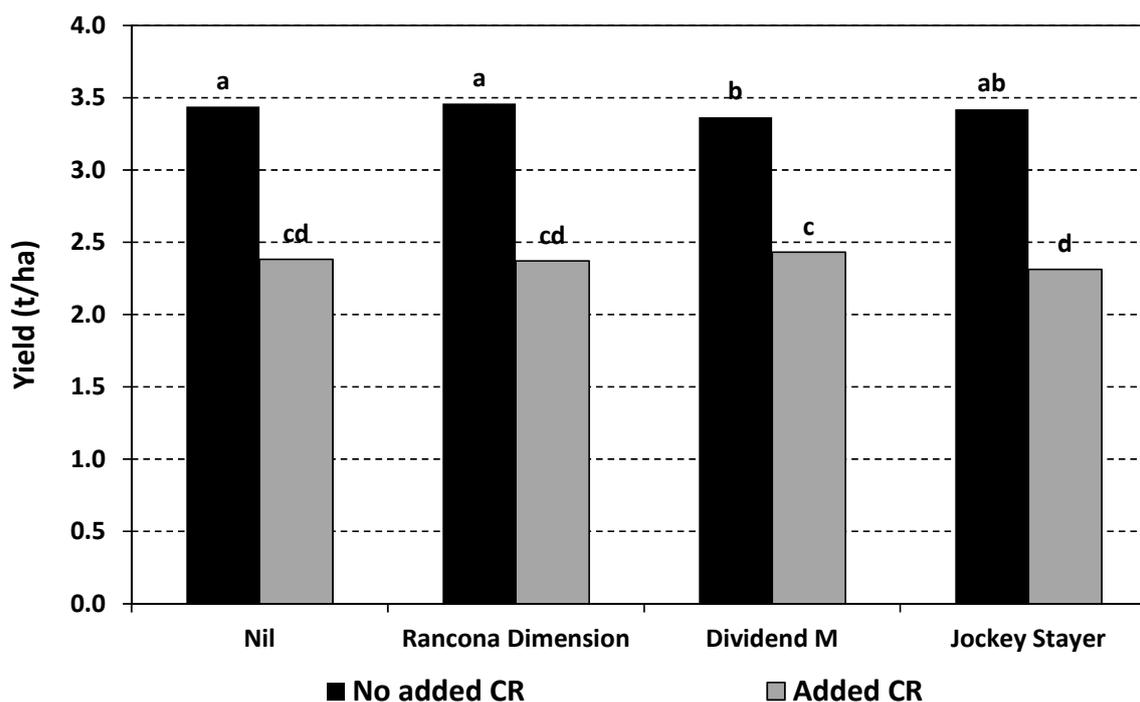


Figure 2. Impact of fungicide seed treatments on the yield of EGA Gregory[®] in the absence and presence of added crown rot inoculum – average 12 sites in 2015

Implications

Rancona Dimension is registered in Australia for the suppression of crown rot infection. Rancona Dimension reduced establishment losses associated with severe early infection, created by the addition of crown rot inoculum to the seed furrow at sowing, to 6% compared to 23% in the absence of a seed treatment. Further research is required to determine if this improvement in establishment is associated with reduced *Fusarium* seedling blight. It should also be established whether such severe establishment losses are an artefact of the inoculation process used in the trials or occurs naturally in paddocks with high stubble-borne inoculum loads. In a separate larger trial conducted at Tamworth in 2015 in which infected stubble at the surface was the inoculum source Rancona Dimension did not have a significant impact on the establishment of EGA Gregory[®] compared to the Nil seed treatment (data not presented). Establishment benefits apparent in the 12 trials unfortunately did not translate into any improvement in grain yield. Rancona Dimension did not provide a significant yield benefit over the use of no seed treatment or the two other commonly used seed treatments examined in this study under high crown rot pressure across 12 sites in 2015.

Although Rancona Dimension is registered for the suppression of crown rot, with activity against early infection and potential establishment losses evident in this study, growers should not expect this to translate into a significant and consistent reduction in yield loss from crown rot infection when the product is used as a standalone management strategy. Integrated management remains the best strategy to reduce losses to crown rot. Growers may like to consider including Rancona Dimension (320 mL/100 kg seed) as one additional component in their integrated management of crown rot.

Acknowledgments

The research undertaken as part of project DAN00175 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. The project is co-funded by the NSW state

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Contact details

Dr Steven Simpfendorfer
NSW DPI
Mb: 0439 581 672
Email: steven.simpfendorfer@dpi.nsw.gov.au

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Reviewed by: Dr Guy McMullen, NSW DPI

Wheat rust in 2015 – where are we heading?

Steven Simpfendorfer, NSW DPI Tamworth

Key words

Stripe rust, management, variety purity, leaf rust, disease standards, Adult Plant Resistance (APR)

GRDC code

DAN00176: Northern NSW integrated disease management

Take home message

- Stripe rust has not gone away!
- Know the difference between a 'hot individual plant' and a 'hot-spot' before creating panic
- If you had stripe rust in your EGA Gregory^ϕ in 2015 it is likely a seed purity issue. Consider freshening up your seed source.
- EGA Gregory^ϕ remains MR to stripe rust and does NOT require fungicide application
- Consider 'up-front' or early season fungicide management of stripe rust in Suntop^ϕ in 2016, especially under higher nitrogen status
- Be aware of the development and spread of new wheat leaf rust pathotypes in your region
- The north is on track with rust management, do not slip on minimum disease standards, any perceived short-term gains are likely to result in long-term pain for ALL.

Stripe rust in 2015

Stripe rust first appeared in wheat crops in north NSW/southern Qld (North Star and Goondiwindi) in moderately susceptible (MS) varieties (Sunzell^ϕ and Gauntlet^ϕ) at the start of August in 2015. Cooler autumn/winter temperatures and rainfall during this period were very conducive to the development of stripe rust in 2015. Stripe rust infection occurs as long as there is leaf wetness of between for 5-6 hours (minimum 3 h) with temperatures below 20°C (optimum 6°C to 12°C). During much of the growing season these conditions usually occur overnight. There were numerous reports of stripe rust 'hot-spots' in the MR-MS variety Suntop^ϕ across regions in 2015. Samples of stripe rust were submitted to the Australian Cereal Rust Control Program (ACRCP) at the University of Sydney's Plant Breeding Institute throughout the 2015 season, with pathotypes 134 E16 A+ (WA pathotype), 134 E16 A+ 17+ (WA Yr 17+ pathotype) and 134 E16 A+ 17+ 27+ (WA Yr 17+27+ pathotype) confirmed in Queensland and northern NSW.

Three non-fungicide treated GRDC funded NVT trials were conducted in northern NSW (North Star, Spring Ridge and Tamworth) in 2015. Early and very high levels of stripe rust developed in the North Star and Tamworth sites with lower and later development of stripe rust occurring at the Spring Ridge site. All trials allowed good evaluation of the relative resistance of wheat varieties and advanced breeding lines to stripe rust in the absence of fungicide protection.

All sites were exposed to natural infection from stripe rust. That is, they were not artificially inoculated with stripe rust spores. The development of significant levels of stripe rust at all three geographically spread sites highlights that stripe rust inoculum was not a limiting factor in the 2015 season. All rusts (stripe, leaf and stem) are **biotrophs** which means they require a living host to survive between seasons. This is primarily volunteer wheat in the case of cereal rusts but wheat stripe rust has been shown to also survive on barley grass in some seasons. Barley grass also gets infected by a barley grass specific stripe rust pathogen that cannot infect wheat but can cause

infection on some barley varieties. Barley stripe rust is not currently present in Australia which is fortunate, as overseas screening indicates that around 80% of current barley varieties would be MS or worse if this exotic pathogen was to establish here (William Cuddy, personal communication). Any samples of stripe rust on barley or barley grass should be submitted to the ACRC for pathotype determination. The higher probability of summer rainfall in northern NSW/Qld is conducive to the survival of volunteer wheat between cropping seasons which is commonly referred to as the **green bridge**. When combined with a wide spread in sowing times of roughly between March for dual purpose wheat varieties through to June for quicker maturing main season varieties this situation is quite conducive to the survival and development of stripe rust.

Early and severe infection levels developed at the North Star site with the WA Yr17+27+ confirmed as the dominant pathotype in the trial. The WA Yr17+ pathotype developed as a mutation of the original WA pathotype, being first detected in 2006. This pathotype further mutated to develop virulence for the Yr27 gene with the WA Yr17+27+ pathotype first detected in 2011, which reduced the resistance level of varieties such as Livingston and Merinda (Figure 1). All three pathotypes are now distributed across the northern region including into Qld.

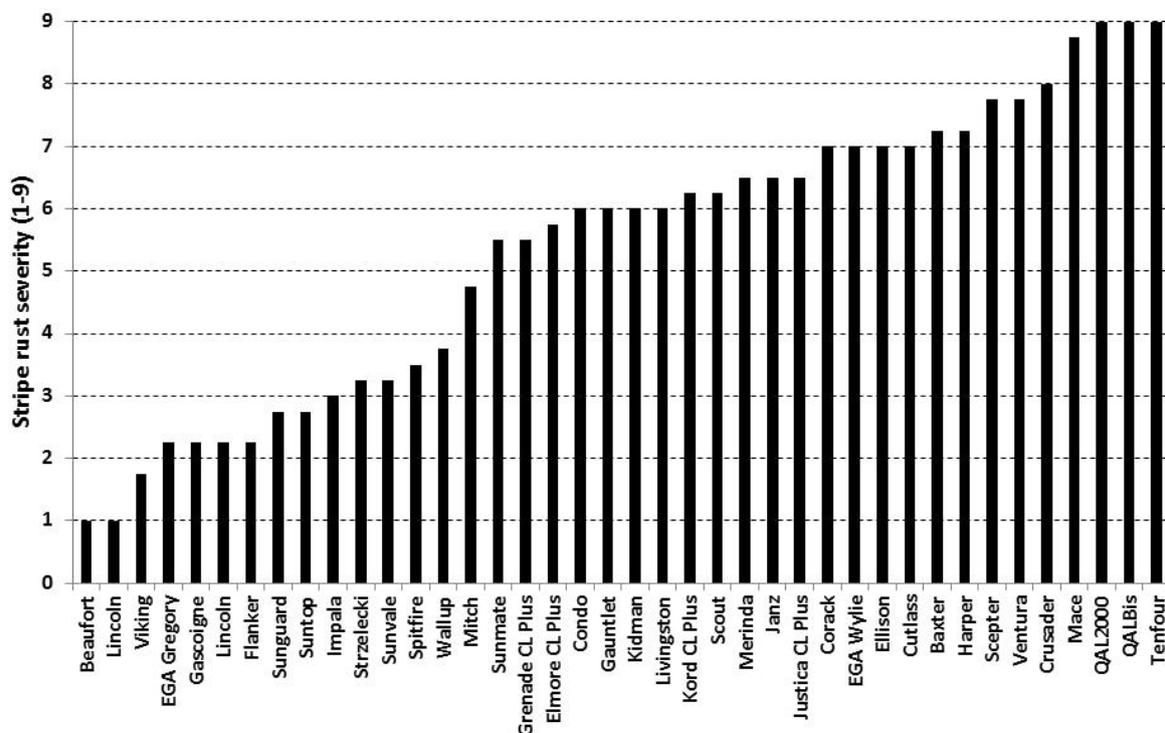


Figure 1. Stripe rust reaction of released wheat varieties in main season NVT - North Star 2015 (Note trial site had early and high stripe rust pressure in 2015 from the WA 17+27+ pathotype. Scores are on the ACRC 1-9 scale where 1 = no pustules evident and 9 = whole leaf covered in pustules. Individual site data is presented above and **not** an overall variety rating which is derived from reactions in multiple trials across regions and seasons)

Stripe rust in EGA Gregory

Two reports of the supposed 'break down' of stripe rust resistance in EGA Gregory occurred around Wongarbron and Warialda in 2015. NSW DPI inspected the EGA Gregory crop at Wongarbron and there were 'hot individual plants' NOT 'hot-spots' evident in the crop. A 'hot-spot' is all plants in at least a 1 m circle with development of pustules and occurs due to higher humidity during winter causing spores to remain in small clumps that are relatively heavy, which limits spread by wind. Spread is therefore mostly over small distances, which results in the appearance of 'hot-spots' of infection usually first appearing in late winter to early spring. All plants along multiple 1 m sections

of row affected by stripe rust were pulled from the EGA Gregory[®] crop at Wongarbone and separated into individual plants. It then became obvious that there were individual plants along the row infected with stripe rust and others with no visible signs of infection. That is, there were infected individual plants ('hot individual plants') but **not** every plant along a 1 m section of row and adjoining rows infected with stripe rust. There were **no** 'hot-spots' evident in the paddock. This process was explained and repeated by the consulting agronomist with the Warialda EGA Gregory[®] crop who similarly concluded that it was 'hot individual plants' and clearly not 'hot-spots'. To complete the picture, individual heads from visually infected and uninfected plants from Wongarbone were collected and sent to the University of Southern Queensland (USQ) for molecular analysis to determine varietal purity. Grain collected from 6 out of 6 plants without visible stripe rust infection were identified as EGA Gregory[®]. In contrast seed collected from 5 of 8 plants with stripe rust infection were identified as NOT being EGA Gregory[®] but all had a similar banding pattern indicating they were all the one contaminant. The actual contaminant variety was not determined but clearly it has increased susceptibility to stripe rust. In both situations the concern around stripe rust appears to be related to more susceptible off-types (contaminants) in the EGA Gregory[®] crops. Pure EGA Gregory[®] remains MR to stripe rust and does not require fungicide management. MR varieties such as EGA Gregory[®] can still develop low levels of stripe rust under high pressure as was evident at North Star in 2015 (Figure 1). However, the level of infection, while visible, does not result in the loss of enough green leaf area to cause significant economic yield loss. If growers are concerned about the levels of stripe rust in their EGA Gregory[®] then they should consider freshening up their seed source to one with a known and higher purity.

Stripe rust 'hot-spots' in Suntop[®]

'Hot-spots' of stripe rust occurred in two crops around Wellington in 2013, several crops across eastern Australia in 2014 and in numerous crops of Suntop[®] in eastern Australia in 2015. 'Hot-spots' of stripe rust first appeared in Suntop[®] crops in northern NSW in early-mid August in 2015. 'Hot-spots' in Suntop[®] across seasons has been generally linked with higher nitrogen status within paddocks with some paddocks only developing 'hot-spots' in the headlands where double the N rate was applied at sowing. Generally, affected Suntop[®] crops had no up-front fungicide management and did not have a fungicide application around GS30, which commonly occurs commercially in combination with an in-crop herbicide. There is no new pathotype of stripe rust with increased virulence to Suntop[®] and it has been confirmed from different paddocks that there is currently no underlying issue with seed purity. That is, crops are pure Suntop[®] and furthermore true 'hot-spots' are evident in affected paddocks and **not** isolated individually infected scattered plants which would be more indicative of an issue with seed purity.

Suntop[®] is rated MR-MS to stripe rust, which indicates that it requires one fungicide input (up-front or early between GS30-32) to limit disease development. This message can become complicated as it is often tweaked to the likely timing of epidemic development (significant green-bridge over summer likely to favour earlier epidemic), conduciveness of environment (west of Newell Highway generally drier and hotter which reduces disease pressure) and sowing time (earlier sowing likely to be more favourable to stripe rust and early epidemic development). Generally, varieties such as Suntop[®] (MR-MS), Lancer[®] (MR) and even EGA Gregory[®] (MR) rely largely on Adult Plant Resistance (APR) genes that slow down the rate of disease development. In general, the resistance of the plant increases with plant age and as the temperature rises. The APR gene in EGA Gregory[®] (*Yr18*) generally appears to express earlier than the gene (*Yr31*) in Suntop[®]. APR in Suntop[®] appears to be more interactive with lower temperatures and higher N levels which both appear to delay the expression of APR within the leaves. The timing of APR expression remains one of the major issues with stripe rust management in the northern grains region which differs with variety, sowing time, temperature and even N status. When 'hot-spots' occurred in many Suntop[®] crops in 2015 the actual infection became more obvious because APR had expressed and killed off infected cells within the leaf and the surrounding cells. This renders the infection non-viable by denying the stripe rust

fungus of living cells to survive in. Yellow flecking of the flag leaf and other leaves on uninfected Suntop[®] plants adjacent to the 'hot-spots' indicated the active expression of APR killing spores landing and trying to infect these plants. A close inspection of the oldest leaves (seedling leaves) within the 'hot-spots' revealed a mass of old discoloured pustules which highlights that the infection had been present in these patches for a considerable period. Suntop[®] still has a very useful level of resistance to stripe rust and is by no means a 'sucker' for stripe rust. This fact is often not easily acknowledged at the grower level when Suntop[®] for example, may be the most susceptible variety they are currently growing. Hence, the appearance of any infection and the estimation of yield loss (loss of green leaf area) can appear exaggerated without a true susceptible variety to compare infection levels with (Figure 1). Personally, the infection levels observed in 'hot-spots' of Suntop[®] in 2015 were consistent with an MR-MS reaction. Varieties such as Suntop[®] which rely on APR as their main source of resistance are worthwhile protecting at early growth stages with seed or fertiliser treatments or an in-crop fungicide application around GS30-32. This will provide protection until APR is expressed later in the season.

Stripe rust management in 2016

The key messages remain the same;

- control the green bridge (volunteer wheat) at least four weeks prior to sowing to delay the onset of epidemics
- select varieties with improved levels of resistance (MR-MS minimum)
- ensure variety identification/purity
- tailoring fungicide strategies to varietal resistance level, rainfall zone, growth stage and seasonal conditions
- monitor crops regularly.

With varieties such as Suntop[®] that rely largely on APR, consider using an in-furrow fungicide to protect early growth. Flutriafol on starter fertiliser has been shown to provide extended protection against stripe rust in the northern region and is a more common component of stripe rust management strategies for susceptible wheat varieties in the southern region. Fluquinconazole seed treatment also protects early growth but tends to not provide the same length of protection as in-furrow treatments in northern trials.

Be 'alert not alarmed' of leaf rust pathotypes

There are two new pathotypes of leaf rust of potential significance to northern NSW and Qld. The first (76-3,5,7,9,10,12,13 +Lr37) was a mutation of an existing pathotype with combined virulence for the genes *Lr13*, *Lr24* and *Lr37*. It was first detected around Warialda on the feed wheat variety Naparoo[®] in 2013 and has only really caused issues in this variety in subsequent seasons. A newer 'SA pathotype' of leaf rust (104-1,3,4,6,7,8,10,12 +Lr37) is an exotic introduction to Australia and was first detected in South Australia in 2014. The SA pathotype of leaf rust has rapidly spread north being detected at Dunedoo, Tamworth, North Star and Gatton in 2015 but not at levels that warranted fungicide application. However, this is a warning for subsequent years and growers should check the rating of varieties to these new leaf rust pathotypes with a minimum disease standard of MS recommended by the ACRCP for the northern region. Impala[®], which has a leaf rust rating of S to existing leaf rust pathotypes, has required fungicide management in northern NSW in recent seasons when conditions (humid and temperatures between 15°C to 25°C) have been conducive to disease development.

Avoid growing susceptible varieties – has the message changed?

No!

The northern region did the right thing by moving away from growing very susceptible varieties such as H45. Numerous field trials across the northern region, largely GRDC funded NVT trials where stripe rust development is routinely controlled with a fungicide management program, highlight that there is no yield penalty associated with growing newer varieties with improved levels of stripe rust resistance. There is a big difference in the level of fungicide intervention required across a season with a susceptible variety (likely three fungicide inputs) compared to an MR-MS variety (one fungicide 'up-front' or around GS30-32) to manage stripe rust in the northern region.

Why are minimum disease standards important?

Minimum disease standards of MR-MS for stripe and stem rust and MS for leaf rust are recommended by the Consultative Committee of the ACRCP for wheat varieties in the northern region (Qld and nth NSW). Selecting varieties with these minimum levels of resistance reduce the build-up of rust epidemics within the region (the more susceptible the variety the bigger issue they are as a green bridge), decrease disease pressure from existing rust pathotypes within the season, reduce the probability of mutations within existing pathotypes occurring with increased virulence to existing rust-resistance genes and reduces the reliance on fungicides as a management tool. The continued production of susceptible and very susceptible varieties, while stripe rust can be controlled with fungicides, jeopardises current and future disease resistance genes. The problem is if you choose to go this way and become reliant on the continuous use of fungicides in susceptible varieties then you are potentially making that decision for the whole industry as rust spores can be spread large distances by wind. Mutations that develop on your farm rapidly spread across regions.

Is fungicide resistance an issue?

A mini-review was recently written on the risk of rust fungi developing resistance to fungicides (Oliver 2014). To summarise, the rust fungi are classified as having a low risk of developing fungicide resistance, which appears justified by long fungicide usage patterns mainly overseas with no confirmed cases of agronomically significant fungicide resistance being reported in a rust pathogen species. The general conclusions from the review were 'Rust fungi have a reputation that suggests they are immune to the development of fungicide resistance, and this has led growers to rely heavily on fungicides for the control of diseases such as stripe rust. This reputation is based on a long history, during which many other species have developed often disastrous resistance to fungicides, especially *Botrytis*, *Zymoseptoria* and powdery mildews, while rusts have remained well controlled'. Within Australia, barley powdery mildew in WA and *Septoria tritici* blotch (*Zymoseptoria*, STB) of wheat in the southern region have been reported in recent years to have developed partial resistance to triazoles. In terms of cereal rusts, the strobilurins (Group 11) are 'protected by a serendipitous intron, DMI fungicides (triazoles, Group 3) are protected by relatively low resistance factors and SDHs (Group 7; medium to high risk of resistance development) have been protected by mixing with other fungicides and their recent introduction'. However, the reviewer still urges vigilance when it comes to the rusts.

It is interesting that in the review (Oliver 2014) the argument that rust fungi are regularly exposed to fungicides but have not yet developed any resistance was largely based on more extended use patterns overseas. "In Europe, where fungicide use on wheat is close to universal, rusts have been regularly exposed to fungicides, even though other species, such as *Blumeria graminis* (powdery mildew) and *Zymoseptoria tritici* (STB), are the prime targets'. It is therefore not too hard to imagine that the converse could occur in Australia where reliance on controlling stripe rust in susceptible wheat varieties is the main target for repeat fungicide applications but this practice is potentially selecting for resistance in other fungal species such as powdery mildew and STB that have a medium to high risk for developing fungicide resistance. Fungicide development and the search for new chemistries in Europe are continually driven by the evolution of resistance within STB to existing and

recently released fungicides. This is **NOT** a good scenario and as an industry we would be wise to learn from their mistakes!

Acknowledgements

The research undertaken as part of project DAN00176 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. The project is co-funded by the NSW state government through the NSW DPI who are also thanked for their support in fully funding my position and laboratory and other infrastructure costs. Information on changes in cereal pathotypes and distribution are developed through annual surveys conducted by the Australian Cereal Rust Program which is led by the University of Sydney with funding from GRDC and NSW DPI. Molecular analysis of varietal purity of EGA Gregory seed collected from the crop near Wongarbone was kindly conducted by Dr Anke Martin at the University of Southern Queensland. Stripe rust variety evaluations were conducted under the GRDC funded NVT system with trials in NSW co-ordinated by Dr Andrew Milgate (NSW DPI, Wagga Wagga).

References

Oliver RP (2014) A reassessment of the risk of rust fungi developing resistance to fungicides. *Pest Management Science*, 70: 1641-1645.

Further information

<http://rustbust.com.au/>

Reviewed by

Professor Robert Park, Dr William Cuddy and Dr Guy McMullen

Contact details

Steven Simpfendorfer

NSW DPI

Ph: 0439 581 672

Email: steven.simpfendorfer@dpi.nsw.gov.au

 Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

Weeds & herbicides concurrent session

Herbicide residues in soils – are they an issue?

Lukas Van Zwieten, Mick Rose, Pei Zhang, Duy Nguyen, Craig Scanlan, Terry Rose, Gavan McGrath, Tony Vancov, Timothy Cavagnaro, Nikki Seymour, Stephen Kimber, Abby Jenkins, Anders Claassens, Ivan Kennedy

Key words

herbicide, soil functions, sustainability, plant-back periods

GRDC code

DAN00180

Take home message

- A national soil survey found that residues of certain herbicides, including; glyphosate and its metabolite AMPA, trifluralin and diflufenican, frequently persist at agronomically significant levels in soils prior to the winter cropping season
- Analysis of international literature suggests that soil biological functions are generally resilient to short term impacts of herbicide application at recommended label rates
- However, longer term impacts of herbicide residues, especially after repeat applications, are less well understood. There is evidence that residues at levels found in the soil survey could reduce crop performance, most likely through direct phytotoxicity. The lack of readily available, soil-specific threshold values for herbicide residues causing damage to i) soil biological functions and ii) plant growth is a key knowledge gap to be addressed by future work in this project.
- Strategies to avoid herbicide residue accumulation and potential damage to soil functions and crops include: routine rotation of pre-emergent herbicides, reliable record keeping to help identify potential residue issues and organic matter addition to help tie-up bioavailable residues and stimulate microbial activity

Background

The move to conservation tillage and herbicide-tolerant crop cultivars means that many farmers are relying on herbicides for weed control more than ever before. Despite the provision of plant-back guidelines on herbicide product labels, site-specific factors such as low rainfall, constrained soil microbial activity and non-ideal pH may cause herbicides to persist in the soil beyond usual expectations. Because of the high cost of herbicide residue analysis, information about herbicide residue levels in Australian grain cropping soils is scarce.

In addition, little is known about how herbicides affect soil biological processes and what this means for crop production. This is especially the case for repeated applications over multiple cropping seasons. In Australia, herbicides undergo a rigorous assessment by the Australian Pesticides and Veterinary Medicines Association (APMVA) before they can be registered for use in agriculture. However, relatively little attention is given to the on-farm soil biology – partly because we are only now beginning to grasp its complexity and importance to sustainable agriculture. Although a few tests are mandatory, such as earthworm toxicity tests and effects on soil respiration, functional services provided by soil organisms such as organic matter turnover, nitrogen cycling, phosphorus solubilisation and disease suppression are usually overlooked.

GRDC recently co-funded a 5-year project (DAN00180) to better understand the potential impacts of increased herbicide use on key soil biological processes. This national project, co-ordinated by the NSW Department of Primary Industries with partners in WA, SA, Vic and Qld, is focused on the effect

of at least 6 different herbicide classes on the biology and function of 5 key soil types across all three grain growing regions.

Here we report on the results of a field survey of herbicide residues in 40 cropping soils prior to sowing and pre-emergent herbicide application in 2015. We discuss the relevance of these residues to soil biological processes and crop health, with a focus on those herbicides most frequently detected. Recommendations are given to minimise potential impacts of herbicide residues on productivity and soil sustainability. We also detail plans for future research and the development of management tools for growers to monitor and predict herbicide persistence in soils.

Methods

- Farm survey data from the GRDC Focus Paddocks project (DAW00213) was collated and analysed to understand herbicide use practices in the WA grain growing regions. The Focus Paddocks project monitored the farming practices, soil properties and crop yields of 180 paddocks spanning the WA wheat-belt for 5 years. Spray records were converted to quantity (as kg of active ingredient) per hectare and ranked in terms of frequency of application for different crops;
- A soil survey was undertaken to provide a representative snapshot of herbicide residue levels in cropping soils at the beginning of the 2015 growing season (April-May), prior to the application of pre-emergent herbicides. Soil samples were taken from 40 paddocks around Australia, including 12 in WA, 15 in SA, 10 in NSW and 3 in Qld. Composite samples (12 subsamples) were taken from a randomly chosen 50 m by 50 m grid in each paddock, at two depths (0-10, 10-30 cm). Samples were analysed for 15 commonly used herbicides using advanced analytical techniques developed and validated specifically for this project;
- Herbicide impacts to soil biology were reviewed by searching the literature using the search terms herbicide AND soil AND (microb* OR function*). Over 300 peer-reviewed publications were analysed for potential impacts of herbicides on soil organic matter turnover, nutrient cycling and disease interactions;
- The potential for direct phytotoxicity to crops was assessed by comparing herbicide residue to literature thresholds for herbicide sensitivity. Because such data are lacking for glyphosate residues in soil, we also conducted a bioassay to determine the effect of soil-borne glyphosate residues on wheat, lupin and canola growth in a sandy (tenosol) soil from Wongan Hills, WA. This soil has low phosphorus buffer index (for Colwell P) of 15 L kg⁻¹, indicating a low potential for P sorption. Glyphosate (as Roundup CT[®]) was thoroughly mixed through topsoil (5 cm) at rates equivalent to 0.33, 1, 3, 9 and 27 times the label rate, and aged for 1 month in the glasshouse prior to sowing. In addition, we tested whether the application of 20 kg ha⁻¹ of P (as potassium phosphate) would alter the toxicity thresholds by remobilising soil-bound glyphosate. Root and shoot biomass was measured after a 6-week growth period.

Exposure – which herbicides are being applied?

Despite farmers and advisers keeping spray records for individual paddocks, aggregated (i.e. industry-wide) data for herbicide use practices are not readily accessible. Information collected in the Focus Paddock Project provides a useful snapshot of which herbicides are being used frequently in different crops (Figure 1). Information is also being collected through the National Paddock Survey Project and will be analysed over the coming year.

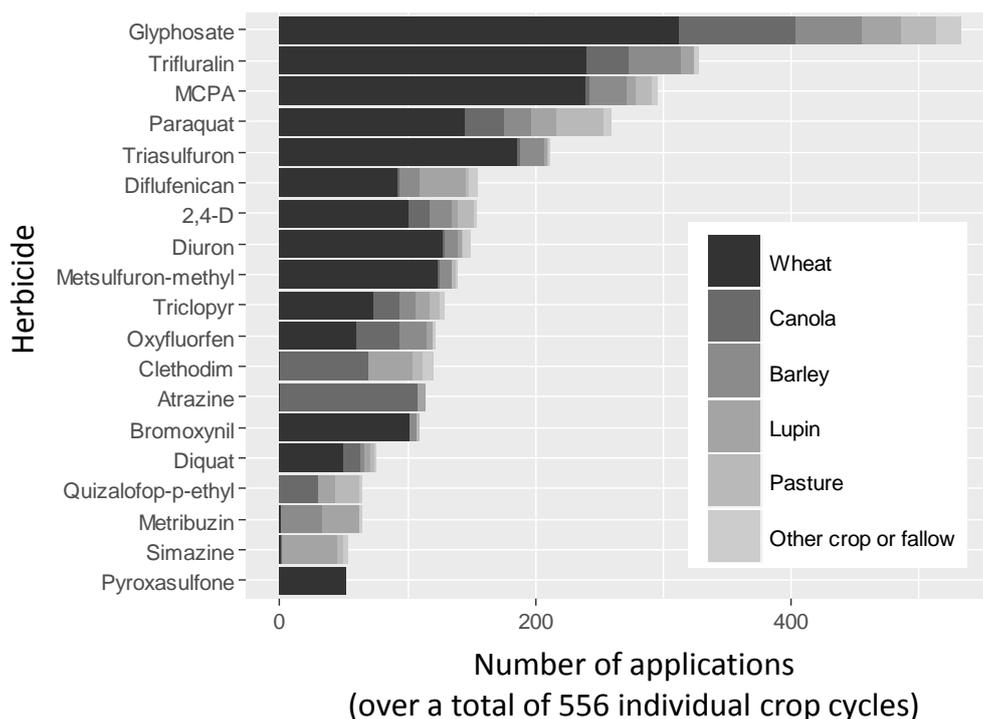


Figure 1. Herbicide use patterns for WA cropping systems. A total of 556 paddock records were obtained in the Focus Paddock survey over the 5 year period.

Glyphosate is the most frequently applied herbicide product in the WA Focus Paddocks, and in all likelihood, other Australian grain cropping regions as well. Glyphosate was used in all crop types/sequences in the WA Focus Paddocks. Given that glyphosate was applied over 500 times to 556 individual crop cycles, this equates on average to almost 1 application per crop. Other commonly used herbicides included those from Group D (trifluralin), Group I (MCPA; 2,4-D; triclopyr), Group L (paraquat), Group B (triasulfuron; metsulfuron-methyl), Group F (diflufenican) and Group C (diuron). Atrazine and glyphosate were the most common herbicides used for weed control in canola. The use of pyroxasulfone (Sakura®) has increased in response to herbicide-resistance.

Exposure – which herbicides are remaining in soil?

The soil survey of 40 different paddocks from around Australia (12 in WA, 15 in SA and 13 in NSW-Qld) detected residues of 11 chemicals out of the 15 analysed (Figure 2). Glyphosate and its primary metabolite, aminomethylphosphonic acid (AMPA) were the most commonly detected residues, with AMPA residues present in every topsoil sample taken. Trifluralin residues were also detected in over 75% of the paddocks surveyed, both in topsoil and in the 10-30 cm soil layer, indicating some vertical movement despite the strong tendency of trifluralin to remain close to the site of application. This is possibly the result of cultivation, however, leaching or movement of particle-bound trifluralin may also occur on lighter textured soils with low organic matter content. Diflufenican and diuron residues were frequently detected in samples from WA paddocks, but less so in NSW-Qld and SA.

Interestingly, despite known application of triasulfuron and metsulfuron-methyl in many of the surveyed paddocks, neither of these residual herbicides was detected in any of the samples tested. This is probably a reflection of their low rates of application, close to the limit of analytical detection. It should be noted that sulfonylurea (SU) herbicides may still have some residual activity at levels below the limit of (currently available) analytical detection. By contrast, the lack of positive detections of frequently applied MCPA reflects its relatively short persistence.

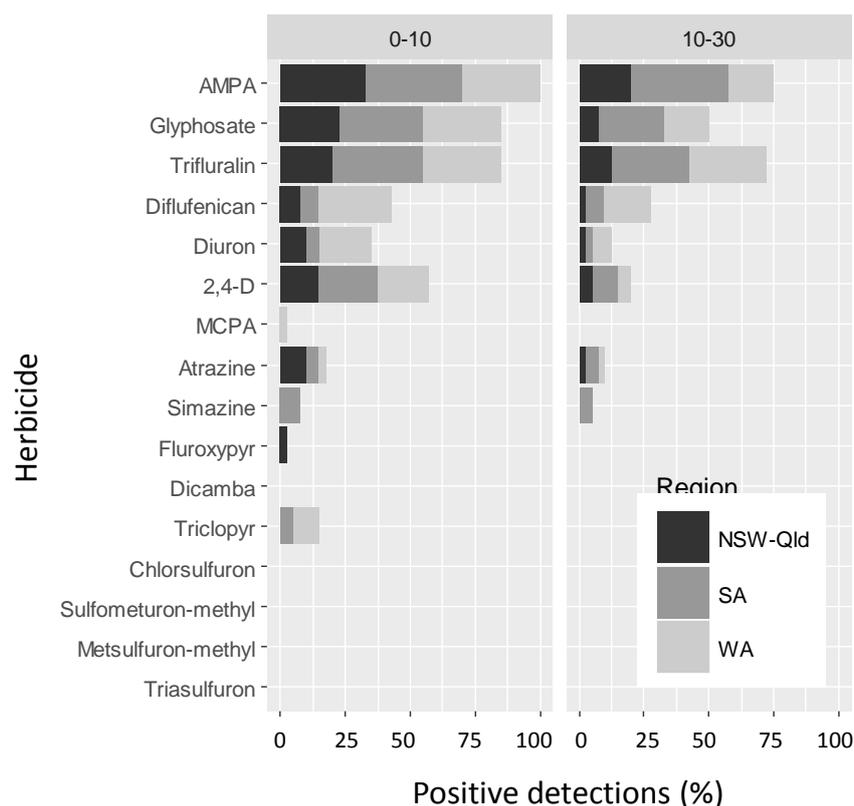


Figure 2. Number of positive detections of herbicides and the glyphosate metabolite AMPA in soil samples from 40 grain cropping paddocks around Australia.

By multiplying herbicide concentrations (mg/kg) by soil bulk density (kg/dm) and area, we estimated the total load of herbicide in the 0-30 cm soil profile for each paddock (Table 1). The average and maximum estimated loads of glyphosate, trifluralin, diflufenican and diuron were all significantly higher in paddocks in WA compared with those in SA, NSW and Qld. This likely reflects the lighter soil types, lower organic matter, dry summers and cool winters, which contributes to lower microbial activity and constrained herbicide breakdown. The higher load of atrazine in SA paddocks is probably a consequence of the higher persistence of s-triazine herbicides in alkaline soils; whilst the higher values for 2,4-D in the NSW-Qld soil profiles was due to a high value in a single paddock which had recently been sprayed.

Notably, in a number of paddocks (especially in WA but also in other states), we found glyphosate in quantities greater than expected from a single spray. This demonstrates a degree of accumulation of glyphosate and its metabolite AMPA over time. Although the half-life of glyphosate is relatively rapid (10-40 days), a significant portion of the glyphosate (and AMPA) is bound to soil and is much less accessible for continued degradation. This, combined with the high frequency of glyphosate use, can lead to a build-up of glyphosate and AMPA in soil. Accumulation of trifluralin was also apparent in a number of paddocks in WA. It should be reiterated that these levels represent the *total* loads, accessible by aggressive chemical extraction, rather than the bio-available fraction. Aging of residues in soil results in stronger binding over time, and a reduction in bioavailability, so any biological effect can be difficult to predict. This is discussed in more detail in the following sections.

Table 1. Residue loads (average and maximum) of herbicide active ingredients (a.i.) in the 0-30 cm soil profile of paddocks by region.

Herbicide	Estimated average load across all sites (kg a.i./ha)*			Estimated maximum load detected (kg a.i./ha)*		
	NSW-Qld	SA	WA	NSW-Qld	SA	WA
AMPA	0.91	0.95	0.92	1.92	1.97	2.21
Glyphosate	0.56	0.48	0.79	2.05	1.05	1.75
Trifluralin	0.08	0.11	0.53	0.14	0.26	1.34
Diflufenican	0.01	0.03	0.04	0.02	0.05	0.09
Diuron	0.14	0.05	0.17	0.16	0.05	0.29
2,4-D	0.20	0.02	0.01	1.00	0.05	0.02
MCPA	0	0	0	0	0	0
Atrazine	0.02	0.03	0.02	0.03	0.05	0.02
Simazine	0	0.04	0	0.00	0.05	0
Fluroxypyr	0.03	0	0	0.03	0	0
Dicamba	0	0	0	0	0	0
Triclopyr	0	0.04	0.01	0	0.07	0.01
Chlorsulfuron	0	0	0	0	0	0
Sulfometuron-methyl	0	0	0	0	0	0
Metsulfuron-methyl	0	0	0	0	0	0
Triasulfuron	0	0	0	0	0	0

*Calculated by multiplying mass concentration (mg/kg) detected by area and average bulk density (derived from soilquality.org) for each soil layer

Toxicity – how do soil functions respond?

A literature review of over 300 published studies identified common themes with respect to herbicide impacts on soil function (Rose et al., 2016). The majority of papers reported negligible impacts of herbicides on beneficial soil functions when applied at recommended rates. Even in the cases where negative effects were observed, they were usually minor and only lasted for periods of less than one month.

However, some exceptions were apparent, especially regarding the effects of repeated herbicide application. For example, there is evidence that the accumulation of some SU herbicides after repeat application can reduce plant-available N, by slowing down the processes controlling N-cycling. Persistence of SUs in soil has also been linked with increased incidence of *Rhizoctonia* diseases in cereals and legumes. These effects are more likely to occur in alkaline soils, where SU herbicides are significantly more persistent. There are also cases in which other herbicides (e.g. glyphosate) can increase the incidence of disease, but these interactions appear to be site-specific and often occur under stressful growing conditions.

Based on this information and the herbicide residues detected in the soil survey, it is unlikely that SU residues are having ongoing negative impacts to soil functions in the paddocks surveyed. However, the high residue loads of glyphosate, its metabolite AMPA and trifluralin may be altering some soil functions or plant-pathogen interactions. The localised nature of interactions with glyphosate, and the lack of specific data on trifluralin, means that firm conclusions cannot yet be made with respect to the residues detected.

Toxicity – how do plants respond?

Because the potential for each herbicide to damage crops varies according to soil, agroclimate and crop, comprehensive phytotoxicity thresholds (given as soil residue concentrations) for assessing plant-back risk are not readily available. Here we focus only on the potential for glyphosate (+AMPA) or trifluralin residues to cause seedling damage, given their high frequency of application and detection in the residue survey.

It is generally accepted that glyphosate is deactivated when it reaches the soil and poses little risk to crops. However, recent research has shown that under certain circumstances glyphosate can be remobilised and become plant bioavailable, including:

1. In the event of P fertilisation, which can compete with glyphosate for binding sites on soil and remobilise bound glyphosate residues (Bott et al., 2011)
2. In the event of glyphosate applied to a high density of weeds soon before sowing, such that dying weeds translocate glyphosate into the soil and act as a more soluble pool of glyphosate to the germinating crop (Tsfamariam et al., 2009)

We used a sandy, low organic matter soil from Wongan Hills, WA, to construct dose-response curves for wheat and lupin encountering glyphosate residues applied one month prior to sowing. To demonstrate circumstance (1), half the test pots received a one-off application of 20 kg/ha P fertiliser (as soluble potassium phosphate) at sowing.

As can be seen in Figure 3, in soil not receiving P fertiliser, wheat biomass was not affected by levels of glyphosate in soil resulting from a 27 kg/ha application rate, whilst lupin biomass was only significantly reduced at rates above 12 kg/ha (when upper 95% confidence level falls below 100% biomass). When P fertiliser was added at 20 kg P/ha, both wheat and lupin showed signs of phytotoxicity at lower glyphosate concentration – for lupin this occurred at levels of glyphosate > 3.5 kg/ha (Figure 3, visual growth shown in Figure 4); and for wheat > 12.5 kg/ha (Figure 3). Previous research has shown that increasing levels of P fertiliser application will continue to lower the phytotoxicity threshold to glyphosate/AMPA residues in soil. We are currently analysing the soil samples from this experiment to determine the residue level of both glyphosate and AMPA in soil. This will give us a more accurate understanding of whether the residues found in the field survey are likely to cause crop growth impacts following P fertilisation.

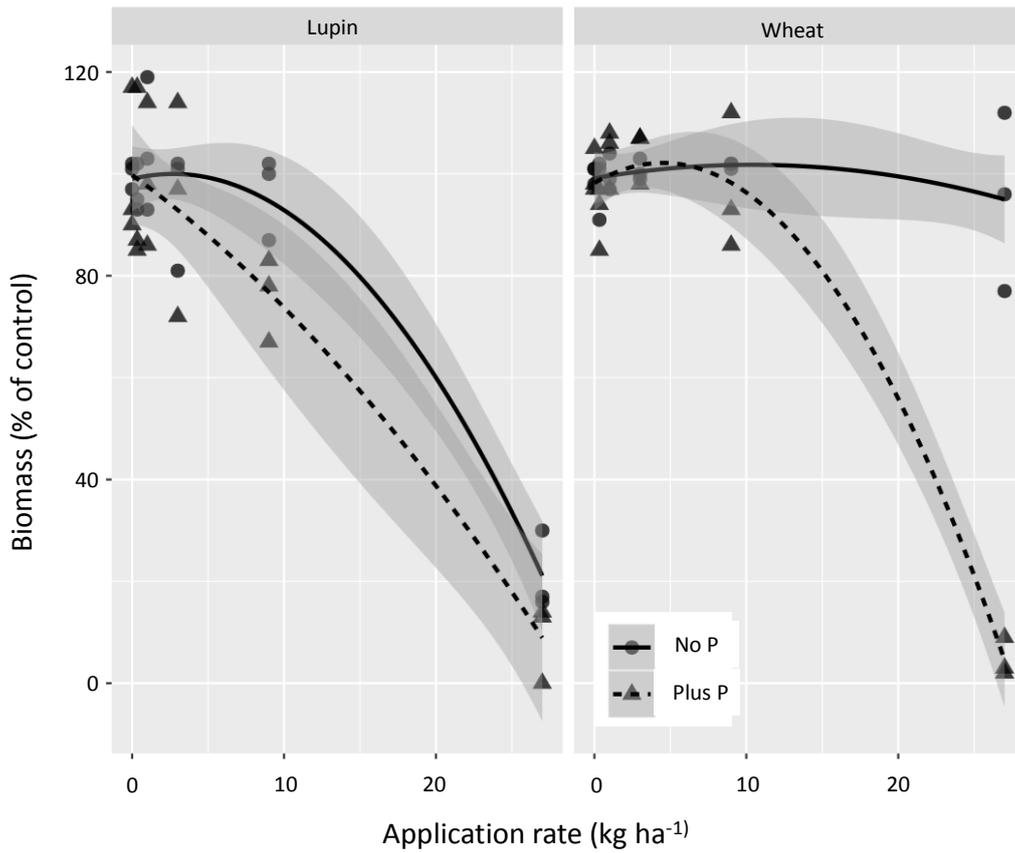


Figure 3. Growth response of lupin and wheat to glyphosate applied to soil one month prior to sowing. P fertiliser (20 kg/ha) was added at sowing to half the pots.

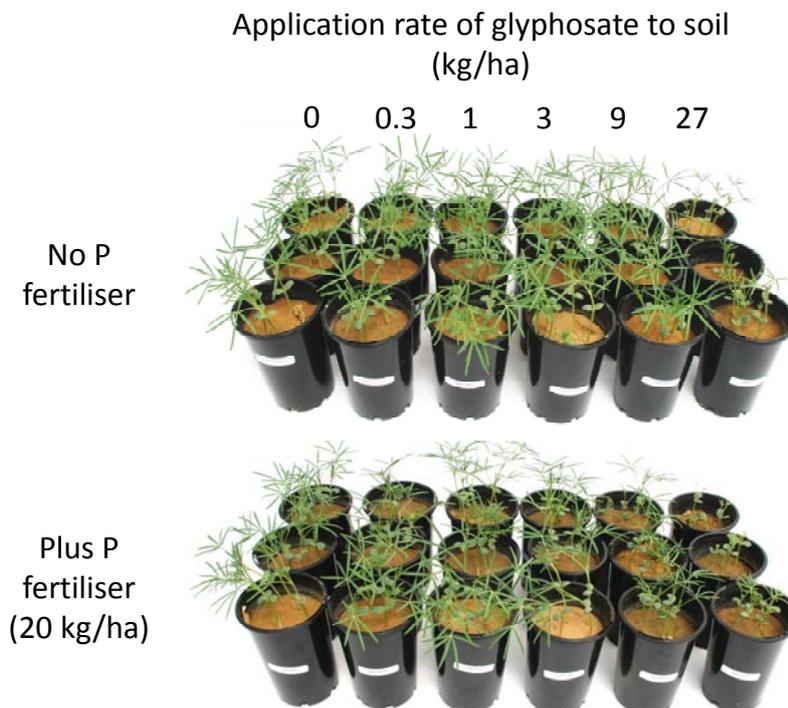


Figure 4. Growth response of lupin to glyphosate applied to soil one month prior to sowing. Note the impact of P fertiliser on lupin growth at glyphosate application rates 9 kg/ha.

With respect to trifluralin, phytotoxicity thresholds for oats vary from 0.1 – 0.2 mg/kg and wheat vary from 0.2 – 0.4 mg/kg depending on the soil type (Hager and Refsell, 2008). Table 2 shows the number of paddocks in which the topsoil trifluralin residue concentration exceeds the lower threshold for oats and wheat, respectively. Again, it must be stressed that the residues detected in our field survey constitute “aged” residues which are likely to be less bioavailable and hence less phytotoxic to crops. Nevertheless, considering that some of these paddocks will receive a pre-emergent application of trifluralin in 2016, the risk of some phytotoxicity is tangible.

Table 2. Number of paddocks exceeding trifluralin lower phytotoxicity thresholds for oats (0.1 mg/kg) and wheat (0.2 mg/kg) in topsoil (0-10 cm)

Region	Trifluralin > 0.1 mg/kg	Trifluralin > 0.2 mg/kg	Number of paddocks surveyed
WA	10	5	12
SA	2	0	15
NSW-Qld	0	0	13

Where to from here?

Ideally, growers and advisers would have tools available for rapid diagnosis of herbicide residues in soil, together with information of the biological relevance of these residues. Our current work is testing rapid in-field dipstick technology (similar to pregnancy test-kits) that can give a semi-quantitative indication of herbicide residue levels in soil within 30 minutes. We are also formulating improved models that can account for the effects of weather and soil type on herbicide persistence, to give growers and advisers the ability to estimate soil residue concentrations in a given paddock at a certain time after herbicide application. Output from current and future glasshouse dose-response experiments on herbicide impacts to soil functions and plant growth will be linked to model output in a handheld, ‘App’ format for quick reference.

Conclusions

- Glyphosate, trifluralin and diflufenican are routinely applied in grain cropping systems and their residues, plus the glyphosate metabolite AMPA, are frequently detected at agronomically significant levels at the commencement of the winter cropping season
- The risk to soil biological processes is generally minor when herbicides are used at label rates and given sufficient time to dissipate before re-application
- However, given the frequency of glyphosate application, and the persistence of trifluralin and diflufenican, further research is needed to define critical thresholds for these chemicals to avoid potential negative impacts to soil function and crop production.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. We would also like to acknowledge the generosity of all farmers participating in this survey for support, access and information regarding on-farm herbicide use. Special thanks to Cindy Cassidy, Tony Pratt and Kellie Jones from Farmlink, NSW; Greg Butler from SANTFA, SA; Clare Johnston and Elly Wainwright from Liebe Group, WA; Sarah Hyde and Georgia Oliver from Facey Group, WA; and Ashley Webb, Annabelle McPherson and Clarence Mercer, NSW DPI, for invaluable assistance with soil sampling and liaison.

Contact details

Lukas Van Zwieten
NSW Department of Primary Industries
1243 Bruxner Hwy, Wollongbar NSW 2477
Ph: 02 6626 1126
Fx: 02 6628 6051
Email: Lukas.van.zwieten@dpi.nsw.gov.au

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Sowthistle – update on glyphosate resistance survey, and overview of resistance testing and management options

Annie van der Meulen (DAF Qld), Michael Widderick (DAF Qld), Tony Cook (NSW DPI), John Broster (CSU)

Key words

Common sowthistle, milkthistle, glyphosate, herbicide resistance

GRDC code

UQ 00062

Take home message

- Common sowthistle populations in the northern region have developed resistance to glyphosate.
- Survey results indicate that glyphosate resistant sowthistle populations are concentrated in northern NSW.
- An integrated approach to managing common sowthistle is recommended to prevent seed set and combat herbicide resistance.
- Herbicide resistance testing is recommended as part of an integrated weed management (IWM) strategy.

Survey of glyphosate resistant sowthistle in the northern region

In the northern region, glyphosate is a highly important herbicide for controlling common sowthistle in fallows. However, in 2013/2014, two populations of common sowthistle (*Sonchus oleraceus*) from northern NSW were determined to be glyphosate resistant.

To establish how abundant and widespread this resistance is across the northern cropping region of Australia, the Queensland Department of Agriculture and Fisheries (DAF) are leading a glyphosate resistance survey of common sowthistle across the region. The research is being conducted in collaboration with the NSW Department of Primary Industries (NSW DPI) and grower solutions groups including the Northern Grower Alliance (NGA) and the Grain Orana Alliance (GOA).

Because the survey objective is to determine the abundance and distribution of glyphosate resistant sowthistle populations across the northern region, it was decided not to bias sampling by specifically targeting “problem” sites or survivors of glyphosate application, leading to an over-estimation the incidence of resistance. To sample as many populations as possible, the decision was made to collect from sowthistle plants growing within both fallow and cropping situations.

Volunteers, mostly local agronomists and some farmers, have assisted in the survey by collecting seed samples, and this has been shown to be a very effective way of sampling the large study area. To ensure that high quality sowthistle seed samples are collected, a “collection kit” was prepared by the research team, which was sent to each seed collector. This kit included a detailed sampling protocol, numbered calico sample bags, and postage-paid, pre-addressed packages for sending the seed samples in for testing. Common sowthistle germinates in any season and can flower all year-round, provided there is adequate soil moisture. If there has been a significant rainfall event within recent months, seed producing plants are likely to be found in many crop and fallow paddocks. With their in-depth local knowledge and easy access to cropping properties, local agronomists and farmers can be on-the-spot to collect seed samples when the time is right.

In brief, the protocol for seed sample collection is as follows:

- Sites need to be cropping properties, located a minimum of 5 km apart.
- The paddock edges should be avoided in sample collection.
- Collect seeds from at least 20 individuals per site sampled.
- Record details of the sample population, including GPS location, on the field data sheet provided.

Once received for testing, the seed samples are stored in a dehumidified cold room at the Leslie Research Facility, so as to preserve seed viability until the time of their inclusion in screening tests. Before going into storage, they are sorted to assess quality, and to remove seed eating insects.

The diagnostic screening of samples to determine glyphosate resistance status is based on survival at 356.4 g a.i./ha of a commercial glyphosate formulation. Dose response experiments conducted at our research facility have determined that this dose accurately discriminates between resistant and susceptible populations. From a practical point of view, for the glyphosate product used in the screening, this dose is equivalent to the upper label rate to control sowthistle plants with five or less true leaves (or no more than 3cm in diameter/height), in a fallow situation or prior to planting a crop in the northern region.

In the screening tests, plants are sprayed at the two-to-four leaf stage and herbicide efficacy is assessed 21 days after herbicide treatment (increasing to 35 days in cold weather). Plants are considered survivors if the growing point (centre of the rosette) is green and/or if new leaves are present. A population is deemed “resistant” (R) if $\geq 20\%$ of the plants survive the glyphosate treatment.

To date a total of 147 sowthistle seed samples have been submitted for glyphosate resistance testing. Of the populations tested, approximately 20% of the populations have shown resistance to glyphosate. For one seed sample, 93% of plants survived glyphosate application at the label rate for small plants. This sample was sourced from survivors of a glyphosate treatment in a fallow situation, located near Gunnedah, NSW.

The good news is that the survey so far indicates many populations remain susceptible to glyphosate, when treated at the small rosette stage and according to label recommendations. Through greater diversity in weed control as part of an integrated approach, it should be possible to retain the effectiveness of this key herbicide for control of common sowthistle.

Samples received to date provide a reasonable geographic coverage of the sampling area (Figure 1). Many samples have been sent in by growers and agronomists in northern NSW and the Southern Downs. However, additional samples are being targeted from central Queensland, the Western Downs, and Maranoa. Growers and agronomists in these areas are particularly encouraged to send in samples – if you can assist, please contact Annie van der Meulen (contact details are provided at the base of this paper).

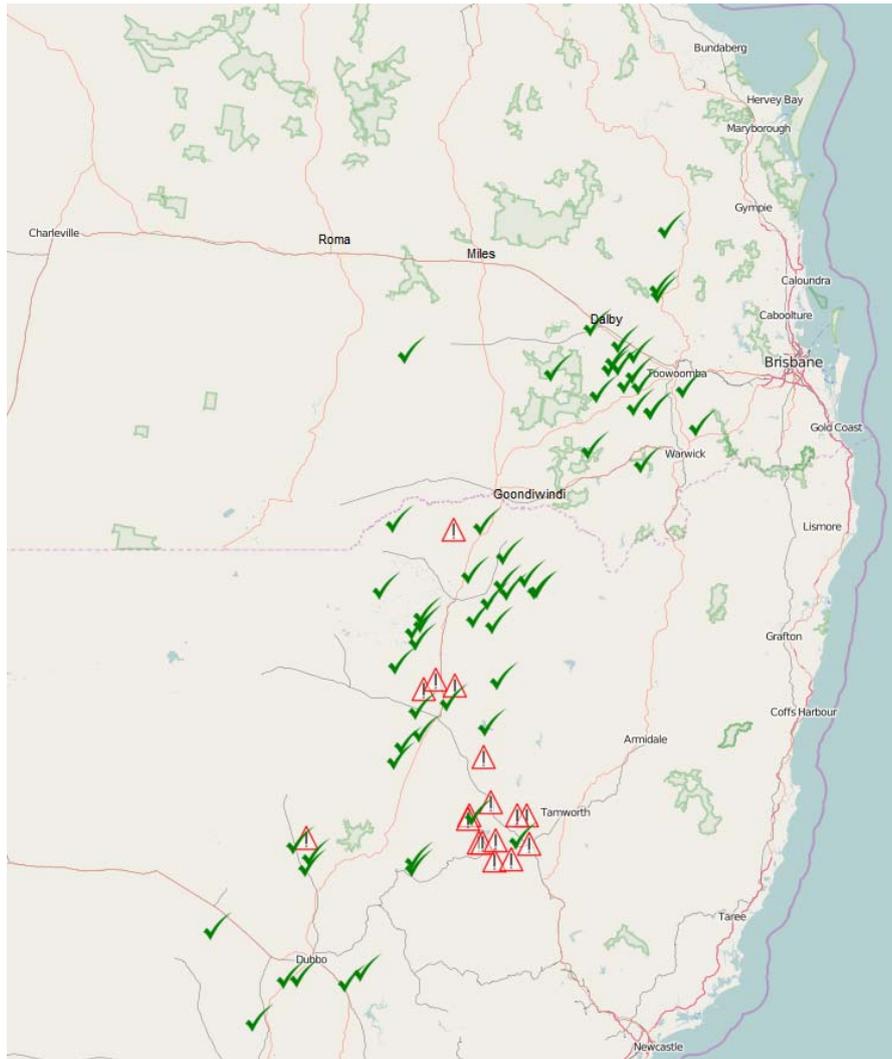


Figure 1. Map showing the location of tested populations. Green tick = susceptible, Red triangle = resistant.

Sowthistle best management

Although glyphosate resistance in common sowthistle is of serious concern, glyphosate remains a viable control option for many populations. Where glyphosate resistance is confirmed, there are other effective options for controlling the weed.

Important control considerations for common sowthistle are as follows:

- It is important to know what herbicides will work. Glyphosate resistance is confirmed to be present in the northern region, and Group B resistance is reported to be widespread.
- Aim for 100% elimination of seed set, including road verges and in channels.
- Maximise crop competition. Grow competitive crop species such as barley at narrow row spacing (e.g. 25cm), and in situations where common sowthistle is a persistent problem, avoid growing poorly competitive crops such as chickpea - this crop has high potential for sowthistle 'blow out.'
- If relying on knockdowns in fallow, treat sowthistle while the plants are small, and double knock to control survivors.
- Apply residuals early in fallow. When using Flame® to control summer grasses, remember to partner it with an herbicide effective for controlling common sowthistle.

It is not advisable to rely on spray failure as an indication of herbicide resistance. Not only is spray failure a costly exercise, but there are multiple possible causes including poor application due to adverse environmental conditions and equipment failure. Herbicide resistance testing costs are typically around \$125-\$150 for a single herbicide, and \$75-\$95 for each additional herbicide tested. This relatively small expenditure could save considerable financial set-backs in lost production, wasted herbicide, and control costs of driving down a large resistant seed bank.

For specific details on testing options for common sowthistle, contact your local agronomist or a commercial seed testing centre:

Charles Sturt University, Wagga Wagga

Contact: John Broster, 0427 296 641, jbroster@csu.edu.au

Plant Science Consulting, Adelaide

Contact: Peter Boutsalis, 0400 664 460, info@plantscienceconsulting.com.au

Future research

A new GRDC-funded herbicide resistance surveillance project commenced in July 2015 and will involve resistance surveys of key herbicide groups commonly used for northern region weed species common sowthistle, flaxleaf fleabane, awnless barnyard grass and feathertop Rhodes grass. This project is led by Charles Sturt University, in collaboration with Queensland Department of Agriculture and Fisheries, University of Western Australia, and the University of Adelaide. In the northern region, the approach for testing and seed collection is currently being developed.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support.

Contact details

Annie van der Meulen

Crop and Food Science, Department of Agriculture and Fisheries, Queensland

PO BOX 2282 Toowoomba QLD 4350

Ph: 07 4639 8847

Email: annemieke.vandermeulen@daf.qld.gov.au

Pre-emergent herbicides: part of the package for FTR management?

Richard Daniel, Northern Grower Alliance

Key words

Residual herbicides, feathertop Rhodes grass

GRDC code

NGA00004: GRDC Grower Solutions for Northern NSW and Southern Qld

Take home messages

1. Feathertop Rhodes grass (FTR) is generally a difficult and costly weed to control with knock-down herbicide strategies
2. A number of residual herbicides provide useful FTR activity but highly unlikely to be standalone options
3. Need to incorporate a range of integrated weed management (IWM) approaches to achieve effective long term management
4. Monitoring for new incursions and effective patch management appear to be key tools for this species
5. Individual paddock rotations may need to change to enable use of effective residual chemistry in preceding fallows or in-crop

The issue

Feathertop Rhodes grass - *Chloris virgata* has become an important weed management issue in many parts of the northern grains region, having previously been more common as a weed of non-crop areas. Some of the likely reasons for this change are:

- FTR is a species with higher levels of natural tolerance to glyphosate and as such has been selected by glyphosate dominated fallow/roadside management strategies
- FTR is generally poorly controlled by either paraquat alone or even a double-knock of glyphosate followed by paraquat
- DAF Qld research has shown that FTR is a one of the first weed species to colonise bare areas (faster than weeds such as awnless barnyard grass, fleabane and sowthistle under the same conditions) and can germinate on rainfall events as small as 10mm
- FTR prefers to germinate from the soil surface with negligible emergence occurring when seed is at depths of 2cm or deeper in the soil
- Minimum/zero tillage practices are likely to have increased the threat posed by this weed as cultivation or seed burial can be effective FTR management tools

It was always expected that as our reliance on knockdown herbicides increased – both in fallow and in-crop, there would come a time when the industry would need to successfully apply more integrated weed management (IWM) approaches for a range of weed targets. For many growers, that time has been with us a few years now! Residual herbicides of course are far from the solution but merely another tool that may assist in the control of a range of weed species.

Residual herbicides for FTR management pre-crop or in fallow

Previous NGA, DAF Qld and NSW DPI trial activity/reports have focussed on the potential of residual herbicides, particularly in fallow, to aid the management of problem fallow weeds such as fleabane or FTR. Using a residual herbicide in fallow appears a logical first step as it should maximise the amount of herbicide present at the time the weed is most likely to be active. However an obvious downside is that in a fallow situation there is no crop competition to assist weed suppression/control and often application happens under adverse conditions.

Although good levels of control can be achieved, variability in control and the issues that have often dogged residual products still need to be better understood and managed e.g. consistency of efficacy across varied soil types, incorporation requirements and stubble loadings, plantback restrictions and how to best maximise crop safety without reducing weed efficacy.

Research has shown that a range of herbicides can provide useful residual FTR activity, however at this stage there is still only one registered fallow herbicide option:

- 100g/ha isoxaflutole 750g ai/kg (eg Balance®)

Additional product registrations for fallow use are being sought. Other herbicides used to provide residual control of summer grass weeds in pre-plant or fallow situations (eg Dual® Gold, Flame® or Treflan®) have been noted to reduce emergence of FTR.

Residual herbicides for FTR in non-crop situations

FTR frequently dominates in non-crop areas with a potential for re-infestation of cropping. Imazapyr based herbicides (e.g. Arsenal®, Arsenal® Express) are registered for control in non-crop areas.

Residual herbicide in-crop

Utilising residual herbicides in-crop will allow the use of additional IWM approaches. In-crop use benefits from:

- Crop competition
- Change in crop being grown
- Residual herbicide often applied under better conditions than in fallow or where a level of mechanical incorporation occurs
- 'Increased disturbance' planting may provide benefits for FTR management via weed seed burial or removal of early weed emergence

Currently there are no registrations for residual control of FTR in-crop although there are a range of Group A herbicides with knock-down registrations for FTR control in summer crops such as cotton, mung beans, soybeans, sunflower and peanuts.

Residual herbicide strategies for awnless barnyard grass control (e.g. Dual® Gold, Flame®, Treflan® and Stomp®) applied in a range of summer crops have been noted to reduce the emergence of FTR.

FTR is predominantly a summer weed but often the first cohort of emergence occurs during the winter crop phase. Screening of registered winter crop residual herbicides for activity against spring emergences of FTR (in addition to other summer grass weeds) has been conducted for the past three seasons with encouraging activity from a range of herbicides used in either cereal or chickpea production. Residual herbicide strategies for the control of a range of both grass and broadleaf weeds (e.g. Balance®, Treflan®, Stomp®, Sakura® and Terbyne®) applied in a range of winter crops have been noted to reduce emergence of FTR.

Other tactics certainly required

Effort is continuing into determining how to ensure more consistent levels of efficacy from at-planting residual herbicides. However in nearly all cases follow up weed management will be required. In fallow situations this often results in the need for follow up fallow applications but may allow the use of optical sprayers to limit both the area treated and cost.

With in-crop application we have the added benefit of crop competition but also a number of rotation crops in which Group A herbicides are registered to allow knock-down control of FTR escapes. Sorghum is still seen as the potential 'blow out' crop for FTR management. Although there are a range of residual herbicides used in sorghum for summer grass management, their length of activity is certainly not season long and there are currently no in-crop knock-down options to control survivors. When combined with the wide row spacings used in sorghum, this creates an environment where FTR often flourishes.

Other options that should be considered for FTR management:

- Salvage cultivation of mature plants and inter-row cultivation for crops such as sorghum when grown on wide rows
- Patch cultivation of new incursions (including manual weeding and chipping)
- Residual herbicides applied to new patches after other tactics employed
- Strategic cultivation for seed burial (providing further tillage is not employed as this may simply return seeds to the soil surface)
- Burning may be a useful tool where blow outs have occurred in patches or even in larger areas

Conclusions – the role for residual herbicides

Our management issues with FTR (together with weeds such as fleabane and awnless barnyard grass) have in part stemmed from an over reliance on glyphosate in the summer fallow. To successfully manage these weeds the industry must continue to adopt a range of integrated management practices using both non herbicide measures eg:

- crop rotation
- strategic and salvage tillage
- intensive patch management for new incursions
- salvage burning
- a wider range of herbicide options (eg residual herbicides) as well as double-knock strategies

This is required to effectively manage these weeds but also to ensure we don't lose glyphosate completely. FTR is a species that appears well suited to intensive patch management as it doesn't appear to be as easily dispersed by wind compared to some of our other fallow weeds eg sowthistle.

Profitability is of course still paramount. The suggestion with these problem weeds is to focus on individual paddocks and adjust rotations to crops that most suit your environmental conditions but also enable the use of effective residual herbicides in the previous fallow or even in crop. Particularly for FTR, the seed bank is only short lived and two years of effective management can ensure that paddocks return to full flexibility of rotational choice.

Acknowledgments

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Richard Daniel
Northern Grower Alliance
Ph: 07 4639 5344
Email: richard.daniel@nga.org.au

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The genetics of glyphosate resistance in barnyard grass, fleabane, windmill grass and feathertop Rhodes grass

James Hereward, University of Queensland

Key words

Herbicide resistance, genetics, genomics, weeds

Take home message

Three out of four species of glyphosate-resistant northern-region weeds have non-target site resistance mechanisms. Only feathertop Rhodes grass (which is not considered resistant) has the Pro106Ser target site mutation.

Introduction

Herbicide resistance mechanisms are broadly categorised as either “target site” or “non-target site” mechanisms. Target site resistance mechanisms are caused by changes to the gene/protein that is targeted by a particular herbicide mode of action (MoA). These targets are well characterised and therefore target site resistance mechanisms are relatively easy to detect genetically. Target site mechanisms are also generally single gene traits so their inheritance is relatively easy to predict. Further, target site mechanisms are, by definition, specific to one MoA. This type of resistance therefore cannot result in cross resistance between herbicide MoA's. On the other hand; every other type of resistance mechanism is categorised as “non-target site resistance” (NTSR). This can include anything from additional waxiness of the plant cuticle through to detoxification pathways and various transportation pathways. “Non-target site” resistance can involve multiple genes, have complex inheritance, and many NTSR mechanisms of small effect can be present in one plant line. This makes the identification of the genetic changes underlying NTSR mechanisms difficult to elucidate by traditional methods. NTSR mechanisms can also potentially confer cross-resistance to more than one herbicide MoA, and are therefore undesirable from a management perspective.

From a theoretical perspective high rates of herbicide application are more likely to select for target site resistance, and low rates are more likely to select for NTSR. There is evidence to support this prediction in metabolism-based NTSR to diclofop in annual ryegrass. Glyphosate can be metabolised by some plants, but the by-products are toxic and no field resistance has been explained by metabolism to date. The structure of the target site (EPSPS gene) of glyphosate also means that relatively few mutations are able to cause target site resistance in the field. The structure of the EPSPS protein may therefore partially explain the relatively long time it has taken for target site resistance to Roundup to develop, as it reduces the chance of developing target site resistance regardless of herbicide rate.

This paper will discuss the ways new gene sequencing technology has been used to assess glyphosate resistance in four species of weeds; barnyard grass, fleabane, windmill grass and feathertop Rhodes grass.

Results and discussion

The only species found where resistance was fully explained by a target site mutation was feathertop Rhodes grass. This species is regarded to be tolerant rather than resistant, however, from a genetic point of view it is resistant as the target site mutation would have only spread throughout the population in response to the selection pressure imposed by glyphosate. Barnyard grass also had a target site mutation in one population (Table 2). This mutation was only present in one of the three genomes (the species is polyploid), and only in one of the two lines that showed strong

resistance. This species therefore shows a mix of target site and NTSR resistance mechanisms across different populations. Fleabane and windmill grass showed no evidence of target site mutations, indicating that both are resistant to glyphosate through NTSR mechanisms. Fleabane has an ancestral duplication of the EPSPS gene; however, this does not explain resistance as it is present in both resistant and susceptible individuals, and across multiple species in the genus. Windmill grass shows some preliminary evidence of additional copies (4x) of the EPSPS gene, this could partially explain resistance but requires further investigation.

Table 1. Mutations present at the EPSPS target site gene for each of the 12 individual plants sequenced, the two mutations that confer glyphosate resistance were scored and all lines were susceptible at the target site with the exception of QBG41.

SAMPLE	Resistance Phenotype	Pro101	RES	Thr97	RES
TC-05	Susceptible	P	SUS	T	SUS
TC-10	Susceptible	P	SUS	T	SUS
QBG61-02	Susceptible	P	SUS	T	SUS
QBG61-03	Susceptible	P	SUS	T	SUS
PJ55-04	Intermediate	P	SUS	T	SUS
PJ55-06	Intermediate	P	SUS	T	SUS
QBG3-01	Intermediate	P	SUS	T	SUS
QBG3-02	Intermediate	P	SUS	T	SUS
QBG41-04	Strong	P/T	SUS/RES	T	SUS
QBG41-10	Strong	P/T	SUS/RES	T	SUS
PLG3-09	Strong	P	SUS	T	SUS
PLG3-11	Strong	P	SUS	T	SUS

Gene expression changes in response to glyphosate treatment in fleabane and barnyard grass were also assessed through two transcriptome experiments. In barnyard grass many more genes show different expression patterns in the strong resistant lines compared to the lines with intermediate resistance (table 2.). This indicates that many genes could be involved with NTSR mechanisms in barnyard grass. In fleabane relatively few genes were differentially expressed (DE) following removal of genes that were DE in susceptible lines, indicating that NTSR in fleabane could be caused by few genes. The genes that were up-regulated in fleabane mostly match to transporter genes.

Table 2. Number of differentially expressed genes in each of the resistant lines of barnyard grass

Line	Resistance	Number of DE genes
QBG3	Intermediate	44
PJ55	Intermediate	56
PLG3	Strong	267
QBG41	Strong	320

Conclusions

Non-target site resistance mechanisms to glyphosate are widespread in the northern region. Understanding the risk of cross resistance requires that the specific NTSR mechanism is known. This used to be very difficult with traditional genetic approaches but new technology and methods are now allowing us to unravel the genetic basis of NTSR mechanisms.

Acknowledgements

This work is supported by the CRDC (Cotton Research and Development Corporation).

Contact details

James Hereward
The University of Queensland
Goddard building, UQ St. Lucia, 4072, Brisbane.
Ph: 07 3365 2769
Email: j.hereward@uq.edu.au

The mobility of P in alkaline clays of the northern grains region

Karl Andersson, Matt Tighe, Chris Guppy, Paul Milham, Tim McLaren, UNE

Key words

Reserve-phosphorus, alkaline soil, vertosol, calcium phosphate, sorbed P

GRDC code

GRS10029

Take home message

- The reserve-P (the P extractable by BSES in excess of Colwell-P) in alkaline soils is made up of mineral and sorbed forms.
- The concentration of reserve-P extracted with an anion exchange membrane (AEM) to mimic root uptake increased sharply at pH 6. This pH is achievable by natural processes of acidification in the soil close to active roots (the rhizosphere). The dissolution of CaP by acidification may be at least as important to P nutrition as slow dissolution.
- The release of reserve-P, through acidification and the extraction of both P and Ca in the laboratory, may explain field observations of rhizosphere acidification and the depletion of reserve-P by crops in neutral-alkaline agricultural soils.
- The ongoing availability of CaP in soils is likely influenced by the form of reserve-P, the capacity of plants to acidify the rhizosphere, and the pH buffer capacity of the soil.
- The improved understanding of the release of reserve-P can help improve agronomic options e.g. species selection and fertiliser rates.

Introduction

The alkaline Vertosols of the northern grains region contain a pool of phosphorus (P) that is rapidly available to plants, and a diminishing reserve-P fraction that has been considered to slowly replenish the available pool. The process of replenishment is not well understood, and this may lead to inefficient use of fertiliser P. Bell et al. (2014) have provided guidelines for Colwell-P and BSES-P to indicate likely responses to the application of P fertiliser at depth. The reserve-P is acid-soluble, and may be native soil P or fertiliser reaction products. The difficulty in estimating the supply of reserve-P to labile-P is illustrated by the weaker correlation between BSES-P and Colwell-P in soils with substantial reserve-P compared to those with low reserve-P (Moody et al., 2013). McLaren et al. (2014) proposed that reserve-P can contribute to the slow replenishment of the soil solution above that of Colwell-P when the Ca:P in the BSES extract is less than 57:1 (on a molar basis). Crop response both with and without P fertilisation in Vertosols (e.g. Dalal, 1997; Pundarikakshudu, 1989; Solis and Torrent, 1989; Wang et al., 2007) and other soils (Hinsinger and Gilkes, 1995; Johnston and Poulton, 1992; Ziadi et al., 2001) have shown that plants access acid-soluble P not measured by the bicarbonate method. It is possible that modification of soil in the rhizosphere, particularly acidification, enables plants to directly access the acid-soluble P fraction.

Methods

We analysed grey or black vertosols for common properties, including pH, EC, Colwell-P, BSES-P, P buffer index (PBI), oxalate extractable Fe, Al and P, exchangeable cations, pH buffer capacity, and

carbon content (both inorganic and organic). We mostly focussed on soils with moderate to high concentrations of reserve-P ($> 300 \text{ mg kg}^{-1}$). The soils had low PBI, were non-sodic and non-saline, and contained 0 to 0.3% carbonate.

We mimicked rhizosphere processes to study the release P from these soils. The technique used repeated extraction of P from soil suspensions while manipulating the pH. We measured the concentration of P that accumulated in solution after 18 h, P that was removed with AEM, or P that was removed with AEM while Ca was also removed with both AEM and cation exchange membranes (ACEM). These steps were repeated 15 to 20 times, while we manipulated the pH of the suspensions so it gradually acidified to $\sim\text{pH } 4$, was held the initial pH, or was gradually acidified then held at pH 6.5 or pH 5.5. Finally, we analysed the forms of P in the untreated and extracted soil with bulk P K-edge X-ray absorption near edge spectroscopy (XANES). The XANES measurements were made at SLRI in Thailand.

Results and discussion

Incremental acidification

The results presented are for three soils: soils 1 and 2 contain moderate concentrations of reserve-P ($\sim 300 \text{ mg kg}^{-1}$), and soil 3 contains high reserve-P soil (6600 mg kg^{-1}). Following the early removal of labile P sources, P recovery remained low until soil pH passed key thresholds (Figure 1). In contrast, previous investigations involving repeated extractions, but without manipulating pH, have found diminishing concentrations of P with increasing extraction time. These thresholds varied little between soils, though soil pH buffer capacity affected the amount of acid required to approach the thresholds. With the solution P concentration kept below $1 \mu\text{M}$ using an AEM, the threshold was pH 6.0–6.3 (AEM-P), i.e. within the range of potential rhizosphere pH. When released P was instead allowed to accumulate in solution (DI-P), a similar release of P occurred, but at pH 5.3–5.5. The concentrations extracted decreased as reserve-P was depleted (soils 1 and 2), or continued to increase where reserve-P remained in the soil (soil 3). Soils 1 and 2 had similar concentrations of reserve-P, but soil 1 contained a larger proportion in a more readily solubilised form. This indicates that the particular form of reserve-P influences its solubility and availability.

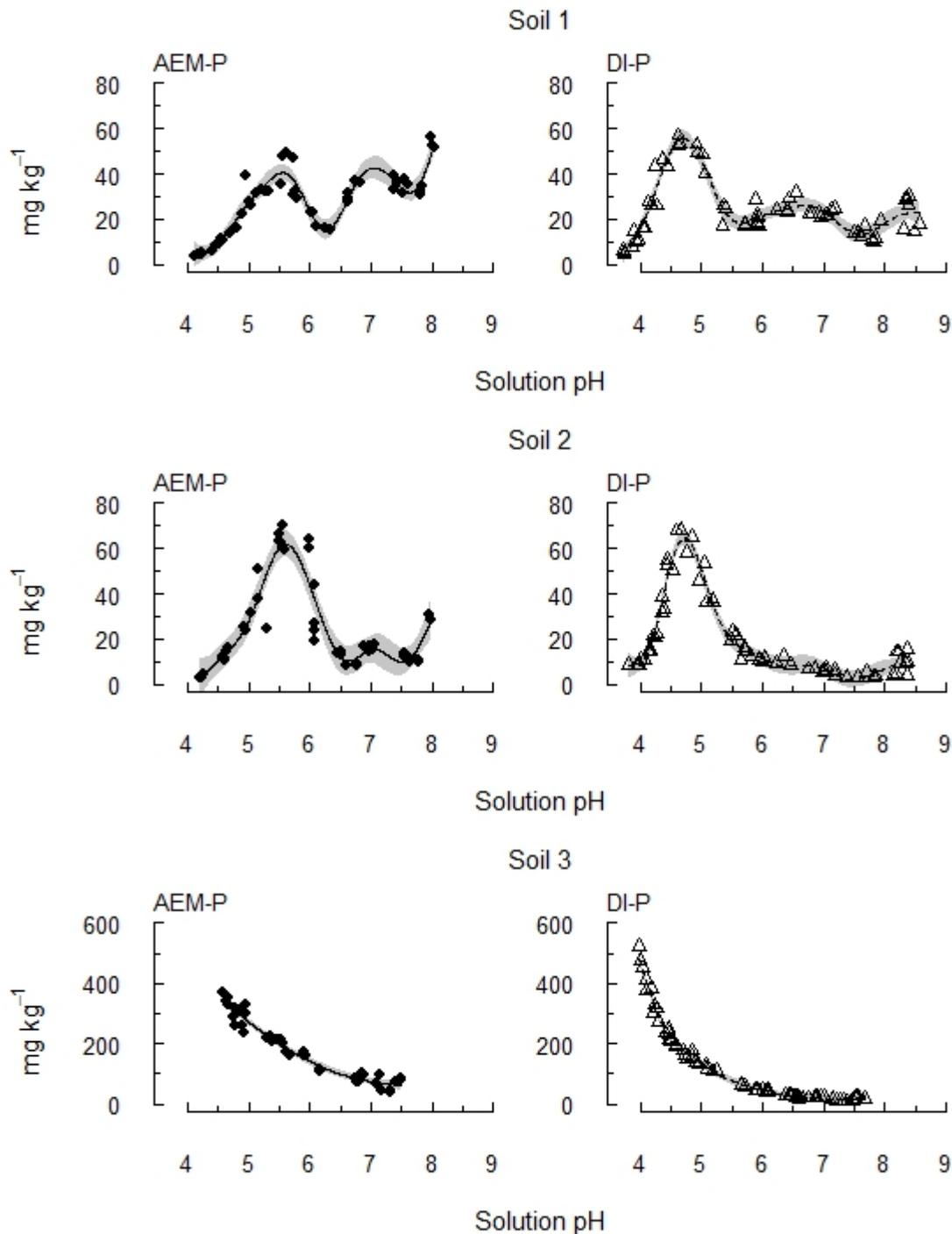


Figure 1. The concentration of P solubilised from each of three alkaline vertosols as pH was incrementally acidified.

Static pH

When the pH was either maintained at the initial level (pHi), or lowered to and held at pH 6.5 or 5.5, more P was released at each lower pH value (Figure 2). As the target pH was established, the concentrations of P extracted with AEM were similar to the concentrations removed at the equivalent pH during the incremental acidification. Pulses of P were released by acidification to pH 6.5 and then to pH 5.5, suggesting multiples pools of different solubility. Importantly, differences in

the solubility of reserve-P were again evident between the soils. The co-removal of P and Ca from solution with ACEM, released approximately twice as much P from each soil in the initial two to three extractions compared to the AEM alone (Figure 2). While reserve-P remained in the soils, greater concentrations of P were extracted with the ACEM as the pH 6.5 and pH 5.5 targets were established than with the AEM.

The equivalent concentration of Colwell-P was depleted early from each soil (Figure 3). Some reserve-P was extracted at pH_i, supporting the concept of slow replenishment of Colwell-P by reserve-P. However, the higher concentrations of P released by acidification of the soils after Colwell-P was removed show the importance of pH to the release of reserve-P. Since plant roots take up both P and Ca, and can acidify the rhizosphere, the results suggest that plants may directly access the acid-soluble P fraction.

Analysis by XANES identified that reserve-P includes CaP mineral phases and sorbed P phases, and that their contribution to the P extracted varied with pH. The mineral phases identified were apatite in each soil, along with the more soluble brushite in two moderate-P soils and octacalcium phosphate in the high-P soil. Acidification to pH 6.5, with AEM in the moderate P soils and ACEM in the high P soil, depleted the more soluble CaP minerals. Further acidification to pH 5.5 also depleted apatite. Smectite-sorbed P, identified in each soil, was depleted with P extraction at each pH level. While only low concentrations of P continued to be extracted at pH 5.5, other sorbed pools were identified which comprise part of the total soil P in excess of the reserve-P. The remaining pools are likely to be less available to plants, and indicate that the BSES-P extraction is a useful indicator of extractable P.

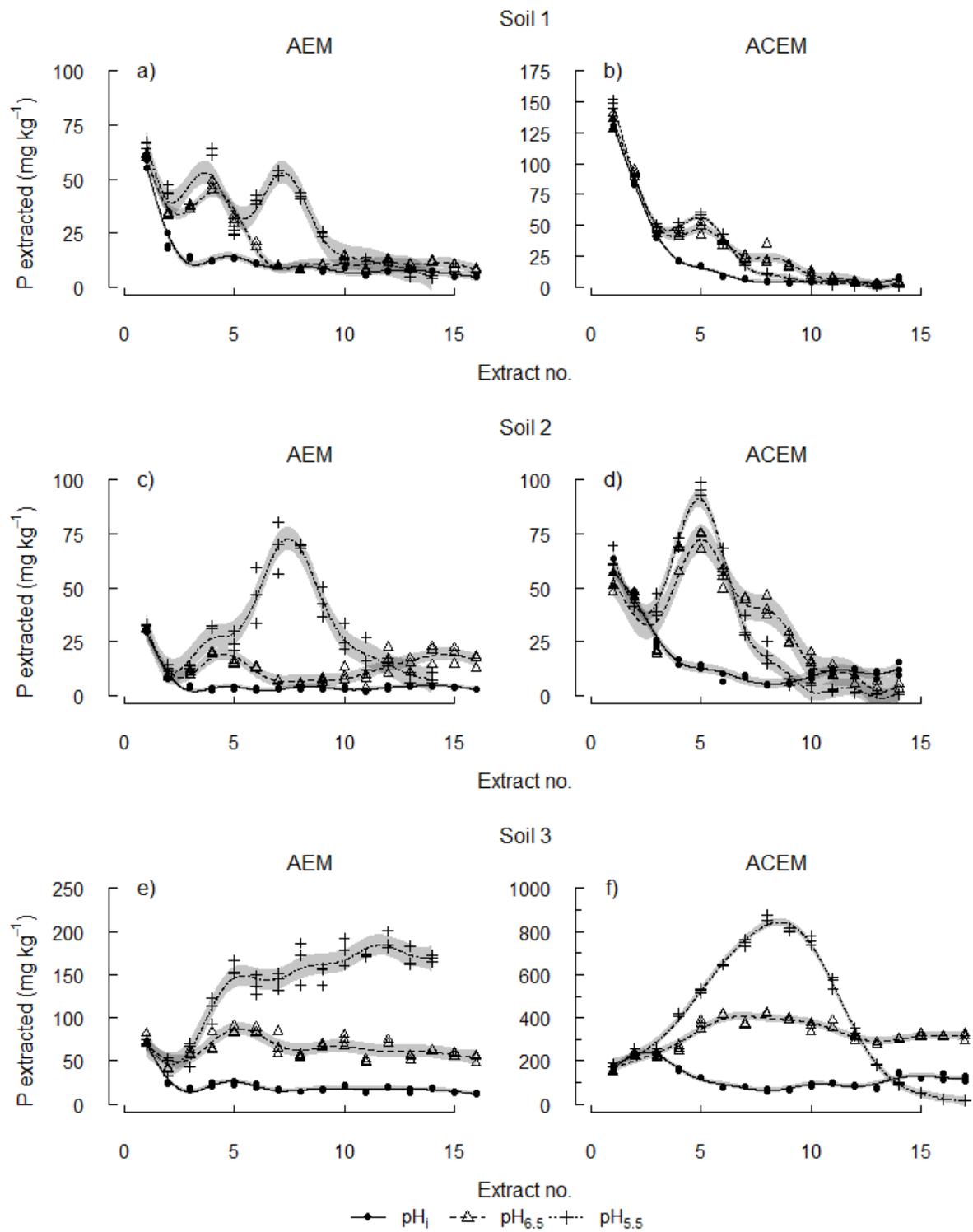


Figure 2. The concentration of P solubilised from each of three alkaline vertosols as pH was maintained at the initial soil pH, pH 6.5, or pH 5.5.

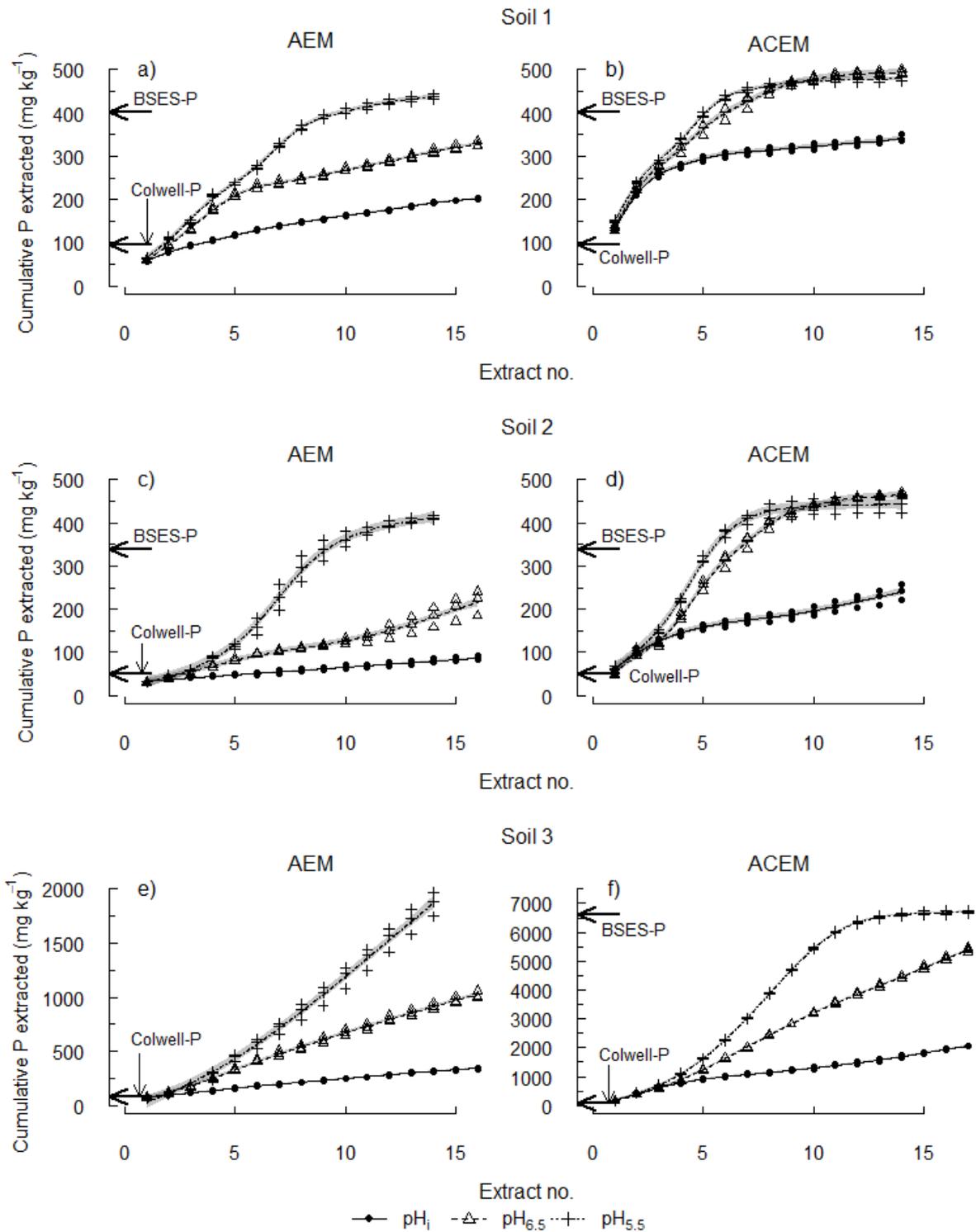


Figure 3. The cumulative concentration of P extracted at pH_i, pH 6.5 or pH 5.5.

Conclusion

The findings suggest that the depletion of acid-soluble P previously observed in agricultural systems on Vertosols may be driven, at least in part, by modification of the soil conditions. Even though rhizosphere acidification is energy expensive for plants, acidification may nonetheless be the process behind the depletion of acid soluble reserve-P in the Vertosols of the northern grains region.

Broader understanding of the pH buffering properties of the soils, and the nature of P reserves, may allow better selection of varieties and management of P fertiliser.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through the support of the GRDC, the authors would like to thank them for their continued support. We also acknowledge the support of the Australian Postgraduate Award, The Australian Synchrotron, and the Thai Synchrotron (SLRI). Results from this research have been published in *Geoderma*. Figure 1 is derived from Andersson et al. (2015), and Figures 2 and 3 are from Andersson et al. (2016).

References

- Andersson, K.O., Tighe, M.K., Guppy, C.N., Milham, P.J., McLaren, T.I., 2015. Incremental acidification reveals phosphorus release dynamics in alkaline vertic soils. *Geoderma* 259-260, 35-44. DOI: <http://dx.doi.org/10.1016/j.geoderma.2015.05.001>
- Andersson, K.O., Tighe, M.K., Guppy, C.N., Milham, P.J., McLaren, T.I., 2016. The release of phosphorus in alkaline vertic soils as influenced by pH and by anion and cation sinks. *Geoderma* 264, 17-27. DOI: 10.1016/j.geoderma.2015.10.001
- Bell, M., Lester, D., Power, B., Zull, A., Cox, H., McMullen, G., Laycock, J., 2014. Changing nutrient management strategies in response to declining background fertility: The economics of deep Phosphorus use, GRDC Grains Research Updates. Grains Research Development Corporation, Coonabarabran, pp. 30-38.
- Dalal, R.C., 1997. Long-term phosphorus trends in Vertisols under continuous cereal cropping. *Soil Res.* 35(2), 327-340. DOI: <http://dx.doi.org/10.1071/S96052>
- Hinsinger, P., Gilkes, R.J., 1995. Root-induced dissolution of phosphate rock in the rhizosphere of lupins grown in alkaline soil. *Soil Res.* 33(3), 477-489. DOI: <http://dx.doi.org/10.1071/SR9950477>
- Johnston, A.E., Poulton, P.R., 1992. The role of phosphorus in crop production and soil fertility: 150 years of field experiments at Rothamsted, United Kingdom. In: J.J. Schultz (Ed.), *Phosphate fertilizers and the environment*. International Fertilizer Development Center, Muscle Shoals, Alabama, USA, pp. 45-64
- McLaren, T.I., Guppy, C.N., Tighe, M.K., Moody, P., Bell, M., 2014. Dilute acid extraction is a useful indicator of the supply of slowly available phosphorus in Vertisols. *Soil Sci. Soc. Am. J.* 78(1), 139-146. DOI: 10.2136/sssaj2013.05.0188
- Moody, P.W., Speirs, S.D., Scott, B.J., Mason, S.D., 2013. Soil phosphorus tests I: What soil phosphorus pools and processes do they measure? *Crop Pasture Sci.* 64(5), 461-468. DOI: <http://dx.doi.org/10.1071/CP13112>
- Pundarikakshudu, R., 1989. Studies of the phosphate dynamics in a Vertisol in relation to the yield and nutrient uptake of rainfed cotton. *Exp. Agric.* 25(01), 39-45. DOI: 10.1017/S0014479700016422
- Solis, P., Torrent, J., 1989. Phosphate fractions in calcareous vertisols and inceptisols of Spain. *Soil Sci. Soc. Am. J.* 53(2), 462-466. DOI: 10.2136/sssaj1989.03615995005300020026x
- Wang, X., Lester, D.W., Guppy, C.N., Lockwood, P.V., Tang, C., 2007. Changes in phosphorus fractions at various soil depths following long-term P fertiliser application on a Black Vertisol from south-eastern Queensland. *Soil Res.* 45(7), 524-532. DOI: <http://dx.doi.org/10.1071/SR07069>

Ziadi, N., Simard, R.R., Tran, T.S., Allard, G., 2001. Soil-available phosphorus as evaluated by desorption techniques and chemical extractions. *Can. J. Soil Sci.* 81(2), 167-174. DOI: 10.4141/s00-040

Contact details

Karl Andersson
School of Environment and Rural Science
University of New England, Armidale
Ph: 6773 3497
Email: kanderss@myune.edu.au

Varietal variation in northern grain responses to phosphorus

Chris Guppy, Sheikh M. F. Rabbi, and Richard Flavel, University of New England

Key words

Wheat, barley, chickpea, phosphorus, root growth

GRDC code

UNE00020

Take home message

After accounting for other varietal choice factors (climate, disease, yield, rotation etc.) some wheat and barley varieties are better suited to certain soil P scenarios. We would not advise varietal selection purely on the basis of P responsiveness, however, if all other things are equal, these traits may assist decision making. There remains potential to target varieties to make better use of the prevailing nutritional environment.

Baxter[Ⓢ], Kennedy[Ⓢ] and Hindmarsh[Ⓢ] are good varieties under low P nutrition. Kennedy[Ⓢ], Sunco, Suntop[Ⓢ] and Shepherd[Ⓢ] grow well in fertile situations. Kennedy[Ⓢ], Spitfire[Ⓢ] and Clearfield® Scope[Ⓢ] barley may acquire more P from deep P bands. Gregory[Ⓢ], Suntop[Ⓢ] and most barley varieties may grow well where surface soil is P enriched, but subsoil P reserves are low.

Minimal early season root plasticity was observed in the 6 chickpea varieties tested. Yorker[Ⓢ] was the most responsive to a P band.

Introduction

GRDC recently invested in quantifying the variation in root response of 10 northern wheat and 5 barley lines to P, K, S and N nutrition. A modification to the project also included responses of 6 chickpea lines to P and K nutrition. Interestingly, and for another paper perhaps, it was not possible to measure significant responses to N, K or S nutrition when encountered in low N, K or S scenarios. It seems P plasticity is the main root adaptation for these lines and this paper focusses on P nutrition.

The data acquired was used to generate a table identifying which varieties may respond well in low soil P, high soil P, stratified P (high surface and low subsoil P) and where growers have placed subsoil banded P. These are conditions growers may face under a range of fertiliser application strategies. For example, low soil P may arise with a history of cropping with minimal P replacement. High soil P may occur where land is recently cleared, or fertiliser application has been maintained with both surface and subsoil placement. Stratified P scenarios arise with regular application of starter P rates or controlled traffic scenarios, and deep placement is a recent development following recognition of subsoil P resource depletion.

Materials and methods

Ten common Australian wheat varieties (cv. Baxter[Ⓢ], Crusader[Ⓢ], Gregory[Ⓢ], Kennedy[Ⓢ], Spitfire[Ⓢ], Sunco, Sunguard[Ⓢ], Suntop[Ⓢ] and Sunvale) and five barley varieties (cv. Clearfield® Scope[Ⓢ], Commander[Ⓢ], Gairdner, Hindmarsh[Ⓢ] and Shepherd[Ⓢ]) were investigated. These varieties represent the most grown, and most likely to be grown, in the major central-eastern Australian cereal areas over the next 3-5 years.

Nutrient acquisition trials were undertaken to assess root proliferation responses to applied fertiliser, critical internal nutrient requirements and annual uptake patterns with a view to recommending varieties best suited for a range of soil nutrition scenarios.

Root plasticity experiments

Five hundred grams of sieved (<5 mm) P and N responsive Red Ferrosol subsoil from Kingaroy was packed in the closed cell polyethylene tubes (aka 'pool noodles'). The soil moisture was maintained at 80% of field capacity throughout the trial. A 4 cm P band (150 mg P kg⁻¹) was placed 3 cm below the surface of the soil. The P was supplied as MAP and the soil above and below the P band was adjusted to the N concentration in the band (68 mg N kg⁻¹) using urea. Basal K, S and Ca were supplied. A negative control containing only N and basal nutrients (No-P), and a positive control containing P at the banded rate throughout the entire soil volume were also established (Uniform P). One germinated seed of wheat was planted approximately 3 mm below the soil surface of each tube. The treatments were replicated 4 times and grown in a glasshouse with day and night time temperatures of 25°C and 14°C, respectively. All plants were grown to the 4th leaf stage. The plants were then harvested, dried at 40°C in oven and weighed. Shoots were digested and analysed for P. Roots were extracted, washed and scanned on a flatbed at 600 dpi (i.e. 42 µm) and analysed with WinRhizo® v. 2009c software to determine root length and average root diameter of each section. Six chickpea varieties (cv Yorker[Ⓢ], Pistol[Ⓢ], Boundary[Ⓢ], Slasher[Ⓢ], HatTrick[Ⓢ], Kyabra[Ⓢ]) were also examined under the above conditions, with a growth period of 25 days.

Nutrient recovery experiments

40 kg of fertile Vertosol soil was packed in large bins and planted to the same 15 wheat and barley varieties. Subsamples were taken for nutrient analysis at 5 dates from 30 days after emergence until maturity; biomass and nutrient concentrations measured at each time point. Basal, N, P, K and S were applied so that growth was nutritionally unconstrained. Data was plotted as nutrient uptake relative to plant dry matter production.

Critical tissue P concentration

One kg of Red Ferrosol subsoil was treated with increasing rates of P (or N) and each of 15 cereal varieties was grown in the glasshouse for 6 weeks. Moisture was maintained at 80% of FC and all other nutrients were applied such that only the nutrient in question was limiting. Plants were harvested, dried, weighed and analysed for P uptake to determine the internal P requirement of wheat and barley varieties.

Results

Root plasticity

All varieties responded to P application in the band, and grew faster as a consequence. All varieties showed plasticity of roots (i.e. proportional RLD increase in band compared to the surface) and produced between 3 and 18 cm cm⁻³ of root in the P enriched patch (3-7 cm) in P band treatment (Fig. 1).

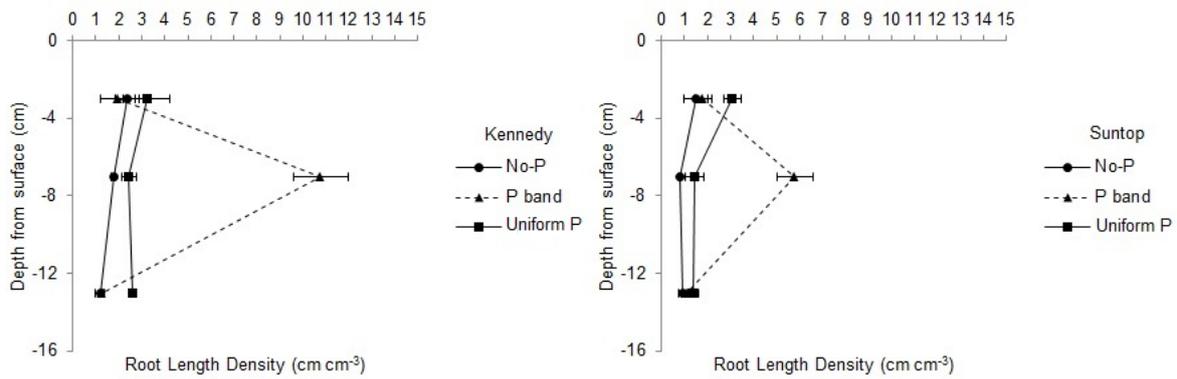


Figure 1. Example of the increase in root length density (RLD) of wheat varieties over 13 cm following either no P application (No-P), a band containing 150 mg P kg⁻¹ (P band) or a uniform profile with 150 mg P kg⁻¹ throughout (Uniform P).

The greatest increase in RLD between the surface and the band was observed in Kennedy[Ⓛ] (Fig. 2). However, statistically speaking there was no difference between the varieties in their ability to proliferate roots in response to encountering banded P. This lack of significant difference is a function of the large variation in root system expression in cereals. The extra root length produced in the P band was up to 4 times higher, and in some varieties 8 times higher. Barley and wheat were not different in their plasticity responses although barley varieties were less plastic at the high end, then wheat varieties.

Recovery of P over time

Most wheat varieties took up P from the soil as they needed it. The relative accumulation of P was in advance of plant growth in most of the barley varieties, but Gregory[Ⓛ] and Suntop[Ⓛ] also took up P before they needed it for biomass accumulation (Figure 3).

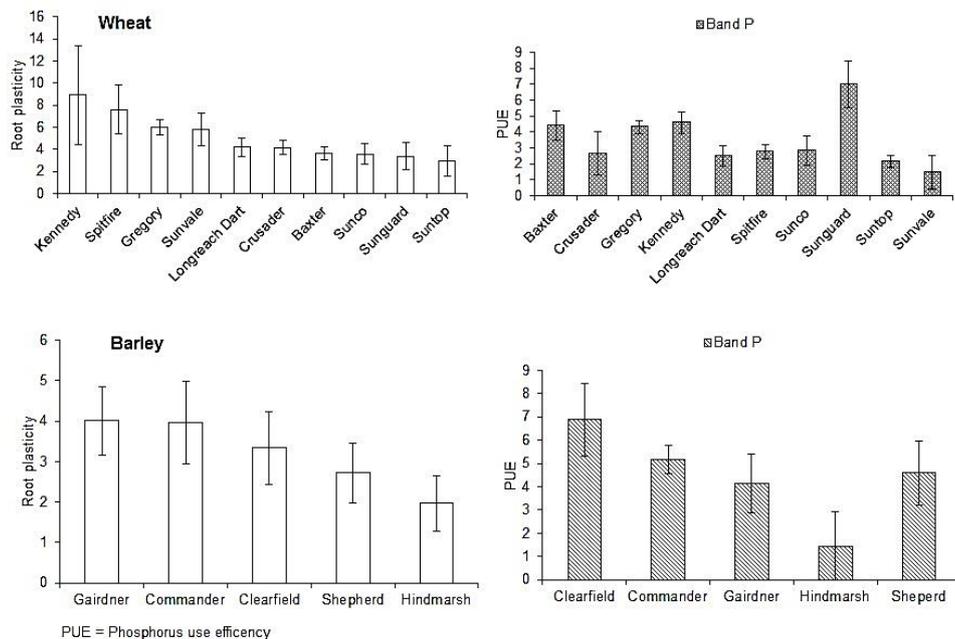


Figure 2. Plasticity of 10 wheat and 5 barley varieties over 13 cm following either no-P application (No-P), a band containing 150 mg P kg⁻¹ (P band) or a uniform profile with 150 mg P kg⁻¹ throughout (High P), and comparison of the P use efficiency of varieties when encountering the band of P.

Acquisition efficiency

The ability of varieties to acquire P under low soil P status was measured through comparing the recovery of P from a low P soil and comparing it with recovery under P sufficient conditions in the same soil. Considerable variation in varietal ability to acquire P from a scarce environment was observed (Figure 4). Baxter[Ⓞ] and Kennedy[Ⓞ], Gairdner and Hindmarsh[Ⓞ] were particularly efficient at acquiring P when in low soil supply, recovering up to twice as much P from the same soil as less efficient varieties.

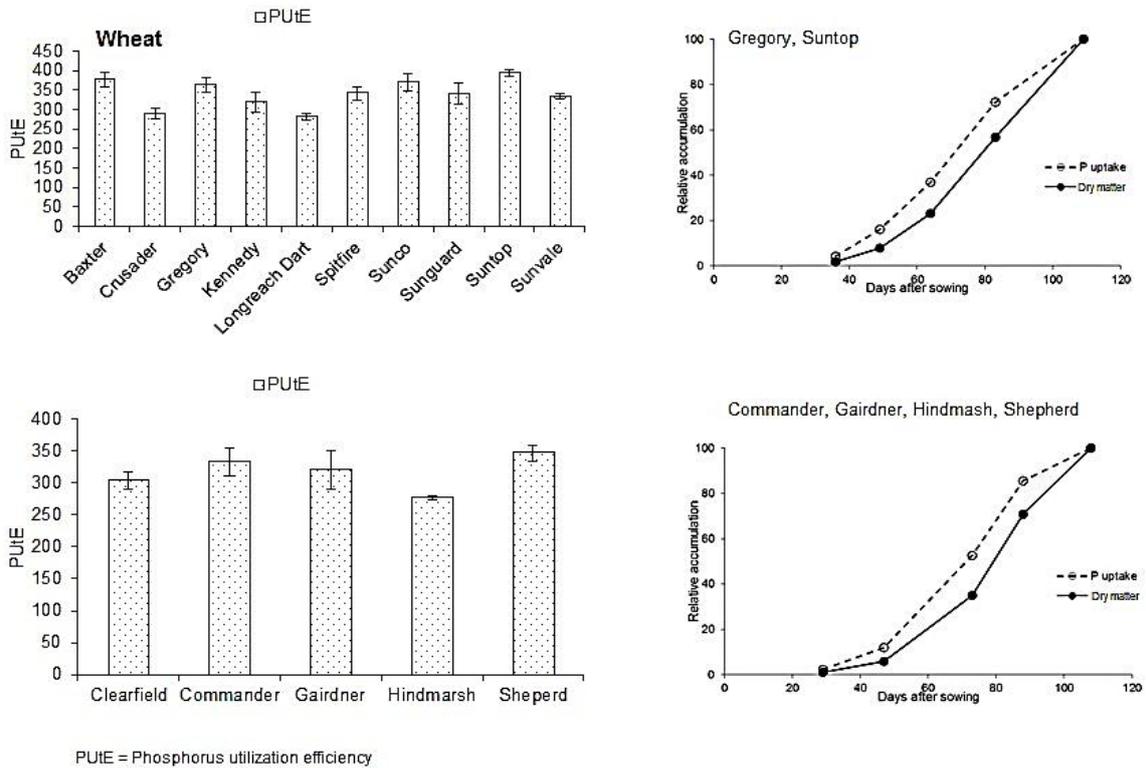


Figure 3. Phosphorus utilisation efficiency (Dry matter/P uptake) of 10 wheat and 5 barley varieties grown to maturity in 40 kg of Vertosol soil. Relative accumulation of P for varieties that acquired P in advance of growth requirements indicated on the right. All other varieties had overlapping P uptake and dry matter curves.

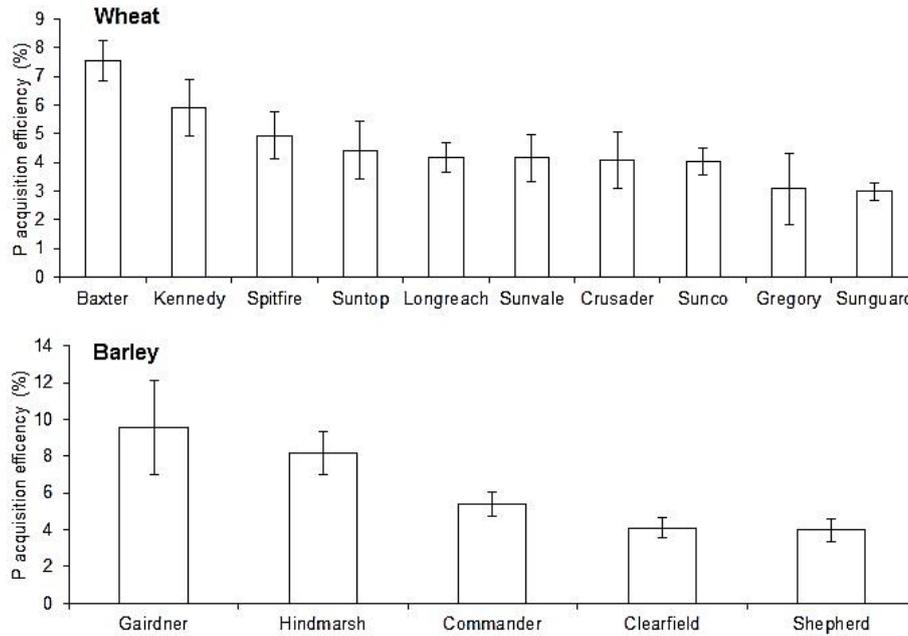


Figure 4. Phosphorus acquisition efficiency (P uptake low P/P uptake sufficient P x 100) of 10 wheat and 5 barley varieties grown in a P responsive Red Ferrosol subsoil

Discussion

Root plasticity of wheat and barley varieties

Root architectural variation in northern wheat, barley and chickpea lines in response to banded P application had not been measured prior to this experiment. All cereal varieties showed root plasticity in the P band by producing more branch roots. These seminal root branches in the P band produced thin roots with higher specific surface area. The diameter of roots in the P band was significantly lower than that of surface layers, suggesting that lateral roots specifically increased specific surface area only where P supply was highest. This study revealed that variation in this trait is small for varieties selected for the northern cereal zone. Two of the wheat varieties tended towards increased plastic responses. Comparison of these with modern southern varieties, and, more importantly, with Federation, landrace or wild wheat lines may indicate how much scope there is for selecting traits that exploit bands of P fertiliser more efficiently. Interestingly, there was limited capacity for early stage lateral root expression in response to banded P in the 6 chickpea varieties tested. Chickpeas were grown for longer time periods than cereals, yet still failed to respond with increased root allocation to P enriched soil. This may account for some of the variable field responses to banded fertiliser applications by chickpea.

Phosphorus uptake and acquisition efficiency

There was considerable genetic variation in the capacity of plants to access P from this P responsive soil. Baxter[Ⓛ] had the highest acquisition efficiency and Sunguard[Ⓛ] the lowest. In a low P environment, longer root lengths may increase surface area and therefore the opportunity to acquire P from the larger surface area. Similarly, there was variation in both how much P was required by individual varieties to generate shoot biomass, and in how far in advance of biomass production varieties acquired the P from the soil. This suggests that some varieties will grow better, and yield higher in soils with low P status. And that some varieties, with the ability to accumulate P in advance of requirements will perform better in scenarios where there is a P rich topsoil that can be exploited and mined for P early in the season before drawing water from P depleted subsoil layers. These traits and varieties are described and summarised in Table 1.

Note: Ranking below is based on the maximum value obtained in each category. High (**H**) = 100-70% of maximum, Medium (**M**) = 70-40% of maximum, Low (**L**) = <40% of maximum. **RLD** = root length density, **AE** = P Acquisition efficiency (uptake in low P soil/uptake in sufficient P soil), **PUtE** = P utilization efficiency (Shoot dry matter/P uptake), **PUE** = P use efficiency (P utilization efficiency × P uptake efficiency), **PAB** = Uptake P in advance of biomass accumulation, **SPB** = Uptake P as biomass accumulates

Table 1. Summary of 15 cereal variety responses to soil P status

Variety	Low P soil				Uniform high P soil			Deep P application				Stratified P	
	Biomass	RLD	AE	PUtE	Biomass	RLD	PUtE	Biomass	Root Plasticity	PUtE	PUE	PUtE	Update Pattern
Wheat													
Baxter [Ⓛ]	H	H	H	M	M	M	L	H	M	H	M	H	SPB
Crusader [Ⓛ]	M	H	M	M	M	H	M	M	M	L	L	H	SPB
Gregory [Ⓛ]	L	L	M	H	M	H	H	M	M	H	M	H	PAB
Kennedy [Ⓛ]	H	H	H	M	H	H	H	H	H	M	M	H	SPB
Dart [Ⓛ]	H	M	M	M	H	H	M	M	M	M	L	H	SPB
Spitfire [Ⓛ]	H	H	M	M	M	H	M	H	H	M	M	H	SPB
Sunco	M	H	M	M	H	H	H	M	M	M	M	H	SPB
Sunguard [Ⓛ]	M	M	M	M	M	H	M	H	L	H	H	H	SPB
Suntop [Ⓛ]	M	M	M	M	H	H	H	M	L	M	L	H	PAB
Sunvale	M	H	M	M	M	H	M	M	M	L	L	H	SPB
Barley													
Clearfield Scope [Ⓛ]	M	M	M	H	M	H	H	H	H	H	H	H	SPB
Commander [Ⓛ]	M	M	M	H	M	M	M	H	H	L	H	H	PAB
Gairdner	H	M	H	M	M	H	M	H	H	M	M	H	PAB
Hindmarsh [Ⓛ]	H	H	H	H	M	H	M	H	M	L	L	H	PAB
Shepherd [Ⓛ]	H	H	M	H	H	H	H	H	M	M	M	H	PAB

In summary, we hypothesised that there would be variation amongst 15 commonly grown wheat and barley varieties in their ability to proliferate and respond to banded P applications. We observed no significant differences in mean in that trait, and observed some evidence that a band is only a temporary, and not particularly efficient, reprieve for roots foraging in low P soil environments. All varieties possess the ability to decrease root diameters and increase root length density when encountering enriched P patches, and there is evidence of increasing variability in those varieties with the greatest mean RLD response. The question remains what level of root plasticity is required for plants to gain most from heterogeneously distributed nutrients in soil and how we can manage the soil or fertiliser placement to optimise these gains against changing environments.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Chris Guppy

UNE, Agronomy and Soil Science

Ph: 02 6773 3567 Fx: 02 6773 3238 Email: cguppy@une.edu.au

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Phosphorus and potassium nutrition

David W. Lester¹, Mike Bell², Rick Graham³, Doug Sands⁴ and Greg Brooke⁵

¹ DAF, Leslie Research Centre, Toowoomba 4350

² QAAFI/SAFS, University of Qld., Gatton 4343

³ NSW DPI Tamworth 2340

⁴ DAF Emerald 4720

⁵ NSW DPI Trangie 2823

Key words

Deep placement, wheat, barley, chickpea, sorghum, fertiliser, zinc

GRDC code

UQ00063

Take home message

Positive grain yield increases with deep phosphorus (P) have been inconsistent across the northern region, with crop type (cereal or legume) and seasonal growing conditions affecting the outcome. Cereal crops (wheat, barley and sorghum) are responding (mainly) due to growing both a larger plant biomass and producing more yield. Chickpeas have not been as consistent, with some very good biomass results not always converting to higher yields, or in some cases no effects on either biomass or yield. Negative yield responses are rare in any species, provided soil is allowed to settle after deep tillage.

Potassium (K) responses have generally been additive to phosphorus, meaning we have to overcome the P limit before K can have an effect, but we have also seen evidence of P by K interactions where the application of P helps overcome a low K situation. Potassium responses are most widespread in Central Queensland, while in Southern Queensland and Northern New South Wales they have tended to be restricted to the upland slopes (predominantly) and some grey box soils where lower soil K supply levels have been measured. Soil testing is a good indicator of response (suggested 10-30 cm profile critical values of <0.2 cmol/kg), while chemical analyses of plant biomass have suggested chickpeas are a good indicator of low K soil supply.

Introduction

Cropping in the northern grains region revolves around the capture, storage and use of predominantly summer rainfall on relatively heavy soils to produce both winter (wheat, barley, chickpea, etc.) and summer (sorghum, maize, mungbean, etc.) crops. Native soil fertility was high for some soil types (primarily the Vertosols) but this has declined over time (Dalal and Probert 1997). As stored moisture is the principal plant water source, subsoil supplies of the largely immobile potassium (K) and phosphorus (P) are exploited and this may (will) not be obvious in surface soil nutrient monitoring. With little P or K fertiliser being used, the consequence is that exports of P and K are significant and primarily related to the grain yield of the crop. The removal of crop nutrients depends on the grain concentration and yield, with average rates of P removal being around 2.9-3.2 kg P/t of grain for wheat, sorghum and chickpea. K removal in chickpea (11.0 kg K/t) has been at least twice that for wheat (4.1 kg K/t) and sorghum (3.1 kg K/t). On average, cropped soils across all these northern regions contained 55% ($\pm 5\%$) of the exchangeable K reserves of the uncropped reference sites. This depletion is resulting in increasingly complex nutrient management decisions for growers, with results clearly confirming the impacts of fertility decline and nutrient removal (Bell et al. 2010, 2012).

The wetting and drying pattern of the soil in the northern region means that some of the subsoils have become largely depleted of nutrients, as the moist soil deeper in the profile is exploited by plant roots especially in winter crops where in-crop rainfall is lower. The topsoil is relatively enriched with K in particular, and so the soil testing protocols require adjustment to take account of stratification of nutrients as well as the supply of exchangeable K. Research has identified some strategies such as deep placement of K along with modified soil testing strategies to identify responsive sites. Subsoil testing for these immobile nutrients (P and cations) does not need to be done frequently as the rate of change is very slow.

In response to these challenges, the hypothesis was developed that relatively high rates of nutrients could be placed in the subsoil (10-30 cm) to provide for several crop phases. The initial application would see some disturbance, with the duration of the responses uncertain. The experiments reported here aim to assess the long-term responses to P and K (and S), alone and in combination, when placed in the soil in bands at between 15 and 20 cm depth.

Results

Central Queensland

Our longest running experiments were set up with sponsorship from the International Plant Nutrition Institute (IPNI). Two nutrient addition experiments were established in which deep banding (~20 cm deep) was used to apply P (40 kg P/ha), K (200 kg K/ha) and S (30 kg S/ha) alone and in combination. The two sites – one at Capella and the other at Gindie – allowed multiple sequential crops to be monitored so medium term effects could be explored. The experiments were established to compare nutrient responses to a deep ripped treatment with no additional nutrients (control). Deep banding occurred in the winter fallow in 2011 and the bands were 50 cm apart.

The Capella site had four crops from 2012 until 2014-15 and demonstrated that P (at this site) was the principle limit, with K and occasionally S having additive effects after P was applied (Fig. 1). Applying P alone increased yield by 8% (or a cumulative 750 kg) but responses varied with crop and season. The initial crop grown after application of the treatments was chickpea and all P treatments (P, PK, PS, PKS) increased yield by at least 450 kg/ha. The following wheat crop in 2013 and chickpeas again in 2014 had some increases but were more influenced by P and K together than P on its own.

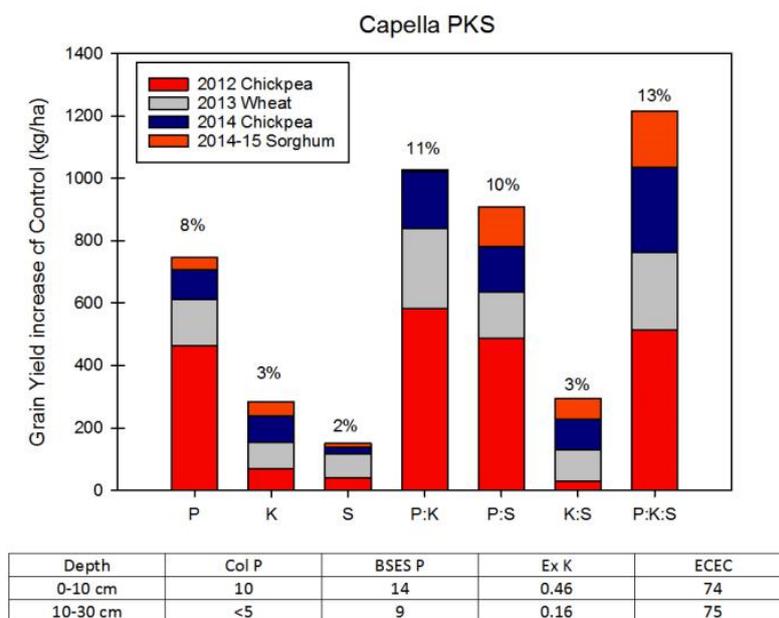


Figure 1. Increase in grain yield for four crops to nutrient application at Capella

The Gindie site was particularly interesting, as while the only nutrient limit at that site in the initial sorghum crop was P, the 2013 chickpea crop data suggested K availability was a greater limitation than P (14% response to P but 27% response to K), while the additive effects of (residual) P and K were substantial (51% grain yield increase). That trend continued into the 2014/15 sorghum crop.

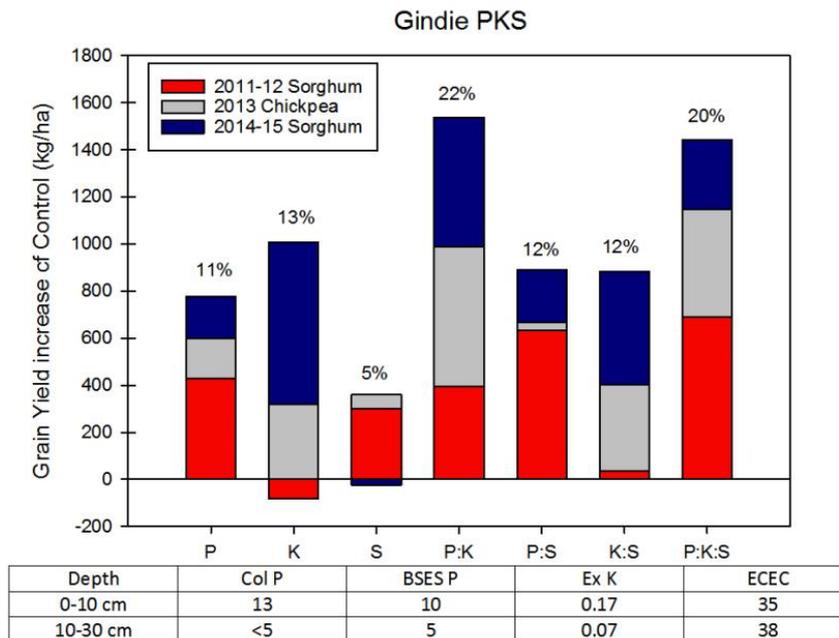


Figure 2. Increase in grain yield for four crops to nutrient application at Gindie

The biomass response to P and K was substantial with chickpea at the Gindie site in 2013 (Fig. 3). The dry matter increase at maturity with PK or PKS treatments was 68% over control (1600 kg/ha). This increase did translate to a yield increase of 530 kg/ha averaged on the same treatments (Fig. 2), but has not always been recorded in crops in Southern Queensland.



Figure 3. Gindie chickpea showing growth in the control treatment (foreground) and with deep PK (background) at 30 August 2013

These two initial PKS sites established that P and K appeared most limiting, and encouraged further investigation with seven rate response sites in CQ (as part of UQ00063) for the nutrients to evaluate increasing rates of addition. Five of these have had their first season of data and two (including the site at Dysart in Fig. 4) are approaching their third crop.

The sorghum responses at Dysart have been consistent between years, and confirm the hierarchy of P (first) and K (second) limitations. The addition of Farmer Reference treatments (FR - existing local

management) in these studies has allowed the deep ripping and basal nutrient (N, Zn) effects (mainly in the initial crop) to be quantified. Relative to current practice, the deep ripping and application of P (the S had no significant impact) increased yields by 16% (900 kg/ha) while the further addition of at least 50 kg K/ha raised that response to 25% (>1400 kg/ha) over the two sorghum crop years. Interestingly, the deep ripped treatments have typically accumulated more P and K – probably due to more thorough root exploitation of the soil profile.

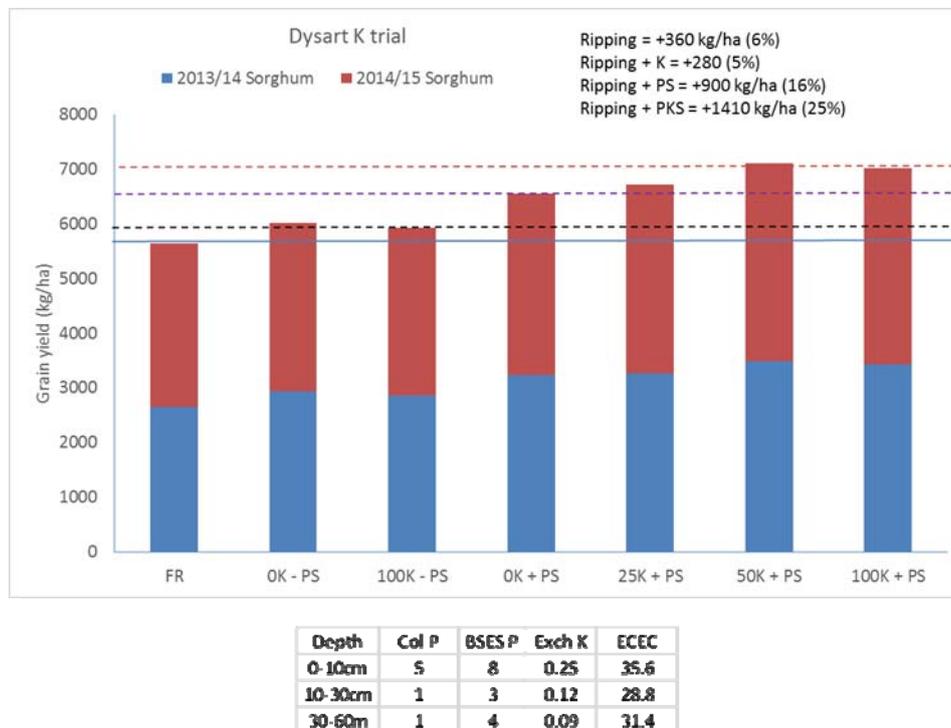


Figure 4. Grain yield response in a potassium rate trial with/without a background PS application in successive sorghum crops grown near Dysart

Similar responses have been recorded at other sites. For example, the initial crop year at Moura in 2015 (chickpeas), with the addition of P (and basal S, Zn) increasing yields by 20% (an additional 350 kg/ha) relative to the FR, while the addition of a further 100 kg K/ha increased the yield advantage to 30% (. an additional 530 kg/ha).

Results for the remaining trials are currently being collated and chemical analysis of the dry matter samples undertaken to assess nutrient recovery.

While still in the early stages of experimentation, the results from Central Queensland are encouraging with cumulative increases in grain yield of around 1000 kg/ha over three or four crops. Single year increases of nearly 500 kg have been measured in chickpea, with combinations of P and K together at a number of sites.

Southern Queensland

The P and K work in Southern Queensland has consisted of a cluster of 6 sites on a line roughly from Goondiwindi to Condamine, a site just east of Goondiwindi, 4 sites east of Warra and one north-west of Wondai in the South Burnett.

Cumulative responses to deep fertiliser application on the western downs sites (exclusively deep P, as K status has been adequate), have been poor, but starter P applications at relatively low rates have proven to be very effective. As an example, a site at Inglestone has grown three crops (Wheat - Chickpea – Chickpea) from 2013 to 2015 (Fig. 5). With no starter application, cumulative grain yield was reduced by nearly 1000 kg/ha, representing a 15% reduction in grain produced. None of the

deep P treatments have demonstrated any effect above that of the basal N, S and Zn application and deep tillage (the 0 P treatments). Whilst unexpected given the low soil P status, this result has been consistent with crop P uptake data showing as much or more P uptake from the low rate of starter P as that from the deep P bands. Over the 3 crop seasons only an additional 5.3 kg P/ha was taken up in crop biomass from the highest deep P rates, and almost all of this was removed in grain.

The poor acquisition of deep P and the relatively strong response to low rates of starter (especially in chickpeas) raises questions around the most effective P application strategy in these drier western environments.

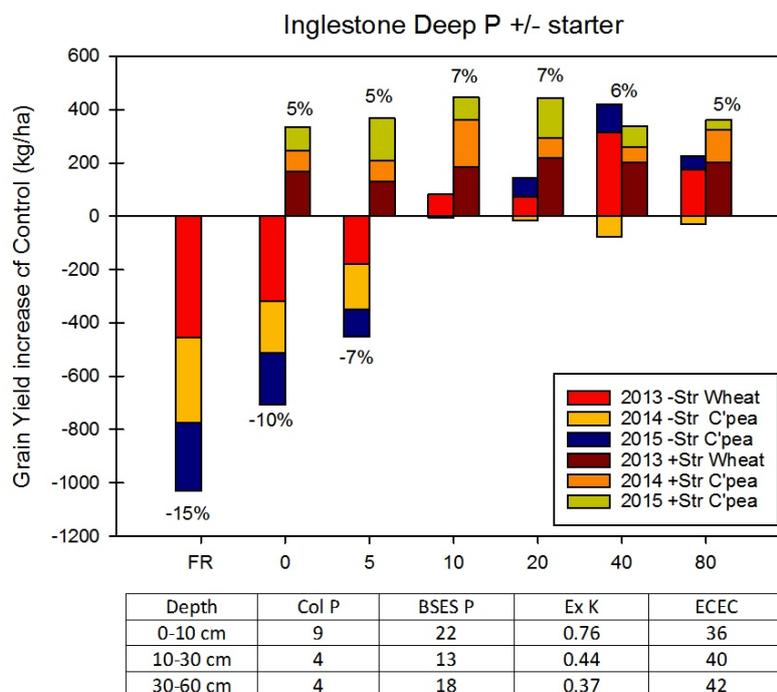


Figure 5. Cumulative difference in grain yield versus district practice with deep placed P with three winter crops grown at Inglestone, Qld from 2013 to 2015

Contrasting the results from Inglestone are those from Wondalli, east of Goondiwindi (Fig. 6). The negative effects of having no starter application were similar to Inglestone (13% or 750 kg/ha yield reduction) with the wheat crop accounting for basically all the loss. However, in the presence of starter there was a nearly linear response to increasing rates of deep P, with 10, 20, 30 and 60 kg P/ha delivering 200, 760, 900 and 1500 kg/ha extra grain in the 2 crop seasons, respectively. This site was characterised by higher yields and average crop P uptake, but the greater P demand only resulted in slightly higher deep P uptake (~7.5 kg P/ha) but with slightly more than half that uptake removed in grain.

The differences in yield responses and crop P acquisition from deep bands between these contrasting sites may have been influenced by factors such as the timeliness of in-crop rainfall and resulting root activity relative to key physiological processes, general water use by crops and (in winter crops) the rate of temperature increase during reproductive development.

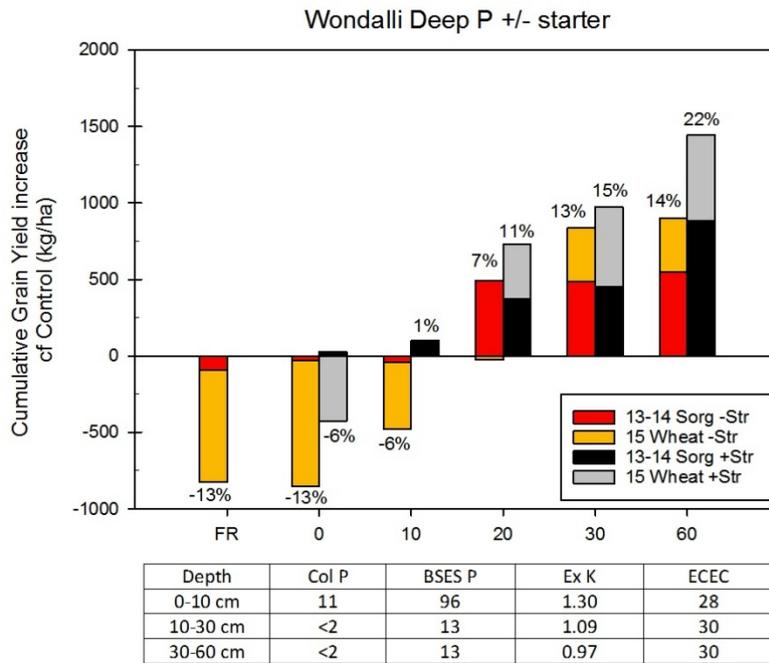


Figure 6. Cumulative difference in grain yield versus district practice with deep placed P with one summer and one winter crop at Wondalli, Qld from 2013-14 and 2015

Upland slope soils in the eastern areas of southern Queensland have been responding well to potassium application (Fig. 7), even the cereal crops which typically have a lower potassium demand than pulse species. In this instance the '0K Nil P' treatment is the benchmark against which responses are assessed. Both crops showed improvements from the addition of both P and K (an additional 1350 kg/ha grain produced), although the initial sorghum crop response (second crop grown as double crop from wheat) suggested that the primary limitation at the site was K.

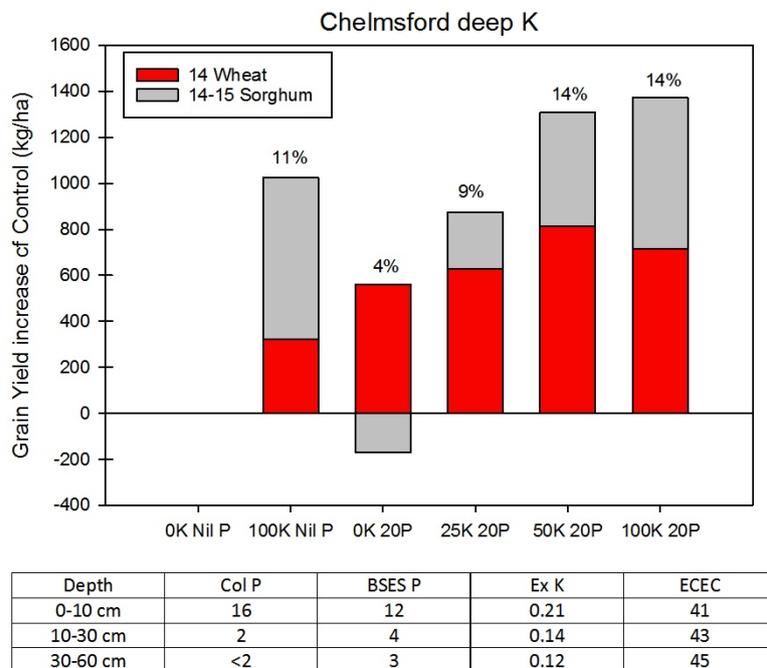
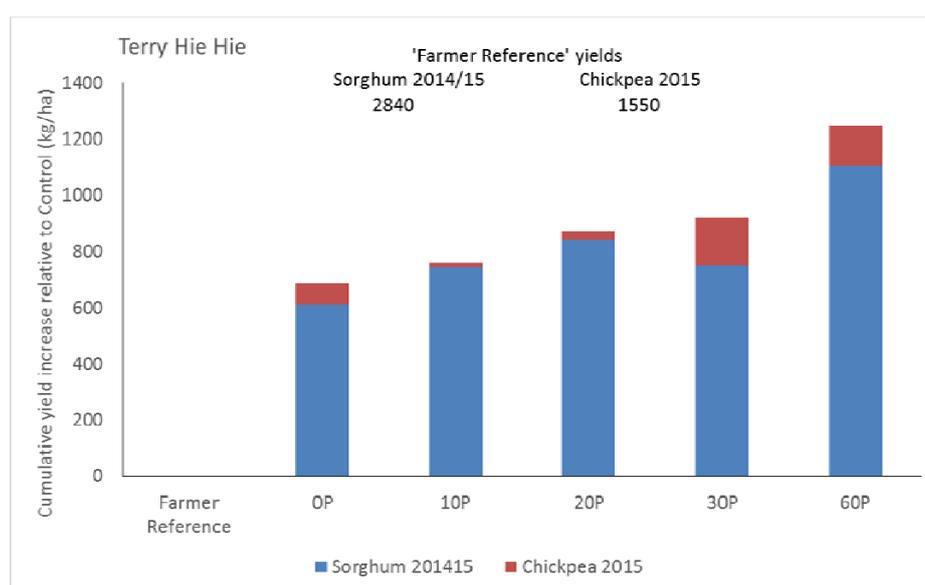


Figure 7. Cumulative grain yield responses in a potassium rate trial with/without a background P application from sorghum in 2014-15 and wheat in 2015 at Chelmsford, Qld

Northern New South Wales

NSW deep placed nutrition sites cover the North West plains, North West slopes, Liverpool Plains and more recently the Central West, although many of these sites haven't had the longevity of the equivalent sites in Queensland. An exception to this however, is the site on the NW slopes at Terry Hie Hie, which was established prior to the 2013 winter season and has now grown 3 crops (wheat, long fallow to sorghum, double crop to chickpeas). Soil test P and K profiles were similar to many other locations. While harvest of the initial wheat crop was lost to an eager contract harvester the subsequent data show some similarity to that from the site at Wondalli (Fig. 6) there was a near linear response to increasing rates of deep P – particularly in the presence of starter P. This response was dominated by the long fallow sorghum crop, and this was particularly interesting given that grain protein contents indicated low available N (7.9% in the FR and OP treatments, decreasing to only 7.0% with high P). The response to deep P may have been even greater if more N was available. Double cropping the chickpea into the sorghum would have meant that AMF levels should have been very good and helped in the recovery of P from the soil.



	Col P	BSES P	Exch K	ECEC
0-10cm	20	44	0.37	26.3
10-30cm	5	15	0.22	28.9

Figure 8. Cumulative grain yield responses to deep P rates applied near Terry Hie Hie in Jan 2013.

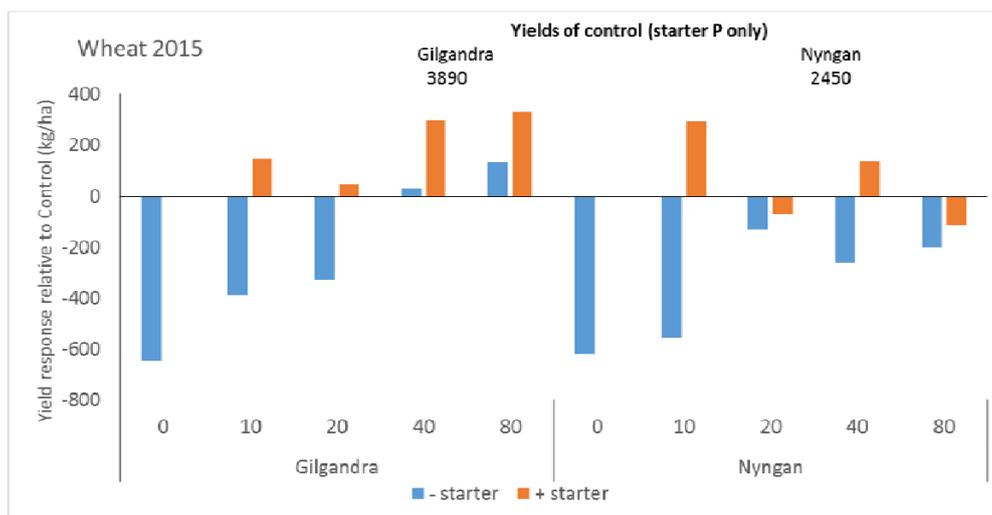
Yields from the initial wheat crop were unfortunately not recorded but data is shown for the subsequent 2014/15 sorghum and 2015 chickpea crops. No starter P was used in the summer sorghum, while starter effects were not significant in chickpea, averages of with and without starter treatments are presented

Most other P sites have only a single year of crop data so far, and results from these sites have been mixed. For example, a site at Garah (Barley in 2015) showed no yield response to either starter P or a range in rates of additional P applied either shallow (5cm) or deep (20cm), despite some obvious biomass differences at anthesis. However the P status of that site was such that starter P responses would not have been expected (Colwell P in the 0-10cm layer was 42 mg/kg) and the P status of the 10-30cm was in the grey area where responses are uncertain (i.e. Colwell P was 6 mg/kg and BSES P was 61 mg/kg). Analysis of biomass to determine crop P uptake has not yet been completed.

The sites in the Central West were contrasting soil types to most other locations (a red Chromosol at Nyngan and a brown Chromosol at Gilgandra) and had deep (20cm) or shallow (5cm) P bands applied just prior to planting. Luckily, post sowing rainfall allowed reasonable establishment at both

sites, however the late deep tillage did have some negative impacts at both sites. This was most evident at Nyngan, where treatments without deep tillage recorded 16% better crop establishment and produced 17% more biomass and 18% more yield, regardless of P rate. The negative impacts of late deep tillage were not as evident in crop establishment at Gilgandra, but shallow tilled treatments still produced >10% more grain than deep tilled treatments, irrespective of P rate – possibly due to impacts on profile moisture reserves. The inclusion of an untilled ‘Farmer Reference’ treatment would have allowed a better estimate of the negative impacts of tillage on crop yield potential in this initial season, but the disturbance effects on starting soil moisture should not feature in subsequent seasons.

Yields of the Control treatment (starter P with no additional P application) were higher at Gilgandra (3850 kg/ha) than Nyngan (2450), and these higher yield potentials coincided with a greater P demand and more consistent response to additional P application. Both sites showed similar yield losses without starter P application (~600 kg/ha, or 16% to 25% of the Control yields for Gilgandra and Nyngan, respectively), with this reliance on starter P reducing as P rates (shallow or deep) increased. However in the presence of starter P it was only at the higher yielding Gilgandra site that additional P applications produced consistent yield increases, with a maximum of 10% (~400 kg/ha) extra grain produced from the 80 kg/ha P applied. The residual benefits of these additional P applications at different placement depths will be followed in subsequent crops – without the confounding effects of the soil disturbance from the deep P placement.

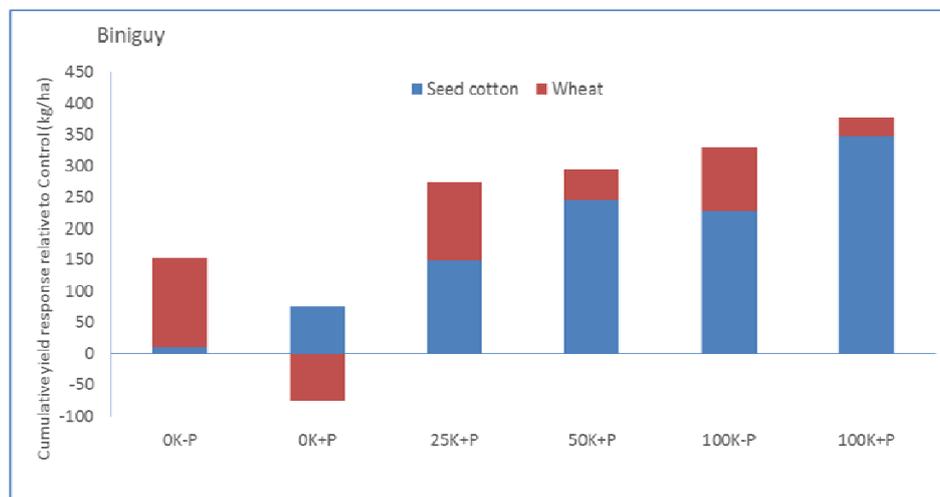


Gilgandra					
	Colwell P	BSES P	Exch K	ECEC	
0-10cm	21	81	1.01	8.4	
10-30cm	7	16	0.58	8.4	
Nyngan					
	Colwell P	BSES P	Exch K	ECEC	
0-10cm	19	50	1.47	8.9	
10-30cm	5	12	0.9	7.2	

Figure 9. Grain yields from 2015 wheat crops at Nyngan and Gilgandra in response to both starter P and additional P at various rates placed either shallow (5cm) or deep (20cm). Data are shown for the average of the 2 application depths

There has been limited exploration of K responsive sites in NSW at this stage, with the exception of another site on the NW slopes near Biniguy where K responses were followed in successive dryland cotton and wheat crops. There were significant responses in seed cotton yield in an extremely dry year in 2013/14, where the reference yields were only 460 kg/ha of seed cotton (fractionally more than 1 bale/ha). Application of 50 or 100 kg K/ha increased yields by >50%, and there was a suggestion of an additive effect of deep P with K. However there was no evidence of any effects of P or K in the following 2015 wheat crop, where the Reference yields were 4050 kg/ha. The relative

importance of subsoil K supplies in the very dry (2013/14 summer) compared to the quite favourable (2015) season would have been marked, in addition to the reported higher critical soil K requirements in cotton than cereal grains. This site also had higher exchangeable K than the Chelmsford site (Fig 7) where significant K responses were recorded in both wheat and sorghum, with the largest differences in the 0-10cm layer, which would have been relatively accessible in the wet 2015 season.



	Col P	BSES P	Exch K	ECEC
0-10cm	15	50.5	0.37	23.4
†0-30cm	3.5	10.5	0.19	27.2
30-60cm	<2	6.5	0.20	29.4

Figure 10. Seed cotton (2013/14) and wheat (2015) yield responses to banded applications of K, in the presence or absence of deep P bands, in a site at Biniguy. Data is presented as the yield response relative to the Farmer Reference treatment (no disturbance or deep nutrient placement)

Results from other 2015 winter sites on the NW plains confirm benefits of starter application, but under some excellent growing conditions have not shown any additional yield response to deep placed P.

General discussion

Current deep placement research is demonstrating mixed outcomes, from consistently good responses in some districts e.g. Central Queensland, to more mixed results in southern Queensland and Northern New South Wales. Part of this divergence in responses is related to the widespread low P and K at most sites in Central Queensland, compared to the more variable but generally slightly higher background fertility in other regions. However other factors affecting the utilization of deep fertilizer bands are also at play. We clearly require a better understanding of how plant roots acquire P (and K) from bands in drier environments (where lower soil moisture contents restrict diffusive supply), as well as how improved nutrient supply interacts with crop physiological processes determining harvestable yields under a range of seasonal growing conditions. This information will allow a clearer understanding of where deep placement will produce the most reliable yield responses.

Where evaluated, responses to starter fertiliser are demonstrable in most of our research sites where Colwell P in the top 10cm is low. Growers are encouraged to continue using starter P fertilisers at rates appropriate for the crop row spacing and soil moisture conditions at sowing. Applying small amounts of P in the seed row at sowing is offering excellent utilisation of the nutrient by the emerging crop.

Yield increases with deep P application are predicated on a crops' ability to access and utilise the nutrient in the band, and the structure of different crop root systems is clearly important in this

regard. Winter and summer grass crops with fibrous root systems appear to make better use of the bands currently applied on 50 cm row distances, with more consistent increases in dry matter, grain yield and P uptake being measured at responsive sites. The more coarsely rooted chickpea crop has not been able to consistently demonstrate the same ability to utilise nutrient applied on this row spacing – although when responses are recorded they can provide good financial returns. The limited ability of chickpeas to proliferate roots in and around a P band shown by Guppy et al. (GRDC Updates 2014) is likely to be contributing to this, so proximity of crop rows and fertilizer bands may be more important in chickpeas than the grain crops. Further work is required to confirm this.

Soil testing for K is proving a reasonable indicator of soil supply, but we do not as yet have reliable links between soil K test results and likely yield responses. However reasonable individual and cumulative yield increases in response to applications of K at rates of 50 or 100 kg K/ha at depth, generally in combination with a P source, are being measured on some low soil test K sites.

References

Dalal RC, Probert ME (1997). Soil nutrient depletion. In 'Sustainable crop production in the subtropics: an Australian perspective'. (Eds AL Clarke and PB Wylie). (Queensland Department of Primary Industries: Brisbane, QLD.)

Bell MJ, Moody PW, Klepper K, Lawrence DN (2010). The challenge to sustainability of broadacre grain cropping systems on clay soils in northern Australia. In 'Proceedings of the 19th World Congress of Soil Science; Soil Solutions for a Changing World. '(Eds. RJ Gilkes and N Prakongkep) pp. 302-305. (IUSS: Brisbane, Australia)

Bell MJ, Lester DW (2012). Multiple nutrient deficiencies in northern grains cropping – latest results and management responses for system profitability. In 'Grains Research Updates.' (GRDC: Goondiwindi)

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

The willing cooperation of many growers in hosting experiments over multiple seasons is gratefully acknowledged and the authors acknowledge the field and technical support provided by their respective project teams across Qld and NSW.

Contact details

David W. Lester
Queensland Department of Agriculture and Fisheries, Toowoomba Q 4350
Ph: 0428 100 538
Email: david.lester@daf.qld.gov.au

Mike Bell
The University of Queensland
School of Agriculture and Food Sciences, Gatton Q 4343
Ph: 0429 600 730
Email: m.bell4@uq.edu.au

Rick Graham
New South Wales Department of Primary Industries, Tamworth, NSW 2340
Ph: 0428 264 971
Email: ricky.graham@dpi.nsw.gov.au

New and emerging disease management options in barley

N. F. Poole and T. Wylie, Foundation for Arable Research (FAR) Australia

Keywords

Fungicide management strategies, Succinate dehydrogenase inhibitor (SDHI), Fungicide Resistance, Integrated Disease Management (IDM), Adult Plant Resistance (APR)

GRDC code

CUR 00019, CCDM/GRDC Program 9 & FAR 00002

Take home message

- Fungicides with new modes of action, such as the Succinate Dehydrogenase Inhibitors (SDHI's - FRAC Group 7) are now being commercialised in the Australian market.
- Initial results with the SDHI's have been very promising against a range of barley diseases such as net blotches and scald as well as wheat diseases such as yellow leaf spot and Septoria tritici blotch (STB).
- The SDHI fungicides are at a moderate to high risk of pathogen resistance development so it is imperative that we don't overuse these products and adhere to anti resistance guidelines.
- As more evidence of fungicide resistance (or insensitivity) in triazoles emerges it emphasises the need to use fungicides as part of an Integrated Disease Management (IDM) approach that capitalises on cultivar resistance and other cultural control measures.
- New research shows that Adult Plant Resistance genes reduces the need for multiple fungicide applications and gives greater timing flexibility to single fungicide applications.

New products for foliar disease control

Research into new fungicide active ingredients

Over the last four years GRDC has not only recognised the need to benchmark the sensitivity of our common pathogens against available fungicide products but also the need to encourage the registration of new active ingredients for the Australian market. The GRDC New Fungicide Actives project led by Curtin University (Project CUR 00019 and the new bilateral between Curtin/GRDC Program 9) has been working with different target diseases in cereals to generate efficacy data that combined with manufacturers' data might lead to the registration of new fungicides with new modes of action. These research projects are beginning to assist with new product registrations that have good activity on important diseases such as powdery mildew, yellow leaf spot (YLS), net blotch and Septoria Tritici Blotch (STB). FAR Australia has led the field research and have already identified a number of new fungicide candidates, which are at various stages of development and registration. Though the work has been conducted on a wide range of diseases the results presented here represent just some of the results achieved to date against net blotch, YLS and STB. To recognise commercial sensitivities, where products have not been registered they have been given a treatment number 1.

New products for the control of NFNB & SFNB

In barley there are a number of new fungicide products that offer a higher level of NFNB, SFNB and scald control than the existing standards such as propiconazole (e.g. Tilt®). These new actives take the form of both seed treatments and foliar fungicides. The introduction of the SDHI fluxapyroxad as

the seed treatment Systiva® from BASF looks set to be a major step forward (Figure 1, 2 & 3). Previous seed treatments have given partial control of NFNB through controlling infection on the seed, but have lacked systemic activity to give foliar disease control. Systiva® potentially changes the management strategies for controlling NFNB, SFNB and Scald in susceptible cultivars and situations, since this new SDHI has good persistence on foliar diseases. In results from CUR00019, fungicide activity is evident up to the point that the second fungicide is traditionally applied to barley at awn emergence (GS49) and on occasions through to ear emergence. As such the product has the ability to replace the first fungicide timing which has traditionally been applied at early stem elongation (GS30-31). Where disease pressure dissipates in the second half of the season, due to lack of rainfall and lower crop canopy humidity there may be no need for a follow up with a foliar fungicide. In addition to Systiva there are new foliar SDHI's which mixed with other fungicide modes of action have good activity on the same stubble borne diseases in barley.

Bixafen a SDHI from Bayer CropScience which has been extensively tested under the Curtin University/FAR Australia collaboration is an example of a SDHI mixed with the triazole prothioconazole (a component of Prosaro®) and is currently undergoing registration in Australia. Figure 1 shows the SFNB control given by this product (proposed trade name Aviator® XPro) applied as two foliar sprays versus two sprays of Tilt®.

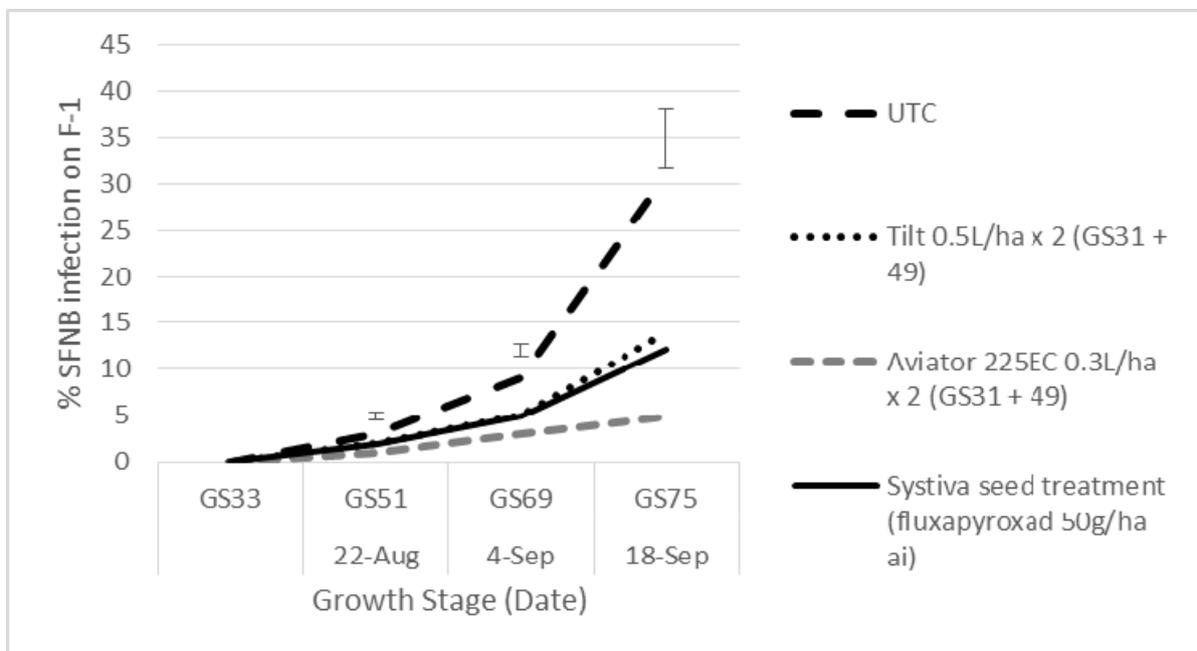


Figure 1. Spot form net blotch (SFNB) control using the new SDHI's Fluxopyroxad (Systiva® seed treatment) and the new SDHI foliar fungicide active bixafen mixed with prothioconazole (Aviator Xpro 225EC®) compared to propiconazole applied as a foliar two spray programme in barley cv Hindmarsh^d – Meckering, WA 2013.

Yield performance and screenings in these trials correlated with disease control assessments (Figure 2), indicating that products containing new active ingredients offer us new and potentially alternative management tools for barley disease control.

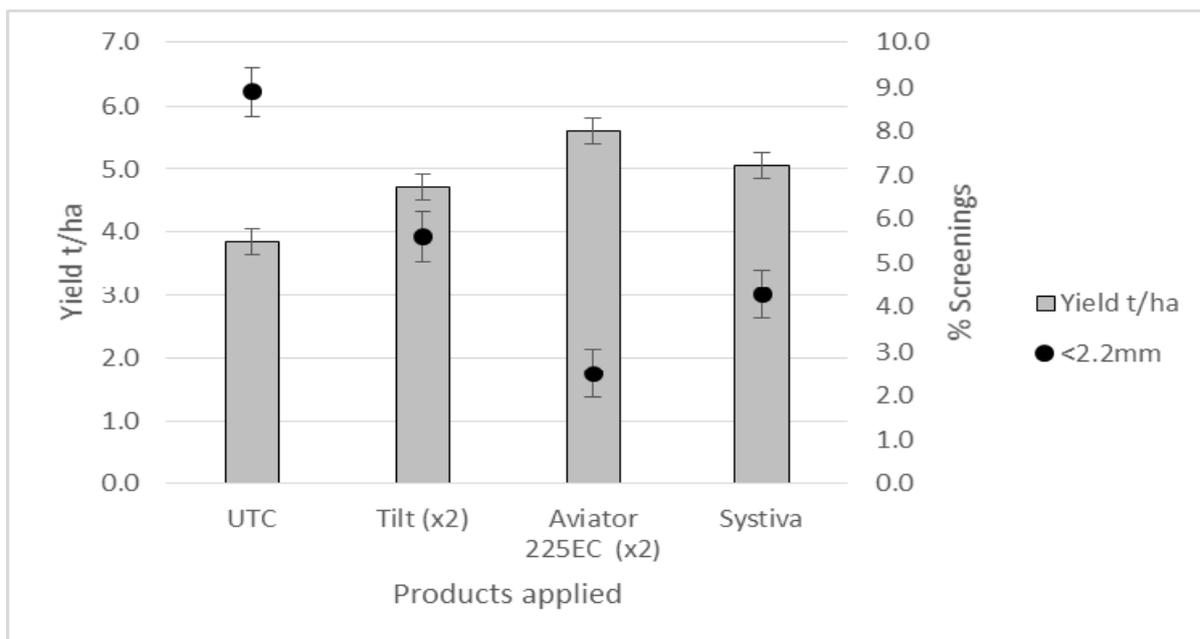


Figure 2. Influence of Spot form of net blotch (SFNB) control on barley yield and quality cv Hindmarsh – Meckering, WA 2013

Notes: Tilt 500ml/ha and Aviator Xpro 300ml/ha (currently undergoing registration & is not commercially available) were applied as foliar sprays twice at GS31 & GS49. Systiva was applied as a seed treatment alone and was not followed up with a later foliar fungicide.

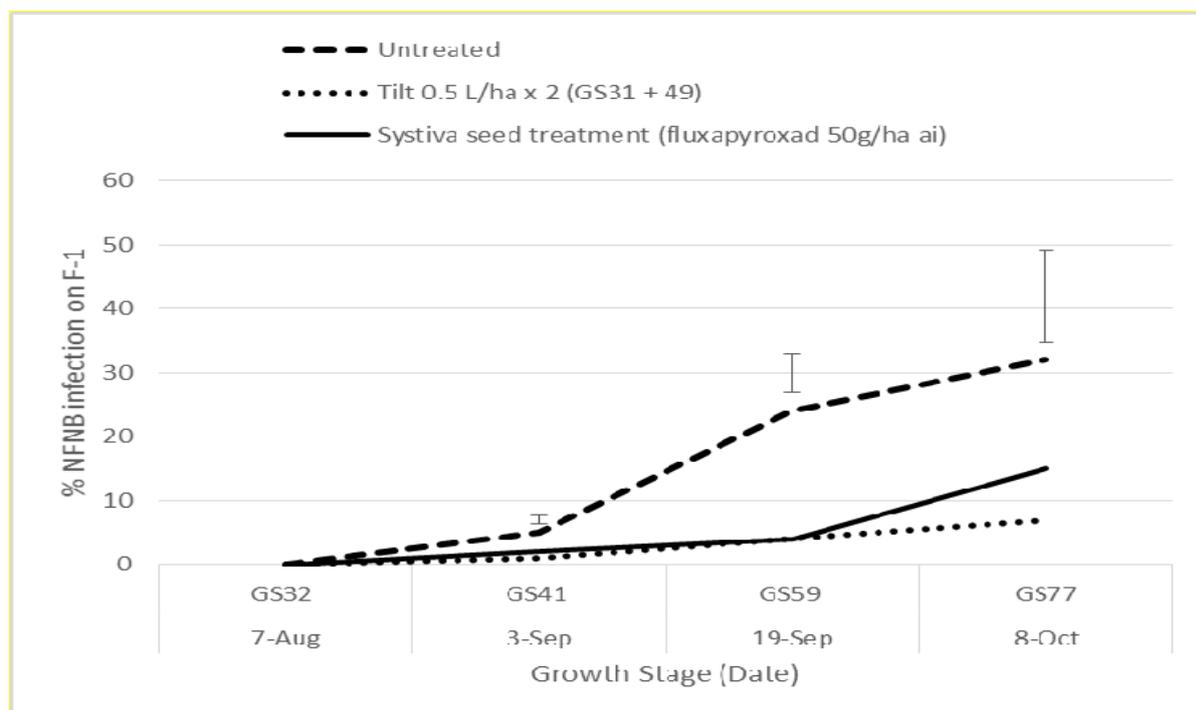


Figure 3. Net form net blotch (NFNB) control with Systiva® seed treatment versus a foliar two spray propiconazole (Tilt®) programme in barley cv Maritime – Ardrossan, SA 2013

A run of drier years in the northern region has produced fewer comparisons. One comparison run by BASF in 2015 at Tamworth has generated results that concur with research data produced further south and in the west. In a trial looking at four barley cultivars the SDHI seed treatments Systiva®

and Vibrance® were tested with and without foliar follow ups. The results revealed useful data on the new fungicide performance as well as the timing for follow up fungicides (Figure 4). Yield responses to Systiva® applied alone averaged 0.25t/ha across the four cultivars when compared to the untreated (range 0.16 – 0.36t/ha).

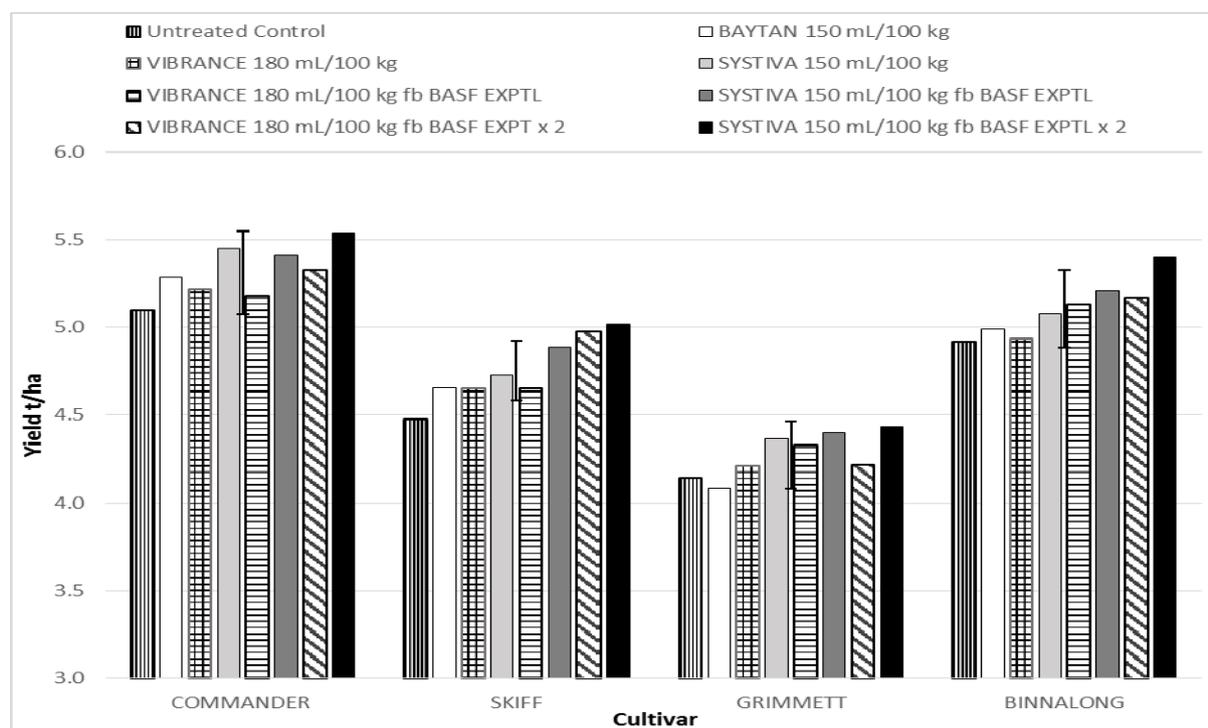


Figure 4. Influence of SDHI seed treatments Systiva® and Vibrance® on barley yields – BASF Research site, Tamworth 2015 (data presented courtesy of BASF)

Adjustments to barley management strategies

The introduction of the fluxapyroxad active as the seed treatment Systiva® provides not only a new fungicide option but an opportunity to have an alternative fungicide strategy to a two spray foliar fungicide approach for susceptible cultivars or high risk rotation positions, such as barley on barley. The use of Systiva® in combination with foliar fungicides is likely to depend on the regional environment and rotation position, disease pressure and length of growing season.

Lower rainfall – shorter season environments

In shorter season environments with lower yield potential where disease pressure is reduced at later growth stages by warmer and drier conditions Systiva® is likely to be sufficient to give season long disease control where net blotch is the key disease. Under these circumstances whilst the products persistence will have dissipated by ear emergence, environmental conditions generally make follow up fungicides far less necessary.

Fungicide resistance risk with SDHI's

SDHI's are at a moderate to high risk of fungicide resistance. Ensure that they are not over used particularly as a seed treatment with no follow up foliar fungicide in successive years. Instead consider using fungicides with a different mode of action in alternating seasons or as a follow up to the seed treatment in the same season.

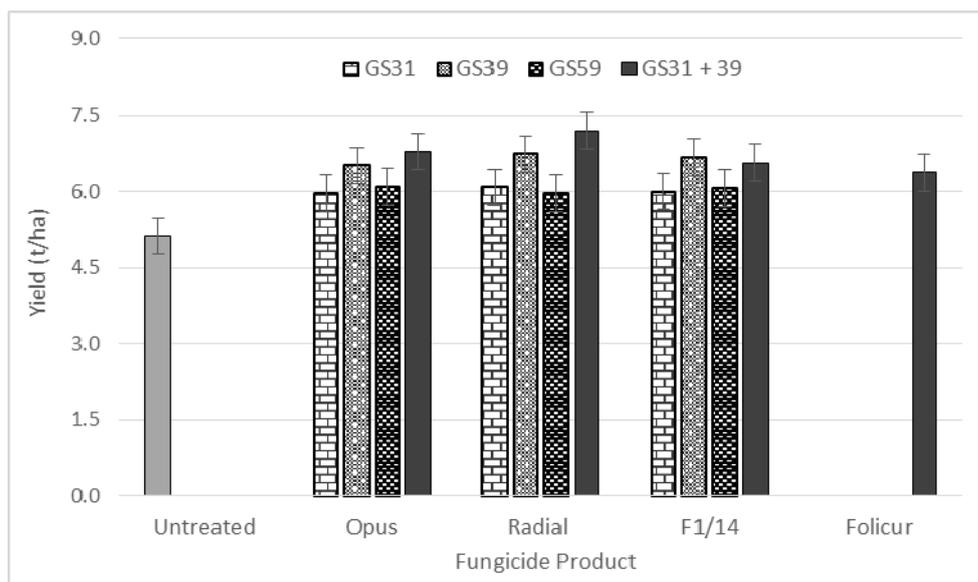


Figure 7. Influence of fungicide product and timing on grain yield (t/ha) of Corack under irrigation. – Cobbitty, NSW 2014
 Opus - Epz – epoxiconazole
 Radial - Epz + Az – epoxiconazole + azoxystrobin
 F1/14 (experimental fungicide containing a SDHI)
 Folicur - Tbz- Tebuconazole

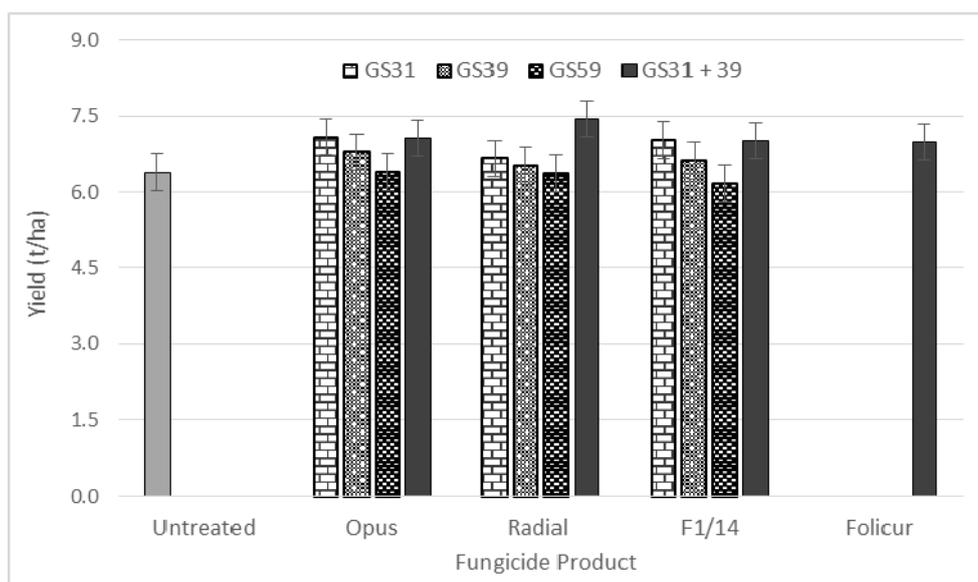


Figure 8. Influence of fungicide product and timing on grain yield (t/ha) of Elmore CL Plus under irrigation. – Cobbitty, NSW 2014.

Conclusions

New GRDC research being conducted on integrated disease management and new fungicides in conjunction with the agrichemical manufacturers shows great promise that will result in better disease management in Australian cereal and pulse crops. However new products with new modes of action are not immune from resistance development, therefore to prolong their activity and that of our existing triazole products we need to use them judiciously and in combination with other control options.

NB: Please note that reference to an agrichemical fungicide in this paper does not constitute a recommendation or that the active ingredient or product referenced carries an approval for control of a specific disease.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Nick Poole
23 High St, Inverleigh, VIC
Ph: 03 5265 1290
Fx: 03 5265 1601
Email: poolen@far.org.nz

Concurrent sessions – Day 2
Cereals & varieties concurrent session

Durum agronomy & variety update

Rick Graham, NSW DPI

Contact details

Rick Graham
NSW DPI
Mb: 0428 264 971
Email: ricky.graham@dpi.nsw.gov.au

The heat tolerance of some northern bread wheat varieties

Richard Trethowan & Rebecca Thistlethwaite, IA Watson Grains Research Centre, The University of Sydney

Key words

High-temperature tolerance, heat tolerance, wheat

GRDC code

US00057

Take home message

Modern wheat varieties have a good level of high-temperature tolerance with newer varieties such as SUNTOP[®], SPITFIRE[®], GBA HUNTER[®], LIVINGSTON[®], and EGA GREGORY[®], producing high yield when late sown. New sources of genetic variation with higher yield and lower screenings have also been identified for future breeding and selection to maintain genetic progress in the heat tolerance of wheat.

The University of Sydney's IA Watson Grains Research Centre at Narrabri is researching the high-temperature tolerance of wheat with the support of the Grains Research and Development Corporation (GRDC). The aim is to identify and develop new genetic sources of heat tolerance that can be exploited by Australia's commercial wheat breeding companies. Large numbers of new materials are screened in the field at Narrabri across dates of sowing between May and August each year. These data are augmented by field based heat chambers that are used to induce heat shock on selected materials. A range of Australian released varieties of relevance to the northern grains region are used as checks. These include SUNTOP[®], SPITFIRE[®], EGA GREGORY[®], GBA HUNTER[®], LIVINGSTON[®], CRUSADER[®] and the older varieties SUNCO and JANZ.

Results indicate that most modern varieties already have high levels of high-temperature tolerance (Figure 1). However, several new genetic sources of variation for heat tolerance have been found that are competitive for yield when optimally sown but significantly superior when late sown including the line NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KAUZ//ALTAR 84/AOS/3/MILAN/KAUZ/4/HUITES/6/KAUZ//ALTAR 84/AOS/3/MILAN/KAUZ/4/HUITES developed by the International Maize and Wheat Improvement Centre (CIMMYT) and imported under the GRDC funded CAIGE project (Figure 2). Importantly, this line also has significantly reduced screenings compared to the modern northern cultivars when late sown (Table 1).

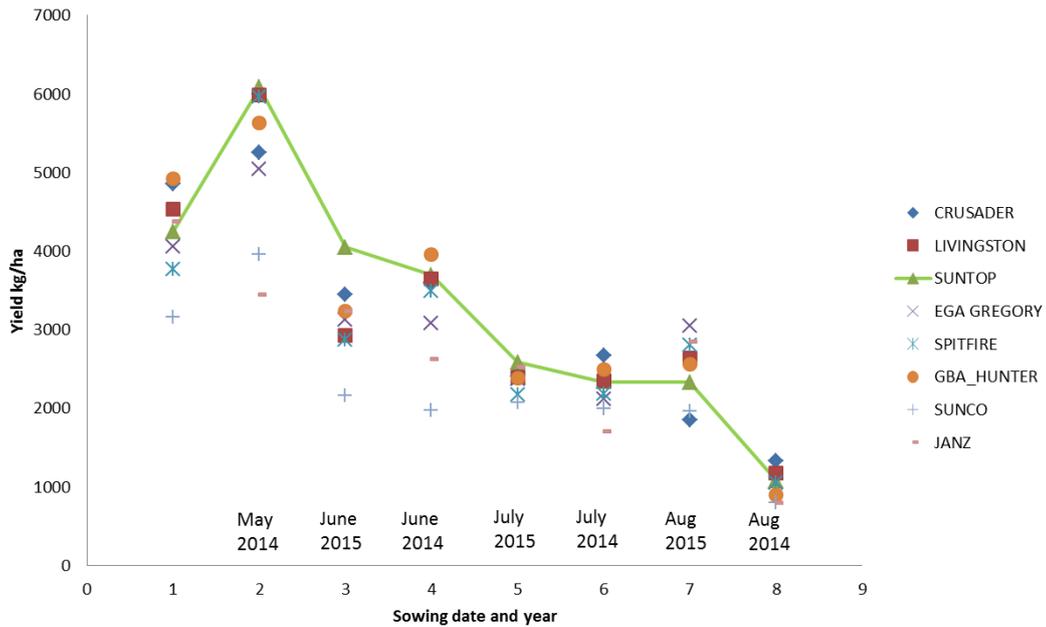


Figure 1. The yield of released cultivars across dates of sowing at Narrabri between 2014 and 2015 (Suntop, Spitfire, EGA Gregory, GBA Hunter, Livingston, Crusader in the graph above are all protected under the Plant Breeders Rights Act 1994.)

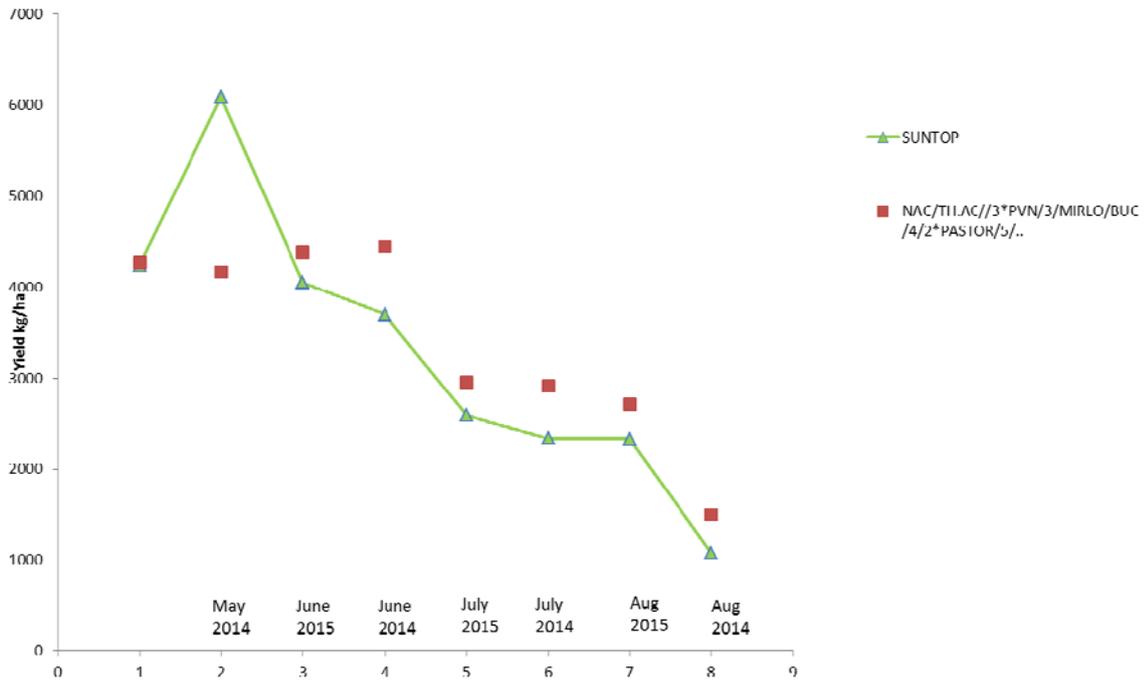


Figure 2. The yield of SUNTOP, and a new source of heat tolerance (NAC..) across dates of sowing at Narrabri in 2014 and 2015

Table 1. The yield and screenings of late sown varieties and new materials at Narrabri in 2015

Pedigree	Yield kg/ha	Screenings %
JANZ	2519 abc	9.2 a
DBW17//DBW17/18293 KC75	2412 abc	9.5 a
NAC/TH.AC//3*PVN/3/MIRLO/BUC/4/2*PASTOR/5/KAUZ..	2950 bc	9.8 a
SUNCO	2073 a	11.2 a
WBLL1*2/BRAMBLING//QUAIU	2607 bc	11.9 a
EGA GREGORY [Ⓟ]	2365 ab	12.7 a
CRUSADER [Ⓟ]	2398 abc	15.3 ab
KAUZ/PASTOR//PBW343/3/KIRITATI/4/FRNCLN	2522 abc	15.3 ab
SUNTOP [Ⓟ]	2585 abc	21.0 cb
LIVINGSTON [Ⓟ]	2389 abc	23.4 c
GBA_HUNTER [Ⓟ]	2375 abc	24.0 c
SPITFIRE [Ⓟ]	2164 a	25.0 c

These new sources of genetic variation are different to current Australian varieties and are therefore potential new parents for Australian wheat breeders. Knowledge of the genetic control of tolerance is well advanced and the development of molecular markers to assist breeders with the introduction of this trait into locally adapted varieties continues.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Richard Trethowan & Rebecca Thistlethwaite
 The IA Watson Grains Research Centre (The University of Sydney)
 Newell Hwy, Narrabri
 Ph: 0400320558, 02 6799 2200
 Email: Richard.trethowan@sydney.edu.au; rebecca.thistlethwaite@sydney.edu.au

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The effect of sowing date, variety choice and N application timing on lodging risk and yield of irrigated wheat

Allan Peake¹, Matthew Gardner², Kerry Bell³, Nick Poole⁴

¹ CSIRO

² AMPS

³ DAF Queensland

⁴ FAR

Key words

Wheat, irrigation, lodging, sowing date, in-crop nitrogen, canopy management

GRDC code

CSA00039

Take home message

- Later sowing does not always reduce lodging risk, as late storms can cause worse lodging in green crops than in mature crops.
- A large yield gain (>1 t/ha) was associated with earlier sowing when no lodging occurred, in the absence of frost.
- Preliminary experiments showed that optimum 'in-crop' N application strategy was different between varieties and locations.

Introduction

In response to increased interest in irrigated grains production, GRDC has funded the 'Better Irrigated Wheat Agronomy' project which is running experiments from 2012-2016. The project aims to improve agronomic recommendations to increase yield and decrease lodging risk in irrigated wheat, although project results are also relevant to dryland growers in high yielding districts.

This paper reports the results from experiments that aimed to (1) examine the effect of sowing date on lodging risk, and (2) determine whether in-crop nitrogen (N) application strategies need to vary between varieties and locations.

Trial program, 2014 & 2015

The experiments discussed in this paper were conducted at Emerald, Spring Ridge, Narrabri and Gatton, and were managed to be pest and disease free through regular application of fungicides and insecticides where appropriate. While all experiments were intended to be fully irrigated, some short term water deficits were occasionally experienced. **It is important to note that the varieties used in these experiments are protected by Plant Breeders Rights legislation within Australia.**

The time of sowing experiments examined a range of varieties sown on two sowing dates (Table 1), to see whether later sowing could be used to reduce lodging risk. The Variety x N Timing experiments were conducted to see whether the canopy management strategy of 'in-crop' N application needs to be implemented differently for different varieties and at different locations. Treatment details from this experiment are presented in both Table 1 and Table 2. The aim of the '200 by GS31' treatment was to supply approximately 200 kg/ha N by GS31 at both locations. This meant that despite the higher sowing N at Spring Ridge, the '200 by GS31' treatment still had

approximately 200 kg/ha N available by GS31, but with less N applied as urea to compensate for the greater sowing soil N.

Table 1. Experimental details for the 'Sowing Date' and 'Variety x N Timing' experiments

Experiment Type	Experiment Name	Sowing Dates	Agronomic Regime
Sowing Date Experiments	Emerald 2014	13 th May 30 th May	Combined*
	Narrabri 2014	15 th May 30 th May	Combined*
	Spring Ridge Delayed N 2014	19 th May 11 th June	In-Crop N
	Spring Ridge Sowing N 2014	19 th May 11 th June	Sowing N
	Narrabri 2015	25 th May 9 th June	Combined*
	Spring Ridge Sowing N 2015	18 th May 10 th June	Sowing N
	Spring Ridge Best Practice 2015	18 th May 10 th June	In-Crop N + PGRs
Variety x N Timing Experiments	Gatton 2015	Long season varieties: 15 th May Quick varieties: 29 th May	See Table 2
	Spring Ridge 2015	Long season varieties: 18 th May Quick varieties: 10 th June	See Table 2

*Results were combined from in-crop N and sowing N experiments because no significant difference was observed between agronomic regimes

Table 2. N regimes and soil N at sowing for the Variety x N Timing experiments at Gatton and Spring Ridge in 2015

N Source	Gatton N Treatments (kg N/ha)				Spring Ridge N Treatments (kg N/ha)			
	<i>Sowing</i>	<i>200 by GS31</i>	<i>Late</i>	<i>Very Late</i>	<i>Sowing</i>	<i>200 by GS31</i>	<i>Late</i>	<i>Very Late</i>
<i>Soil N at Sowing</i>	50	50	50	50	130	130	130	130
<i>Fertiliser N Sowing</i>	210				270			
GS31		150	100			80	30	
GS39	15	75	125	125		120	130	130
GS49				100			40	70
<i>Season Total</i>	275	275	275	275	400	330	330	330

Results & discussion points

Cautionary notes

The performance of agronomic treatments and varieties varies between locations and years. **New agronomy or varieties should be tested on a small scale to ensure they are suitable for different locations and farming practices, as results from our experiments may not be repeated at different locations or in different years.** Some of the varieties are not commonly grown in the Northern

Region so it is important to ensure they can be marketed before choosing to sow them. Finally, because diseases were controlled in these experiments, some varieties discussed in this paper could perform differently in an environment/year with high disease pressure if fungicides were not used.

Season conditions in 2014 & 2015

The 2014 season was generally cooler and had higher yield potential than 2015 (in which most sites experienced a hot finish). Frost was not considered to have had an effect on yield in any of the experiments. Lodging was easily induced in 2014 at all locations, but in 2015 substantial lodging was only observed at Gatton.

Effect of sowing date on lodging and yield

Earlier sowing is known to give higher wheat yields in dryland situations, if frost can be avoided. However in irrigated conditions there is a risk that when lodging risk is high, earlier sowing may increase lodging and decrease yield. This was observed at two sites in 2014; Narrabri and 'Spring Ridge - Delayed N' (Figure 1). However in the other two 2014 experiments (Emerald, 'Spring Ridge - Sowing N') the opposite effect was observed, as storms caused worse lodging in the greener, later sown plots, leading to lower yields.

In 2015, a large yield advantage was observed in the early sown treatments at all sites, no doubt due to the hot dry finish and absence of any significant lodging (Figure 1).

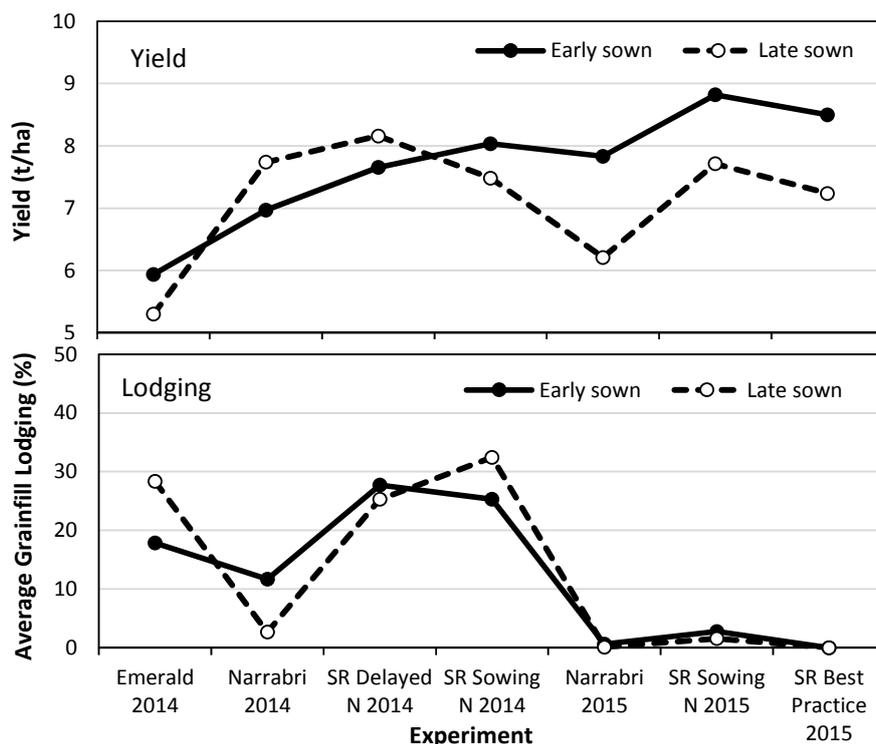


Figure 1. Effect of sowing date on yield and lodging (calculated as the mean of all varieties) for experimental sites in 2014 and 2015

The effect of N-application timing on yield and lodging for different varieties and locations

Previous experiments at Gatton have shown that wheat can recover extremely rapidly from N stress in a subtropical environment. We have begun detailed experiments to examine the best strategy for N application and whether it is the same for all varieties in different locations. This was only the first year of these experiments so the results should be treated with caution.

At Gatton in 2015, the results showed that for the quick maturing varieties Suntop[®] and Kennedy[®], the best-practice N application strategy ('200 by GS31') yielded more and lodged less than the sowing N strategy (Figure 2). Later application of N made only a small difference to grain yield and remarkably, the 'very late' strategy yielded similarly to the sowing N strategy despite having been severely N stressed at GS39. These results are typical of previous canopy management experiments we have conducted in sub-tropical locations.

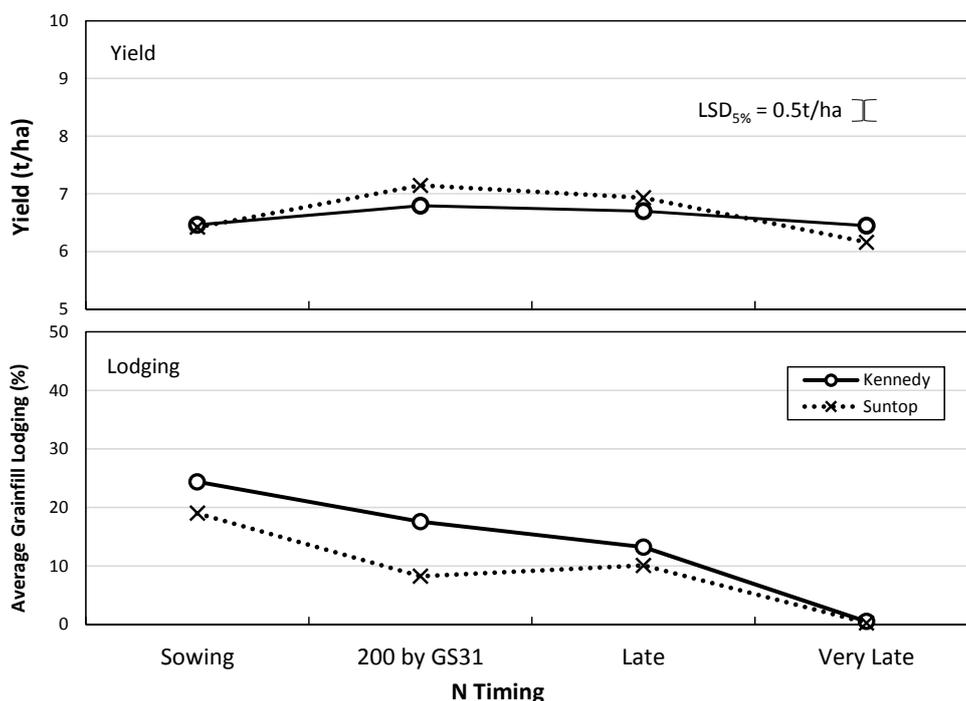


Figure 2. Effect of N strategy on yield and lodging of the quick varieties Suntop[®] and Kennedy[®] at Gatton, 2015

However the longer season varieties at Gatton showed a different response to N timing (Figure 3). Cobra[®] and Trojan[®] had higher yields associated with the '200 by GS31' treatment compared to the Sowing N treatment, but did not have a lodging reduction associated with the yield increase. Mitch[®] and Lancer[®] showed different trends, with Lancer showing a slight yield increase as N application was delayed further, and Mitch[®] achieving the best yields when N was applied at sowing.

Due to changes in variety flowering response between environments, the varieties were allocated differently into the long season and quick maturing groups at Spring Ridge. It should also be noted that the results at Spring Ridge were influenced by the absence of any substantial lodging (hence no lodging graphs are shown). The longer season varieties (Figure 4) and most of the quicker varieties (Figure 5) at Spring Ridge generally yielded the best when N was applied at sowing. The exception was Cobra[®] which yielded better in the '200 by GS31' N treatment. The same trends may not have been observed if severe lodging had been experienced.

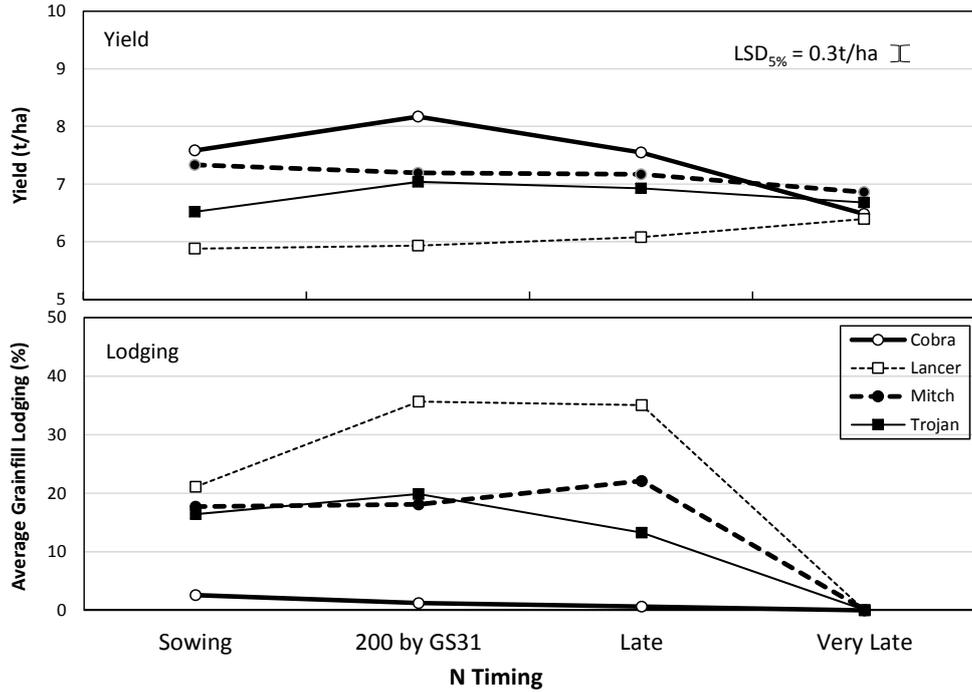


Figure 3. Effect of N strategy on yield and lodging of long season varieties at Gatton, 2015

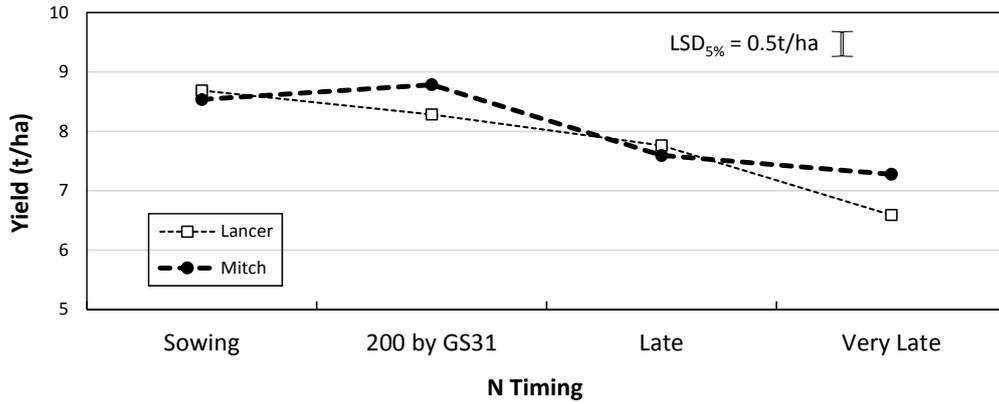


Figure 4. Effect of N strategy on yield of long season varieties at Spring Ridge, 2015

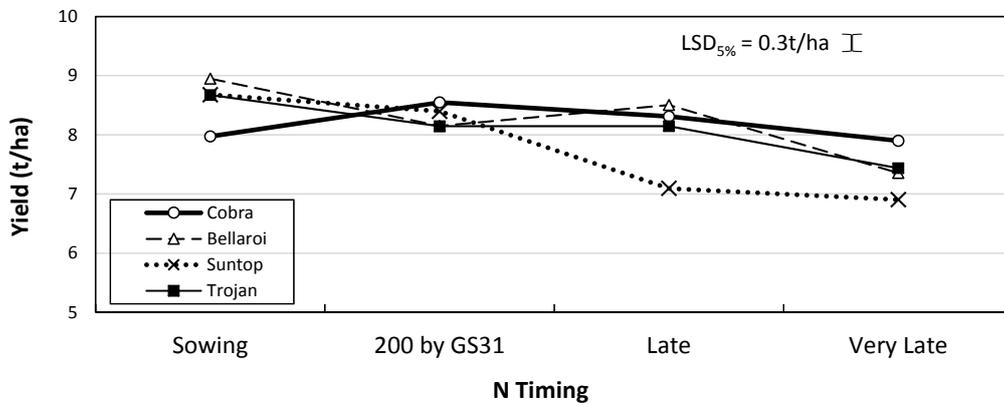


Figure 5. Effect of N strategy on yield of quick varieties at Spring Ridge, 2015

Summary & conclusions

The results of the experimentation in 2014 and 2015 have challenged some of the established theory around avoiding lodging. Later sowing has been previously observed to reduce lodging – however we saw in the 2014 experiments that lodging was sometimes worse in later sown plots, because storm damage was greater in green crops than mature/dry crops.

Additionally, while ‘in-crop’ N application continues to reduce lodging risk for quick varieties in warm environments, we are not always observing the same trend in longer season varieties or alternative environments. While further experimentation is needed to examine more site x year combinations, it could be possible that newer, more lodging resistant varieties don’t respond to ‘in-crop’ N application as consistently as the older varieties we began experimenting with in 2009.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, and the authors would like to thank them for their continued support. We also thank farm and technical staff at the DAFQ Emerald Research Farm, CSIRO Toowoomba, the CSIRO Gatton Farm, and the University of Sydney’s Plant Breeding Institute (Narrabri) for their assistance in managing these experiments, along with Angus Murchison of Spring Ridge for hosting some of the experiments.

Further reading (available from the GRDC website at www.grdc.com.au)

Fact Sheet (Northern Region): ‘Reducing lodging risk in irrigated wheat’

GRDC Goondiwindi Update Paper (2012) by Peake et al. “Agronomy for high yielding cereal environments: varieties, agronomic strategies and case studies”

GRDC Goondiwindi Update Paper (2014) by Peake et al. “Beyond 8 t/ha: varieties and agronomy for maximising irrigated wheat yields in the northern region”

GRDC Goondiwindi Update Paper (2015) by Peake et al. “Irrigated wheat agronomy x variety trials: 2014 Trial Update”

Contact details

Dr Allan Peake
CSIRO Agriculture, 203 Tor St, Toowoomba.
Ph: (07) 4688 1137
Email: allan.peake@csiro.au

Ⓓ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

High yield cereals

Rick Graham, NSW DPI

Contact details

Rick Graham

NSW DPI

Mb: 0428 264 971

Email: ricky.graham@dpi.nsw.gov.au

Nematodes & soil health concurrent session

Impact from *Pratylenchus thornei*, Macalister 2015

Brendan Burton and Linda Bailey, Northern Grower Alliance
Kedar Adhikari, Sydney University Narrabri

Key words

Pratylenchus thornei, yield, tolerance, wheat

GRDC code

NGA00004: GRDC Grower Solutions for Northern NSW and Southern Qld

Take home message

1. Multi-crop and variety trials were conducted over strips of 'medium' and 'high' *Pratylenchus thornei* (*Pt*) pressure.
2. Site characterised by generally high crop yields (cereals~4-5.5t/ha, chickpeas ~3.5-4.0t/ha) combined with lower levels of *Pt* yield impact.
3. Negligible decline in *Pt* population during the 21 month fallow leading up to the winter trials being planted.
4. No evidence of yield impact from *Pt* in the brassica, faba bean, chickpea and barley trials.
5. Greater yield loss observed in the wheat trials compared to the barley and broadleaf crops at this site.
6. Addition of crown rot inoculum together with 'high' *Pt* pressure significantly increased mean yield loss (~30%) over a set of six wheat varieties compared to either the effect from crown rot inoculum alone (~13%) or *Pt* alone (~8%).

Background

Previous work has highlighted that the root-lesion nematode, *Pratylenchus thornei* (*Pt*), is one of the key 'diseases' for winter cereal production in the northern grains region. *Pt* is a major constraint due to: the large impact on yield and economics when intolerant wheat varieties are grown, broad geographic distribution with *Pt* populations frequently at high levels and the susceptibility (*Pt* hosting ability) of key rotation crops such as chickpeas and faba beans.

Successful *Pt* management will involve a range of practices including on-farm hygiene and soil testing to identify problem paddocks. However crop and variety choice are still the major tools used for management. Wheat varieties are well characterised in terms of *tolerance* (yield impact suffered during the year of crop production) and *resistance* (impact from variety on the multiplication or build-up of *Pt*). Both characteristics are important for long term management.

This paper reports on trial work conducted between 2013 and 2015 at a site located near Macalister, approximately 40km north-west of Dalby, Qld. The activity was designed to improve our understanding of the differences in tolerance between a range of winter crops and varieties followed by an assessment of the impact of these options on subsequent *Pt* densities. An approach was used to create alternating strips of differing *Pt* population where the impact of increased *Pt* numbers on each variety could be evaluated. While our intentions from a trial point of view were to create strips of 'low' and 'high' *Pt* populations, in actual fact we ended up with strips of 'medium' and 'high' *Pt* population based on the Predicta B® risk category rating. For this reason, the strips will be referred to as medium (or 'med') and 'high' for the remainder of the paper.

Primary aims

1. Evaluate the impact from *Pratylenchus thornei* (*Pt*) on the **yield and economic returns** from a range of winter crops and varieties
2. Examine the impact from different winter crops and varieties on the **multiplication of *Pt***

Trial activity 2013

Soil testing was conducted in a paddock that had grown chickpeas in 2012. Initial samples were taken at 0-30cm on the 4th April 2013, and analysed by the PreDicta B method revealing an initial population of ~6 *Pt*/g soil. The site also appeared suitable due to a suspected low level of crown rot given only one wheat crop had been grown in the paddock over the past ten years. In addition, negligible levels of other common plant-parasitic nematodes (*Merlinius brevidens*) were found and *Pratylenchus neglectus* were not detected.

The aim in 2013 was to create 'strips' of alternating *Pt* population to allow multi-crop evaluation in 2014. Commercial strips, 18m wide, of Strzelecki[®] wheat or Caparoi[®] durum were planted on the 11th June 2013. Strzelecki[®] was used to maximise the increase in *Pt* population and Caparoi[®] durum was selected as an option that limits multiplication. Strzelecki[®] is rated as S-VS (susceptible to very susceptible) and Caparoi[®] is rated as R-MR (resistant to moderately resistant) for *Pt* resistance - or multiplication.

The first significant rainfall event at the trial site following the 2013 harvest was in March 2014 when approx. 150mm rainfall was received. Unfortunately, this rainfall was not sufficient to enable the trial program to be initiated for winter 2014.

The first soil sampling opportunity for *Pt* following harvest of the wheat strips was conducted on the 13th June 2014 once the topsoil had sufficiently dried following the March rain. This sampling provided a first measure of the population differences between the alternating strips. The extended dry period continued into the spring of 2014, and consequently the summer trials planned for 2014 were also deferred.

Further soil sampling was conducted on the 18th February 2015 leading into the 2015 winter season. Soil moisture conditions in autumn 2015 allowed the planting of all the winter season trials. Another round of *Pt* sampling was carried out on the 12th August 2015 to confirm *Pt* population size prior to the summer crop plantings.

Variety and fallow Impact on *Pt* populations

Figure 1 shows the comparison of *Pt*/g soil (at a depth of 0-30cm) in the strips where Strzelecki[®] and Caparoi[®] durum had been grown in 2013 together with the initial site result. Strips sown to Strzelecki[®] in 2013 had significantly higher *Pt* populations than where Caparoi[®] had been sown at all three sampling times. At both sampling times in 2015, there was still approx. a 7-10 fold difference in *Pt* population between the strips with levels of ~3-4 *Pt*/g soil following Caparoi[®] and ~29 *Pt*/g soil following Strzelecki[®].

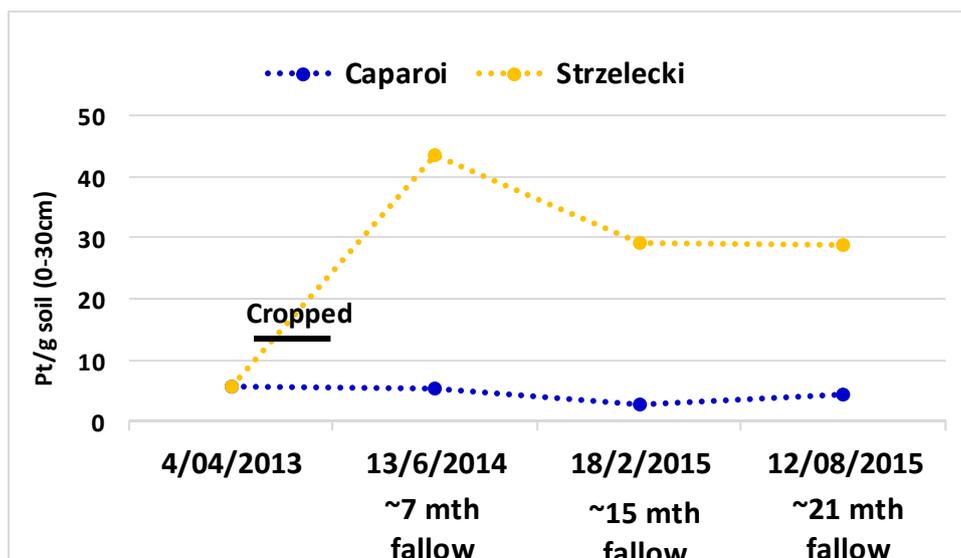


Figure 1. *Pt* population change over time following either Caparoi[®] or Strzelecki[®] production in 2013

Trial activity 2015

A total of 14 different trials of the major winter cereal and broadleaf cropping options were evaluated as split plot trials. Seed size and % germination were assessed for all seed lots with sowing rates adjusted to plant equivalent numbers of viable seeds for each crop. All crops received Granulock Z Xtra at 40kg/ha. Commercial crop protection products (and chipping) were used to manage weeds, foliar diseases and insect pressure.

There were four replicates in all trials with the exception of the faba bean and canola trials where eight replicates were included due to the limited number of treatments. Plots were sown at ~9m length x 5 rows on 36cm row spacing. Strips sown to Strzelecki[®] in 2013 were described as having 'high' *Pt* pressure and the strips sown to Caparoi[®] were described as having 'med' *Pt* pressure. **NB the population in the 'med' *Pt* pressure strips was still in excess of the widely used commercial 'threshold' of 2 *Pt*/g soil.**

Individual trial details are shown in Table 1. Trials LB1501- LB1503 and NVT trials were conducted as standard split plot trials comparing variety performance in the 'med' and 'high' *Pt* strips. Trials LB1504-LB1509 had additional factor(s) included.

Table 1. Key details of individual trials conducted in 2015

Trial description	Planting date	Number of varieties	Additional factors	Target plant stand/m ²
Minor crop resistance Screen	28/05/2015	8	-	-
Brassica evaluation	31/03/2015	6	-	30
Faba bean evaluation	15/05/2015	6	-	20
Chickpea NVT	28/05/2015	16		25
Chickpea potential nematicides		2	+/- seed treatment	25
Chickpea Deep P		2	+/- P fertiliser	25
Wheat Deep P		3	+/- P fertiliser	90
Wheat potential nematicides		2	+/- seed treatment	90
Wheat: impact of crown rot (CR)		7	+/- CR inoculum	90
Durum NVT		10	-	90
Main wheat NVT		36	-	90
Barley NVT		30	-	90
Early wheat NVT		24	-	90
Row spacing x Plant Population		2	2 row spacings, 2 plant populations	50 & 100

Trial assessments

Key in-crop assessments were establishment, 'greenness' (measured by NDVI), yield for all crops and grain quality for all cereals and brassicas.

Yield

The following graphs show the pattern of significant yield differences within varieties of the same crop between 'med' and 'high' *Pt* pressure. Significant yield differences within varieties were found in the early wheat, main wheat and durum NVT trials. Significant yield differences were also found in the *P thornei* x crown rot trial.

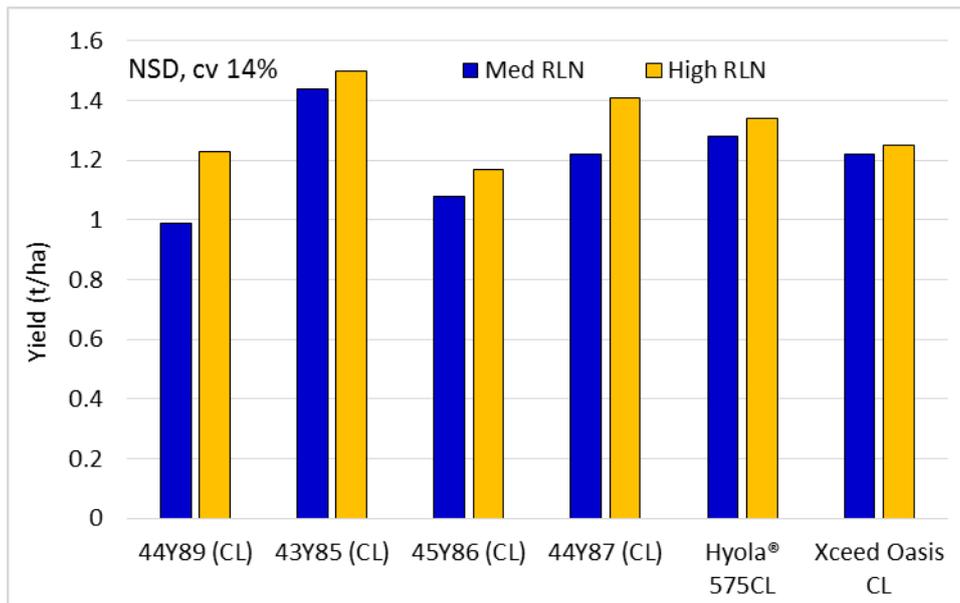


Figure 2. Brassica yields in the ‘med’ and ‘high’ Pt strips (all canola except the *B juncea* Xceed Oasis CL)

- There was no significant yield loss for any commercial variety between the ‘med’ and ‘high’ Pt strips.

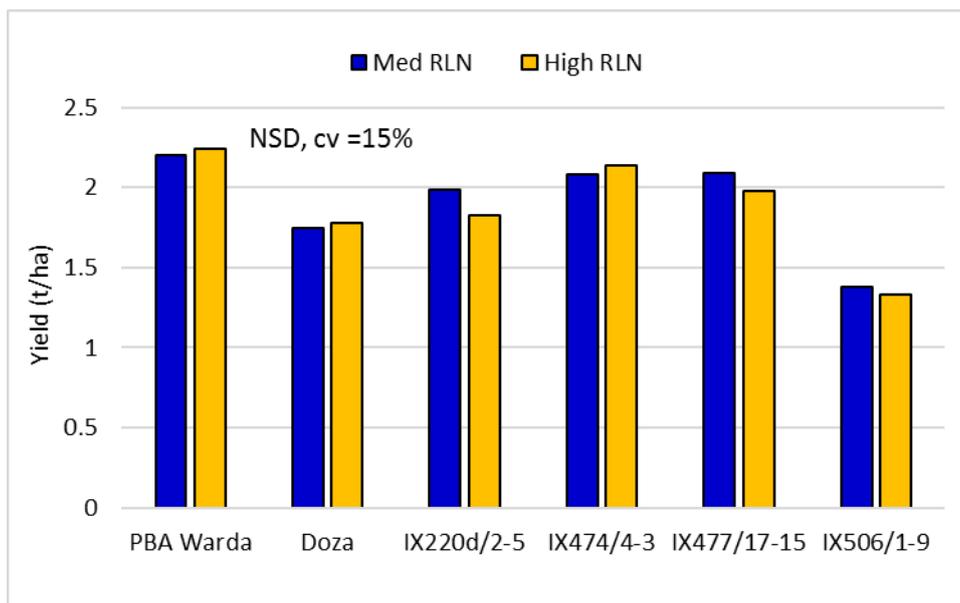


Figure 3. Faba bean variety yields in the ‘medium’ and ‘high’ Pt strips (Doza[®] and PBA Warda[®] are protected under the Plant Breeders Rights Act 1994)

- There was no significant yield loss for any commercial variety or line between the ‘med’ and ‘high’ Pt strips.
- High level of yield variability due to leaf rust and early crop senescence.

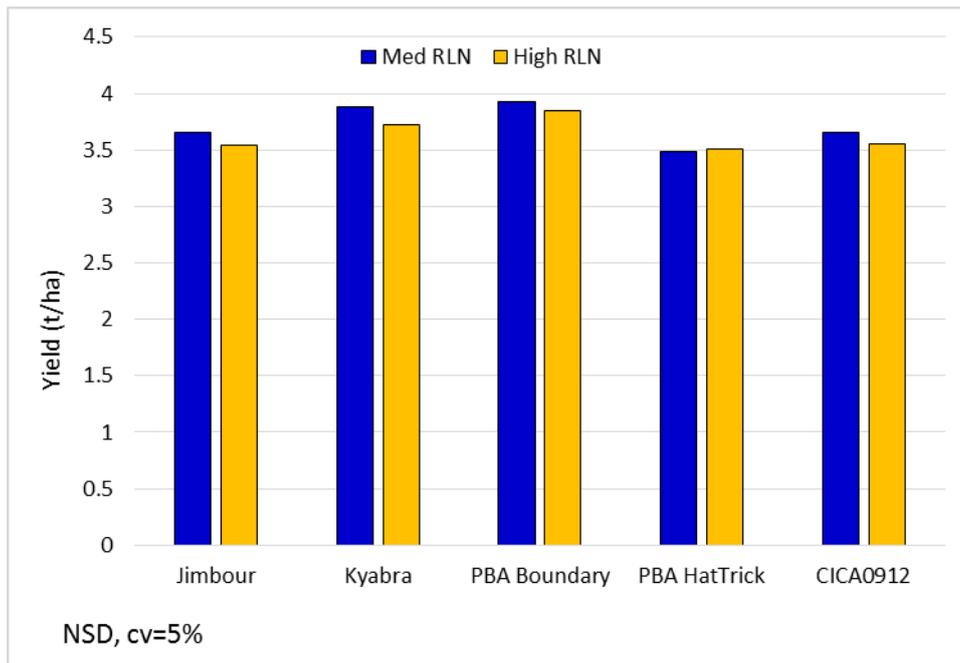


Figure 4. Chickpea yields for key lines in the ‘med’ and ‘high’ *Pt* strips (Kyabra[®], PBA Boundary[®] and PBA HatTrick[®] are protected under the Plant Breeders Rights Act 1994)

- NB only the current commercial lines and next variety planned for release are graphed
- There was no significant yield loss for any commercial variety or line between the ‘med’ and ‘high’ *Pt* strips.

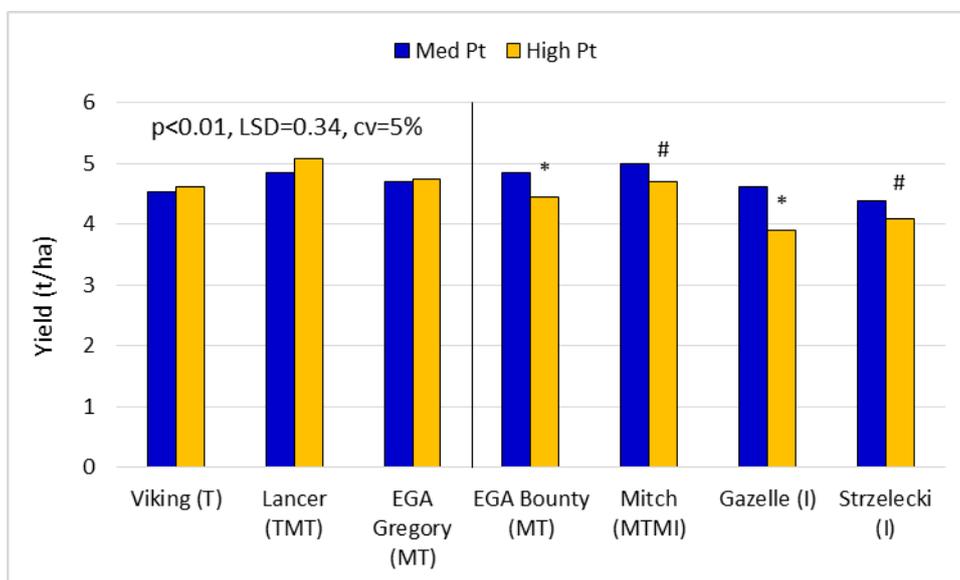


Figure 5. Early sown wheat yields for key lines in the ‘med’ and ‘high’ *Pt* strips. (Lancer[®], EGA Gregory[®], EGA Bounty[®], Mitch[®], Gazelle[®] and Strzelecki[®] are protected under the Plant Breeders Rights Act 1994)

- *indicates the variety had a significant yield reduction in the ‘high’ *Pt* strips at $p=0.05$
- # indicates the variety had a significant yield reduction in the ‘high’ *Pt* strips but only at $p=0.10$

NB the letter following the variety name indicates the *Pt* tolerance rating with the poorer rated varieties to the right of the solid vertical line. Varieties to the left of the vertical line are included for benchmarking purposes only.

- Mitch[Ⓟ], Gazelle[Ⓟ] and Strzelecki[Ⓟ] all recorded significantly lower NDVI readings in the 'high' *Pt* strips when assessed in September. EGA Bounty[Ⓟ] was significant at the 10% level
- All these varieties also recorded significant yield losses in the 'high' *Pt* strips at either the 5 or 10% level

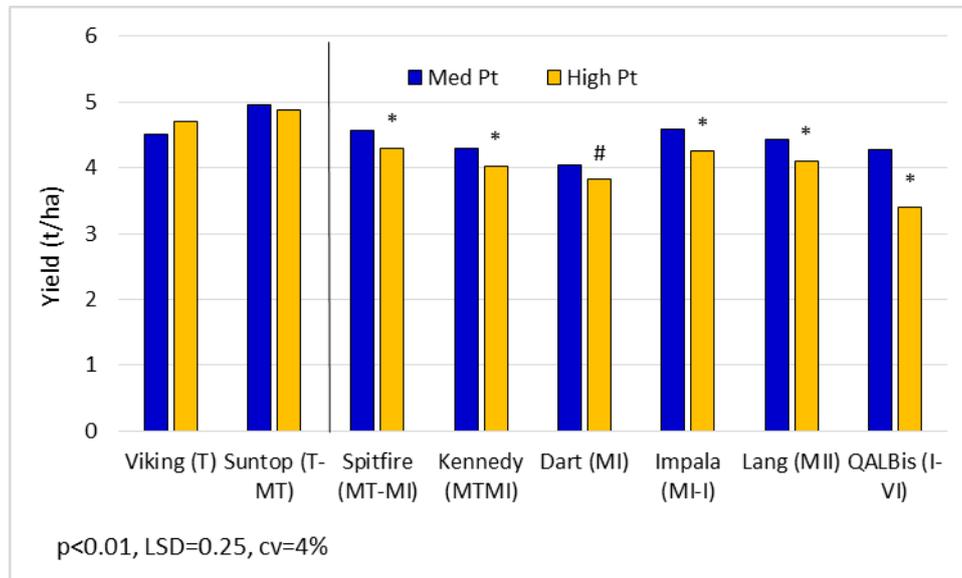


Figure 6. Main sown wheat yields for key lines in the 'med' and 'high' *Pt* strips. (Suntop[Ⓟ], Spitfire[Ⓟ], Kennedy[Ⓟ], Dart[Ⓟ], Impala[Ⓟ] and Lang[Ⓟ] are protected under the Plant Breeders Rights Act 1994)

*indicates the variety had a significant yield reduction in the 'high' *Pt* strips at p=0.05
 # indicates the variety had a significant yield reduction in the 'high' *Pt* strips but only at p=0.10

NB the letter following the variety name indicates the *Pt* tolerance rating with the poorer rated varieties to the right of the solid vertical line. Varieties to the left of the vertical line are included for benchmarking purposes only.

- There were a larger number of varieties in the main sown wheat NVT that recorded significantly lower yield in the 'high' *Pt* strips
- In addition to the commercial lines in figure 6, four experimental lines also recorded significant yield losses

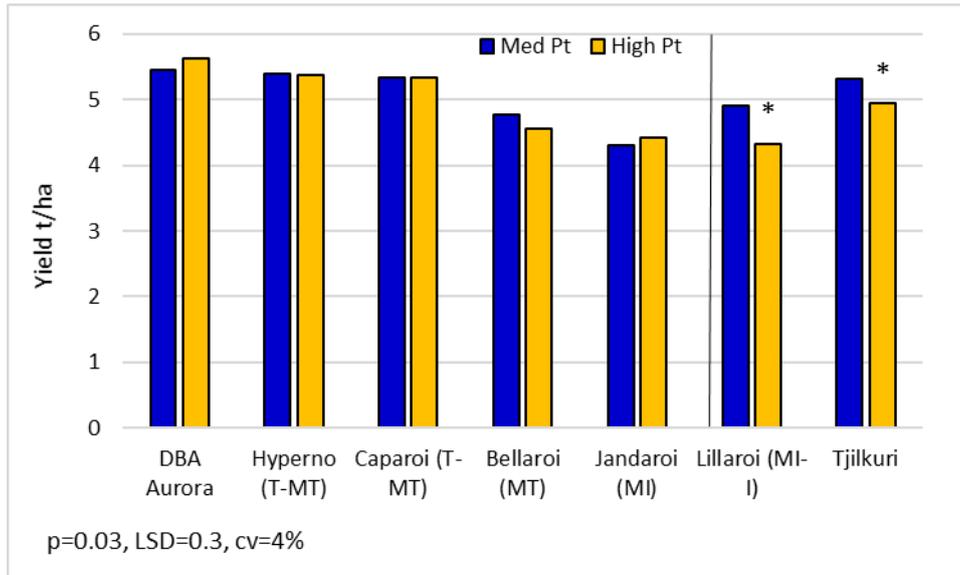


Figure 7. Durum yields for key lines in the ‘med’ and ‘high’ *Pt* strips. (DBA Aurora[Ⓟ], Hyperno[Ⓟ], Caparoi[Ⓟ], Bellaroi[Ⓟ], Jandaroi[Ⓟ], Lillaroi[Ⓟ] and Tjilkuri[Ⓟ] are protected under the Plant Breeders Rights Act 1994)

*indicates the variety had a significant yield reduction in the ‘high’ *Pt* strips at p=0.05

NB. Varieties to the left of the vertical line are included for benchmarking purposes only with the poorer rated varieties for *Pt* effects to the right of the solid vertical line. The letter following the variety name indicates the *Pt* tolerance rating.

- Only two varieties within the durum NVT trial at this site recorded significant yield reductions when moving from ‘med’ to ‘high’ *Pt*.

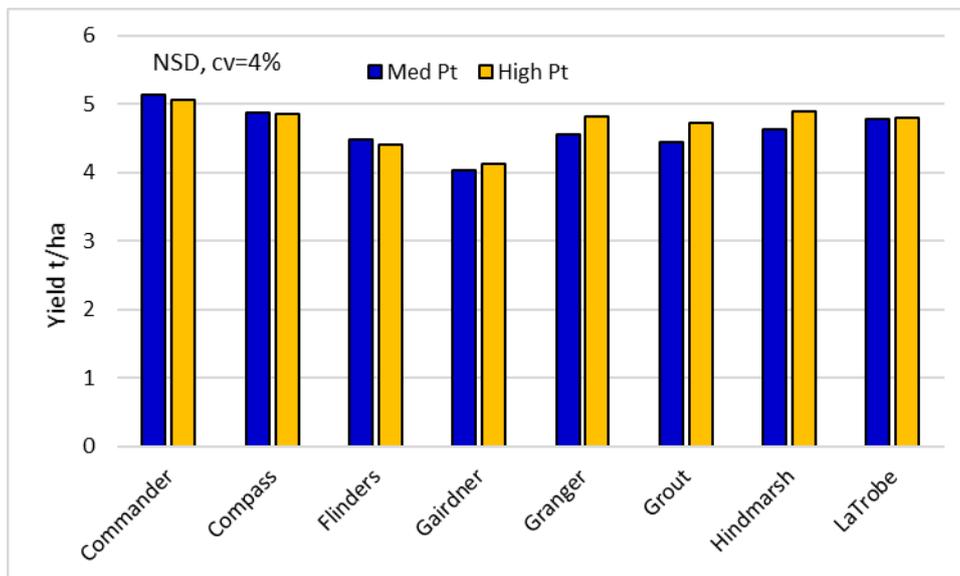


Figure 8. Barley yields for key lines in the ‘med’ and ‘high’ *Pt* strips. (Commander[Ⓟ], Compass[Ⓟ], Flinders[Ⓟ], Granger[Ⓟ], Grout[Ⓟ], Hindmarsh[Ⓟ] and La Trobe[Ⓟ] are protected under the Plant Breeders Rights Act 1994)

- There was no significant yield loss for any commercial variety between the ‘med’ and ‘high’ *Pt* strips.
- The barley varieties tested appeared more tolerant than the range of wheat varieties sown at the same time

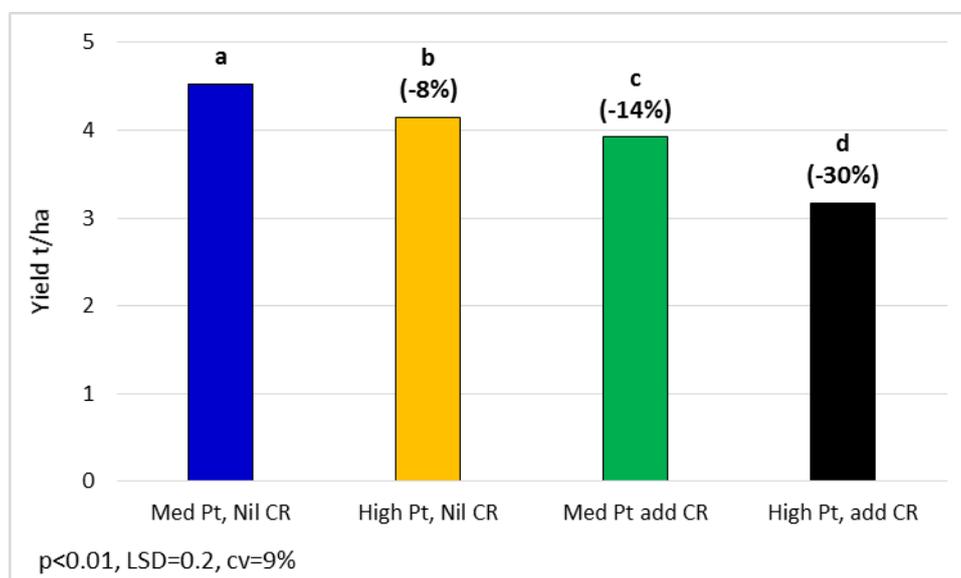


Figure 9. Wheat mean yields for six varieties with or without added crown rot (CR) inoculum. The six varieties include Spitfire[Ⓛ], Sungard[Ⓛ], EGA Gregory[Ⓛ], Sunmate[Ⓛ], Mitch[Ⓛ] and Elmore CL[Ⓛ].

Treatments that do not share the same letter are significantly different at p=.05

- When moving from ‘med’ *Pt* strips to ‘high’ *Pt* strips without adding CR, the mean yield reduction was 0.4t/ha over all six varieties.
- The addition of crown rot inoculum resulted in a mean yield loss of 0.6t/ha, while remaining under the ‘med’ *Pt* strips.
- When moving from ‘med’ *Pt* strips to ‘high’ *Pt* strips, in addition to adding crown rot inoculum, the mean yield reduction was 1.4t/ha over all six varieties.

Conclusions

This trial was conducted to allow a sound scientific evaluation of the impact of *Pt* on the yield of a broad range of winter crops and varieties and subsequently to measure the crop impact on *Pt* population (ie rotational impact and fit). Trial results indicate that there was no significant difference in yield within varieties of canola, faba bean, chickpea and barley between low versus high nematode populations. However, significant yield reductions were recorded for varieties in the early wheat, main wheat and durum NVT’s. In addition, significant yield losses were also recorded in the CR x RLN interaction trial.

Data still to come

Soil coring to determine the impact of the crops and varieties on *Pt* multiplication (the second key trial aim) will be conducted in early 2016. Grain quality analysis is also planned to take place in early 2016. Dual EM readings have been taken from all treatment plots to estimate the remaining soil water after harvest.

Acknowledgements

This was an exceptional trial in both size and complexity but also in the way it was managed. Sincere thanks to Rob Taylor and DAF Qld for field trial activity and their ability to successfully manage the multi-crops grown. Thanks also to AGT, BASF, Austgrains, Pacific Seeds, Pioneer, University of Sydney PBI, Seedmark, and Seednet for providing seed or inoculants.

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Brendan Burton
Northern Grower Alliance
Level 1, 292 Ruthven Street Toowoomba 4350
Ph: 0428 979 170
Email: brendan.burton@nga.org.au

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Managing grain crops in nematode-infested fields to minimise loss and optimise profit

Kirsty Owen, Tim Clewett, Jason Sheedy, John Thompson, DAF Queensland

Key words

Root-lesion nematodes, *Pratylenchus thornei*, *Pratylenchus neglectus*, tolerance, resistance, wheat, barley, chickpea, weeds

GRDC code

DAV00128 National Nematode epidemiology and management program
DAQ00188 National Variety Trials

Take home message

- Test soil for nematodes and plan crop rotations that target the species identified.
- Resistant crops will reduce high root-lesion nematode populations but several consecutive resistant crops and fallow may be needed to reduce very high populations.
- Tolerant crops can produce good yields when root-lesion nematodes are present but try to select tolerant varieties with high levels of resistance to have the biggest impact.
- Chickpea yield loss of current varieties due to *P. thornei* was 6.5% (provisional result).
- Liverseed grass (*Urochloa panicoides*) was susceptible to *P. neglectus*; grass weeds were poor hosts of *P. thornei* (provisional results).

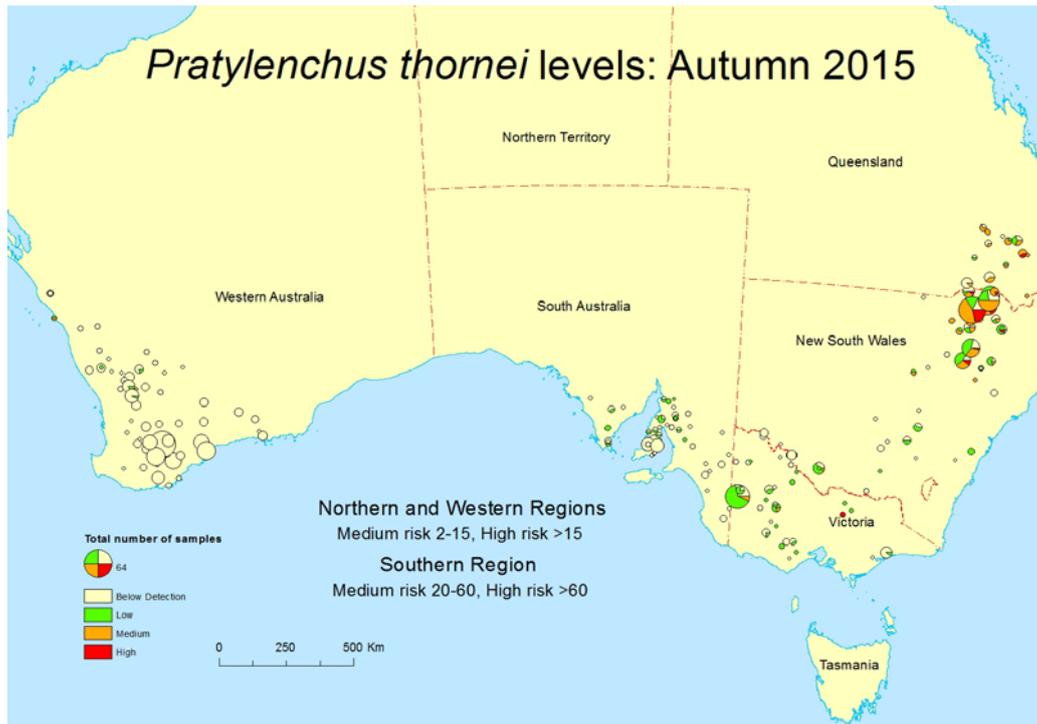
Current status of root-lesion nematodes in the northern grain region

Management of the root-lesion nematodes, *Pratylenchus thornei* and *P. neglectus* starts with knowing the populations you have present in your paddocks. PreDictaB® (South Australian Research and Development Institute (SARDI)) offers soil tests for both species of root-lesion nematodes. Their website for contact details is

http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b (or search for PreDictaB).

Maps of the distribution of *P. thornei* and *P. neglectus* from samples submitted to PreDictaB are available on-line and reproduced in this paper (Figure 1a and b). Results from autumn 2015 show that *Pratylenchus thornei* is more widely distributed and found in greater, more damaging populations than *P. neglectus* in the northern grain region. In the northern region, paddocks with more than 15 *P. thornei*/g soil or 15,000/kg soil by the PreDictaB test are considered high risk for crops. However, in the northern region, even populations of *P. thornei* classified as medium risk by PreDictaB, that is 2–15/g soil or 2,000-15,000/kg soil can cause substantial yield loss of intolerant wheat varieties in warm wet growing seasons conducive to nematode reproduction in the roots.

(a)



(b)

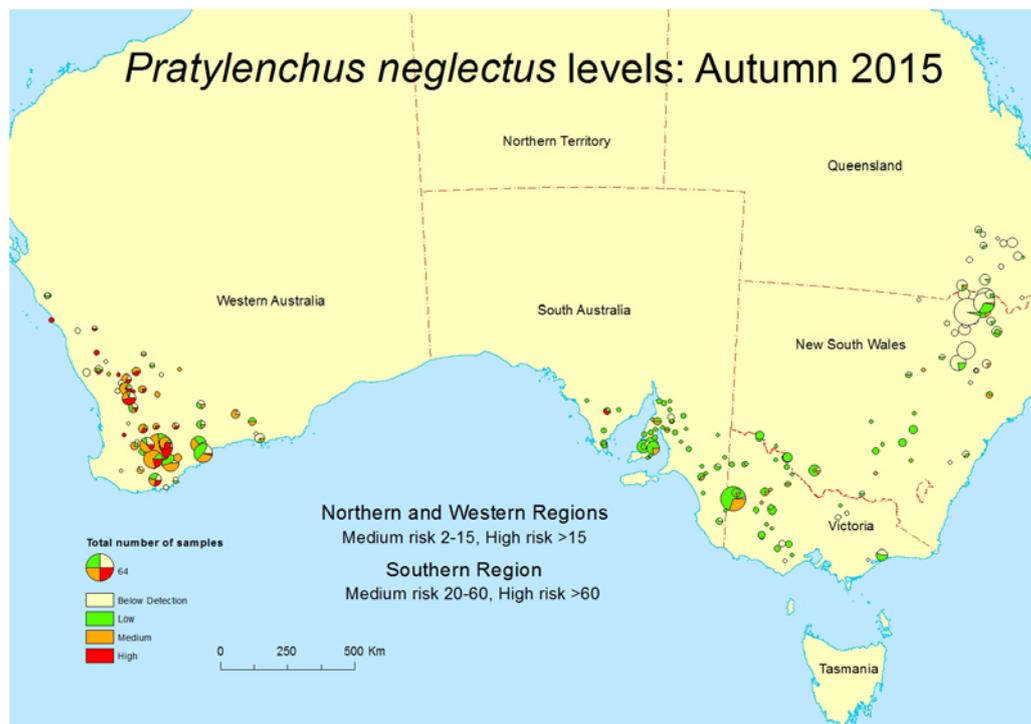


Figure 1. The distribution and risk of causing yield loss of samples submitted to PreDictaB, SARDI in autumn 2015 for a) *Pratylenchus thornei* and b) *P. neglectus*. Maps are reproduced with permission from http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b

Once you know which root-lesion nematode species is present in your paddock and the population size, you can plan your crop rotations to 1) select tolerant varieties so that yields are maximised and 2) reduce the size of the populations by growing resistant crops. **Tolerance** is the impact of root-lesion nematodes on plant yield and **resistance** is the ability of the nematode to reproduce on the plant. Each species of root-lesion nematode has a unique and broad host range including cereals and legumes (Table 1). A summary of the host range of *P. thornei* and *P. neglectus* is available in the article '2015 Root-lesion nematodes Northern Region, GRDC Tips and Tactics'. Download a copy at the GRDC website (or search for root lesion nematodes northern grain region Tips and Tactics).

<http://www.grdc.com.au/Resources/Factsheets/2015/03/Root-Lesion-Nematodes>

Table 1. Comparison of the risk of build-up of *Pratylenchus thornei* and *P. neglectus* for crops (from Tips and Tactics, Root-lesion nematodes Northern Region, GRDC 2015)

Crop	<i>P. thornei</i>	<i>P. neglectus</i>
Cereals		
Barley	Medium to high	Low to medium
Canary seed	Low	Low
Maize	Low	Low
Millet	Low	Low
Oats	Low	NT
Sorghum (grain)	Low	Medium to high
Triticale	Medium to high	Low
Wheat	Low, medium to high	Low, medium to high
Legumes		
Blackgram	High	Medium (p)
Chickpeas	Medium to high	Low to medium
Cowpeas	High	NT
Faba beans	Medium to high	Low
Field peas	Low to medium	NT
Navy beans	High	NT
Pigeon peas	Low	NT
Oilseeds		
Canola, mustard	Low to medium	Medium to high
Cotton	Low	Low
Linseed	Low	Low
Soybeans	High	Low
Sunflowers	Low	Low
Pastures, forage		
Brassica (forage)	Low to medium (p)	NT
Lablab	Low	NT
Sorghum (forage)	Low	Medium to high

Within some crops there is variation in the susceptibility and resistance of varieties, and this is indicated where a range of risk ratings is shown. New varieties or hybrids may differ in their risk ratings from the overall rating for a crop species. NT, Not tested; p, provisional rating

Low risk Caution High risk

New results

Tolerance of wheat and barley

Each year, new varieties and advanced lines of wheat are tested as part of the National Variety Trials for tolerance (which is the impact of root-lesion nematodes on plant yield) and resistance (which is the ability of the nematode to reproduce on the plant). Barley varieties are tested for resistance to root-lesion nematodes. The results of repeated experiments from the field and glasshouse are shared nationally with other nematode researchers and a consensus rating of tolerance and resistance is produced. These results are available at the NVT website (<http://www.nvtonline.com.au/>)

At the NVT website, to compare wheat or barley varieties, use the Variety Profile Comparison Tool which is located on the bottom right of the homepage. The current ratings of tolerance or resistance to *P. thornei* or *P. neglectus* (as well as other diseases and agronomic characteristics) can be viewed for up to three varieties at once. This resource will have older varieties which may have been removed from the current state Variety Guides. Low risk varieties will be highlighted in green and will have good levels of tolerance or resistance. Newer varieties that have been tested in a limited number of experiments have ratings that are listed as provisional (p) and these ratings may change when more data is obtained (see Table 2 for examples of the tolerance and resistance of wheat).

The most recent Queensland or NSW Wheat and barley variety guides can also be downloaded at the site and they contain the latest information for current wheat varieties.

Table 2. Examples of the tolerance and resistance ratings of recently released wheat varieties to the root-lesion nematodes, *Pratylenchus thornei* and *P. neglectus*, in comparison to cv. Strzelecki. Note that tolerance can be independent of resistance and that responses can differ for *P. thornei* or *P. neglectus*. Data for varieties is available from NVT.online.au (accessed 15/01/2016). Provisional ratings (p) may change in updated guides.

Wheat variety	<i>P. thornei</i>		<i>P. neglectus</i>	
	Tolerance	Resistance	Tolerance	Resistance
LongReachGauntlet [Ⓟ]	MT	MR	MTMI (p)	S
LongReach Viking [Ⓟ]	T (p)	MRMS	IVI (p)	S
Mitch [Ⓟ]	MTMI (p)	MS	T (p)	MS
Sunmate [Ⓟ]	TMT (p)	MR	MTMI (p)	MSS
Suntop [Ⓟ]	TMT	MR	MT (p)	MSS
Strzelecki [Ⓟ]	I	SVS	MT	S

Low risk Medium risk High risk

T, tolerant; *TMT*, tolerant-moderately tolerant; *MT*, moderately tolerant; *MTMI*, moderately tolerant-moderately intolerant; *I*, intolerant; *IVI*, intolerant-very intolerant

MR, moderately resistant; *MRMS*, moderately resistant-moderately susceptible; *MS*, moderately susceptible; *MSS*, moderately susceptible-susceptible; *S*, susceptible; *SVS*, susceptible-very susceptible

Chickpea

Previous data with older chickpea varieties demonstrated up to 20% yield loss where *P. thornei* was present at damaging levels (Reen *et al.* 2014). We wanted to see if new cultivars and advanced lines suffered yield loss due to *P. thornei*. Chickpea varieties were grown on plots with *P. thornei* populations at moderate (4.5/g soil at 0–30 cm soil depth) or low (1.4/g soil at 0–30 cm soil depth) levels. This was done by growing a moderately resistant or a susceptible wheat variety in the

previous season. Results showed that yields were 6.5% lower for the combined means of chickpea varieties grown on the moderate *P. thornei* plots compared to the low *P. thornei* plots (Figure 2). No significant differences were detected for yield loss of the chickpea varieties between the low and high *P. thornei* plots. This experiment will be repeated in 2016 and analysed with national data on chickpea varieties to produce ratings. New data on the resistance of chickpea to both *P. thornei* and *P. neglectus* will be produced during 2016.

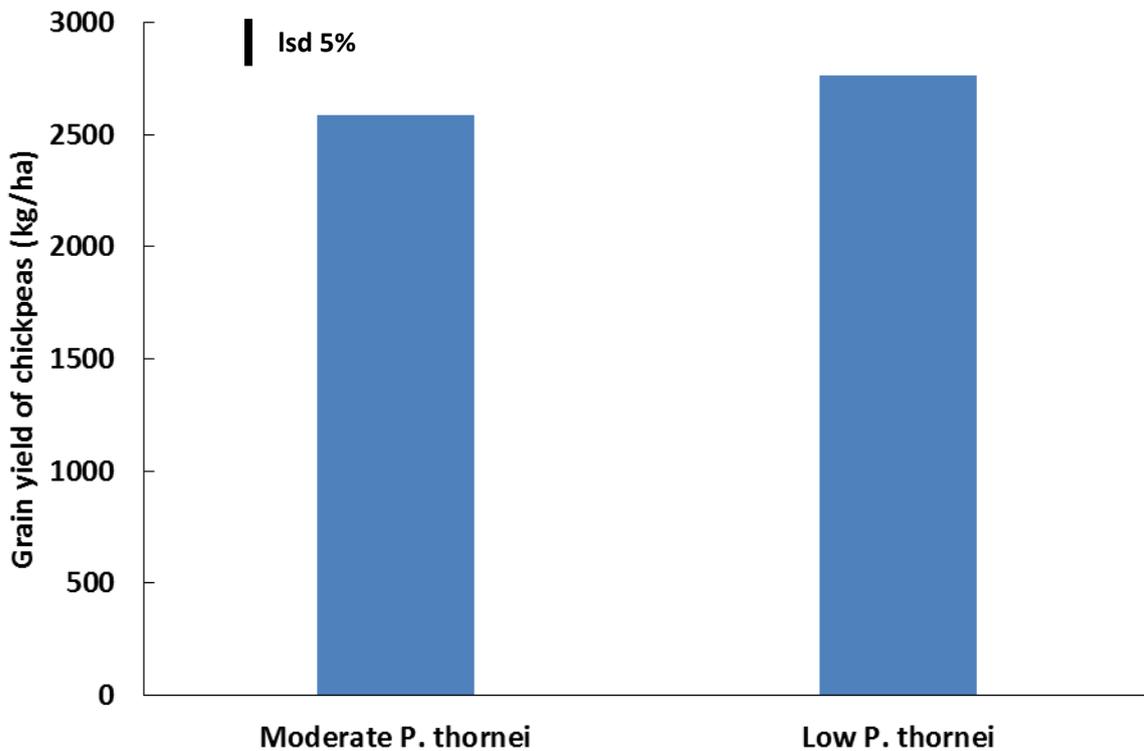


Figure 2. The grain yield of chickpea was reduced by 6.5% when plants were grown on plots with moderate levels of *P. thornei* (4.5/g soil at 0–30 cm soil depth) compared to plots with low levels of *P. thornei* (1.4/g soil at 0–30 cm soil depth) ($P=0.05$). Means of nine chickpea varieties are presented.

Weeds

We wanted to learn more about the resistance and susceptibility of weeds to *P. thornei* and *P. neglectus* in the northern grain region in order to understand their potential impact in the management of root-lesion nematodes. The reproduction of *P. thornei* or *P. neglectus* on grass weeds was assessed 16 weeks after inoculation in glasshouse experiments. The grass weeds tested were, Awnless barnyard grass (*Echinochloa colona*), Feathertop Rhodes grass (*Chloris virgata*), Liverseed grass (*Urochloa panicoides*), Windmill grass (*Chloris truncata*) and Wild oats (*Avena fatua*). For *P. thornei*, Windmill grass, Awnless Barnyard grass, Liverseed grass, Feathertop Rhodes grass and Wild Oats were poor hosts (resistant) and populations were not significantly different to the resistant controls ($P=0.05$) (Figure 3a).

For *P. neglectus*, Liverseed grass was a good host (susceptible) and was not significantly different from the susceptible controls ($P<0.05$). Feathertop Rhodes grass, Windmill grass and Wild oats were poor hosts (resistant) of *P. neglectus*, and Awnless Barnyard grass was an intermediate host and was similar to the moderately resistant-moderately susceptible control (Figure 3b).

How do you use this information to manage root-lesion nematodes?

When you have your soil test results back, plan your crop rotations to reduce root-lesion nematode populations. Rotations will differ depending on whether you have *P. thornei*, *P. neglectus* or both species. Very high nematode populations are reduced by increasing the number of resistant crops grown consecutively in rotations. It may take two or more resistant crops to reduce damaging populations. When root-lesion nematodes are present, tolerant crops will produce higher yields than intolerant crops. However not all tolerant crops are resistant. The NVT website lists ratings of tolerance and resistance for wheat and barley and the GRDC Tips and Tactics factsheets are available for information on other crops. Keep an eye on how root-lesion nematode populations change during rotations especially if weeds like Wild oats or Liverseed grass have been poorly controlled. You can't eliminate root-lesion nematodes from soils, but with careful planning you can minimise their impact on your farm profits.

References

Reen, RA, Thompson JP, Clewett TG, Sheedy TG, Bell KL (2014) Yield response in chickpea cultivars and wheat following crop rotations affecting population densities of *Pratylenchus thornei* and arbuscular mycorrhizal fungi. *Crop and Pasture Science*, **65**, 428–441.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

We would also like to thank the Northern Grower Alliance for their funding and interest in determining the resistance of weeds to root-lesion nematodes; Michael Widderick and Michelle Keenan, DAFQ for advice and supply of weeds seed; Kevin Moore and Kristy Hobson for advice and supply of chickpea seed; PreDictaB, at SARDI for providing the distribution maps; the Gywnne family for the use of their land for our experiments; and Kerry Bell, DAFQ, for design and analysis of experimental data.

Contact details

Kirsty Owen
Centre for Crop Health, University of Southern Queensland
Leslie Research Centre, PO Box 2282, Toowoomba, 4350 QLD
Ph: 07 46 311 239
Email: Kirsty.Owen@usq.edu.au

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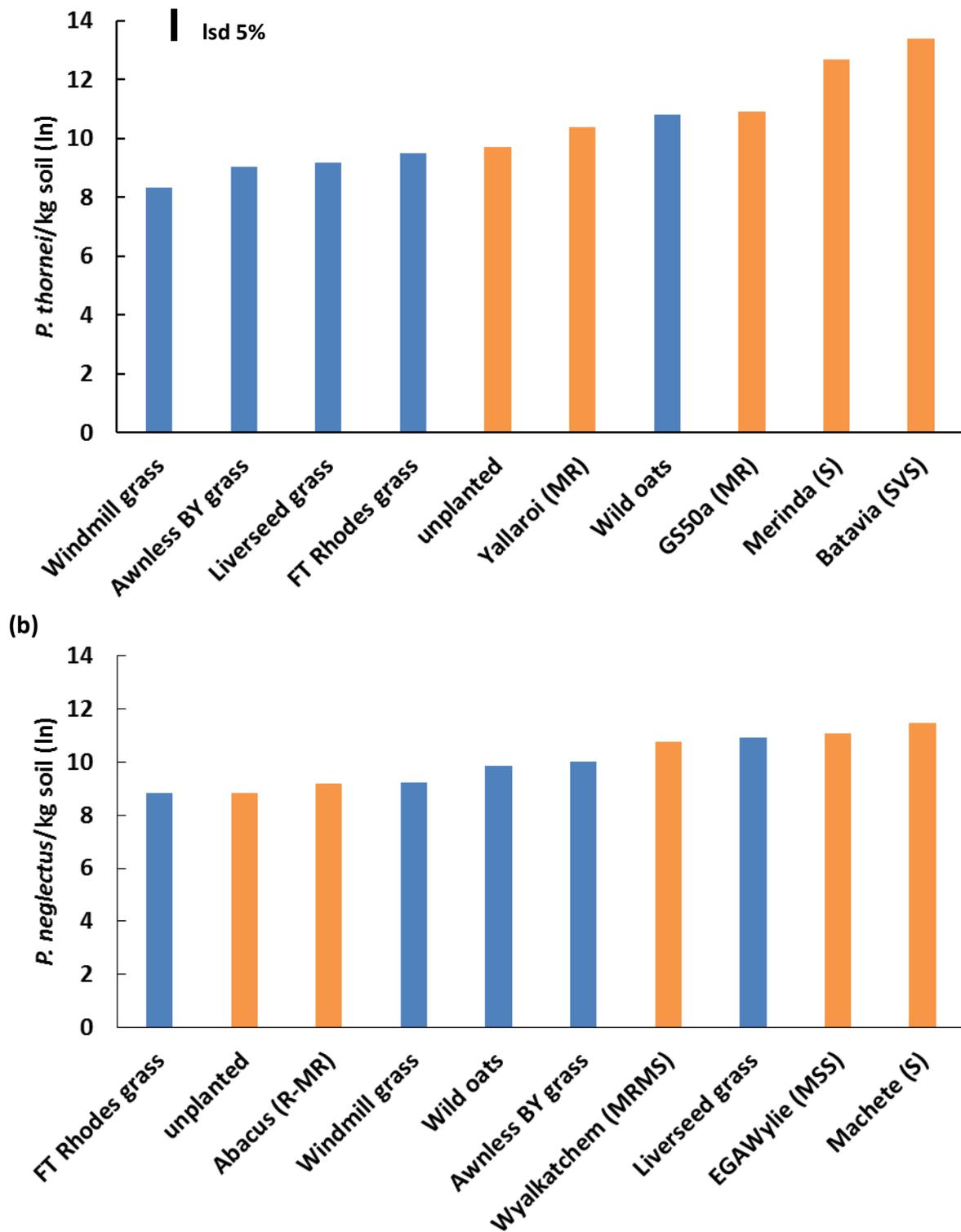


Figure 3. Final populations of a) *P. thornei* or b) *P. neglectus*/kg soil (ln) after 16 weeks growth of grass weeds (blue bars) in comparison to cereal (Yallaroi is durum; Abacus is triticale; all others are wheat) and unplanted controls (orange bars). For *P. thornei* all weeds tested were poor hosts (resistant) and populations were not significantly different to the resistant controls. For *P. neglectus*, Liverseed grass was susceptible ($P < 0.05$). FT Rhodes grass is Feathertop Rhodes grass, Awnless BY grass is Awnless Barnyard grass.

(\bar{d}) for cereal cultivars listed in the figures.)

Root-lesion nematodes (*Pratylenchus thornei*): how long does it take to reduce their population within the soil?

Jeremy Whish¹ and John Thompson²

¹CSIRO Agriculture, 203 Tor Street, Toowoomba, QLD 4350, Australia

²Centre for Crop Health, Institute for Agriculture and the Environment, University of Southern Queensland, Toowoomba, Qld 4350, Australia

Key words

Root-lesion nematode (*Pratylenchus thornei*); modelling population decline

GRDC code

CSE00055

Take home message

- Know your soil's Root-lesion nematode (*P. thornei*) population size
- Test your soil for Root-lesion nematodes. *P. thornei* populations greater than 40,000 per kg at harvest will require a double break of around 40 months free of a host to reduce the population below the accepted threshold of 2000 Pt/kg. *P. thornei* populations greater than 10,000 per kg at harvest will require a single break of around 30 months free of a host to reduce the population below the accepted threshold of 2000 Pt/kg.
- Weeds can be a host so fallows must be weed free and free of volunteers

Background

The root-lesion nematode *Pratylenchus thornei* (Pt) is a major pest of cereal and pulse crops on the heavy clay textured soils of the northern grains region of eastern Australia. *P. thornei* has a broad host range covering many cereals and pulses (Castillo and Vovlas, 2007; Nicol and Rivoal, 2008) highlighting its economic importance as a major pathogen of grain production worldwide. In Australia, yield losses in intolerant wheat varieties as a result of *P. thornei* have been estimated at between 44 and 80% (Thompson, 2008; Thompson et al., 2012), resulting in an estimated annual cost to the industry of \$38 million (Murray and Brennan, 2009). Genetic control by breeding tolerant and resistant varieties has been considered the best long-term approach for this pathogen (Thompson et al., 1999). Wheat lines with superior tolerance have been developed, which has meant the regional wheat yield potential has continued to be achieved. However, tolerant varieties can continue to increase the nematode population, creating high pathogen levels in the soil and posing a serious risk to other host crops that do not have tolerant or resistant lines available.

How long does it take a *P.thornei* population to decline in the absence of a host.

Fallowing or the use of consecutive non-host crops such as sorghum (O'Brien, 1983) has the potential to significantly reduce *P. thornei* populations (Owen et al., 2014; Thompson et al., 2012). However, this can take a long time and never completely eliminate the pest as low numbers of *P. thornei* were still present in soils fallowed continuously for 8 years (Peck et al., 1993). This is in contrast to another *Pratylenchus* species (*P. coffeae*) where an 11-month absence of a host reduced the population to zero (Trinh et al., 2011). To understand the rate of decline in a nematode population we monitored different starting populations for a 30 month host free period in a Vertosol on the Darling Downs at Formartin.

What we did

Following two consecutive wheat crops using wheat cultivars with different levels of tolerance and resistance a range of nematode populations were created in the soil. At the harvest of the second wheat crop the nematode population from each plot was recorded and characterised as high, (H >20,000Pt/cm²/1.2m profile), medium (M >10,000Pt/cm²/1.2m profile), low (L >5,000Pt/cm²/1.2m profile) and very low populations (VL <5,000Pt/cm²/1.2m profile) calculated as the sum of nematodes across the whole profile. Over the next 30 months, soil samples were collected from these plots to monitor the change in nematode population over time. Two 1.8 m soil cores were collected from each plot and divided into 8 layers (the top four being of 15 cm and the bottom four of 30 cm) Nematodes were extracted from the soil and manually counted to give a live nematode population estimate for each soil layer. The rotation over the 30 months was, long fallow from wheat to sorghum then long fallow from sorghum to wheat. In the fallow commencing in 2011 no sorghum was sown due to drought.

Our results

In this experiment, the majority of nematodes resided in the soil surface layers. Over the 30 months without a host crop the bulk of the populations reduced to below the damage threshold of 2000/kg or ~2/cm³. The majority of the reduction occurred in the surface layers (Figure 1). The 0-15 cm layer at the surface showed the fastest decline in population numbers (Figure 2).

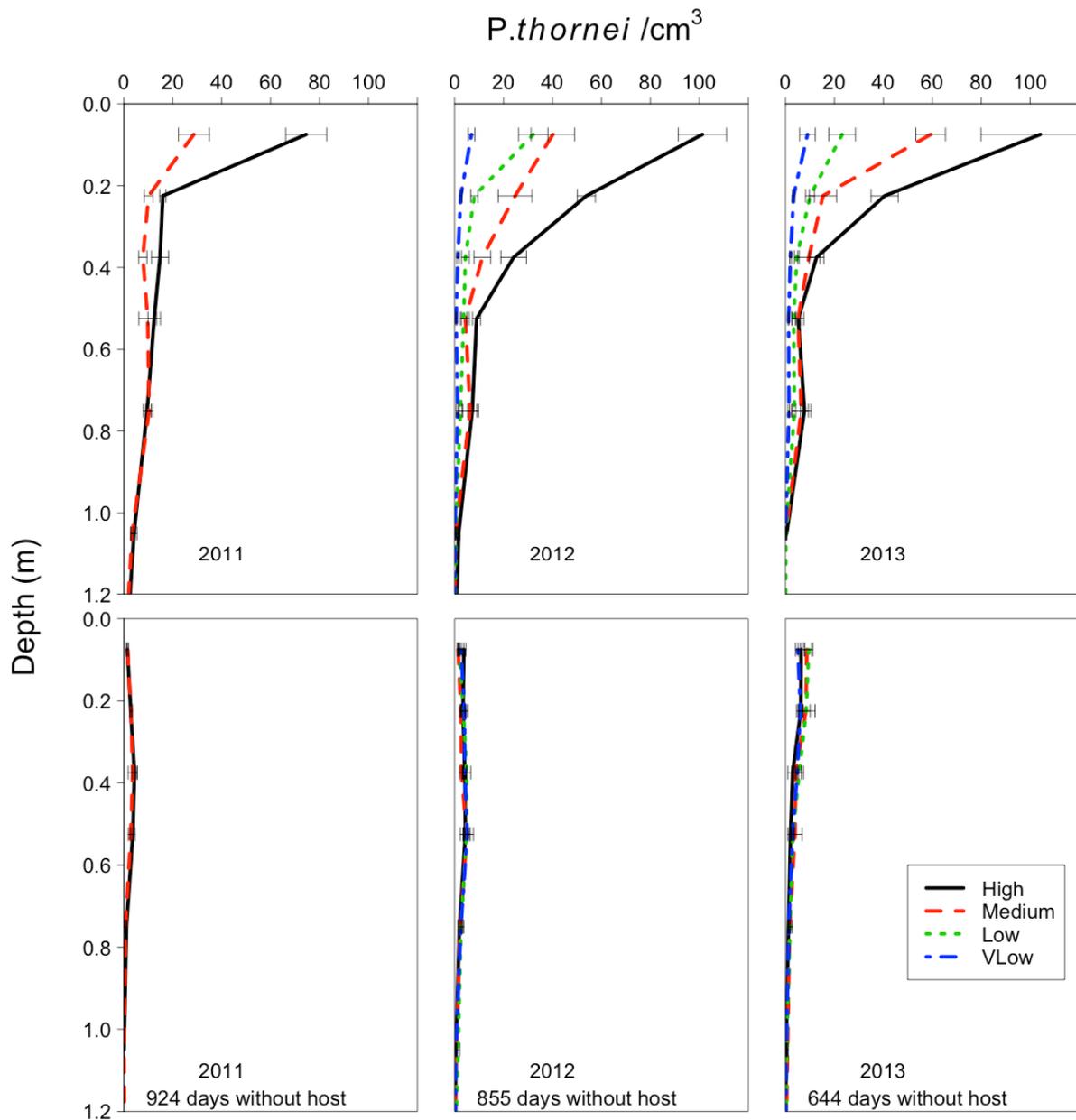


Figure 1. Distribution of *Pratylenchus thornei* at the start (top row) and end (bottom row) of the three non-host long fallows. The different lines indicate the different starting population classes (High, $H > 20,000 \text{Pt/cm}^2/1.2\text{m}$ profile), medium (M $> 10,000 \text{Pt/cm}^2/1.2\text{m}$ profile), low (L $> 5,000 \text{Pt/cm}^2/1.2\text{m}$ profile) and very low population (VL $< 5,000 \text{Pt/cm}^2/1.2\text{m}$ profile) calculated as the sum of nematodes across the whole profile. Standard errors are indicated for each sampling point.

To understand the rate of decline or how many nematodes died per day a negative exponential function was applied to the data (Figure 2) which went part way to describe the observed data. Note how a sharp drop occurs in the surface layer but not in the second or third layer population densities.

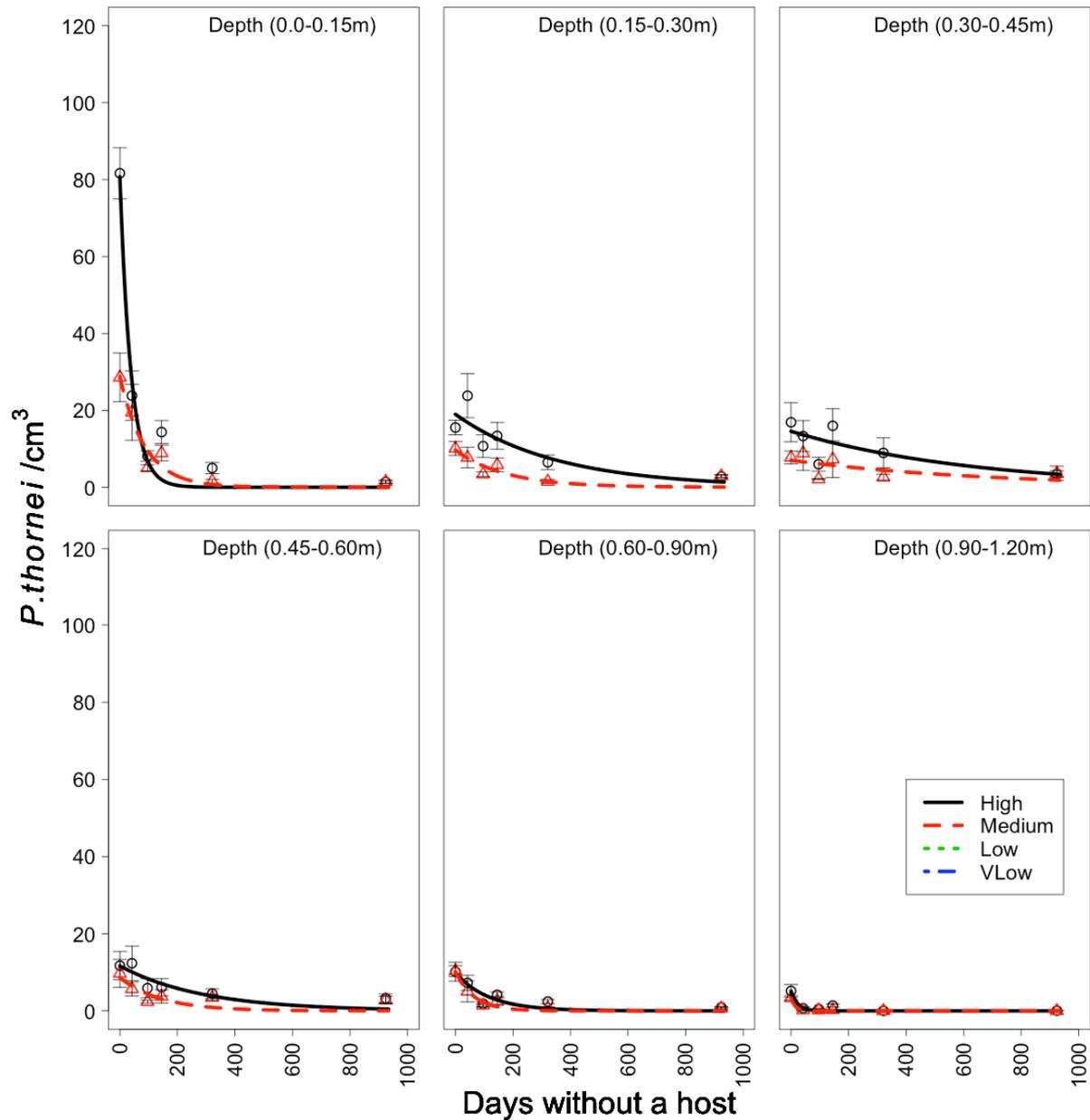


Figure 2. The negative exponential function $Y=ae^{-bt}$, where y = nematode density per soil layer, t = time in days, a = the intercept and b = the slope parameter, fitted to the high and medium population data at each soil layer over the 30-month fallow commencing in November 2011. Standard errors are presented for each of the observed population measurements.

A similar rate of decline was found in each of the non-host periods for each layer. This information was combined with knowledge of temperature and moisture to build a dynamic nematode decline model that worked with APSIM. The completed model was tested against the observed data. The observed predicted regression (Figure 3) shows the model accounted for 95% of the error. The predicted model curves highlight how the inclusion of dynamic modelling or temperature and moisture combined with age class mortality rates of the different nematode life stages improved the prediction in the early stages of the fallow (Figure 4).

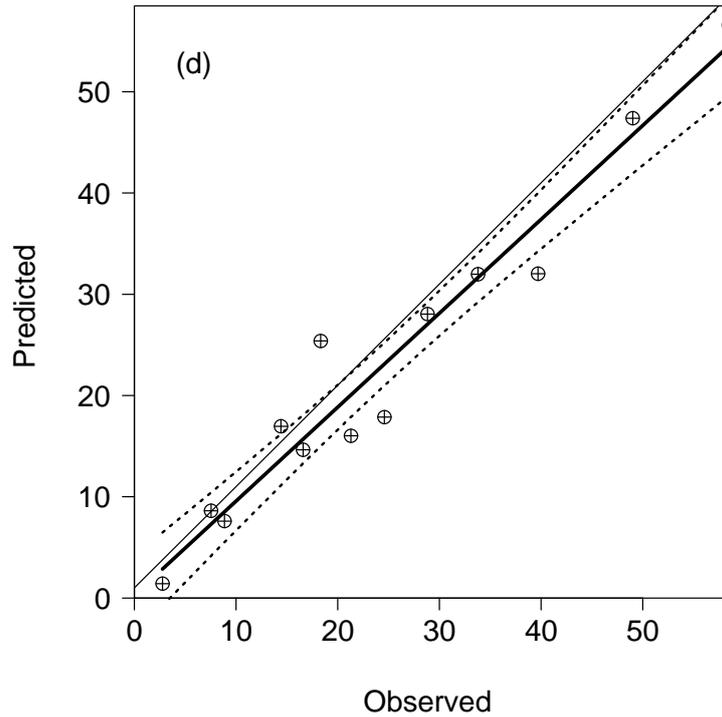


Figure 3. The observed predicted regression (Fig. 1d) shows good correlation between the observed and predicted data, $y = 0.93x + 0.28$, $R^2=0.94$.

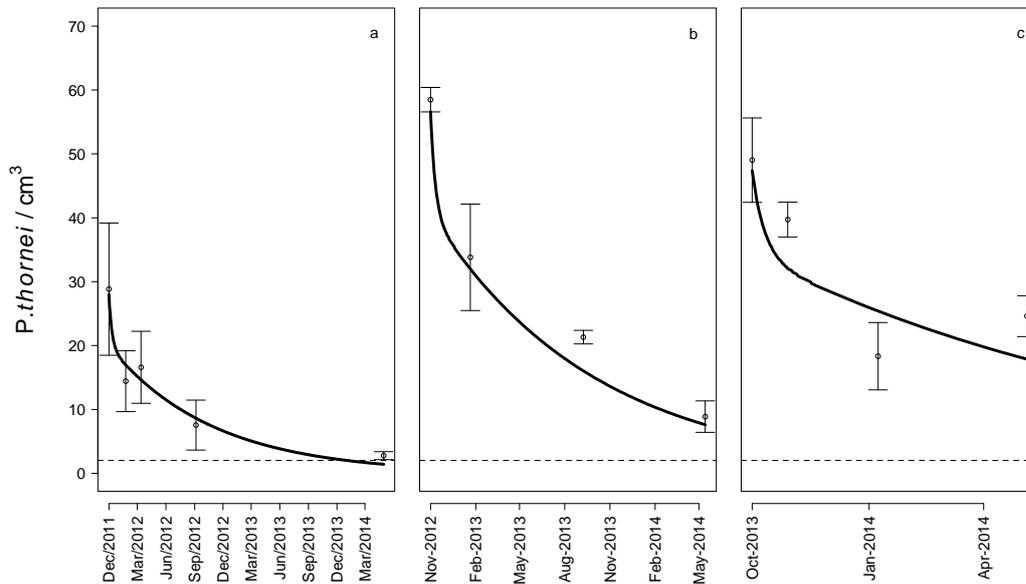


Figure 4. The observed (points) and predicted (line) population data declining from maximum population at harvest of the preceding wheat crop and the decline over the break. The longest decay curve (a) included a non-host sorghum crop sown in October 2012. The shorter curve (b) commenced in November 2012 and there was no sorghum crop planted due to drought. The final curve (c) commenced in 2013 and had a sorghum crop planted in October 2014. The dashed horizontal line represents the damage threshold below which minimal yield loss will occur in a susceptible wheat crop.

Using the developed model, the time taken to reduce different sized nematode populations to below the damage threshold of 2000 nematodes per kg was calculated (Figure 5).

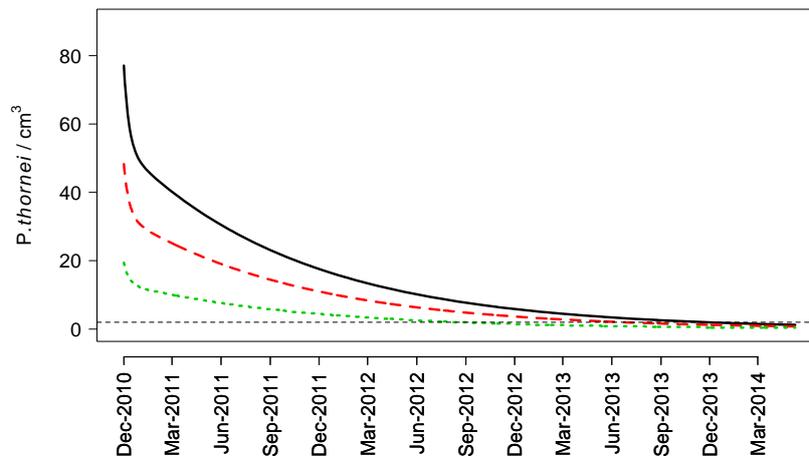


Figure 5. The effect of starting population (80 Pt/cm³ ~80,000/kg, solid black line; 50 Pt/cm³ ~50,000/kg, dashed red line; 20 Pt/cm³ ~20,000/kg, dotted green line) on the time taken for the *P. thornei* population to reduce below the economic threshold.

So what?

The scenario analysis (Figure 5) highlighted the importance of the initial population when reducing nematode populations below the damage threshold. High population of 80 nematodes per cm³ (~80,000 Pt/kg) took four years to reduce below the threshold. This would require 2 non host crops such as sorghum and fallows to reduce the population. A moderate initial population of 50 nematodes per cm³ took three and a half years (Figure 6), requiring the equivalent of a single non host summer crop and fallows. A population of 20 nematodes per cm³ took 24 months. The long survival mechanisms of root-lesion nematodes highlight the importance of knowing the size of the population at the end of each season. Once a population increases, non-host, resistant crops or fallows are required to reduce the population below the damage threshold. Planting susceptible or tolerant crops within this time period will increase populations to higher levels that will take longer to reduce, thereby limiting cropping options, and potentially reducing the profitability of the overall farming system. As resistant wheat varieties are released they can be used to provide a winter decline option to increase non-host periods within the rotation.

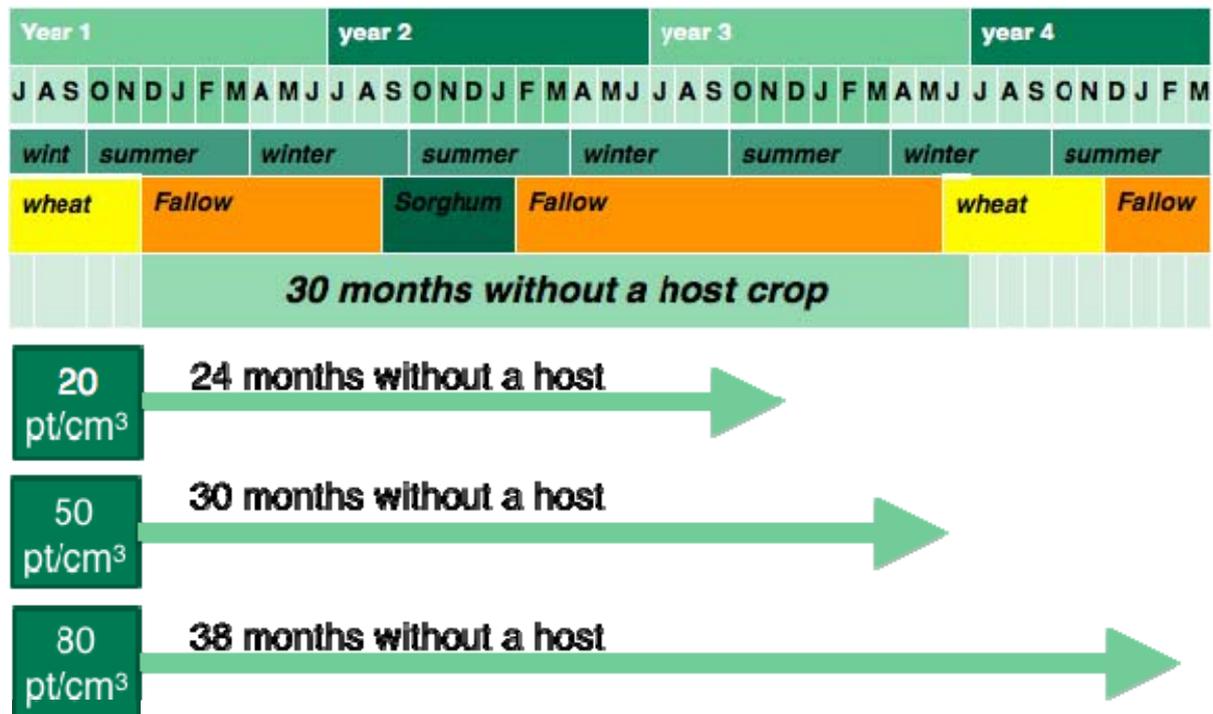


Figure 6. An example of a non-host fallow showing the time required to reduce different starting populations of root-lesion nematode.

Where to next

Further testing of the model is required to ensure it captures the influences of different soils, soil temperatures and moisture conditions. Understanding the survival mechanisms of *P. thornei* and what causes the initial sharp decline may provide some insight into tactical ways to reduce populations faster and maintain low populations for longer

References

- Castillo P., Vovlas N. (2007) *Pratylenchus* (Nematoda: Pratylenchidae): Diagnosis, biology, pathogenicity and management. Chapter 7. In *Biology and ecology of Pratylenchus*. Nematology Monographs and Perspectives Series 6. pp. 305–324 Eds D.J. Hunt, R.N. Perry, Leiden-Boston:Brill,.
- Murray, G.M., Brennan, J.P., 2009. Estimating disease losses to the Australian wheat industry. *Austral. Plant Pathol.* 38, 558–570. doi:10.1071/AP09053
- Nicol, J.M., Rivoal, R., 2008. Global Knowledge and its Application for the Integrated Control and Management of Nematodes on Wheat, in: Mukerji, K.G. (Ed.), *Integrated Management and Biocontrol of Vegetable and Grain Crops Nematodes*. Springer, pp. 251–283.
- O'Brien, P., 1983. A Further Study on the Host Range of *Pratylenchus thornei*. *Austral. Plant Pathol.* 12, 1. doi:10.1071/APP9830001
- Owen, K.J., Clewett, T., Bell, K., Thompson, J.P., 2014. Wheat biomass and yield increased when populations of the root-lesion nematode (*Pratylenchus thornei*) were reduced through sequential rotation of partially resistant winter and summer crops. *Crop Pasture Sci.* 65, 227–15. doi:10.1071/CP13295
- Peck, D.M., Thompson, J.P., Clewett, T., Haak, M.I., 1993. The root lesion nematode *Pratylenchus thornei* survives extended clean fallows and build up quickly with wheat cropping, in: Presented at the th Biennial APPS Conference Hobart, July -th,, pp. 29–32.
- Thompson, J.P., 2008. Resistance to root-lesion nematodes (*Pratylenchus thornei* and *P. neglectus*) in synthetic hexaploid wheats and their durum and *Aegilops tauschii* parents. *Aust. J. Agric. Res.* 59, 432. doi:10.1071/AR07222

- Thompson, J.P., Brennan, P., Clewett, T., Sheedy, J.G., Seymour, N., 1999. Progress in breeding wheat for tolerance and resistance to root-lesion nematode (*Pratylenchus thornei*). Austral. Plant Pathol. 28, 45–52.
- Thompson, J.P., Zwart, R.S., Butler, D., 2012. Inheritance of resistance to root-lesion nematodes (*Pratylenchus thornei* and *P. neglectus*) in five doubled-haploid populations of wheat. Euphytica 188, 209–219. doi:10.1007/s10681-012-0689-x
- Trinh, P.Q., Wesemael, W.M.L., Nguyen, C.N., Moens, M., 2011. Decline of *Pratylenchus coffeae* and *Radopholus arabocoffeae* populations after death and removal of 5-year-old arabica coffee (*Coffea arabica* cv. Catimor) trees. Nematology 13, 491–500. doi:10.1163/138855410X528505

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, CSIRO and the University of Southern Queensland, and the authors would like to thank them for their continued support.

Contact details

Jeremy Whish
CSIRO
Ph: 07 46881419
Email: Jeremy.whish@csiro.au

Reviewed Neal Dalgliesh and Kirsty Owen

Biological suppression of root-lesion nematodes in northern grain-growing soils

Nicole Seymour¹, Graham Stirling, Jady Li

¹Queensland Department of Agriculture and Fisheries

Key words

Pratylenchus thornei, biological suppression

GRDC code

DAQ00164

Take home message

- Biological suppression does occur in most soils we tested from the northern grain-growing region, showing that populations of *P. thornei* are being reduced by parasites and predators.
- Suppression was found to be greater in the top 10cm of soil than at deeper layers (e.g. 30-45 cm). Practices such as zero tillage with stubble retention enhanced suppression. Without these practices, we estimate that RLN multiplication would be significantly greater, especially in top soils, and this would result in much greater losses in the productivity of susceptible crops.
- Several antagonists of *Pratylenchus* were found in northern grain-growing soils such as nematode trapping fungi, predatory nematodes, parasitic bacteria and root-colonising fungi that enhance the plant's resistance to nematodes. Further research is focussing on these organisms as they are likely to be contributing to the suppressiveness of the soils.

Root-lesion nematodes (*Pratylenchus thornei* and *P. neglectus*) cost Australian growers in excess of \$250 million/annum. Control of this pest relies on an integrated management program that includes the use of tolerant or resistant varieties, crop rotation and good farm hygiene, but even then costs to production can be high. Enhancing the suppressiveness of soil to root-lesion nematodes is a control option that deserves some consideration. Disease suppression is defined as the ability of a soil to suppress disease incidence or severity even in the presence of the pathogen, host plant and favourable environmental conditions. The vast array of organisms in the soil can provide a degree of biological buffering against pathogens. Disease reduction results from the combined effects of many antagonists acting collectively and mediated through inputs of organic matter (general suppression) and direct antagonism by a limited number of organisms (specific suppression).

This project aimed to better understand the suppressive nature of grain-growing soils and provide growers with methods to enhance suppressiveness of their soils to root-lesion nematodes.

Over 4 years, a total of 24 different sites from northern NSW and southern Qld were sampled to test the suppressiveness of the soils. This included several farmer paddocks and 3 long-term farm management trial sites with several fertiliser or tillage treatments. Also, seven of the sites were comparisons of cropped and pasture or native/scrub remnant soils that were in close proximity to gain an understanding of the impact cropping may have on suppressiveness to root-lesion nematodes.

Repeated studies (2010 - 2014) of the different soils, through the use of glasshouse and laboratory bioassays, consistently showed general suppressiveness to root-lesion nematodes does exist in a variety of soils. We also found that a 10% addition of suppressive field soil to a sterilised soil (heated at 60°C for 45 mins) is sufficient to reduce RLN multiplication by 60-90%, showing that the suppressive effect was biological and could be transferred or added to a less suppressive soil.

Table 1. Final *Pratylenchus thornei* numbers in a glasshouse pot-based suppression assay for soil from three different sites (Numbers followed by the same letter within each site are not significantly different $P = 0.05$)

Site	Final <i>P. thornei</i> population (nematodes/g soil)		
	Sterilised soil	Unsterilised soil	Sterilised + 10% unsterilised
Hermitage Fallow Management trial, Warwick, Qld	86 a	12 b	12 b
Billa Billa, Qld (ex-wheat and remnant scrub soil)	71 a	18 b	24 b
Billa Billa, Qld (ex-sorghum soil)	89 a	21 b	25 b
Colonsay fertiliser trial, Norwin, Qld	66 a	24 b	53 a

We have also examined suppressiveness at different depths in the soil profile (since *Pratylenchus* nematode populations tend to be highest at depths of 30-60 cm). General suppression of plant parasitic nematodes is much greater in soil from 0-15cm than soil from 30-45cm. The figure below indicates that there are less plant parasitic nematodes at 0-15cm (coinciding with the higher levels of microbial populations) and that heating removes the microbial community and hence the suppressive effect.

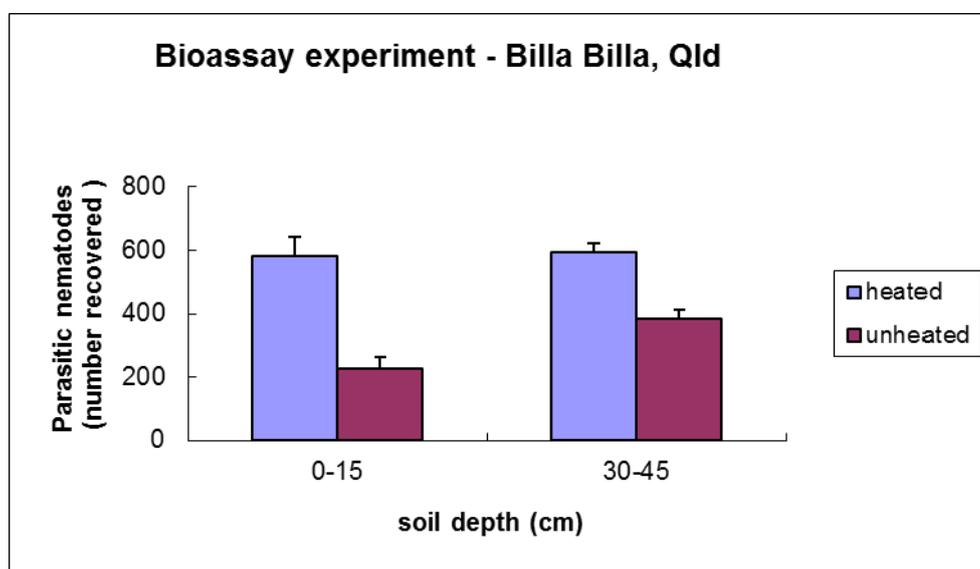


Figure 1. Results of one bioassay on a soil from a cropped (wheat/sorghum) paddock from Billa Billa showing that biological suppression of parasitic nematodes (difference between numbers recovered after adding nematodes to the heated and unheated soils) is greater in the 0-15cm layer of soil than in the 30-45 cm layer

Over 130 soils from the northern region were surveyed for the presence of organisms that may suppress RLN. A range of natural enemies were found, including *Pasteuria*, a bacterial parasite (found in 25% of soils), nematode-trapping fungi (in 42% of soils) and predatory nematodes (in 77% of soils).

Of the 25% of grain-growing soils where root lesion nematodes and *Pasteuria* spp. were present, only 6% of the RLN population were infected. This bacterium has the potential to infest and kill root-

lesion nematodes but populations appear too low to currently be having any great impact. More study is required to better understand the lifecycle and ecology of this highly specialised parasite as prior to this project, it had never been previously observed in Australia on *Pratylenchus thornei*.



Figure 2. Root-lesion nematode (*Pratylenchus thornei*) infested with parasitic bacteria (*Pasteuria* sp.) as indicated by the red arrows.

Four different species of nematode-trapping fungi were found in 26 different soils from the northern region using traditional isolation techniques. A method was also developed to detect these fungi using DNA extraction from soil (DAQ00164/ DAV00105 collaboration).

The addition of a fungal endophyte (*Fusarium nygamai*) previously isolated from wheat roots growing in a soil from a property near North Star, NSW reduced *P. thornei* multiplication by 40% in a pot assay. More studies are required to confirm these results and determine whether this fungus is a potentially useful biocontrol organism. Several other endophytic fungi were isolated from roots but are yet to be tested for suppressive activity. Overseas work has shown that the presence of endophytic strains of *Fusarium* in roots enhance the plant's capacity to defend itself from nematode attack.

Key farm practices that may enhance suppressiveness to root-lesion nematodes were examined. A field trial at Hermitage Research station, near Warwick, Qld, was specifically designed to study the impact of organic amendments (0, 5, 10 and 20 t organic matter/ha, incorporated into the top soil on application) and various cropping regimes (continuous fallow, sorghum with residue retained, sorghum with no residue retained) on RLN (*P. thornei*) multiplication in wheat grown after these treatments. In the first year, we found more beneficial nematodes and lower RLN numbers in surface soils, only in the highest organic matter treatment and where sorghum was grown and stubble was retained. Two and three years later, these earlier seen increases in suppression were not as evident and did not affect crop yield. However improved soil biology, especially in the surface soils, was still present when soil was cropped continuously compared to fallow. The trial showed that intensive cropping is more influential on RLN suppressiveness than addition of up to 20t/ha of organic matter. Soil chemical and physical differences measured did not appear to influence suppressiveness significantly and fertiliser (N, P) applications did not alter suppressiveness.

Implications

- Suppression does occur in most soils we tested from the northern grain-growing region showing that populations of *P. thornei* are being reduced due to biological activity. Suppression was

found to be greater in the top 10cm of soil than at deeper layers (e.g. 30-45 cm), and practices such as zero tillage with stubble retention enhanced suppression.

- Maintenance of a healthy topsoil through diverse organic matter inputs will preserve the suppressive potential of soils against RLN .
- Heavy rates of stubble (up to 20t/ha) increased general suppression of RLN in the short term. This coincided with high levels of microbial activity.
- The presence of a crop for longer periods of time and the associated input of root exudates may have provided a better environment for sustained microbial activity and hence suppression of RLN.
- Growers using no-till, stubble retention practices and cropping when soil moisture allows are probably doing a great deal toward enhancing the suppressiveness in their top soil. Without these practices, we estimate that RLN multiplication would be significantly greater especially in top soils and therefore lead to much greater losses in productivity of susceptible crops.

More work is required to confirm the biological control agents found to be present in our grain-growing soils can have a significant impact on RLN populations on a broad-scale.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support.

Contact details

Nikki Seymour
Department of Agriculture and Fisheries
Leslie Research Facility, Toowoomba
Ph: 07 46398837
Fx: 07 46398800
Email: Nikki.seymour@daf.qld.gov.au

Soil health, soil biology, soilborne diseases and sustainable agriculture

Graham Stirling

Key words

Soil organic carbon, disease suppression, soil food web, grain cropping, pasture.

Take home message

- Healthy soils contain a myriad of beneficial organisms that suppress soilborne pathogens through competition for habitat and food; production of antibiotics and toxins; or via predation or parasitism.
- Organic carbon is the single most important soil health indicator. Increases in soil organic carbon (particularly biologically-available forms) are intimately linked to the size, composition and activity of the soil microbial community; enhanced retention and cycling of nutrients; improved aggregate stability; and increased water-holding capacity.
- Key management practices to promote healthy soils are continuous inputs of organic matter; permanent plant residue cover; a diverse rotation sequence; minimum tillage; and avoidance of compaction through traffic control.
- Once good farming systems are in place, incremental improvements can be made through cover crops and legumes in the rotation; integration of crop and livestock production; organic amendments and mulches; improved nutrient-use efficiency; optimised water management; site-specific management of inputs and integrated pest management.
- Pastures can play an important role in improving soil health, reducing losses from soilborne diseases, and managing risk in Australia's broadacre cropping systems. There are many benefits to be gained by integrating crop and animal production, but the extent of the gains will be determined by the level of management inputs and the skill and passion of the land manager.
- While livestock may be detrimental to soil health, negative impacts can largely be overcome with best-practice management: Grazing must be carefully monitored to maintain soil cover (at least 50-70%); Rotational grazing can assist to more evenly distribute nutrient returns across a paddock and minimise soil compaction from grazing; Another option is to convert the herbage from pastures into hay or silage and use it to feed animals off-site.

Introduction

Our capacity to feed the world's ever-increasing human population is dependent on the thin layer of soil covering the earth's surface. It not only provides a physical support for plants but also filters water, detoxifies pollutants and provides a home for a huge range of beneficial organisms that decompose organic matter, supply nutrients to plants and compete with the fungal, bacterial and nematode pathogens that cause disease. However, this non-renewable resource is continually subject to water and wind erosion, is further degraded by compaction and tillage, is rendered unproductive by salinisation and desertification, and is easily ruined by mismanagement.

This paper explains the inextricable link between soil health and sustainable agriculture: agriculture can only survive in the long-term if soils are farmed in ways that not only repair historical damage but also improve their physical, chemical and biological properties. It argues that a soil cannot be considered healthy unless it contains an active and diverse soil biological community and then goes on to provide a list of the management practices that can be used to improve a soil's biological status. These and many other topics are covered in much greater detail in a new publication, 'Soil

health, soil biology, soilborne diseases and sustainable agriculture. A guide', details for which can be found at the end of the paper.

Organisms in the soil food web and their function

A teaspoon of a fertile agricultural soil will contain tens of millions of bacterial cells, more than 10 km of fungal hyphae, thousands of protozoa, hundreds of nematodes and numerous insects, mites and small animals. Some of these organisms will damage the roots of plants but the main role of the soil biological community is to provide the following ecosystem services:

- improve the soil's structural characteristics
- fix nitrogen from the atmosphere
- help plant roots take up water and nutrients
- minimise losses of nutrients to the environment
- mineralise nutrients from organic matter
- degrade pollutants, pesticides and other contaminants
- produce compounds that promote plant growth
- protect plants from attack by pests and pathogens

Unfortunately, some of the organisms that provide these services have disappeared from our agricultural soils. Thus, many soils now retain water and nutrients less efficiently and are affected by structural problems such as hard setting and surface sealing. Also, pests and pathogens rather than beneficial organisms tend to dominate the soil biological community, and this means that crops often fail to reach their yield potential.

The key role of carbon in maintaining soil health and sustaining the soil biological community

One of the main reasons growers face root disease and soil health problems is that the amount of organic matter in their soil has declined to unacceptable levels. Since the carbon in soil organic matter stabilises soil structure, promotes aggregation of mineral particles, increases water infiltration rates, improves water holding capacity, stores and releases nutrients and contributes to cation exchange, it has a huge impact on soil properties. It is also important from a biological perspective, as it nourishes the organisms that cycle nutrients and compete with pests and pathogens.

In agriculture, organic carbon is obtained from four sources:

- 1) crop residues that accumulate on the soil surface;
- 2) root exudates and the decomposing remains of old roots;
- 3) manure from grazing animals and
- 4) amendments such as compost that are imported from elsewhere.

Although organic inputs to soil should ideally come from a range of sources, the above sources all play a vital role, individually and collectively, in sustaining the soil food web. Bacteria and fungi multiply rapidly when a new food source becomes available and they commence the decomposition process. A myriad of litter transformers and ecosystem engineers (arthropods, earthworms and enchytraeids) then break up this material and incorporate it into soil, increasing the rate of decomposition. Provided carbon inputs are regular and the decomposition process is allowed to proceed unhindered, the end result is higher soil carbon levels and an active and diverse biological community capable of providing a huge range of benefits (see the figure below).

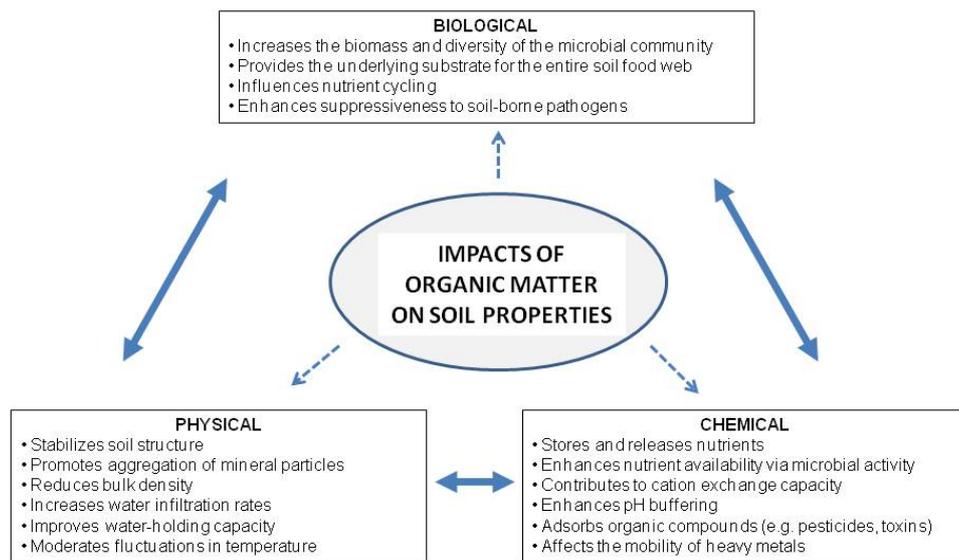


Figure 1. Impacts of soil organic matter on soil properties

Impact of natural enemies on soilborne pathogens

The fungi, bacteria and nematodes that cause soilborne diseases do not exist in isolation. They live in a complex and dynamic environment and are associated with an enormous number of other organisms that interact with them in many different ways.

- **Competition.** This is a universal phenomenon within the soil food web, as a huge range of microbes and small animals are continually competing for habitable space, or for food sources. When a competing soil organism accesses a resource before it can be acquired by a pathogen (e.g. it utilises root exudates that may be required to stimulate spore germination or enhance the infection process), it diminishes the capacity of the pathogen to cause disease.
- **Antibiosis.** Many soil bacteria and fungi produce soluble or volatile antibiotics that kill, inhibit or repel other organisms. These antibiotics may act against plant pathogens, with one of the best-studied examples being suppression of the take-all pathogen of cereals by a group of antibiotic-producing bacteria known as the fluorescent pseudomonads.
- **Toxin production and lysis.** Some soil organisms produce toxins that immobilise or kill neighbouring organisms, while others produce enzymes that digest the cell wall or cuticle of their prey. Both these mechanisms are thought to contribute to the biological control of soilborne fungal pathogens.
- **Predation.** This occurs when one organism (the prey) is killed by another, often larger, organism (the predator). Protozoans, nematodes and microarthropods all have the capacity to consume other soil organisms. Some predators feed indiscriminately on a wide range of organisms while others have quite specific food preferences.
- **Parasitism.** Parasites are highly adapted species that live in or on another organism (the host) and obtain all or part of their nutritional resources from that host. Bacteria and viruses

are known to parasitize protozoans and nematodes, but fungi are probably the most important parasitic organisms in soil. Numerous fungal parasites of arthropods and nematodes are known, and mycoparasitism (parasitism of one fungus by another) is also relatively common.

In a healthy soil, all the above mechanisms will be operating, and this means that the soil has some capacity to suppress the pathogens that cause disease. The most common form of disease suppression (usually referred to as '**general**', '**non-specific**' or '**organic matter-mediated**' suppression) is most likely to be observed in soils with high levels of organic matter. Numerous organisms are involved, and they act collectively through the mechanisms listed above.

A second form of disease suppression (usually known as '**specific**' suppression) results from the activities of a limited number of relatively specific antagonists, and typically develops in situations where pest populations have remained high for some time. Parasites that are adapted to using the pest as a food source take advantage of the situation and multiply rapidly, causing high levels of mortality.

Enhancing suppression of soilborne diseases in grain crops

Rhizoctonia is an important pathogen of Australian cereal crops, but on-farm observations in South Australia over the last 30 years have shown that when the soil is managed appropriately, naturally-occurring antagonists will keep it under control. Although the organisms responsible for suppressing the disease have not been identified, recent studies using DNA-based techniques have shown that the bacterial and fungal communities in disease-suppressive and non-suppressive soils are quite different. A range of bacterial taxa and several groups of fungi known to exhibit antifungal activity are found in higher frequencies in suppressive soils. What is clear from this work is that disease suppression is not due to a single microbial group. It almost certainly involves many different biocontrol microbes and it is likely that they interact synergistically to suppress the pathogen.

Field and glasshouse trials have shown that soils become suppressive to *Rhizoctonia* root rot when practices such as cultivation and stubble burning are removed from the farming system and replaced with full stubble retention, limited grazing, more frequent cropping, limited or no cultivation and nutrient inputs that are sufficient to meet crop demand. Thus, a combination of practices that increase inputs of biologically available carbon are required to enhance levels of disease suppression.

Another example of general disease suppression occurs in the northern grain-growing region, this time against root lesion nematode (*Pratylenchus thornei*), a widely distributed pest. Nematode population densities are particularly high at depths below about 25 cm but are usually much lower in surface soils, partly because organic carbon levels in this zone are high enough to support a diverse range of natural enemies, including nematode trapping fungi and predatory nematodes. The challenge of the future is to increase soil carbon levels down the soil profile, thereby enhancing predatory activity at depth.

The best known Australian example of specific disease suppression is the natural control of root-knot nematode (*Meloidogyne* spp.) on grapevines by a bacterial parasite (*Pasteuria penetrans*). A closely related species of this bacterium has been found on root-lesion nematodes in the northern grain-growing region. Although levels of parasitism are relatively low at present, the proportion of parasitised nematodes is expected to increase with time, provided the host-parasite relationship is not disturbed by tillage. However, continuing research is required to determine whether *Pasteuria* will eventually provide some control of this important pest.

Improving soil health in grain farming systems

If an agricultural soil is to provide a full range of ecosystem services, the following crop and soil management practices must be integrated into the farming system. Benefits will be limited if only some of these practices are adopted.

- Continuous inputs of organic matter
- Permanent plant residue cover
- A diverse rotation sequence
- Minimum tillage
- Avoidance of compaction through traffic control

Once the above practices are integrated into a farming system, incremental improvements can then be made by focusing on the following:

- Biomass-producing cover crops
- Inclusion of legumes in the rotation
- Integration of crop and livestock production
- Organic amendments and mulches
- Improved nutrient-use efficiency
- Optimised water management
- Site-specific management of inputs
- Integrated pest management

Although the practices listed above provide farmers with a range of management options, the actual practices that can be integrated into a farming system will be influenced by climatic factors, production goals and the economic realities of farming. Thus, it is impossible to be prescriptive about best-practice farming systems to improve soil health. Many potentially useful technologies and practices are available, and it is up to the land manager to adapt them to local conditions and constraints.

Pastures as a tool to improve soil health in grain cropping systems

One of the most effective ways of increasing levels of soil organic matter and improving the health of soils used for cropping is to integrate a pasture phase into the farming system. Carbon inputs into the soil will increase under pasture, as perennial plants have a higher root to shoot biomass ratio than annual crops, and grow for a longer proportion of the year. Because pasture soils are not regularly disturbed by tillage implements, this carbon tends to remain in the soil rather than being lost to the atmosphere as CO₂.

Although research has shown that pastures increase soil microbial biomass and enhance biodiversity, it is important to recognise that the livestock which graze them may impact negatively on soil health. Their most important effects are listed below.

- **Soil structural degradation.** Trampling by sheep and cattle can impact negatively on soil structure. However, compaction effects are mainly limited to the upper 15 cm of soil and tend to be concentrated in animal traffic areas such as gateways, camps, and around troughs. Recent research indicates that crops which follow a well-managed pasture are usually not markedly affected by the shallow surface compaction caused by livestock.

- **Ground cover and soil erosion.** Livestock contribute to soil erosion by removing ground cover and loosening the soil surface, so stocking rates need to be carefully managed.
- **Drying of the soil profile.** In rain-limited environments, pasture will utilise stored soil water that could otherwise be used by the following crop.
- **Spatial relocation of nutrients.** Grazing animals excrete most of the nutrients ingested from pasture, but in the absence of appropriate management, they tend to be concentrated in stock camps and/or lost from urine patches.
- **Redistribution of weed seeds.** Livestock spread weed seeds when they graze, and bury them by trampling.

The conclusion that can be drawn from the points made above is that livestock may be detrimental to soil health, but their negative impacts can largely be overcome with best-practice management. Grazing must be carefully monitored so that a minimum level of soil cover (at least 50-70%) is always maintained, while practices such as rotational grazing can be used to more evenly distribute nutrient returns across a paddock, and to minimise the soil compaction effects of grazing animals. Another option is to convert the herbage from pastures into hay or silage and use it to feed animals off-site.

The take-home message is that pastures can play an important role in improving soil health, reducing losses from soilborne diseases, and managing risk in Australia's broadacre cropping systems. There are many benefits to be gained by integrating crop and animal production, but the extent of the gains will be determined by the level of management inputs and the skill and passion of the land manager.

Further reading and information:

A new book targeted to growers and advisers explains how to build an active and diverse soil biological community capable of improving soil structure, enhancing plant nutrient uptake and reducing losses from soilborne diseases. Written by soil biologists with experience in a wide range of farming systems, the book cited below provides an overview of the management practices that can be used to restore the health of agricultural soils, enhance plant resilience to stress and improve profitability and sustainability.

Stirling GR, Hayden, HL, Pattison AB, Stirling AM (2016) Soil health, soil biology, soilborne diseases and sustainable agriculture. A guide. CSIRO Publishing, Melbourne. 280 pp. ISBN 9781486303045

Contact details

Dr Graham Stirling
 Biological Crop Protection Pty. Ltd.
 3601 Moggill Road, Moggill, QLD, 4070
 Ph: 07 3202 7419
 Mb: 0412 083 489
 Email: graham.stirling@biolcrop.com.au

Tactical agronomy of safflower and linseed: place in the rotation, yield potential, time of sowing, plant growth and marketing

Kathi Hertel, NSW DPI

Key words

safflower, linseed, biodiesel, oleic acid, genetically modified

GRDC code

DAN00197

Take home message

- Safflower and linseed are winter oilseed crops best suited to be grown in rotation with cereal crops. Agronomic attributes include roles in integrated disease, weed and pest management programs.
- Limited market development of linseed and safflower restricts their current contribution to farming systems.
- The development of safflower crop technology for the biodiesel industry presents the potential of a significant addition to crop options in northern farming systems.
- Safflower is heat and drought resistant, adaptable to arid and semi-arid climates as well as irrigation.
- Linseed is best suited to medium to high rainfall environments in the NGR.
- Linseed can play a key role in managing of root lesion nematodes. It is resistant to *Pratylenchus thornei* and *P neglectus*.

Introduction

Safflower and linseed are winter-spring growing oilseed crops offering key benefits to diverse summer and winter crop systems as well as components of mixed production systems.

As oilseed crops, benefits include improved productivity of subsequent crops, lifting farm income, reducing the impact of disease and weeds; and producing edible and industrial quality oil and meal. Their integration offers the opportunity to enhance overall environmental, production and economic sustainability.

These crops are grown largely for the food industry in Australia. Safflower has received focused attention as an industrial oilseed and potentially represents a significant new crop industry for the Northern Grains Region (NGR). Research to establish baseline data to develop agronomic management is crucial for future industry development of safflower and linseed.

Safflower

Safflower comprises cultivars that are of two oil types, high in linoleic or oleic fatty acids. Safflower historically has remained a secondary crop. Linoleic cultivars were principally marketed as a component of feed mixes for birds and small animals; and oleic cultivars used in manufacturing industries producing paints, resins, pharmaceuticals and cosmetics.

Areas sown to safflower vary widely, ranging between 6100 and 45 000 ha in the decade from 2003 (FAO 2015). Reasons for this include few available cultivars, susceptibility to alternaria (*Alternaria carthami*) and phytophthora (*Phytophthora cryptogea*), limited agronomic research, disappointing farmer experiences and adverse seasons. A history of inconsistent prices and market opportunities because of competition from both alternative oilseed crops and the continuing development of petroleum substitutes have further hampered adoption.

Commencing in June 2004, a strategic partnership by CSIRO and GRDC established the Crop Biofactories Initiative (CBI), a 12 year program to examine the potential of plants to make alternative compounds for specific industrial uses, including biofuels, bioplastics and biolubricants derived from high oleic oils.

CBI scientists developed a GM process to produce super high oleic oil (SHO) safflower. Conventional oleic genotypes currently comprise approximately oleic acid levels of 75% of total oil content. SHO lines contain up to 95% oleic acid. In 2015, CSIRO issued a licence to GO Resources to commercialise GM safflower technology.

Rotation fit

Rotation benefits include:

- Late winter crop option if there is a late break or failed establishment of the winter crop
- Potential to double crop out of sorghum
- Heat and drought tolerant oilseed crop suited to lower rainfall areas where canola and sunflower are not adapted.
- Broadleaf crop option – break crop for cereal diseases including Crown rot (*Fusarium pseudograminearum*), Common root rot (*Bipolaris sorokiniana*), Yellow leaf spot (*Pyrenophora tritici-repentis*) and Spot form of net blotch (*Pyrenophora teres f maculata*).
- Resistant to both *P thornei* and *P neglectus* root lesion nematodes.
- Safflower is regarded as a good host to arbuscular mycorrhizae fungi (AMF), promoting the increase of AMF in the soil.
- Safflower is subjected to a different weed spectrum to most other crops. It offers the opportunity to control late germinating weeds and/or herbicide resistant winter weeds and to incorporate additional IWM strategies.
- Greater crop enterprise diversity to spread economic and production risk.
- Used in a soil ameliorant role to improve soil structure. Used strategically as a first crop in the rotation after cotton to break up subsoil to remove compacted layers, improve aeration and water infiltration; and root development to subsequent crops (anecdotal reports of rooting depths of 2.2 m)

Other advantages include:

- Alternative crop suited to both dryland and irrigation.
- Low input, low maintenance and easy to grow.
- Crop inputs and machinery requirements similar to wheat production.
- Sowing and harvest windows effectively spread peak workloads and machinery use over a longer period, increasing efficiencies and harvest timeliness of different crops.

- Widely adapted to various soil types, but best suited soils with high water holding capacities.
- Safflower is a competitive crop against weeds after the mid to late spring period.
- With deep roots, and providing sufficient water is available, safflower is tolerant of hot summer conditions during crop maturation.
- Utilises soil water deep in the soil profile. Lowers the water table with dissolved salts, reduces water logging in following crops and improves N efficiency by utilising leached N at depth.
- Increasing climate variability presents opportunities for safflower as an oilseed as it can grow on less rainfall than other major oilseed crops such as canola, sunflower and soybeans. Potential to be grown across a wide geographic area.

Sowing time

- Main sowing window is June to August.
- Flowering can commence in 85 – 140 days ie at the end of October and during November (depending on genotype, sowing date and environment).

Harvest

- Safflower matures in 110 – 170 days. Harvest period in northern NSW is normally from mid-December through to the end of January, varying with location, seasonal conditions and sowing date.
- The rate of dry down of seeds and stems can vary. Harvest delays can occur when drying down to 8% moisture content in the seed (delivery standard) where stems have not dried down sufficiently. Stem dry down can be slowed when periods of rain and high humidity occur and when low crop populations produce plants with thick stems.
- Where food and birdseed markets demand clean bright white seed, timely harvest is imperative.

Yield potential

- In most seasons, average dryland yields are 1 – 1.2 t/ha.
- Anecdotally, the highest known commercial yield is reported to be 3.3 t/ha under irrigation in northern NSW.

Marketing safflower

Safflower is currently mainly grown as an oilseed crop comprising two main oil types:

Linoleic acid is a polyunsaturated (omega-6) fatty acid. The most widely grown linoleic oil cultivar is Sironaria, released by CSIRO in 1987. Linoleic genotypes contain >75% linoleic acid. Linoleic cultivars are grown for seed and oil.

Seed

Safflower seed is used in birdseed and small animal feed mixes. Visual seed appearance is an important market criterion, preference given to a bright white appearance. Sironaria is the preferred variety. Other varieties like S317 (an oleic oil variety) are not desirable for this market because of inherent varietal characteristics like a creamy coloured seed coat and grey stripe on the seed.

Large price variations between seasons are common due to the speculative nature of production. The small market for birdseed and small animal feed mixes is easily over supplied.

Linoleic oil

Linoleic oil is an edible oil, used in products such as salad oils and soft margarines. It is also used in the manufacture of pharmaceuticals, cosmetics and paint in some other countries.

Similarly, overseas in the USA as an example, a by-product after oil extraction is the high fibre meal. The fibre is important in stock with low fibre diets eg- feedlots and dairy. The meal containing around 24% protein is used as a livestock protein supplement. Meal from de-hulled seed has about 40% protein with reduced fibre content.

Oleic acid is a monounsaturated fatty acid. Oleic varieties include S317 and S517 which are grown their oil, for use the food industry for frying and in the manufacture of pharmaceuticals, cosmetics, soap, paint additives, adhesive and sealant compounds, plastics and lubricants.

Current oleic safflower production, comprising principally S317, targets the food industry, supplying manufacturers, wholesalers and food service operators. Export in the form of oil or as seed varies with the costs of crushing and oil extraction. Recent increases in crushing costs from \$150 / t to \$300 /t mean that seed imports have replaced oil imports (Bill Slattery, *pers comm*).

Presently, India is the main market for oleic safflower oil for the food industry, looking to import around 30 000 t seed. Australia currently falls well short to meet this, struggling to supply 4000 t seed.

Safflower is grown under contract on a per hectare basis. Prices paid for oleic safflower in 2014 were \$490 /t and in 2015 - \$520 /t. Prices are quoted ex-farm, ex-GST. Contracts are written to Australian Oilseed Federation (AOF) Standards. Payments are based on the percentage of oil in the seed and test weight at 8% moisture and 4% impurities. The baseline oil content is 38% with applied 2% discounts and premiums. In 2014, all deliveries exceeded 38% oil.

Potential industry growth

The unique properties of oleic acid also make it of potential use in biodiesel production. GRDC reports that market analysis indicates global demand for high-purity oleic acid oil could require more than 100 000 ha of the new safflower varieties. As an indication of potential, the size of the Australian cotton industry is estimated to be 270 000 ha in 2015/16 by Cotton Australia.

“Cotton soils” could be classified as “safflower soils”. Depending on water availability with seasonal conditions, pricing comparisons of crop choice and water costs, and field rotations, some level of substitution may be a potential viable option for some growers.

The NGR’s is characterised by a variable climate where agriculture comprises diverse cropping systems. Predominantly comprising soils with high water holding capacity, it is an environment that suits safflower with its heat and drought tolerance. Oleic oil synthesis within the seed is favoured by warmer finishing conditions, promoting high oleic content.

The existing expertise with modern agricultural technology, including GM crop production, and the region’s pre-existing oil crushing facilities, combine to offer opportunities for the development of an industrial safflower oil enterprise in farming systems.

Economics will determine industry growth with competition from profitable crop options.

Issues / problems that may be encountered when growing safflower

Genetically modified (GM) crop

The incorporation of GM safflower cultivars into a farming system may involve guidelines and strategies under a Stewardship program to ensure appropriate on-farm crop management and throughout the grain supply-chain.

Soil water use characteristics

Safflower uses more water than other winter crops, attributed to its deeper rooting depth and longer growing season. The deep rooting habit dries the soil profile. This has implications for subsequent crops, limiting crop potential where soil water reserves are not replenished by sufficient rainfall in dryland situations. When conditions remain dry, planned crop sequences may be disrupted.

Adequate stored soil moisture at sowing is crucial. Safflower production is a greater risk crop in low rainfall areas when there is low stored soil water at sowing. Limited starting soil moisture and lack of timely in-crop rainfall will produce poor or variable safflower yields.

CSIRO research conducted in the late 1980's at Dalby – Queensland, compared soil water use in safflower, wheat and chickpeas. Sown 2 June, safflower extracted 375 mm, compared with wheat - 212 mm and chickpea - 195 mm (Beech & Leach 1989). This equated to WUE of safflower 2.6 kg /ha/ mm, wheat 6.8 kg / ha/ mm and chickpea 4.9 kg / ha/ mm.

More recently, GRDC funded research conducted in western Victoria in 2000 and 2001 (Waschmann et al 2003) reported safflower used 100 mm of additional water compared to wheat in wetter seasons. Whilst all crop species measured similar daily water use, safflower's longer growing season (34 – 40 days more than wheat) meant it used additional soil water. To achieve similar yields to canola, safflower used an additional 120 mm. Safflower yielded 3.71 t/ha and canola 3.44 t/ha.

Disease

Seasonal conditions largely determine the incidence and severity of disease in safflower. Management includes preventative strategies and variety resistance. The main issues of concern in the NGR are alternaria and Phytophthora.

Alternaria leaf spot (*Alternaria carthami*) when present at high infection levels can result in significant yield loss of up to 50%. Oil (and protein) content can be reduced. Safflower is resistant.

Phytophthora root rot (*P. cryptogea*) (and *Pythium* root rot). Safflower is resistant to phytophthora.

Rust (*Puccinia carthami*) may cause significant yield loss where infection occurs early in the season. Inoculum survives in crop residues and alternative host *Carthamus* species like safflower. **Disease carryover** – Safflower is a potential host to sclerotinia (*Sclerotinia sclerotiorum*). Other alternate host crops include sunflower, mustard, canola and chickpea.

Pests

Wireworms and false wireworms are intermittent pests.

Heliothis need to be monitored at budding and during flowering. Definitive thresholds are required.

Thrips at budding and flowering can cause significant yield losses. Well grown safflower is reported to be quite tolerant of damage. Regional research to define damage levels, pest thresholds yield losses are required.

Bird damage

Safflower offers an attractive alternative food source to birds. Some degree of crop loss can be expected. The timing of crop maturity places safflower after the winter crop harvest period and just prior to sunflower seed fill.

Weed management

Safflower is subjected to a different weed spectrum to most other crops. Its sowing window offers the opportunity to control late germinating weeds and/or herbicide resistant winter weeds and to incorporate additional IWM strategies.

Options may include cultivation, changing timing and application; and herbicide MOA eg- bipyridyl herbicides (Group L) such as paraquat. Safflower is a competitive crop against weeds after the mid to late spring period.

In cotton production systems, inter-row cultivation and shielded sprayers can be a key tactical option in weed management in safflower.

Herbicides and weed management

Herbicide registrations

There are few registered herbicides for use on safflower. Registrations for pre-emergent weeds in Sironaria safflower are trifluralin (TriflurX®), pendimethalin (Stomp®) and tri-allate (Avadex® Xtra). These herbicides control a narrow range of weeds species. Post-emergent registrations are limited to Group A's such as diclofop-methyl (Rhino®) and propaquizafop (Shogun®). Their effectiveness is dependent on the resistance profile of the post-emergent options.

Broadleaf weed control is limited to metsulfuron-methyl (Ally®) and crop competition.

Weed control prior to planting is necessary. Safflower is planted in the cooler months and so subsequent growth is slow, making the crop vulnerable to competition from weeds. As the crop canopy rapidly increases in spring, crop competition increases.

Variety sensitivity

Pre-1998 and in 2008 Devexco conducted herbicide tolerance testing with metsulfuron-methyl, pendimethalin and trifluralin. It was reported that there was a narrow safety margin with pendimethalin on S317.

Diclofop-methyl and tri-allate appear safe on Sirothora and Sironaria cultivars.

There has been some limited work conducted on some high oleic genotypes with metsulfuron-methyl (Ally®) using rates up to 7.5 g /ha ai applied at the 4 – 6 leaf stage. Results showed no significant effect on yield, seed size or oil quality.

In 2014, further crop safety work was conducted on Sironaria with metsulfuron-methyl as well as other potential post emergent broadleaf herbicides at 2 – 4 leaf and 4 – 6 leaf growth stages. Results are pending, but significant crop damage was measured with some herbicides.

Paddock selection

Knowledge of the weed density and spectrum of individual paddocks is essential. Similar to other broadleaf winter crops, avoid situations where there are high populations of broadleaf weeds present.

Safflower's seasonal time of year and matching growth pattern is different to other crops. The stem elongation growth stage begins in the late spring period. Rapid canopy development increases the crop's competitive ability, creating greater stress on small weeds. At the same time, the expanding crop canopy can inhibit weed target herbicide coverage. Safflower crops sown mid-June and July commence flowering in late October to early November, preventing herbicide and mechanical control options.

This timing of safflower growth and development has implications for management of specific weed species in the northern grains region.

Black bindweed (*Fallopia convolvulus*) emerges mid-winter to mid-spring.. There are confirmed reports of herbicide resistance to metsulfuron-methyl, so reliance of pre-emergent herbicide strategies is important.

Species like fleabane (*Conyza bonariensis*) germinate throughout the year; however wet springs stimulate maximum germination. Similarly common sowthistle (*Sonchus oleraceus*) germinates year round, with emergence determined largely by rainfall events.

Summer active weeds like awnless barnyard grass (*Echinochloa colona*) and barnyard grass (*Echinochloa crus-galli*) can be potential problems, particularly where wider crop spacing reduces crop competition. Barnyard grass germinates throughout late spring and during summer. In contrast, liverseed grass mostly germinates in a single flush in late spring. As you move further north, the spectrum changes to be dominated by feather-top Rhodes (*Chloris virgata*), particularly on lighter textured soils.

Plant-back periods

Metsulfuron-methyl is registered for early post-emergent weed control in safflower. Its use in safflower has implications for some subsequent crops. The re-plant interval is 14 months before sorghum, maize or millet can be planted. This would prevent a possible double-crop sequence if soil water availability was suitable. Planting a successive broadleaf crop is not recommended.

Conclusions

The suitability of safflower to the NGR environment combined with industrial crop technology creates a potential new industry - the ability to produce renewable high purity oleic acid oil suited to a range of compounds that can replace non-renewable petroleum-based industrial chemicals. However, further agronomic research and development is required.

More safflower cultivars are needed to increase adaptation and marketability. The release of quicker maturing cultivars may increase the reliability and yield through improved harvest index (HI) and WUE. Disease resistance to Alternaria and Phytophthora would be important desirable features.

Better understanding of plant growth and development of safflower coupled with water use patterns are needed to develop and adapt agronomic recommendations like sowing time, crop population and row spacing to environments across the NGR and interactions with crop yield and oil quality.

As part of a rotation, safflower's long growing season and high water requirement will impact on subsequent crop choices and performance. The economics of safflower need to offer at least similar benefits and profitability to growers as alternate crop choices. The development of stable market opportunities is integral to future industry development. Wider weed and pest control options and registrations are needed.

Linseed

Linseed is a winter growing oilseed crop grown for its seed and oil. Linseed contains alpha-linolenic acid, polyunsaturated oil. Alpha-linolenic acid is classed as an omega-3 fatty acid, considered to be an essential fatty acid in human health diet.

End uses have changed in recent decades as advances in technology have resulted in synthetic substitutes where linseed oil was used. Greater focus on human health and natural products has resulted in most of the Australian linseed crop grown for seed, and a lesser extent oil, in the food industry.

Linseed contains 35 – 40% oil, with alpha-linolenic acid levels of between 45 and 60%. Linoleic (omega-6) fatty acid levels, desirable for its human health attributes, are generally between 17 and 22%.

Rotation fit

- Linseed is a winter oilseed crop alternative.
- Linseed grown after cereal crops is effective in reducing soil borne root diseases including Crown rot (*Fusarium pseudograminearum*) Common root rot (*Bipolaris sorokiniana*), Yellow leaf spot (*Pyrenophora tritici-repentis*) and Spot form of net blotch (*Pyrenophora teres* f *maculata*).
- Linseed is resistant to both main species of root lesion nematodes – *Pratylenchus thornei* and *P neglectus*.
- Linseed has a high arbuscular mycorrhizae fungi (AMF) host dependency, promoting the increase of AMF in the soil.
- As well as grass selective herbicides, a number of broadleaf herbicide options are registered, covering a wide spectrum of broadleaf weed species and including Group C and Group I herbicides.

Sowing time

Linseed is generally planted in mid-May to mid-June in northern NSW.

Soils

Linseed is adaptable to soils ranging from vertosols to loam-textured soils. Linseed will grow on acid soils where pH_(Ca) levels are as low as 4.5, if exchangeable aluminium levels are also low. Linseed performs best on well-structured heavier-textured soils. It is not suited to sandy soils. Linseed is classified as having a low to moderate tolerance to salinity.

Varieties

There is presently no active breeding program in Australia since the closure of the CSIRO breeding program several decades ago.

Glenelg is an early to midseason maturing variety that was released in 1970. A white-flowered public variety, it is the most widely grown variety in northern NSW, accounting for more than 95% of the crop area.

Croxtan is a long season public variety. Blue-flowered, Croxtan has been grown since 1985 in mostly southern Australia, but with small production areas in the cooler higher rainfall slopes area east of Moree.

LM14 and **LM17** are two cultivars licenced to Austgrains Pty Ltd at Moree. Both blue flowering types, their maturity lies between Glenelg and Croxtan.

Row spacing

Linseed is generally grown on row spacing varying between 18 cm (7") and 38 cm (15").

Plant growth

Linseed has a very small seed. Seed placement, particularly depth and soil contact with moist soil is critical for even crop emergence. Early plant growth is slow during cooler seasonal temperatures after planting. After emergence, a single main stem elongates. This is usually followed by the growth of one or two pairs of basal branches that extend almost to the height of the main stem.

A seed head consisting of clusters of buds forms. Each flower bud opens, eventually forming a capsule (boll) potentially producing up to 10 seeds.

Linseed is an indeterminate crop. Flowering can continue for several weeks extended period until seasonal conditions and /or plant resources cause flowering to cease. Seeds ripen within the capsules, crop senescence indicated by yellowing, then browning of leaves, stems and capsules. Mature seeds rattle within the capsule.

Yield potential

Linseed is suited to the higher rainfall areas of the NGR, with best performing crops generally grown east of the Newell Highway. Linseed does not tolerate periods moisture or temperature stress during the flowering period. Spring rainfall patterns have a large influence on crop yields. Reported average yields range between 1.0 and 1.5 t/ha.

Pests

Heliothis is the most significant pest in linseed in the NGR. One, sometimes two pesticide applications are required. Heliothis can damage the crop before budding, but are most prevalent during budding-flowering.

Disease

Few diseases have been reported to be of concern in linseed in the NGR. The relatively small production area and annual variations of the crop contribute to low inoculum levels and long paddock rotations between crops. Potential disease issues of linseed include:

Fusarium wilt (*Fusarium lini*) has been reported to a major disease in southern Australia, but with few recent reports in northern NSW. Glenelg is very susceptible to fusarium wilt, the main reason why it is no longer grown in southern Australia. It has been replaced by Croxton, the only resistant variety. The reaction of LM14 and LM17 are not known.

Pasmo (*Mycosphaerella linorum*) Pasmo is a fungal disease that may cause yield and seed quality. The last known reports of Pasmo in NSW linseed were in the 1970's and 1980's during moist conditions in spring. It has not been considered to be a major disease risk in linseed production. Neither Glenelg or Croxton are resistant to Pasmo. The status of LM14 and LM17 is unknown.

Marketing

The market for linseed is small, anecdotally between 12 000 and 20 000 t per annum for the domestic human consumption market. The limited market demand and sometime plentiful supply cause large variations in prices season-to-season.

Most of the northern Australian linseed crop is grown under contract on a per hectare basis. The licenced cultivars LM14 and LM17 are grown under contract for delivery to Austgrains Pty Ltd at Moree.

Payment is based on 7.5% moisture receival standards.

Linseed permits

Permit ID	Description	Expiry date
PER81763	Indoxacarb / Linseed / Helicoverpa spp.	31-Aug-16
PER81877	Steward / Linseed / Flax / Heliothis	31-Dec-16

(Source: APVMA)

References

Beech GJ & Leach DF (1989) Comparative growth, water use of chickpea, safflower and wheat in south-eastern Queensland. *Australian Journal of Experimental Agriculture* 29 (5) 655-662

Waschmann N, Norton R, Jochinke D & Knight S (2003) Proceedings of the 11th Australian Agronomy Conference, Geelong, Victoria (Australian Society of Agronomy).

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Trial co-operators gratefully acknowledged: Jack Goodrum “Myling” Tullloona, Alan Riordan “Nullabeen” Nea (via Breeza) and IA Watson Plant Breeding Institute – Sydney University – Narrabri

Technical support: Stephen Beale, Joe Morphew, Mitch Whitten, Tim Grant, Rosie Holcombe, Stacey Cunningham, David Cain, Stephen Morphett, Pete Formann and Jim Perfrement – all NSW DPI

Valued comments: Jim Simpson – Austgrains (Moree) and Bill Slattery – Fabi Foods Pty Ltd, Tony Cook - NSW DPI

Contact details

Kathi Hertel (R&D Agronomist)

NSW DPI

Locked Bag 1000, NARRABRI NSW 2390

Mb: 0427 104 344

Email: kathi.hertel@dpi.nsw.gov.au

Faba bean agronomy – ideal row spacing and time of sowing

Rebecca Raymond³, Kerry McKenzie¹, RCN Rachaputi²

¹ Department of Agriculture and Fisheries, Tor St Toowoomba

² QAFFI, Kingaroy

³ Department of Agriculture and Fisheries, Goondiwindi

Key words

faba bean agronomy, row spacing, plant population, time of planting, sowing,

GRDC code

UQ00067

Take home message

Changes in agronomy can affect yield of pulses.

In general increasing row spacing may decrease yield in faba bean varieties

A linear reduction in yield of faba beans can occur if sowed after late April however increase in harvest index was found

Background and aims

Despite the potential environmental and economic benefits, the adoption of winter pulse crops in the Queensland Grains Region is around 20% of total cropping area. To increase the share of pulses in the total cropping area, strategies are required to enable growers to more consistently realise the potential productivity and profitability of pulse cultivars in their farming systems.

Winter pulses (chickpea and fababean) currently comprise approximately 20% of total cropped area in the Queensland Grains Region although the adoption varies depending on the growing region and of course price, this has risen from around 8% since the start of the project. Chickpea (*Cicer arietinum*) is the most adapted winter pulse crop in the Queensland with the area expanding to historically high levels in 2010. Seasonal yields of chickpea ranged from 0.5t/ha to 2t/ha depending on the timing and severity of biotic and abiotic stresses during the growing season. Although yields as high as 2.5t/ha have been achieved in varietal evaluation trials, the average yield during the 2008 – 2011 was approximately 1.2t/ha in the focus regions included in this project (Source: ABS statistics), suggesting a significant potential to increase productivity. However, pulse agronomy trials in SQ have consistently demonstrated an increase in harvestable yield by 20- 60% depending on the seasonal conditions, through reducing row spacing. A modest 10% increase in yield would result in a \$20 to \$25 increase in gross margin (based on a \$200/ha gross margin). Over a winter pulse area of 125,000 ha, the increase in crop production would be valued at \$2.5 to \$3 million per annum.

Fababean (*Vicia faba*) is gaining popularity in the northern grains region thanks to higher prices in recent seasons and improved varieties. Although southern regions dominate the production for Australia; Northern NSW and Southern Qld are looking more favourably upon faba bean as part of their rotation as a break crop for disease and for its nitrogen fixing ability. Yield of faba beans ranges from 2-4t/ha however the pulse agronomy trials have shown a potential of up to 5.5t/ha.

Although the area sown to winter pulses in Queensland has increased over the last three years, there have been many challenges for growers with erratic seasonal conditions and a range of disease pressures on yield and quality. Growers' attitude to pulse crops is also influenced by forecast prices relative to other cropping options including cotton and experiences from the previous season. The

area of winter pulses in the region needs to be stabilised and the reliability of achieving seasonal yield potential improved.

The Pulse Agronomy project has consulted widely within the pulse industry to determine the priorities to be investigated throughout the term of the project.

There have been two seasons of faba bean trials at the Garah site as part of the Northern Pulse Agronomy Project; the 2014 season saw the planting of three cultivars PBA Warda^(D), PBA Nasma^(D) and Cairo on one planting density of 25p/m² and on varying row spacings (25, 50, 75, 100cm). This season saw significant effects of the agronomic treatments observed with varieties responding positively to decreasing row spacing. In addition, 2014 (Dalby) showed a linear reduction in yields after the sowing date of April 23rd.

Winter 2015 saw the inclusion of varied planting densities (5, 10, 20, 30p/m²) across the same 4 row spacings (25, 50, 75, 100cm) looking at 2 cultivars PBA Warda^(D) and PBA Nasma^(D).

A seed size trial was also conducted at a Dalby site which had 3 different seed sizes of the PBA Nasma^(D) (IX220-D) cultivar planted at 75cm row spacing at 4 different planting densities. This trial was designed to determine the effects of seed size on yields and whether it is possible to grow a larger proportion of large seeds from smaller parent seeds as there is potential for issues with the larger faba bean seed blocking air seeders.

Time of sowing trials were also conducted at both Warra and Hermitage Research Station in 2015, each site sowing on three dates starting in April and concluding in late May. The initial plan was to begin these sowing dates in late March however rain forced the delay of sowing at both locations. These trials were at varying targeted plant densities on 75cm row spacing.

Results

Row spacing effects on yield

Overall, average yields were obtained at the Garah site and significant effects of the agronomic treatments were obtained. There was deemed to be no significant difference overall between the cultivars PBA Warda^(D) and PBA Nasma^(D) however PBA Nasma^(D) had an overall higher yield at 3.24t/ha over PBA Warda^(D) at 2.97t/ha (**table 1**). These results are consistent with those found in 2014 at the same site.

Table 1. Effect of cultivar on yield, Garah 2015 (LSD = 0.321)

Cultivar	Grain yield (t/ha)
PBA Warda ^(D)	2.97a
PBA Nasma ^(D)	3.24a

The narrower row spacings of 0.25m and 0.5m have significantly out yielded the wider spacings of 0.75m and 1.00m in both 2014 and 2015.

Table 2. Effect of row spacing on yield, Garah 2015 (LSD = 0.454)

Row Spacing	0.25	0.5	0.75	1.0
Mean Yield (t/ha)	3.43a	3.49a	3.18b	2.33c

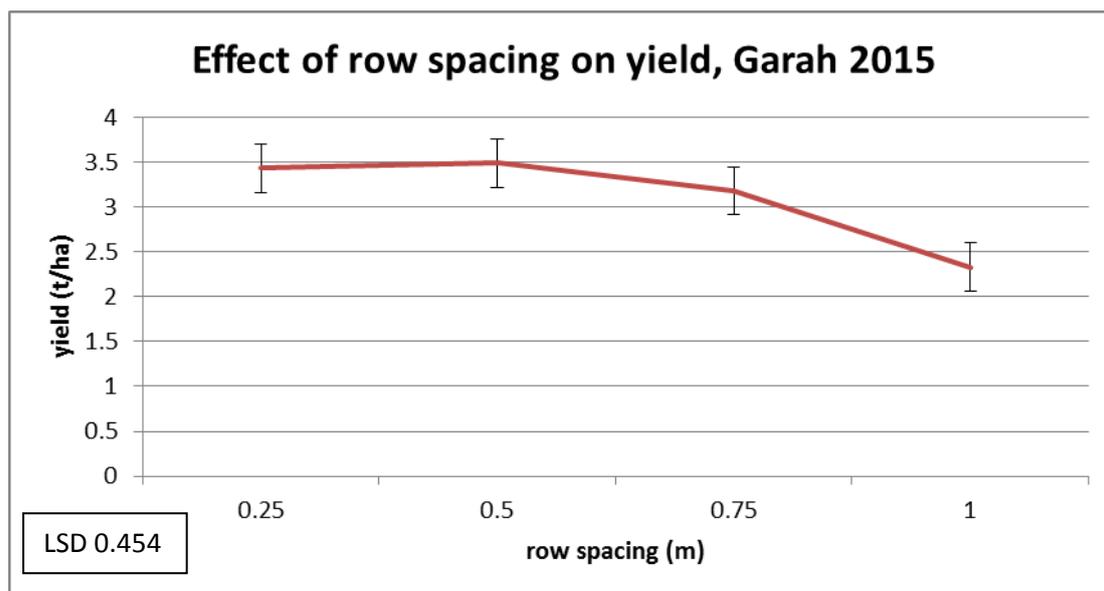


Figure 1. Effect of row spacing on yield, Garah 2015

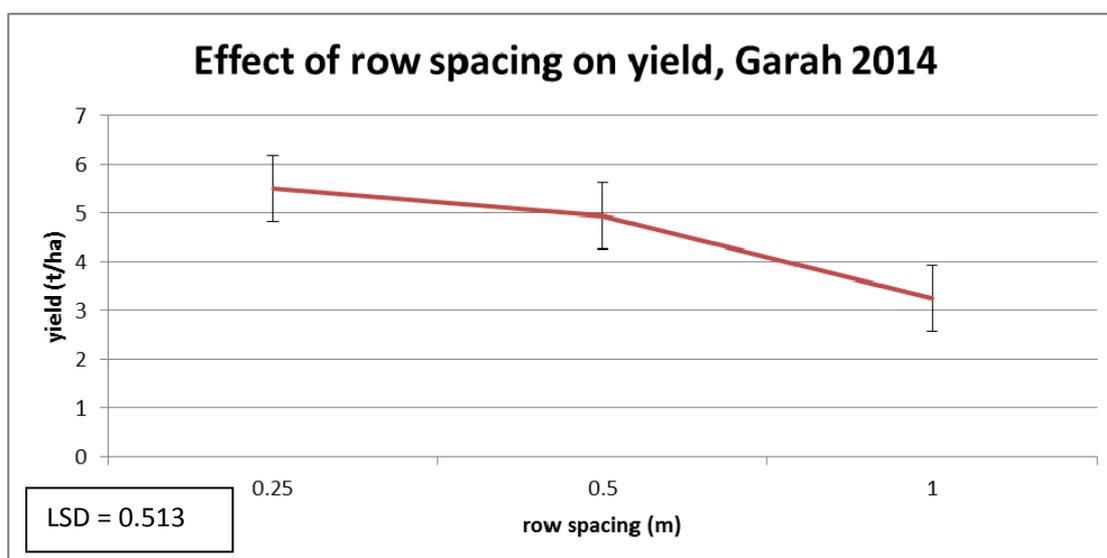


Figure 2. Effect of row spacing on yield, Garah 2014

Overall, in both years that row spacing and yield have been investigated at Garah, significant effects of the agronomic treatments were observed with both varieties responding positively to decreasing row spacing.

Effect of plant population on yield

In 2015, populations were investigated as an effect on yield however no significant differences were found between the 5, 10, 20 and 30p/m². It is thought that this is due to the crop ‘hitting a wall’ and running out of moisture at grain fill. When looking at total dry matter (t/ha) in the same crops population was different with 5p/m² being significantly lower than the 10, 20 and 30p/m² treatments. Further analysis of water use needs to be completed however early suggestions are that the crop has run out of moisture at grain fill and the plots with higher populations have had less moisture available to finish off and as a result have not been significantly higher in yield as expected at the higher planting density.

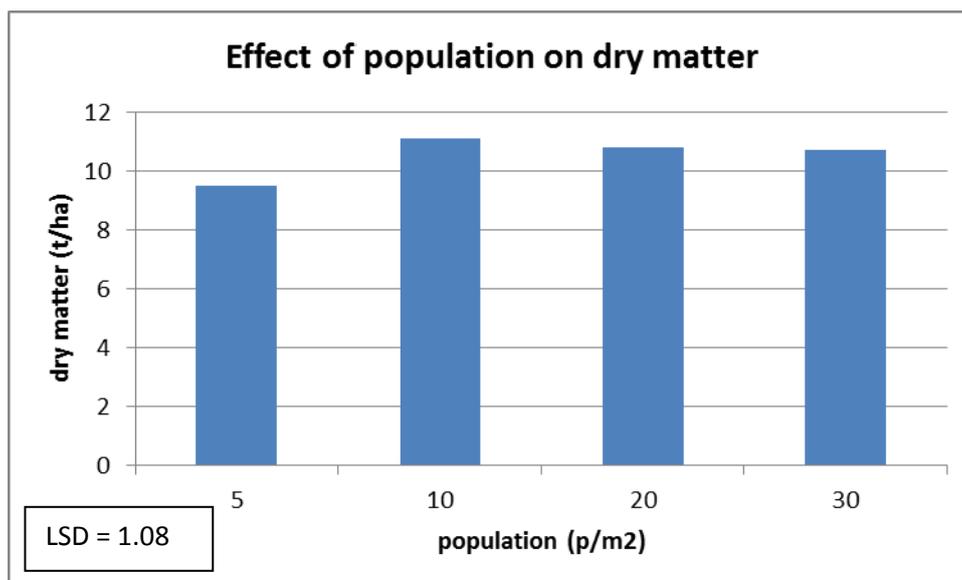


Figure 3. Effect of population on dry matter (t/ha)

Table 3. The effect of population on dry matter

population	5	10	20	30
dry matter	9.5b	11.1a	10.8a	10.7a

Effect of time of sowing on yield, drymatter and harvest index

A time of sowing trial was conducted near Dalby in winter 2014 which showed that there was a linear reduction in yield post the planting date of April 23rd; the result of this trial can be seen in figure 4.

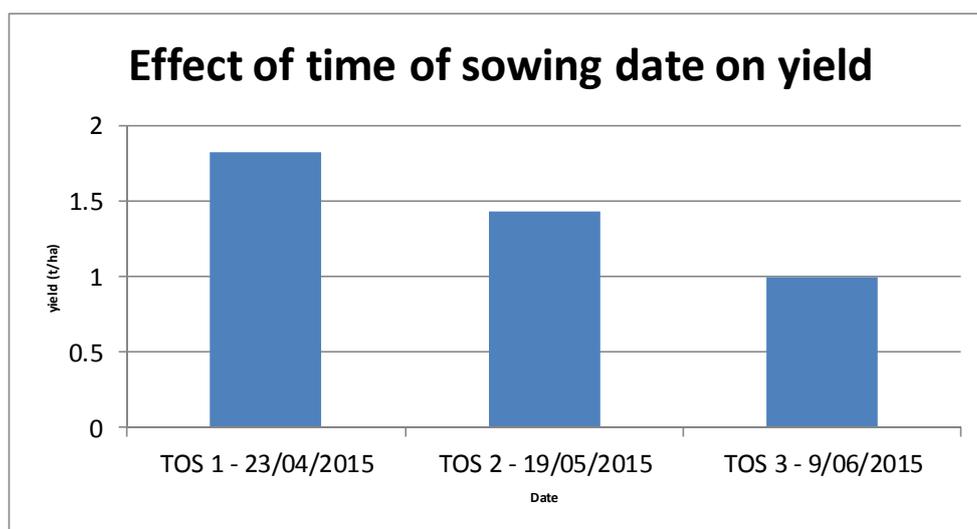


Figure 4. Effect of time of sowing date on yield, Dalby 2014

This trial was repeated in winter 2015 at the Hermitage Research Station (HRS) near Warwick, Qld and at Warra, Qld. At both locations there were three sowing dates planted at 75cm row spacing

and on four targeted plant populations 5, 10, 20, 30p/m². It was anticipated that the sowing dates would be 3 weeks apart however due to wet weather it was not possible. The dates used for the trial at each location can be seen in table 4.

Table 4. Sowing dates at Warra and Hermitage Research Station (HRS)

HRS 1	17/04/2015	Warra 1	9/04/2015
HRS 2	20/05/2015	Warra 2	28/04/2015
HRS 3	12/06/2015	Warra 3	21/05/2015

At HRS there was no statistical difference between the yields between the first and second time of sowing however there was a significant drop in yield of 300kg from TOS 1 and 500kg from TOS 2 out to the third sowing date.

A similar result was found at Warra, the first two sowing dates showed nil significant difference as did the difference between the second and third dates however a marked drop in yield was found between the first and third dates.

Table 5. Effect of time of sowing on yield, Warra (Isd 0.5) & HRS (Isd 0.36) 2015

	TOS 1	TOS 2	TOS 3
Warra	3.56a	3.31ab	2.84b
HRS	3.6a	3.8a	3.3b

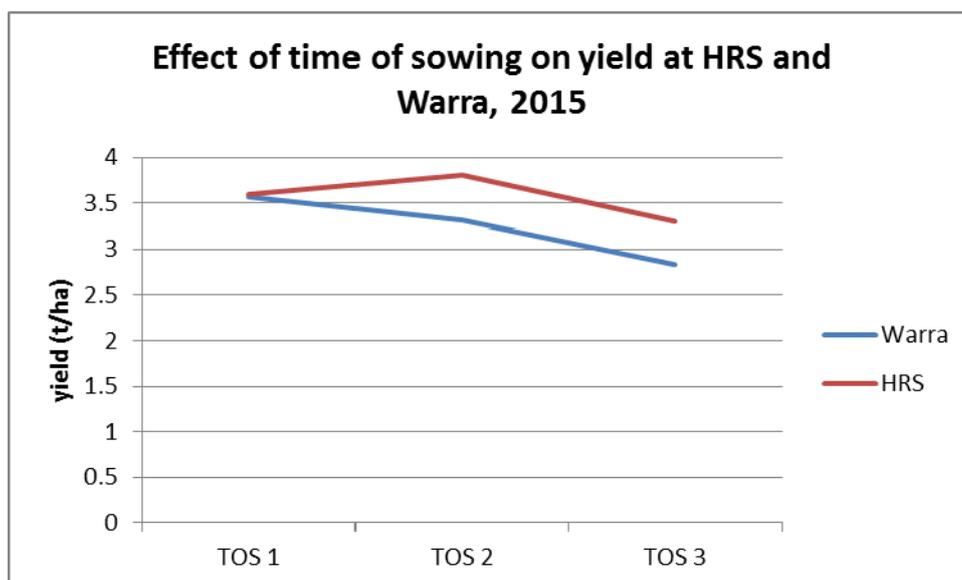


Figure 5. Effect of time of sowing on yield at HRS and Warra, 2015

From the two years of data it can be concluded that the current suggested sowing time of late April would still be appropriate and that crops planted into May and beyond could expect a linear reduction in yields. Further work could be completed with more emphasis placed on earlier sowing dates to identify if earlier than late April is appropriate.

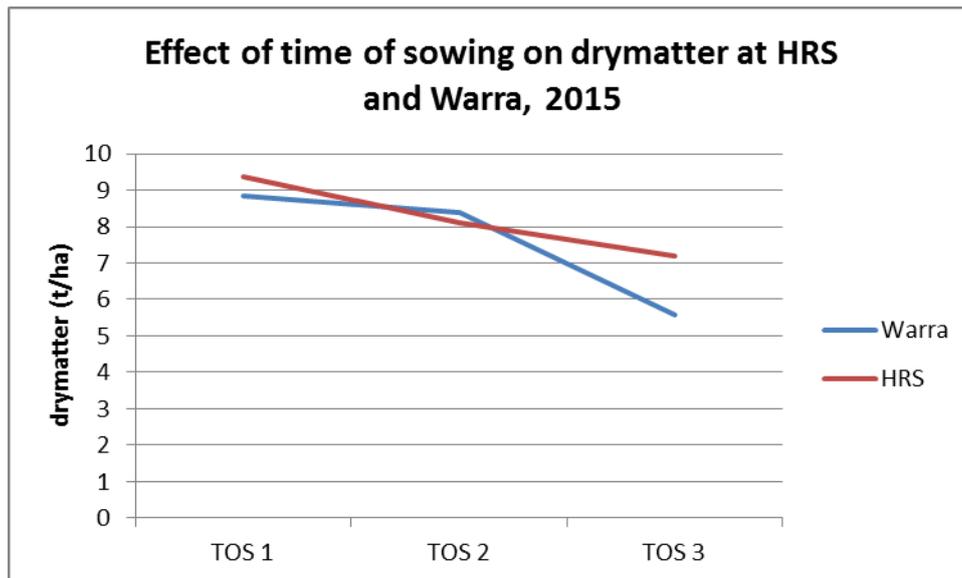


Figure 6. Effect of time of sowing on total drymatter at HRS & Warra, 2015

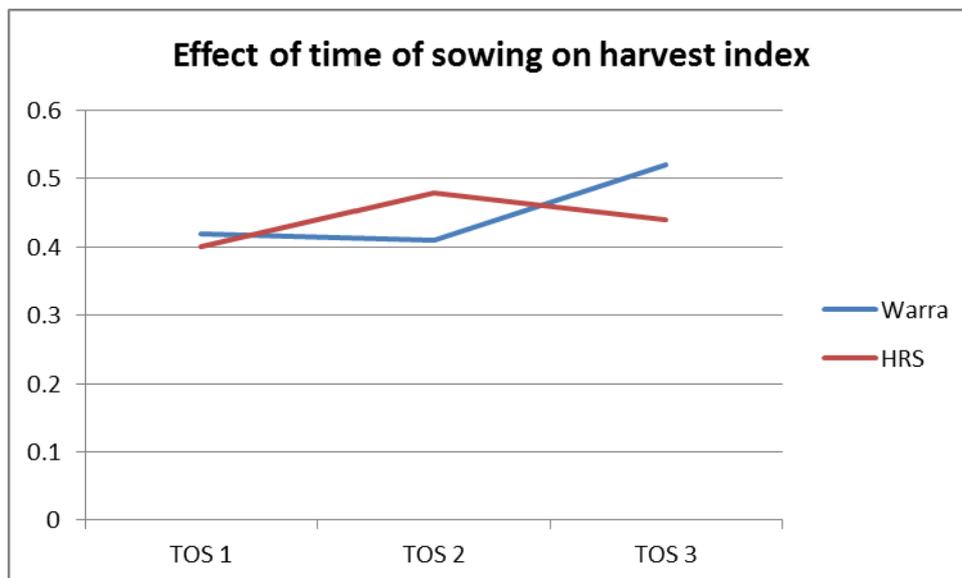


Figure 7. Effect of time of sowing on harvest index, HRS & Warra 2015
(LSD Warra – 0.08, HRS – 0.048)

Results indicate that total drymatter declines post the first TOS at both locations; the 2015 season saw crops initially grow a large amount of vegetation on available moisture however we cannot determine from this trial the reason that TOS 2 & 3 did not follow the same pattern. The harvest index has increased for TOS 2 & 3 at both locations however yield is lower. More investigation is needed into crop growth of faba beans to enable us to better understand the crop partitioning and in turn increase yield and harvest index rather than growing large biomass and not being able to convert to yield.

Effect of seed size

When using PBA Nasma[®] as a cultivar in trials in 2014 it was found that the seed size was 25% larger and an average seed weight of 78g/100 seeds compared with the 58g/100 seeds of PBA Warda[®] (figure 8) could pose an issue blocking airseeders. As a result of this, a trial was designed to

investigate whether planting seed size has an influence on yield and also seed size of the resultant crop.

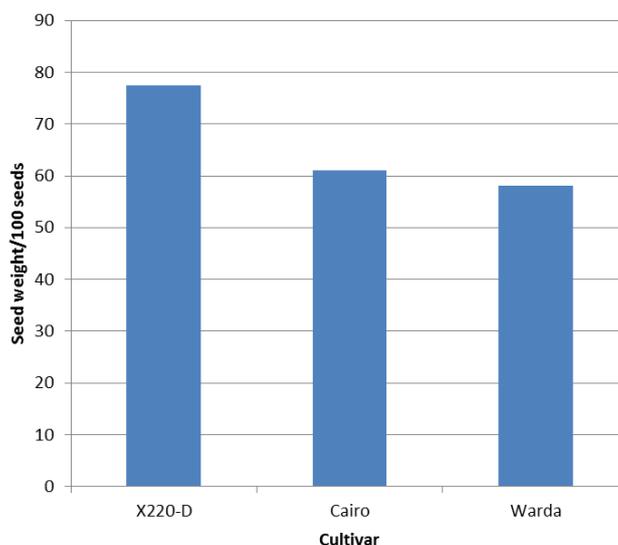


Figure 8. Faba bean seed weights by cultivar

The seed for the trial was graded into three different sizes and planted at four different populations on row spacing of 75cm. The trial was planted in May due to rainfall, which was later than anticipated and could have led to a yield reduction.

Table 6. Effect of seed size on yield

	dimensions	Seed weight (g)	
Size 1 (small)	25/64"	52.32	1.95a
Size 2 (medium)	28/64"	66.93	2.03ab
Size 3 (large)	33/64"	84.19	2.23b

Table 6 shows that there was a significant difference in the yield achieved between the small and large seed sizes but not between each of those and the medium seed size.

When harvested, each of the three seed size plots were then graded out into the same three sizes, the proportion of each seed size that was taken from each plot can be seen in figure 9.

Each of the sizes grew a larger proportion of medium seed than the size of its parent seed however size 1 grew more size 1 than size 3, size 2 grew more size 2 and similar amounts of size 1 and 3 and size 3 grew a larger amount of size 3 than size 1, this can be seen visually in figure 9.

It is not a recommendation to grade out larger sized seed to increase seed numbers for weight, marketing factors have not been taken into account in this trial.

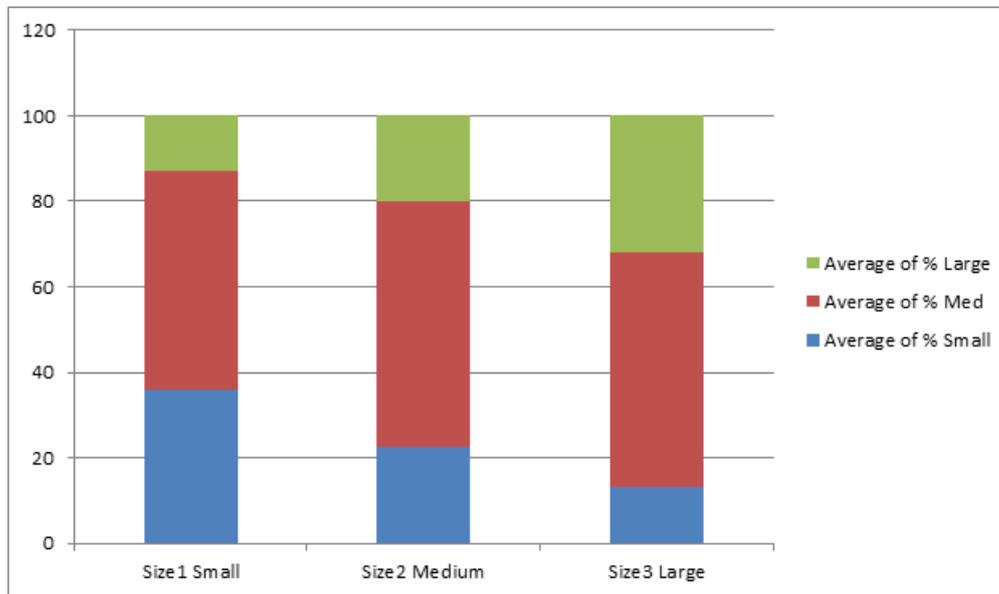


Figure 9. Effect of seed size planted on % seed size produced

Conclusion

Narrow row spacing (25/50cm) consistently yield higher than wider row spacings (75cm and above) for faba beans.

This effect has been seen across 2 years and differing seasons and environments.

Row spacing has a larger effect on yield than plant population.

Earlier planting of faba beans is best to maximise yields, however later plantings are after one year of trials producing lower biomass and as a result, higher harvest index, more investigation is required.

Acknowledgements

Many thanks for the support of Stephen Krosch, Katrina Conway, Rod O'Connor and for trial co-operators Glenn Milne, Wade Bidstrup and the Moloney Family.

Contact details

Rebecca Raymond
 Department of Agriculture and Fisheries, Queensland
 Mb: 0428 879 900
 Email: Bec.raymond@daf.qld.gov.au

Ⓟ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

Northern NSW Pulse Agronomy Project –nutrition in chickpea 2015

Andrew Verrell^a and Leigh Jenkins^b

NSW Department of Primary Industries, Tamworth^a and Trangie^b

Key words

chickpea, nutrients, grain yield,

GRDC code

DAN00171 - Northern Pulse Agronomy Initiative project (winter pulses)

Take home messages

- Phosphorus was a limiting factor to grain yield in 2015
- Zinc was limiting yield at three locations
- Iron was a limiting factor on a grey-brown vertosol with a 50 year cropping history

Introduction

The 2015 season was characterised by episodic cold weather events during flowering and terminal drought during grain fill. These seasonal conditions impacted heavily, reducing the potential yield of chickpeas across most areas of the northern NSW cropping zone.

The Northern Pulse Agronomy Initiative project had a range of experiments covering a number of agronomic themes in 2014. This paper will report on the outcomes of the nutrition experiments across northern NSW.

What we did?

Nutrients were applied in a nutrient omission format at seven locations across central and northern NSW. In nutrient omission trials, one nutrient is deliberately omitted in each treatment, while all other nutrients are applied at rates considered as non-limiting. It is therefore not possible to determine optimum nutrient application rates directly from the results of these experiments.

The 12 treatments were; Zero nutrients, All nutrients, - N, - P, - K, - Ca, - B, - Cu, - Zn, - Mn, - Mg, - Fe.

Application method varied between nutrients. Both P and N were applied at sowing, at 10 kg P/ha as Trifos and 10 kg N/ha as urea, respectively. Ca, Mg, Zn, Mn, Cu and Fe were applied as chelates in a foliar spray. K was applied as Potassium citrate and B as Boron ethanolamine as foliar sprays. Besides N and P (applied at sowing), all other nutrients were sprayed on the crop at mid vegetative period. PBA HatTrick[®] was sown at all sites at 30 plants/m².

What we found?

Grain yield data for the seven experimental locations is contained in Table 1. Rowena showed no significant responses to applied nutrients. The Trangie, Edgeroi and Coonamble sites showed yield responses to applied Zn of, 28%, 18% and 7%, respectively. Coonamble, Nowley, Moree and North Star had responses to applied P of, 4%, 15%, 15% and 11%, respectively.

The Coonamble site, a grey-brown vertosol which has been cropped since the early 1960's, also showed an 8% yield response to applied Fe.

Table 1. Effect of selected nutrient omission treatments on grain yield (kg/ha) in chickpea at northern NSW sites in 2015

Treatment	Trangie (kg/ha)	Rowena (kg/ha)	Edgeroi (kg/ha)	Coonamble (kg/ha)	Nowley (kg/ha)	Moree (kg/ha)	North Star (kg/ha)
Minus-Zn	559b	788a	1498b	1816b	1619a	1928a	2129a
Minus-P	626ab	986a	1613ab	1864b	1425b	1697b	2005b
Minus-Fe				1804b			
All	714a	1019a	1772a	1947a	1643a	1956a	2226a

Values with the same letter are not significantly different at $P>0.05$

Conclusions

- Frosts and cold periods during flowering at sites led to floral abortion and a reduction in yield;
- Extended dry periods at sites during September and October led to pod and seed abortion ;
- Older cropping country is showing responses to applied P as well as Zn and in one instance Fe

Acknowledgements

The research undertaken as part of project DAN00171 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC. The authors would like to thank them for their continued support. Thanks to Mat Grinter, Michael Nowland and Jayne Jenkins and Scott Richards (all NSW DPI) for their technical assistance in the trial program.

Contact details

Dr Andrew Verrell
 NSW Department of Primary Industries
 Mb: 0429 422 150
 Email: andrew.verrell@dpi.nsw.gov.au

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Northern Winter Pulse Agronomy - Faba bean density experiments - 2015

Andrew Verrell^a and Leigh Jenkins^b

NSW Department of Primary Industries, Tamworth^a and Trangie^b

Key words

faba bean, plant density, frost

GRDC code

DAN00171 - Northern Pulse Agronomy Initiative project (Winter pulses)

Take home message

- Sow faba beans at 20 plants/m² in northern regions
- Sow faba beans at 30 plants/m² in central regions
- Doza[Ⓛ] appears more prone to frost damage than either PBA Warda[Ⓛ] or PBA Nasma[Ⓛ]

Introduction

The 2015 season was characterised by severe frost events, episodic cold weather during flowering and terminal drought during grain fill. These seasonal conditions impacted heavily on crop performance, reducing the potential yield of faba beans across most areas of the northern NSW cropping zone.

The NPAI (Winter Pulse) project conducted a range of experiments covering a number of different agronomic themes in 2015. This paper reports on the outcomes of a series of faba bean variety x density experiments across northern NSW.

What did we do?

Faba bean, variety x density, experiments were conducted at five locations across northern NSW in 2015. Three varieties were sown; Doza[Ⓛ], PBA Warda[Ⓛ] and the new line PBA Nasma[Ⓛ]. Four target plant densities were examined; 10, 20, 30 and 40 plants/m². All five trials were grown under dryland cropping conditions (i.e. not irrigated).

The three lines selected represent the two preferred commercial lines (Doza[Ⓛ] and PBA Warda[Ⓛ]) and the new large seeded line PBA Nasma[Ⓛ]. The difference in seed size for these commercial lines is shown in Figure 1 where PBA Nasma[Ⓛ], on average, has seed that is 40% larger than Doza[Ⓛ].

What did we find?

For grain yield, there were no significant interactions between variety and plant density; only main effects (see Table 1). PBA Warda[Ⓛ] and PBA Nasma[Ⓛ] out yielded Doza[Ⓛ] at two of the five sites (Coonamble and Tamworth); while at Trangie, PBA Nasma[Ⓛ] out yielded both Doza[Ⓛ] and PBA Warda[Ⓛ] (Table 1). Plant density showed significant responses at two sites; Cryon plateaued at 20 plants/m², while at Trangie peak yield was obtained at 30 plants/m² (Table 1). The remaining sites showed no yield response to plant density.

Frosts were prevalent across the northern region in 2015 and the Tamworth site suffered a number of severe frosts. From the 28th July to the 8th of August, 6 frosts were recorded ranging from -1.3 to -3.5°C. This resulted in frost damage, causing elongating stems to develop a bent stick (hockey stick) appearance and blackening of leaf margins. Treatments were scored for frost damage on a 1-9 scale on the 7th August, with 1 representing no frost damage and 9 equal to plant death. Variety ratings

are shown in Figure 2 with Doza significantly worse than both PBA Warda and PBA Nasma for symptoms of frost damage.

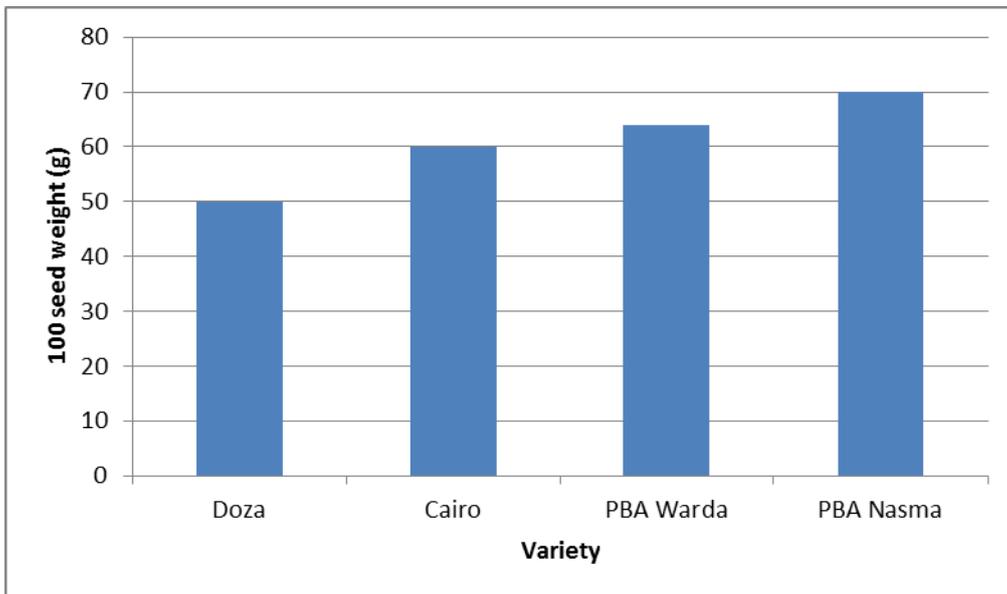


Figure 1. Average 100 seed weight (g) for selected faba bean varieties

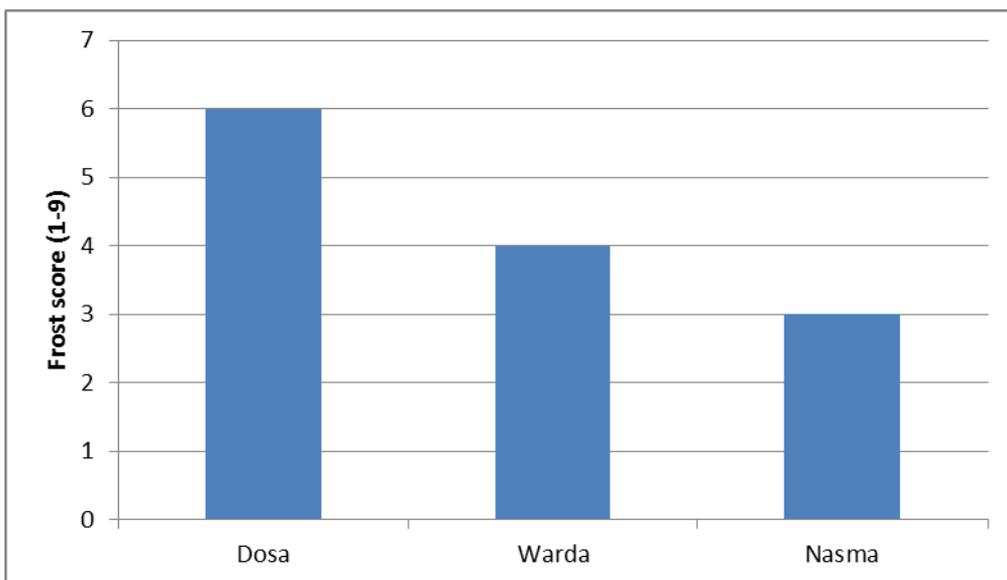


Figure 2. Frost scores for faba bean varieties (1 = no symptoms, 9 = plant death)

Table 1. Grain yield (kg/ha) for the main effects of variety and plant density at five locations in 2015

Treatment	Bullarah	Coonamble	Cryon	Trangie	Tamworth
Variety		<i>Grain yield (kg/ha)</i>			
Doza [Ⓟ]	1602a	2900b	1547a	2036b	2954b
PBA Warda [Ⓟ]	1687a	3280a	1700a	2246b	3296a
PBA Nasma [Ⓟ]	1685a	3452a	1686a	2658a	3359a
Density		<i>Grain yield (kg/ha)</i>			
10	1498a	3376a	1373b	1975c	3177a
20	1670a	3411a	1772a	2275b	3329a
30	1768a	3246a	1673a	2515a	3210a
40	1666a	3270a	1745a	2489a	3096a

Values with the same letter are not significantly different

Conclusion

Limited data from the first year of trial results in 2015 suggests that for northern and western sites 20 plants/m² is a preferred target plant density, while in southern areas 30 plants/m² is a better option to achieve optimum yield of faba beans grown under dryland cropping conditions.

Large seed does not necessarily confer higher yield; with PBA Nasma[Ⓟ] out yielding PBA Warda[Ⓟ] at only one location, Trangie.

Doza[Ⓟ] appears more prone to frost damage than either PBA Warda[Ⓟ] or PBA Nasma[Ⓟ]. Frost tolerance is a key attribute for the faba bean breeding program in northern NSW, with new releases (particularly PBA Nasma[Ⓟ]) targeted at having better tolerance than Doza[Ⓟ].

Acknowledgements

The research undertaken as part of project DAN00171 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC. The authors would like to thank them for their continued support. Thanks to Michael Nowland, Matt Grinter, Jayne Jenkins, Scott Richards and Gerard Lonegran (all NSW DPI) for their assistance in the trial program.

Contact details

Dr Andrew Verrell
 NSW Department Primary Industries
 Mb: 0429 422 150
 Email: andrew.verrell@dpi.nsw.gov.au

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PBA Nasma[Ⓛ] faba bean – effect of seed size at sowing on grain yield

Andrew Verrell^a and Leigh Jenkins^b

NSW Department of Primary Industries, Tamworth^a and Trangie^b

Key words

faba bean, seed size, frost, grain yield

GRDC code

DAN00171 - Northern Pulse Agronomy Initiative project (Winter pulses)

Take home messages

- At present, there is no evidence to suggest that seed size at sowing has an impact on grain yield in cultivar PBA Nasma[Ⓛ]
- Seed size at sowing is positively related to seed size at harvest
- Further experimentation is needed

Introduction

In cereals, large initial seed size frequently confers distinct advantages in terms of seedling vigour, hardiness, improved stand establishment, and higher productivity (Grieve and Francois, 1992). Spilde (1988) found, for barley and wheat that grain produced from small-sized seed averaged 4 and 5% less yield than that from medium sized seed and 6 and 8% less yield than that from large-sized seed, respectively.

However, studies comparing faba bean genotypes of different seed sizes indicated a negative relationship between seed mass and grain yield (Laing *et al.*, 1984; White and González, 1990; White *et al.*, 1992; Sexton *et al.*, 1994). Lima *et al* (2005) found faba bean plants originating from small seed presented a higher relative growth rate and net assimilation rate than plants from large seed. Large seed did not affect grain yield, but reduced the number of seeds per pod, increased the 100-seed mass, and reduced the harvest index.

The new faba bean cultivar, PBA Nasma[Ⓛ], produces very large seed averaging 70g/100 seeds compared to cultivar Doza[Ⓛ], at 50g/100 seeds. An experiment was conducted to examine the effect of seed size at sowing, at a fixed population, on grain yield and seed size distribution at harvest.

What did we do?

Seed supply for this newly released cultivar was in limited supply which restricted experimentation to two sites (TAI and TARC) in 2015.

The seed was passed thru a set of nested circular mesh sieves and partitioned into four seed size categories; < 7mm, 7-8mm, 8-9mm, >9mm. The corresponding 100 seed weights for the seed size categories, < 7mm, 7-8mm, 8-9mm, >9mm; were 34.6, 48.1, 69.5 and 90.0g, respectively.

Randomised complete block experiments consisting of the four seed size treatments and four replicates were sown at target plant densities of 20 and 10 plants/m² at TAI and TARC, respectively.

What did we find?

The seed size distribution of the 25kg seed lot used to obtain the seed categories for sowing these experiments is contained in Figure 1. The predominant seed size was the 8-9mm category which accounted for 72% of the total seed supply.

All plots attained their target plant densities (data not shown). At TAI, plants grown from the largest size seed produced 19% and 8% more biomass than the small seed size category at 25th June and 3rd August, respectively. Seed size categories were scored for frost damage on the 7th of August but there was no significant difference.

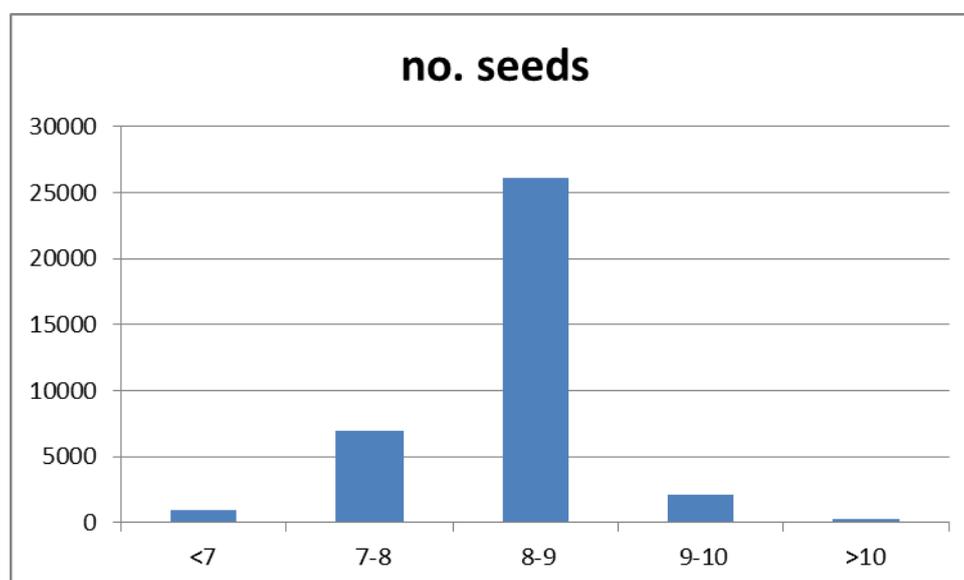


Figure 1. Seed size distribution and number of seeds per category for the seed lot used for sowing experiments.

Table 1 contains data on the effect of seed size category at sowing on plant height, height to top pod, grain yield and hundred seed weight for the TAI experiment and grain yield and 100 seed weight for the TARC experiment.

At TAI, the plants grown from seed smaller than 7mm in size were significantly shorter than all other seed categories while there was no difference in height to top pod across the seed categories (see Table 1). There was also no significant difference in grain yield between any of the seed size categories. Hundred seed weight did vary significantly and the large seed category, on average, produced heavier grain than the small seed category.

At TARC, grain yield was significantly higher for the two large seed size categories compared to the very small seed category (by 13%). Hundred seed weight had a similar response to seed size category as found at TAI, 100 seed weight increasing with seed size at sowing (see Table 1).

Table 1. Effect of seed size category at sowing on plant height, height to top pod, grain yield and hundred seed weight for TAI and grain yield and hundred seed weight for TARC

Seed size category	TAI				TARC	
	Plant height (mm)	Height to top pod (mm)	Yield (kg/ha)	100 seed weight (g)	Yield (kg/ha)	100 seed weight (g)
<7mm	1240b	1000a	3287a	55.80c	1696 c	48.1d
7-8mm	1358a	1124a	3144a	65.0ab	1726bc	50.9c
8-9mm	1329a	1030a	3267a	59.4bc	1921ab	55.2b
>9mm	1376a	1078a	3557a	68.80a	2013 a	60.0a

Values with the same letter are not significantly different at P>0.05

Conclusion

Plants grown from large seeds were taller and had significantly more biomass than the plants grown from small seed. However this did not translate into a significant difference in grain yield at TAI but did in the TARC experiment. There may be an interaction with plant density and seed size given these different results (TAI 20 and TARC 10 plants/m²). These results are similar to that of Agung and McDonald (1998) in South Australia where yields for cultivar Fiord averaged about 400 g/m² but were not consistently related to seed size, although the highest yielding accession at their sites were large-seeded.

The size of seed produced at harvest was positively related to seed size with the largest seed category producing the biggest size seed compared to the small seed category (see Table 1) at both experimental sites.

Acknowledgements

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References

- S. Agung and G. K. McDonald (1998). Effects of seed size and maturity on the growth and yield of faba bean (*Vicia faba* L.). *Australian Journal of Agricultural Research* 49(1) 79 - 88
- C. M. Grieve, L. E. Francois (1992). The importance of initial seed size in wheat plant response to salinity. *Plant and Soil*, Vol 147, Issue 2, pp 197-205
- Laing DR, Jones PG, Davis JHC (1984) Common bean (*Phaseolus vulgaris* L.). In: Goldsworthy PR, Fisher NM (eds), *The Physiology of Tropical Field Crops*, pp.305-351. John Wiley, New York, USA.
- Elvis Rodrigues Lima; Aline Silva Santiago; Adelson Paulo Araújo, Marcelo Grandi Teixeira (2005). Effects of the size of sown seed on growth and yield of common bean cultivars of different seed sizes, *Braz. J. Plant Physiol.* vol.17 no.3
- Sexton PJ, White JW, Boote KJ (1994) Yield-determining processes in relation to cultivar seed size of common bean. *Crop Sci.* 34:84-91.
- L. A. Spilde (1988). Influence of Seed Size and Test Weight on Several Agronomic Traits of Barley and Hard Red Spring Wheat. *Journal of Production Agriculture*, Vol. 2, No. 2, p. 169-172
- White JW, González A (1990) Characterization of the negative association between seed yield and seed size among genotypes of common bean. *Field Crops Res.* 23:159-175
- White JW, Singh SP, Pino C, Rios BMJ, Buddenhagen I (1992) Effects of seed size and photoperiod response on crop growth and yield of common bean. *Field Crops Res.* 28:295-307.

Contact details

Dr Andrew Verrell
NSW Department Primary Industries
Mb: 0429 422 150
Email: andrew.verrell@dpi.nsw.gov.au

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Recent insect pest management research findings and the application of results in the field

*Melina Miles, Adam Quade, Richard Lloyd and Paul Grundy,
Queensland Department of Agriculture and Fisheries. Toowoomba, Qld.*

Key words

Scarabs, Helicoverpa, thresholds, green mirid, faba beans, canola

GRDC code

DAQ00196

Take home message

1. Green mirids do cause spotting on faba bean seed. Both adults and late instar nymphs are damaging and warrant control in faba bean crops. No threshold is available yet.
2. Preliminary thresholds for Helicoverpa in canola are proposed, based on research that showed the consumption rate per larva to be 2.4g of grain.
3. Knockdown products currently used for Rutherglen bug (RGB) are either more effective, or as effective, as a range of 'new' products screened. Residual activity still being investigated.
4. Cultivation shows promise as an option for reducing high densities of scarab larvae.
5. The interaction between scarab density and efficacy of seed dressings and in-furrow treatments (IFT's) needs further investigation.

Recent research outcomes

Confirmation of green mirid damage potential in faba beans

A replicated trial that caged mirid adults and nymphs on developing and maturing pods was conducted in 2015. The purpose of the trial was to establish conclusively whether mirid feeding caused spotting on the seed, and whether mirids warranted further research as a pest of faba beans.

Pods at two development stages were included in the trial, 1) fully filled, but still green and 2) immature, seed approximately 30% filled. Either 2 adult mirids, or 2 late instar nymphs were confined on a pod for 10 days, and there were control pods on which there were no mirids. At the end of the 10 days the mirids were removed from the 'cages' and the cages replaced to protect the pods from being damaged by any other insect or weather. Cages remained on the pods until the pods were mature and dried down (harvestable). During this time cages were checked, and treated where necessary for small nymphs that hatched from eggs laid by the mirids in the trial.

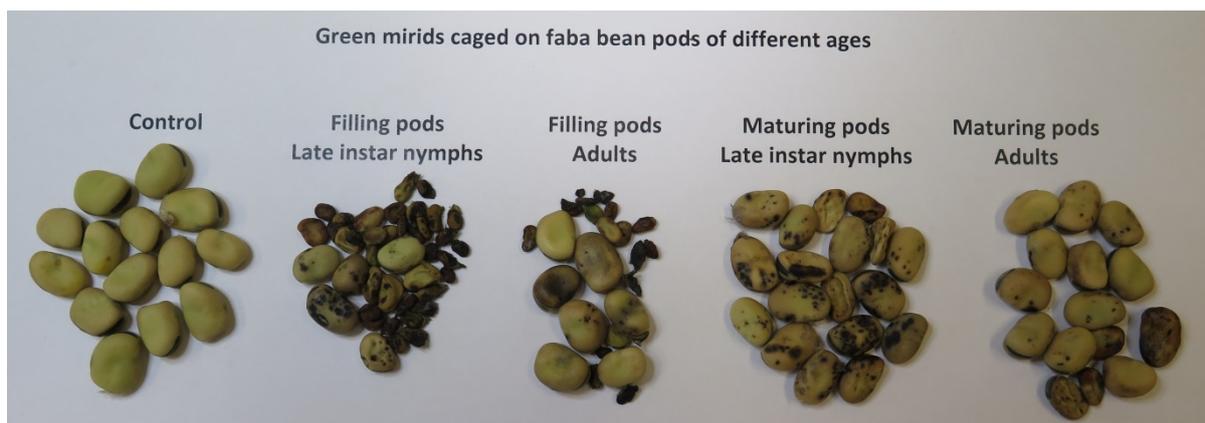


Figure 1. Effect of green mirids caged on faba bean pods of different ages

As shown in the figure above, mirids did consistently cause spotting on the seed coat. Adult and late instar mirids caused similar damage. When filling pods were exposed to mirids, a significant proportion of seed did not develop. This trial result clearly demonstrates the damage potential of mirids in faba beans, both in terms of quality (spotting) and yields (small seed).

This trial was not designed to address the question of threshold. We cannot extrapolate from these data to estimate how many mirids will cause significant seed spotting or screenings. These are areas of research that will be addressed next winter.

Preliminary threshold for helioverpa in canola

To date, thresholds available for managing helioverpa in canola have been based on 'best guesses'. In 2015 we conducted a replicated trial to determine the consumption rate of helioverpa larvae in canola. A consumption rate is a vital component of an economic threshold, and is an estimate of the yield and crop loss likely to occur. It is calculated from the lifetime consumption of a larva. In other words, it is a reflection of the amount of yield loss that would occur if the larva was not controlled.

The trial involved confining individual larvae on canola racemes and allowing them to feed until they pupated. These data were compared with data from racemes that had no helioverpa feeding. In summary, results of the trial are:

- i) The consumption rate of a helioverpa larva is estimated to be 2.4 grams of grain per larva.
- ii) On average a larva damaged 10.5 pods and consumed 124 seeds.
- iii) Larvae showed no preference for pod size/maturity

If we use the following equations, we can calculate the potential yield loss and economic thresholds for a range of crop and cost of control values – presented in the tables below.

$$\text{Potential yield loss (t/ha) per larva} = D \times P \times V$$

Where D = estimated yield loss per larva (t/ha)

P = pest density per sampling unit (e.g. per m²)

V = crop value (\$/t)

$$\text{Economic threshold (larvae/m}^2\text{)} = C / (V \times D)$$

Where C = cost of control (\$/ha)

V = crop value (\$/t)

D = estimated yield loss per larva (t/ha)

Table 1. Potential yield loss (\$/ha) from helcoverpa larvae in canola

Crop value (\$/t)	Number of larvae per m ²			
	1	2	3	4
400	9.60	19.20	28.80	38.40
450	10.80	21.60	32.40	43.20
500	12.00	24.00	36.00	48.00

Table 2. Economic threshold (larvae per m²) of helicoverpa in canola

Cost of control (\$/ha) (application + insecticide)	Crop value (\$/t)		
	400	450	500
20	2.1	1.9	1.7
25	2.6	2.3	2.1
30	3.1	2.8	2.5
35	3.6	3.2	2.9
40	4.2	3.7	3.3

These thresholds are preliminary, and as it usual in the development of thresholds, the next stage is to repeat the trial as well as to evaluate the effectiveness of the proposed thresholds in adequately preventing economic yield loss in commercial crops. It is expected that we will have greater confidence and firm thresholds within 1-2 seasons.

The other aspect of helicoverpa management that has not yet been addressed, and is critical to the use of economic thresholds, is a reliable sampling method. This will be addressed this coming winter.

Rutherglen bug in canola stubble

Despite their apparent hardiness in the field, Rutherglen bug (RGB) have proven to be very difficult to maintain in laboratory bioassays. We have conducted a number of bioassays to evaluate the efficacy of a range of insecticides that we considered useful either as knockdown products, or with potential as barrier treatments to limit movement into summer crops from canola stubbles. To date we have screened 11 products for knockdown efficacy, and none of the 'new' products were superior to those currently used.

Problems with keeping RGB alive for more than 4 days in the lab, has limited our ability to evaluate the residual efficacy of the products. We will pursue this again in 2016.

What is now clear from agronomist observations and our monitoring of canola fields is that the RGB are present in the canola crops as they are filling pods and maturing. The RGB lay eggs in the soil (up to 400 eggs per female), resulting in an explosion of nymphs in 2-4 weeks after the adult RGB are seen. Although not typical, nymphs will move up the plants and onto the pods. More commonly they remain on the soil and base of plants. Where canola is windrowed, the nymphs may move to shelter under the windrows and feed on the shed seed. The risk of RGB damage to seed through direct feeding is not well understood and warrants research. Overseas research suggests that the risk of impact on grain (oil content/quality) decreases as the crop matures and dries down.

Scarabs damaging summer and winter crops

Scarab damage to establishing crops has been reported from the Darling Downs to Northern NSW. The highest number of reports of scarab infestation, and crop loss caused by scarabs, has been from the eastern Downs, but this may be a result of a higher level of awareness in these areas. Sorghum is

the crop most frequently reported with crop loss, but crop loss has also been confirmed in sunflower, maize, mungbean, and wheat.

Species and lifecycle

At least 4 species of larvae have been collected from fields. In the majority of cases, there is a predominance of one species in affected fields. Whilst a definite identification is still not available (identification can only be made from beetles, and the beetles are only active for a short period between Oct-Mar), we believe the most common species is *Othnonius batseii*, the black soil scarab.

Other species of beetle are currently with a scarab taxonomist for identification.

Scarabs generally have a 1-2 year lifecycle, which can be longer if the larvae do not have suitable growing conditions (too dry, inadequate food source). This means larvae can be present in fields 12 months of the year. The larvae feed on roots, impacting on plant growth and ability to tolerate moisture stress. The impact of scarab feeding is visible as slowed crop growth, plant death (often in patches), delayed maturity and lodging.

Damaging densities

Whilst we do not yet have a defined threshold, observations of crop loss and infestations indicate that densities above 15 larvae per sqm (to 15 cm depth) are associated with significant crop loss. This tentative threshold is influenced by a number of conditions including crop, scarab species, soil moisture, cultivation, sowing equipment, use of seed dressings and in-furrow treatments. At present, we think that at densities below 15 per sqm, seed dressings and in-furrow treatments may provide some protection. At higher densities, particularly those above 25 larvae per sqm, observations suggest that even at-sowing treatments do not prevent significant crop loss.

Management options

Cultivation

Two replicated trials have been conducted, comparing the impact of a single offset disc and chisel plough on scarab larvae densities. The results from these trials showed that cultivation, either with disc or chisel plough, reduced larvae numbers significantly (Figure 2). In these trials the cultivation resulted in a full disturbance of the soil surface and correspondingly high reductions in soil moisture. Subsequent sorghum planting at the Cecil Plains site did not establish well in the cultivated plots. We have monitored the impact of several commercial fields where the growers have cultivated infested patches in the field. The results from these fields have shown similarly large decreases in the larval populations.

The impact of cultivation on soil moisture is a major impediment to the potential uptake of cultivation to manage high density infestations. However, it may be possible to be more targeted with cultivation and achieve the same outcome. Examination of the distribution of larvae across the plant row and inter-row shows a concentration of larvae on the plant row in the majority of fields (Figure 3). This pattern of distribution opens up the possibility of more targeted tillage, with reduced disturbance. This area of work clearly requires further research and development.

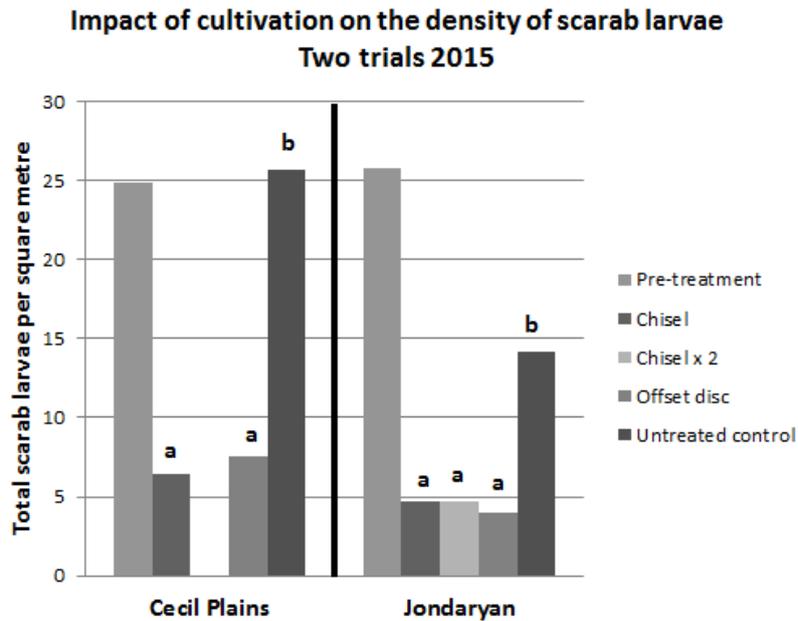


Figure 2. Cultivation with an offset disc or chisel plough reduced scarab larvae densities significantly. Two passes with the chisel plough (Jondaryan only) did not further reduce larval numbers. Means with the same letter above the bar are not significantly different from each other.

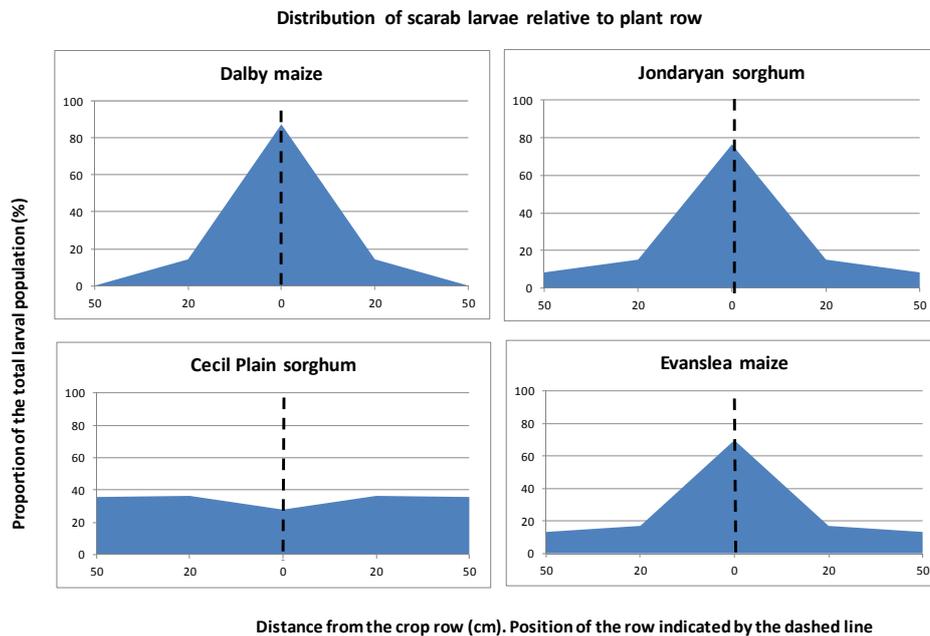


Figure 3. Distribution of scarab larvae in crops on 1m row spacing, showing the concentration along the plant row in three of the four examples

Insecticide treatment

Once a crop is planted, there are no insecticide options for controlling scarab larvae. Consequently, any attempt to mitigate the impact of larvae either by killing them or repelling them from the root zone must be implemented at sowing.

In 2015 we evaluated a range of in-furrow treatments (IFT) and seed treatment options to see what benefit they may be in establishing sorghum in a heavily infested field (average of 26 larvae per square metre). As discussed above, it is likely that there are larval densities at which even effective seed treatments and IFT will not provide adequate protection. However, the trial results (Figure 4) show significant increases in seedling biomass at 53 days after sowing (DAS) with a number of treatments. At the time of writing, no in-furrow or seed treatments have registered label claims for the control of scarabs. The plots treated with two seed dressings (C and D) showed significant increases in biomass compared with the untreated controls. In combination with IFT, there was a further increase in biomass with some treatments.

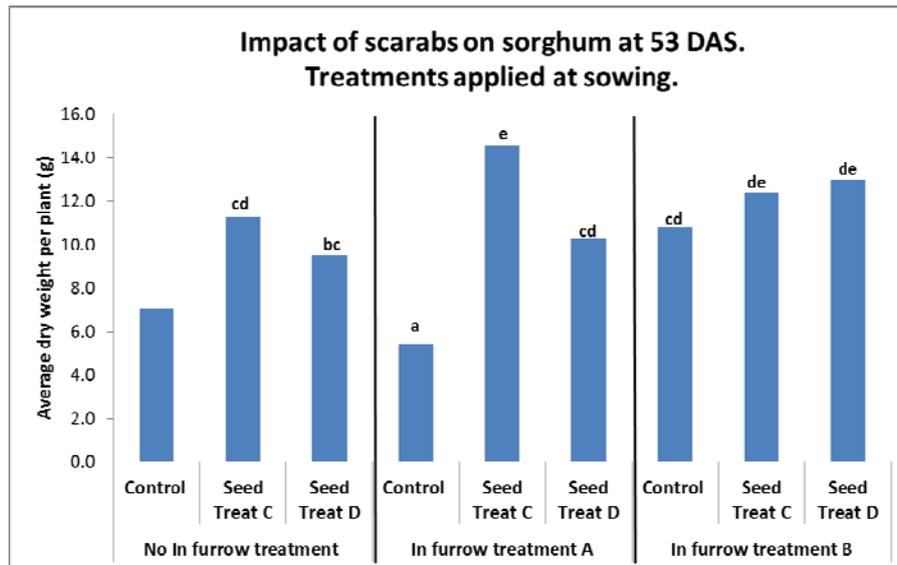


Figure 4. Scarab larva impact on seedling sorghum (to 53 DAS) was significantly reduced with the application of some in-furrow and seed treatment combinations.

We also saw a significant yield increase in wheat, in the same field, in a trial evaluating the efficacy of seed treatments in winter crops.

The use of IFT and seed dressings for a long-lived pest like scarab larvae is not simple. It is probable that the insecticides will deter larvae from the zone in which they are active, but as roots grow out of the treated zone they may then be damaged by larvae. These interactions need investigation.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

We are extremely grateful for the generous support of many growers and agronomists who have allowed us to sample their field or undertake trial work, and made us aware of insect pest issues affecting them. In particular, we acknowledge the assistance and opportunity for field work and discussion provided by James Ryder, John and Paul Griffiths, Glenn Milne, Belinda Chase, Mike Balzar, Steven Hegarty (Vanderfield), Graeme Sutton (Bayer) and Trevor Philp (Pacific Seeds). Much of our field work would not be possible without the assistance of the field staff at the Hermitage Research Station and the Regional Research Agronomist network. The DAF Biometry team, in particular Kerry Bell, has provided valuable assistance with the analysis of trial data.

Contact details

Melina Miles
Queensland Department of Agriculture and Fisheries
203 Tor St, Toowoomba, Qld.
Ph: 0407113306
Fx: 07 46881199
Email: melina.miles@daf.qld.gov.au

Soil water workshop concurrent session

Better profits from good soil water decisions

Peter Wylie and Simon Fritsch, AgriPath

Key words

Soil water, water use efficiency, yield gap, rotations, opportunity cropping

Take home message

Profit on the average farm can be doubled by good planning of farming systems, operations, crop choice and attention to detail on crop agronomy. Crop margins can be improved by optimising soil water storage and making decisions based on soil moisture, seasonal outlook and time of planting.

Water Use Efficiency benchmarks can be used to estimate attainable yield for various amounts of soil water or the total water available, if looking back in hindsight. WUE has a wide variation and the accuracy of estimating attainable yield is improved if benchmarks are used for low, medium and high yields. For wheat and sorghum these WUE benchmarks in the Northern Region are 9, 12 and 15 kg/ha/mm for low, medium and high yields respectively.

Introduction

Average farm profit on grain farms in Queensland, according to ABARE surveys, is around 2-3% Return on Assets Managed (ROAM). From here there a large gap, to move up to the profits achieved by the Top 20% of benchmarked farmers, of 8 to 10% ROAM. Top performing farms produce an additional \$500,000 profit each year compared to their peers.

Part of this profit gap is the difference between average farm yields and the attainable yields which result from good farming practices. Across the Northern Grain Region this yield gap is some 50 to 90%. Farm profitability would more than double with a 50% increase in yield.

Closing the yield gap requires getting a lot of things right, which requires time to be spent on management, seeking advice and planning for good crop margins and farming operations.

Good yields are about more than weeds and fertilisers. Farming systems are the key to good profits. Well-planned rotations which manage disease, nematodes and weeds can provide extra gains in crop yields, by improving timeliness and reducing grain losses from weather risks.

Yields are a product of soil water, in-crop rainfall and water use efficiency. Good farm profits depend upon making good decisions based on soil water and profit margins which might be achieved from various planting opportunities.

1. Impact of soil water on yield and gross margins

Good practices for storing rainfall during fallow may result in an extra 20mm of soil water, which on the average can result in an extra 400 kg/ha of wheat and around 50% more profit. Extra soil water, not only produces more grain, it improves the water use efficiency on the total amount of water used by the crop.

The results of wheat yields at Dalby, modelled using APSIM, show an extra 27mm of soil water increased WUE from 9.5 to 10.5 kg/ha/mm and yield by 579 kg/ha. At Roma an extra 25 mm increased yield by 442kg/ha.

Table 1. Effect of soil water capacity on water storage and crop yield
APSIM modelling by G. Mclean, DAFF Qld. 2014

Soil PAWC mm	Wheat May 30 Plant	Planting soil water	In-crop Jun - mid-Oct	Harvest soil water	WUE kg/ha/mm	Yield average kg/ha
150	Dalby	144	188	28	9.5	2885
180	Dalby	171	188	29	10.5	3464
	Increase	27			21	579
150	Roma	133	164	23	8.7	2383
180	Roma	158	164	24	9.5	2825
	Increase	25			18	442

Profit would increase from \$160/ha to \$276/ha with an extra 27mm at Dalby, a rise of 60% and for a yield increase of 0.35 t/ha from an extra 20mm at Roma, profit would rise 65% from \$128 to \$196/ha.

2. Optimising soil moisture

Building a healthy soil is the key to good infiltration of rainfall. In most seasons there is some heavy rainfall which causes runoff during a summer fallow. Soil cover is maximised by zero-tillage and a well-planned rotation. With minimal compaction as a result of controlled traffic the soil will have an improved infiltration rate. With high levels of organic matter input, soil structure and earthworm numbers improve over the years, rather than decline.

At Dalby, rainfall during a summer fallow is 460 mm on average, of which around 25%, or 115 mm is stored for the next crop. Most soils can store much more than this and good fallow management may increase storage to 28% and result in average soil water storage of 130mm.

Good control of weeds during fallow is important for good water storage. Delayed weed control or a few escapes can quickly reduce the water stored by 20 mm or more. A good rotation program is important for managing weeds and herbicide resistance.

Residual herbicides can keep down weed control costs and help in managing glyphosate resistance grass weeds. Residual herbicides can also improve timeliness by taking the pressure off the fallow spraying, when weed control in hot weather is needed in a short space of time. Residual herbicides require planning and sometimes locking in a crop sequence, to avoid problems with plant back periods and effects on the following crops.

Good spray techniques are important for good weed control and soil water storage. Farmers should seek advice on nozzle selection, water rates, adjuvants, speed of spraying and weather.

3. Attainable Yield projections based on WUE

Rather than use a fixed estimate of attainable wheat or sorghum yields for a district, it is more useful to calculate attainable yield using water use efficiency (WUE) benchmarks for a particular soil type or the amount of soil water available.

WUE calculations in summer rainfall areas need to take into account soil moisture at planting and harvest. Evaporation is variable in the Northern Grains region. It should be ignored, because it shows high WUE in a dry season when in fact it can be quite low. WUE is calculated by dividing grain yield by water available, which is soil water at planting, plus in-crop rainfall less an estimate of soil water at harvest.

Data from 200 farm and trial observations on wheat in the Northern Region over the 7 years 2005 to 2013, has shown an average yield of 3.36 t/ha with a WUE of 12.3 kg/ha/mm.

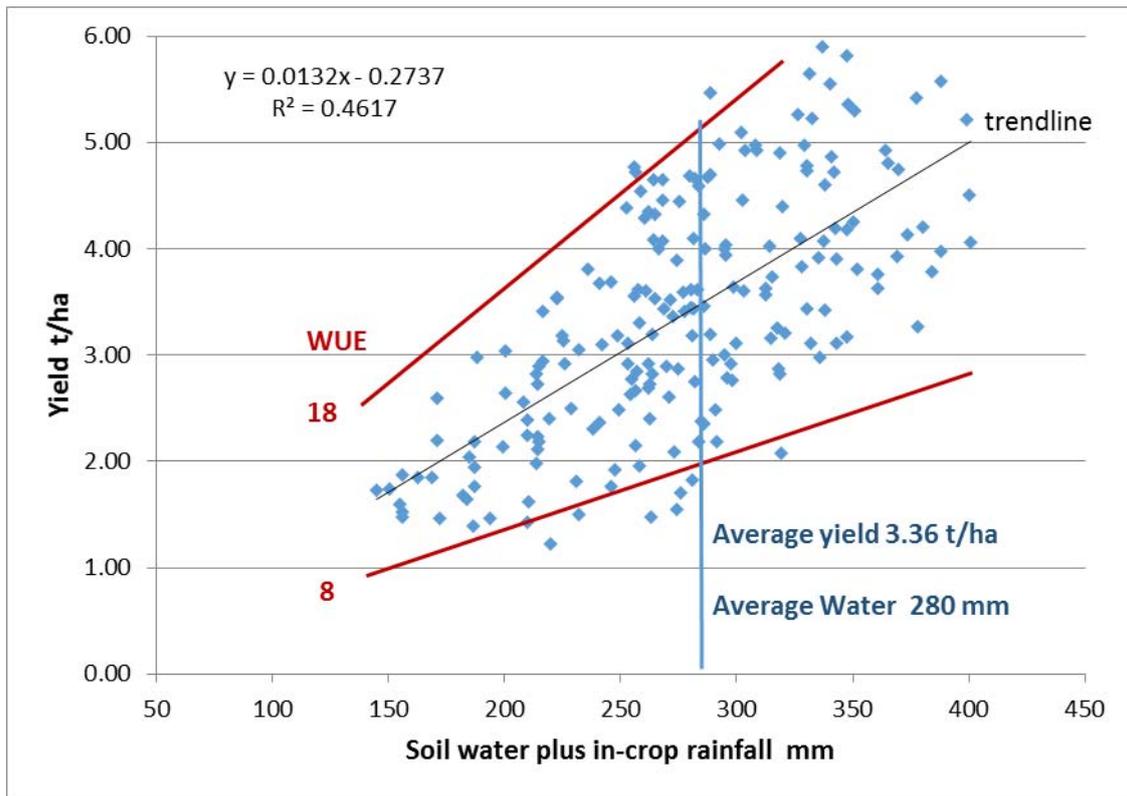


Figure 1. Yield of wheat vs water available in the Northern Grains Region (Trial data and farm records 2005-2013, collated by Agripath)

WUE is mostly within the range of 8 -18 kg/ha/mm, with the major variation being an increase in WUE as the yield increases. One explanation for WUE improving is the increase in Harvest Index, which is the ratio of grain to the total above ground biomass. At low yields the harvest index is low due to fewer heads per plant, each with less grains and lower grain weight. The harvest index of wheat is 0.2 at a yield of 2 t/ha and peaks at 0.4 when yields are above 4 t/ha. (See Figure 2)

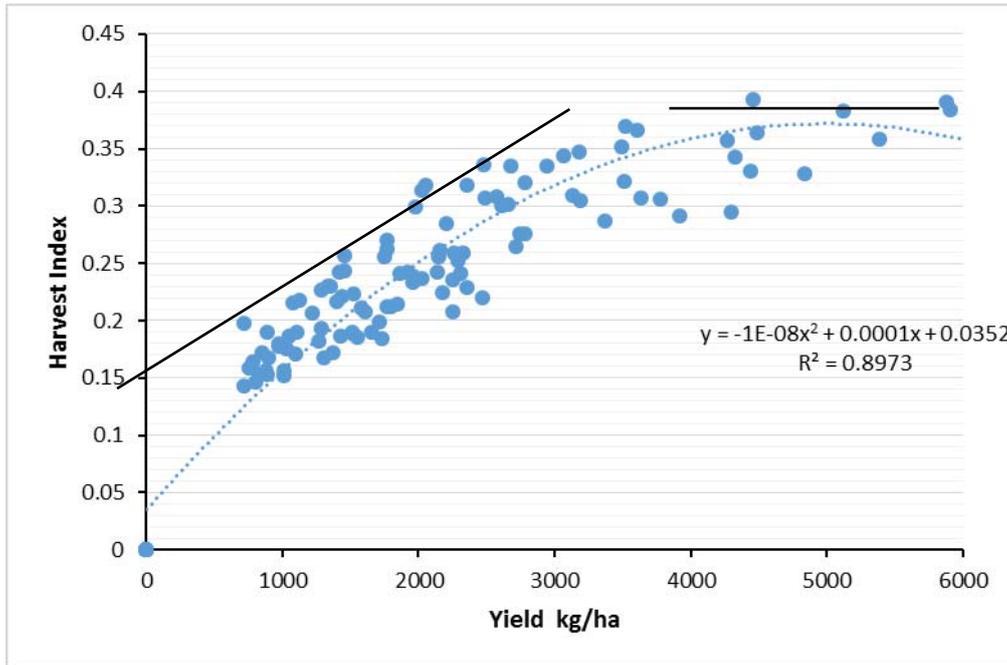


Figure 2. Harvest Index of wheat at Dalby (100 years of Apsim simulated yields)

Table 2. WUE data and benchmarks at low, medium and high yield levels

Data is from trials and farm records, across the Northern Grains Region: 2007-2013

	Low yield	Medium	High yield
Wheat yield range	<2.5 t/ha	2.5-4 t/ha	>4 t/ha
Observed WUE	9.01	11.86	15.07
STDEV	1.87	1.92	2.04
Benchmark for WUE	9	12	15
Sorghum yield range	<3 t/ha	3-5 t/ha	>5 t/ha
Observed WUE	8.6	11.4	15.2
STDEV	1.48	2.13	2.60
Benchmark for WUE	9	12	15
Chickpea yield range	<1.5 t/ha	1.5-2.5 t/ha	>2.5 t/ha
Observed WUE	6.55	8.55	10.46
STDEV	1.02	1.61	1.81
Benchmark for WUE	7	9	11

The wide range in WUE values means that using the average of 12 kg/ha/mm is a crude benchmark. Using more than one number for WUE will improve the accuracy and usefulness of this benchmark, both in predicting yield and reviewing yield in hindsight. Data in Table 2, shows the average WUE for wheat in the Northern Region at low, medium and high yields.

These values for WUE are in accordance with the French and Schultz benchmark of 55 kg/ha of wheat biomass per mm of water transpired. When soil evaporation is included in the equation, 37 kg/ha of biomass is produced per mm of water (French and Schultz 1984). At a low yield level, with a harvest index of 0.2, there would be 7.4 kg/ha of grain per mm, rising to 14.8 kg/ha of grain, with a harvest index of 0.4 at high yields.

Attainable yields in the table below are derived from average rainfall and the WUE benchmarks derived from a mix of trial and farm data. They compare well with APSIM modelled yields which show variation in potential yield for soils of different plant available water capacities (150 to 200 mm).

Average rainfall during summer, from November to May, at Dalby is 460mm, with the potential to store 130 mm of soil water. An extra 30 mm of soil water at the start of the fallow brings this to 160 mm on average at wheat planting. With average winter rainfall from June to September of 173 mm this means 303 mm of water is available to a wheat crop, which at 12.5 kg/ha/mm is an attainable yield of 3.78 t/ha.

Table 3. Attainable yield estimates of wheat and sorghum in Southern Queensland

Attainable wheat yield (t/ha) – Southern Qld - May 30 plant								
	Planting soil water	In-crop Jun - mid-Oct	Soil water at harvest ¹	Available water (mm)	WUE kg/ha/m ²	Yield average ³	APSIM yield 150mm ⁴	APSIM yield 180mm ⁵
Roma	138	152	22	267	11	2.94	2.38	2.82
Goondiwindi	141	176	25	292	11.5	3.35	3.4	3.92
Meandarra	135	151	27	260	11.5	2.99	2.63	3.07
Dalby	160	173	30	303	12.5	3.78	2.9	3.83
Pittsworth	165	180	31	314	12.5	3.92	3.8	4.82
Attainable sorghum yield – September 30 plant								
Springsure	148	139	44	243	11	2.67	4.56	5.57
Roma	150	200	35	315	11	3.46	3.55	4.32
Goondiwindi	149	203	28	324	12	3.89	3.61	4.34
Dalby	162	248	40	369	15	5.54	4.88	6
Pittsworth	167	263	41	390	16	6.24	6.08	7.33
<ol style="list-style-type: none"> 1. Soil water at harvest time estimated by APSIM – average over 100 years 2. WUE benchmarks from trial and farm data collated by Agripath 3. Yield calculated from average rainfall (Rainman) and WUE 4. APSIM simulated yield over 100 years, for a soil with 150mm PAWC 5. APSIM yield with 180mm PAWC soil, 200mm at Dalby and Pittsworth 								

4. Making decisions on double crops

Decisions on which crops to grow and the rotation program are important for good farm profit. Changes to fallow length and planting opportunity crops should be based on potential crop margins, which are influenced by soil water and commodity prices. Too much opportunity cropping can result in a string of low margin crops and low farm profitability. Including some long fallow in cropping plans can reduce risk and boost profit in dry years.

In the example below, the combined margin of a double crop of mungbean and the following crop of sorghum is less than a sorghum crop on long fallow. This may not always be so and depends upon the price. The key is to evaluate the potential margin of the crop based on soil moisture and to decide whether it is good enough to proceed.

Table 4. Margins from crops with different fallow length and price

	Mungbean double crop Average \$/t	Sorghum after mungbean	Sorghum on long fallow	Mungbean double crop High \$/t
Yield (t/ha)	1	3.5	6	1
Price	680	240	240	1200
Gross \$/ha	680	840	1440	1200
Fertiliser:	30	118	178	30
Seed	40	35	35	40
Fallow sprays	40	40	60	40
Weeds, Pests	75	45	45	75
Fuel & Repairs	90	90	105	90
Harvest costs	50	50	55	50
Freight & Misc.	45	92	145	45
Labour and machinery	160	190	215	160
Total costs	530	660	838	530
Gross Margin	150	180	602	670

There are advantages of long fallows, where soil water storage allows, such as reducing the pressure of harvest and allowing more use of residual herbicides – which may in turn help manage herbicide resistance and keep down the cost of fallow weedicides.

Decisions on fallows and other aspects of crop sequencing should be made to favour the most profitable or pillar crop. If sorghum is the pillar crop, then it might be appropriate to grow some or all of it on a long fallow from wheat or barley. If chickpea is the most profitable crop, then it is not given the best opportunity for yield if it is all grown as a double crop after sorghum. If there is not a reasonable amount of soil water to grow as a double crop after sorghum, some chickpea may be grown on a fallow. In western districts, sorghum might well be late planted and harvested in May or June. A fallow over the next summer may store good soil moisture for a high margin chickpea crop.

5. WUE declines with soil water and planting time

One of the most important determinants of wheat yield is the decline in yield which occurs with delays in planting. The WUE of wheat declines around 0.5 kg/ha/mm for each week of delay past the optimum time around mid-May, increasing to 0.8kg/ha/mm after mid-June. Yield loss from late planting is worst in dry years with a hot finish. If WUE is 12 kg/ha/mm for wheat at Dalby, planted in mid-May, it will decline to around 8 kg/mm for wheat planted in early July.

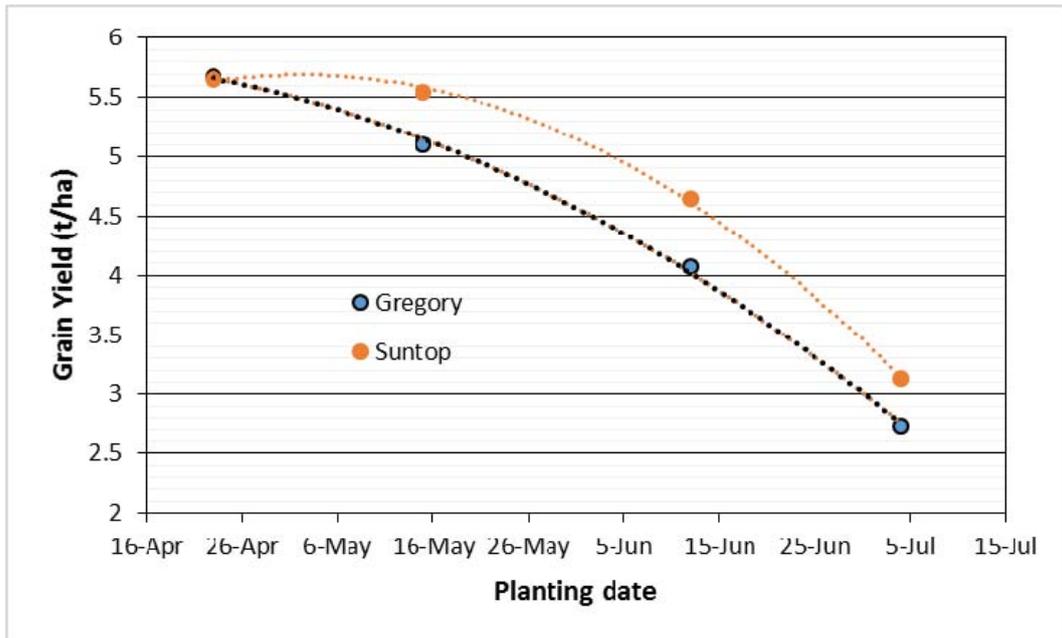


Figure 3. Yield of wheat at four sowing times, Narrabri 2014 (Graham et al 2015)

The loss in yield makes a huge difference to profit potential, with estimates of profit from wheat at the optimum time of more than four times that of wheat planted six weeks late.

Table 5. Effect of planting time on WUE, yield and profit of wheat.
Data from Agripath benchmarking

	Darling Downs Good soil water: 150 mm		Darling Downs Low soil water: 90 mm	
	mid May	Late June	mid May	late June
Wheat planted:	mid May	Late June	mid May	late June
Average water (mm)	295	295	235	235
Water use efficiency	12.8	9	11	7.7
Yield (t/ha)	3.78	2.65	2.58	1.81
Price	250	250	250	250
Gross \$/ha	944	664	646	452
Fertiliser	134	104	100	90
Seed	30	30	30	30
Weeds, Pests	75	75	75	75
Fuel & Repairs	90	90	90	90
Harvest costs	50	50	50	45
Freight & Miscell.	91	75	74	62
Labour & Machinery	181	181	181	181
Total costs	651	605	600	573
Gross Margin	293	59	46	-120

This loss from late planting is much greater than the risk of loss from frost. Even late plantings can be damaged by frost, while it is not much of a proposition to grow wheat with a profit potential which

may be less than \$50/ha. See Table 5. This effect of planting time on profit highlights the benefits of moisture seeking on wheat margins, if more wheat crops can be planted at the optimum time.

6. Using yield estimates to vary management decisions

Yield estimates using soil water and WUE benchmarks can be useful for making better decisions on fertiliser and other aspects of crop agronomy, such as varietal selection or seeding rate.

An example is that sorghum yield potential in the higher rainfall areas is likely to exceed 10t/ha in 30% of years, but yields in these years are likely to be limited by nitrogen supply. Adjusting N application at planting can be profitable using yield estimates at planting, based on soil moisture and seasonal outlook. Improved soil moisture and seasonal outlook (Table 6) show rising yield estimates. The SOI is more useful for summer crop than winter crop and rainfall for much of the Northern Grains Region is greater on average with a positive SOI, rather than a negative one.

A second way to improve nitrogen supplies to improve sorghum yields in above average rainfall years is to apply feedlot manure or recycled organics. An application of 10 t/ha of feedlot manure will contain around 160 kg N, mostly in an organic form. In a dry summer there will be little nitrogen released from the manure, but in a wet season, 30 to 50 kg of N may be mineralised. If an additional 40 kg N becomes available in a wet season, it could be enough to improve sorghum yields by 2.5 t/ha, assuming grain protein in a high yielding year is likely to be around 8%.

Table 6. Nitrogen required by Sorghum according to soil moisture and seasonal outlook – Dalby

Soil water mm	In-crop rainfall SOI <-5*	Average expected rainfall	In-crop rainfall SOI >+5*	Expected WUE kg/ha/mm	Yield estimate t/ha**	Nitrogen required kg/ha
80	218			11	3.28	56
80		245		11.5	3.74	63
80			266	12	4.15	70
160	218			14	5.29	90
160		245		15	6.07	103
160			266	16	6.82	116
**Water use efficiency rises from 11 to 16 with increasing yield						
*SOI is for August and September prior to a Sept 30 sowing, with data from Rainman.						

A third way to improve the supply of N for a good year is simply to increase the annual N fertiliser rate. If the rate was increased to 22kg N/t., rather than a 17kg/t target, this would result in an extra 30 kg N being applied for a yield estimate of 6 t/ha. The extra N could increase yield by around 1.5 t/ha in a good year. If 4.5 tonnes of extra sorghum was produced in the highest yielding 3 years over a 10 year period, this could be worth \$1000 for an outlay of \$420/ha. In the drier seasons, some of the extra N would be exported from the farm as higher protein levels in the grain, but overall the extra N might contribute to a small increase in N reserves in soil organic matter.

7. Rotations and resilient farming systems

Good farming systems involve crop selection, rotations, sound practices for zero-tillage and planting, combined with good risk management. Well-planned rotations which manage disease, nematodes and weeds not only improve crop yields, they can improve timeliness, keep down costs and reduce grain losses from weather risks.

It is not possible to make good profits without managing problems such as nematodes and crown rot. In combination these two problems could be dragging down wheat yields by 20% and profit by 40%. Nematodes require a plan to keep soil populations low, using break crops, such as sorghum and canola. New varieties of wheat, such as Suntop , offer potential to suppress nematode populations.

Management of weeds, particularly glyphosate resistant summer grass weeds, is another factor driving decisions on rotations. Rotation plans which include some fixed cropping plans and long fallows can pave the way for increased use of residual herbicides to help reduce costs and to better manage glyphosate resistance.

Timeliness of operations, a poor strike or harvest losses can affect yield and drag down profit. A rotation program which provides diversification of crops can make a big difference to the timeliness of planting and harvesting. For example, a program with barley, wheat and chickpea has a planting and harvest window spread over two or three weeks, rather than one week for wheat alone.

8. Monitoring moisture and analysing data on yield, WUE and profit

In most years, somewhere on the farm, a high yielding area of crop shows what is possible. Yield maps, EM surveys, soil moisture and fertility testing and trials measured by yield maps can help to understand yield differences and the limitations of soils on a farm.

Moisture is the key to grain yields and measuring soil water holding capacity and soil water at planting time can improve decision making. EM measurements allows rapid assessment of soil moisture and soil moisture variability across paddocks.

Benchmarking of crop yields and WUE can indicate where there may have been problems with such things as fallow moisture storage, timeliness or not enough fertiliser.

References

- French R. and Schultz J. 1984. Water use efficiency of wheat in a Mediterranean-type environment. 1 The relation between yield, water use and climate. Aust. J. Agric. Res. 35(6) 743-764
- Graham R. 2015. Wheat variety response to sowing time. GRDC Grains Research Update Goondiwindi.

Acknowledgements

The research undertaken as part of this project is made possible by the growers and the support of the GRDC, the author would like to thank them for their continued support. Some of the information comes from a GRDC project: The economics of closing the Yield Gap in the Northern Grains Region.

Contact details

Simon Fritsch
Agripath Pty Ltd
21 Bourke St, Tamworth, NSW
Mb: 0428 638 521
Email: simon@agripath.com.au

Peter Wylie
Agripath Pty Ltd
4 Alfred St, Dalby, Qld 4405
Mb: 0429 361 501
Email: peterwylie@agripath.com.au

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General plenary session day 2

Weeds and crop stubble as a pathogen 'host' or reservoir. What species are involved with what crop impact - implications for management A PhD presentation

Sue Thompson^{1,2}, Stephen Neate¹, Yu Pei Tan³, Roger Shivas³, Elizabeth Aitken⁴

¹ University of Southern Queensland, Toowoomba Q;

² PhD candidate, University of Queensland, St. Lucia Q;

³ Ecosciences Precinct Herbarium, DAF, Dutton Park. Brisbane Q

⁴ University of Queensland, St. Lucia Q;

Key words

Diaporthe, *Phomopsis*, Fusarium, pathogens, survival, alternative hosts, weeds, stubble, residues, sunflower, sorghum, soybeans, mungbeans

GRDC code

DAQ00186

Take home message

1. Green and Brown Bridges are aiding survival of some pathogens.
2. Dead weeds as well as crop stubble and live crop and weed alternative hosts can provide an inoculum reservoir for pathogens.
3. *Diaporthe/Phomopsis* species can have multiple hosts and more than one species can infect a single host.
4. Familiarisation with the pathogens in each crop of the rotation and their means of survival, plus a whole of farming system overview is essential to minimise build-up of pathogens.

A study initially investigating the pathogen(s) responsible for damaging lesions on sunflower has revealed an unexpected twist which highlights not only the role of live plants as alternative hosts but also dead weeds left in and around zero and low till cropping systems.

Diaporthe/Phomopsis species are known to cause serious stem cankers on sunflower and soybean, pod and stem blight in soybeans, cankers on many other crops such as grapes, roses and lupins in Australia and overseas, plus a range of other diseases on a wide variety of plants. A serious outbreak of stem canker on sunflower on the Liverpool Plains in 2010 was the catalyst for investigations to quantify the diversity of *Diaporthe* species initially on sunflower but then on other crops, to gain an understanding of the host range of these species and to study different modes of survival in northern farming systems.

To date, eleven new *Diaporthe* species have been described from this study including the highly virulent *D. gulyae* (Persoonia Journal Thompson et al. 2011, Thompson et al. 2015). Glasshouse inoculations revealed that *D. gulyae* was the most virulent species on sunflower, and highly virulent on soybean, chickpea, safflower, lupin and a range of other potential crop hosts.

Since the commencement of this study, 1700+ isolates of *Diaporthe* from both living plants and dead stubble of crops and common weeds have been collected, purified, stored, and most have been identified using both morphological and molecular techniques. As well as the eleven newly described species, another 10+ will be formally described in the future. In Australia, to date 13 *Diaporthe* described or new species have now been isolated from sunflower stem cankers, and 11 species

associated with live soybean plants. *Diaporthe helianthi*, a highly damaging species on sunflower in the United States and Europe, has not been found in Australia.

From a management perspective, identifying alternative hosts and the pathogenicity of these new and known *Diaporthe* species for each host is of importance. Using a combination of isolations from field grown plants and crop residues from infection trials at Gatton, field crop and weed plants, crop and weed residues and artificial inoculations in glasshouses and growth cabinets, it has been revealed that all of these new species have a range of crop hosts (Table 1).

Table 1. Some examples of moderately- and highly-virulent *Diaporthe* species isolated from field grown live (L) and dead (D) plants or stubble and seeds (S) of crops and weeds

Host	<i>Diaporthe</i> species			
	<i>gulyae</i>	<i>kongii</i>	<i>masirevicii</i>	<i>novem</i>
Crops				
chickpea		L	L	
sunflower	L, D,S	L	L, S	LD
soybean	L	L	L,D	
mungbean	L	L	L	
Maize	L	L	L	
Weeds				
bathurst burr	L, D			
bishop's weed	D			
bitou bush			L	
cobblers peg	D,L			
mallow				D,L
noogoora burr	L, D			
saffron thistle	L			
sesbania	L		L	
thornapple	D			D
turnipweed	D	L, D	L, D	D,L
vetch				D

For example,

(i) *D. gulyae* is highly virulent on sunflower, chickpea, soybean and mungbean, and has been isolated from naturally-infected, field grown plants of soybean, sunflower and mungbean.

(ii) *D. kongii* is highly virulent on chickpea, sunflower and mungbean, and has been isolated from naturally infected plants of chickpea, sunflower and mungbean.

(iii) *D. masirevicii* is highly virulent on chickpea, soybean, sunflower, lupin, and mungbean, and has been isolated from field grown plants of all except lupin.

(iv) Multiple *Diaporthe* species have been isolated from seed (sunflower, soybean, sorghum, lupin, other crops) — of significance for broadening the distribution of seed borne pathogens.

Diaporthe kongii, *D. gulyae* and *D. masirevicii* have been isolated from symptomless, field grown plants of maize suggesting that these species may form an endophytic association with maize plants, which is highly significant from the context of aiding survival on 'non-host' crops in the rotation.

The wide host range of many of these *Diaporthe* species also extends to live and dead plants as well as residues of common weeds in the northern region (Table 1). For example, *D. gulyae*, the most virulent of all species discovered during this study has been isolated from lesions on live plants of the crops sunflower, soybean, and mungbean as well as the weeds bathurst burr, noogoora burr, saffron thistle and sesbania and cobblers peg, and from dead plants of bathurst burr, bishop's weed, cobbler's peg, noogoora burr, thornapple and turnipweed. Another new species, *Diaporthe masirevicii*, which has moderate virulence on soybean and sunflower, has also been isolated from living plants of the weeds bitou bush, sesbania and turnip weed.

Other recognised *Diaporthe* species have also been identified from a range of hosts. The first record of *Diaporthe novem* in Australia was recorded from a sunflower crop on the Darling Downs. This species has subsequently been found associated with a range of crop and weed hosts including thornapple and turnip weed and is also highly virulent soybean and a range of other potential crop hosts.

These findings are very significant and have important implications for northern farming systems. Firstly, *Diaporthe/Phomopsis* species have been shown to be capable of being:

- (i) pathogens of a range of crop and weed species causing stem lesions (in mungbean, sunflower, soybean and weeds)
- (ii) lodging and yield loss in sunflower when conditions are conducive, and early senescence, pod infection and yield loss in soybean
- (iii) saprophytes by invading and surviving on dead plant residues of many crops and weeds,
- (iv) potential endophytes which invade plants of certain hosts, eg., *D. gulyae* in maize without displaying symptoms.

Consequently, depending on the *Diaporthe* species, living volunteer plants of crop hosts and living plants of weeds in paddocks and adjacent areas can act as the "green bridge" between highly susceptible crops, while colonised dead plants and stubble of crop and weed hosts can act as the dead or "brown bridge" between major crops. Almost 30 months after the severe *Diaporthe* lodging event in sunflower crops on the Liverpool Plains, *D. gulyae* was isolated from the 'brown bridge' of sunflower and noogoora burr stubble lying on the soil surface after zero till farming practices and two cereal crops planted into the sunflower stubble.

Although this study has focussed on the *Diaporthe/Phomopsis* species, many other known pathogens have also been identified. This indicates that crop and weed residues are also aiding survival of other genera such as the *Fusarium* spp. (eg. root, leaf and head infection in sorghum), *Colletotrichum* spp. (eg. leaf, stem and pod infection of soybeans), *Sclerotinia* spp. (500+ crop and weed hosts), *Macrophomina* spp. (charcoal rot of sorghum, sunflower, mungbeans and soybeans) and *Alternaria* spp. (leaf spots multiple crop hosts).

In some cases, species are also surviving in non-damaging infection sites such as small necrotic spots on the 'green bridges' of crop plants and weeds. For example, *Fusarium andiyazi*, one of the sorghum stalk rot pathogens, was identified from a leaf spot on a live plant of the weed vetch on the edge of a cultivation at Moree; *D. ambigua* (damaging lesions on stone fruit trees overseas and not previously recorded in Australia) was isolated from small lesions on sunflowers at Nobby in Qld, noogoora burr at North Star and thornapple stubble near Carroona in NSW.

This study reveals that *Diaporthe/Phomopsis* species have wider host ranges than previously thought and suggests it is considered likely that the same will be found for other groups of pathogens such as the *Fusarium* species which are also opportunistic colonisers of both live and dead plant tissues.

It is apparent that these fungi form a group of pathogens/saprophytes that are potentially capable of surviving on both "brown" and "green" bridges between growing seasons in the northern region and that the role of weed stubble in aiding survival has been largely unrecognised. Since the introduction

of zero and minimum tillage systems, crop and weed stubble is commonly found across the various cropping systems of the northern region. An inoculum reservoir can be found in these residues regardless of the presence of the primary crop host.

The impact of strategic tillage on the survival of these groups of pathogens in crop and weed residues under Australian conditions is largely unstudied. Crown rot researchers, (Simpendorfer et al. NSW DPI) have looked at the role of tillage for the *Fusarium* crown rot pathogen in Australia and multiple tillage investigations have been completed by overseas researchers.

A GRDC funded project has been initiated with the aim of looking more intensively at alternative hosts and survival of the *Fusarium* species on sorghum as well as early studies on the impact of burial on infected sorghum. (J White, USQ. DAQ00186).

Generally, it is well recognised that the incidence of stubble borne pathogens is increasing in the northern region farming systems – this *Diaporthe/Phomopsis* case study reveals that infected weed stubble, as well as the more commonly accepted crop stubble left on the soil surface, is providing inoculum reservoirs for significant crop pathogens across northern region farming systems. It also highlights the importance of considering a whole of farming systems approach for the control of pathogens rather than concentrating on the pathogens of each crop individually.

Collaboration between Ms Thompson and the SARDI team led by Dr Alan MacKay has led to the development of primers and probes for six *Diaporthe/Phomopsis* species which infect a range of crops. When complete, the PreDicta B® type test will allow stubble testing for *Diaporthe gulyae*, *kongii*, *novem*, *sojiae*, *masirevicii* as well as a biosecurity tool for the exotic *D. helianthi*. Initial validation tests for *D. gulyae* and *D. kongii* in sunflower and soybean stubble will commence in the near future. These probes have the potential to be used for commercial sunflower and soybean production and have the potential to expand into other crops.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC which funded this work and to USQ and UQ for their continued support.

Additionally, the authors would like to thank Pacific Seeds (Advanta) for provision of a trial site and upkeep over a number of years – without this site much of this work could not have been successfully undertaken.

We also thank Nuseed and KB Ornamentals, PB Agrifoods, NSW DPI researchers and extension personell and the DAF Hermitage Pulse Team for their ongoing support and generous assistance as well as the many growers and advisors in all regions who have enthusiastically provided samples for analysis and access to sites for inspection.

To the Australian Sunflower Association and Australian Oilseeds Federation – thank-you for your long term moral support and monetary assistance for attendance to disseminate the results of this study at many conferences and meetings, state, national and international, over many years.

Contact details

Sue Thompson
CCH, University of Southern Queensland
West St, Toowoomba Q 4350
Mb: 0477 718 593
Email: sue.thompson@usq.edu.au

Reviewed by: Prof. Stephen Neate, Centre for Crop Health, USQ. Toowoomba. Qld.

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Recent improvements in biomass partitioning and transpiration efficiency of modern Australian wheat varieties – any opportunity for the future?

Andrew Fletcher and Karine Chenu

University of Queensland, Queensland Alliance for Agriculture and Food Innovation (QAAFI)

Key words

Wheat, water-use, tillering, staygreen, drought, breeding

Take home message

- By selecting for greater yield in rainfed conditions, Australian wheat breeders have historically selected indirectly for varieties with greater transpiration efficiency, which produce more crop per drop.
- Modern wheat cultivars have less infertile tillers, and less early senescence than a few decades ago. They allocate more biomass to reserve and reproductive organs.
- Tiller viability and early staygreen are reaching a maximum with limited room for progress in the future.
- Further improvement could be made in transpiration efficiency, to breed for varieties which produce more crop per drop.

In Australia, wheat is mainly grown under rain-fed conditions and experiences major water stress that limits productivity (Chenu *et al.*, 2013). Although severe water stresses are expected to slightly decrease in the Northern Region in the coming decades, drought is projected to remain a major limitation for wheat yield (Watson *et al.*, 2015; Lobell *et al.*, 2015).

While the physiological responses of wheat to water deficit are very complex, it is likely that traits associated with drought tolerance have been indirectly selected through conventional breeding programs in drought-prone areas. By looking at fifteen elite Australian cultivars released between 1973 and 2012, possible changes in traits related to drought adaptation were investigated. Cultivars were chosen to have with wide adoption and narrow phenological range: Suntop[®] (2012), Scout[®] (2010), Mace[®] (2009), Gladius[®] (2007), Drysdale[®] (2002), Wyalkatchem[®] (2001), Yitpi[®] (1999), Krichauff (1997), Frame (1994), Janz (1989), Machete (1995), Spear (1984), Hartog (1982), Warigal (1978), Condor (1973).

Plants were grown at a density of 100 plant m⁻² in the 'Pot in Bucket' (PIB) system adapted from Hunter *et al.* (2012), and had a continuous supply of water from independent water jugs, which allowed transpiration to be measured for each pot from 25 days after sowing until flowering. Phenology, plant growth and development were recorded weekly. Transpiration efficiency was calculated as the ratio between dry biomass over cumulated water transpired from 25 days after sowing until flowering.

No trending change in plant biomass, but an increased proportion of resources goes to reserve and reproductive organs.

Plant biomass did not significantly change between 1973 and 2012 (Fig. 1a) but the partitioning of that biomass changed (Fig. 1b-f). Modern varieties tended to partition more biomass to stems and spikes, at the expense of the leaves. Interestingly, the decrease in leaf biomass was a result of a decrease in dead leaves, while green-leaf biomass at flowering did not significantly change over the last decades. Hence, breeders seem to have indirectly selected for lines with reduced pre-flowering senescence that invest an increasing amount of resources towards reserve and reproductive organs, which ultimately translates in greater yield (Sadras and Lawson, 2013).

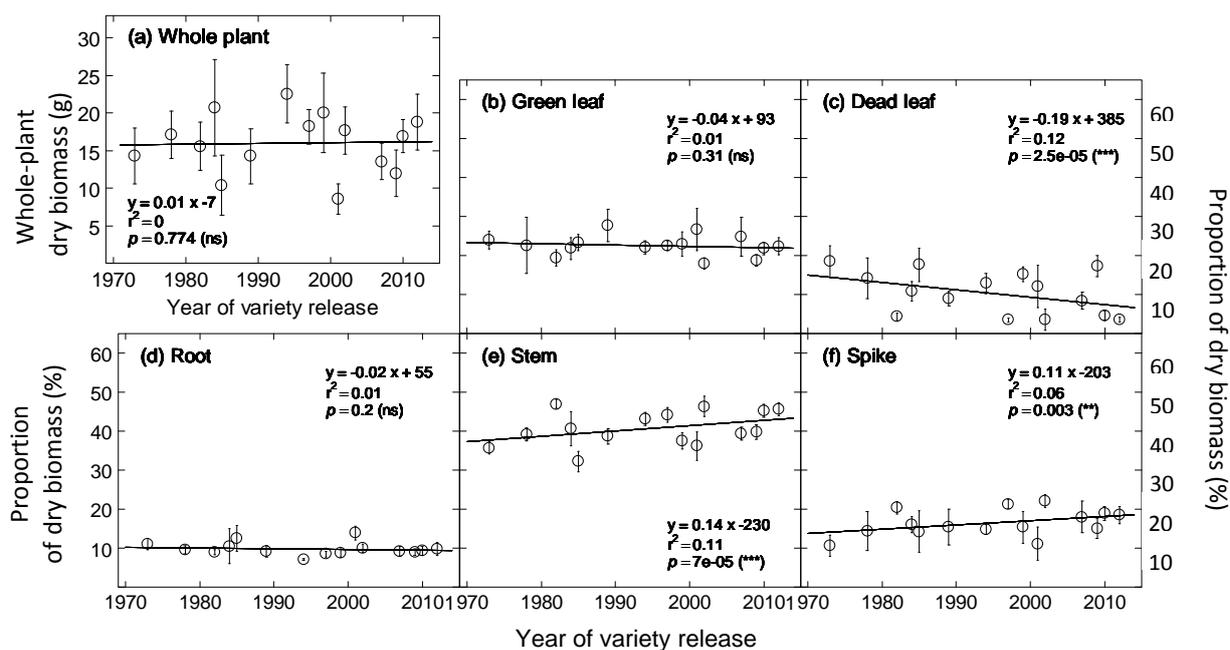


Figure 1. Change in biomass over year of variety release for (a) whole-plant dry biomass, and the portion of dry biomass allocated to (b) green leaves, (c) dead leaves, (d) roots, (e) stems, and (f) spikes at flowering. Error bars correspond to 95% confidence interval ($n = 5-10$). Linear regressions were calculated on row data (individual pots for root biomass or individual plants for all other traits). Abbreviations: ns, not significant; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.

For the varieties studied, the proportion of biomass allocated to the stems and the spikes at flowering has increased by +0.14% and +0.11% per year, respectively. The most noticeable effect was for the spikes which increased from 13 to 18% of total plant biomass over the last four decades (Fig. 1f). For comparison, the stem portion increased from 37% to 42% during the same period (Fig. 2e).

This change in partitioning can be at least be partly explained by a change in tillering (Fig. 2). While the number of total tillers has slightly but significantly decreased, the number of fertile tillers has substantially increased (from 5.5 to 7.0 between 1970 and 2010; Fig. 2b). Accordingly, the number of infertile tillers has drastically and very significantly decreased to the point that most modern varieties have almost no infertile tillers (Fig. 2c).

Overall, the changes observed in tillering, senescence and biomass partitioning reflect that modern varieties (i) invest less resources in plant structure that die relatively early during the crop cycle, but (ii) accumulate more biomass in reproductive organs (spike) and in reserve tissues (stems), which can benefit yield under late drought conditions (Dreccer *et al.*, 2009).

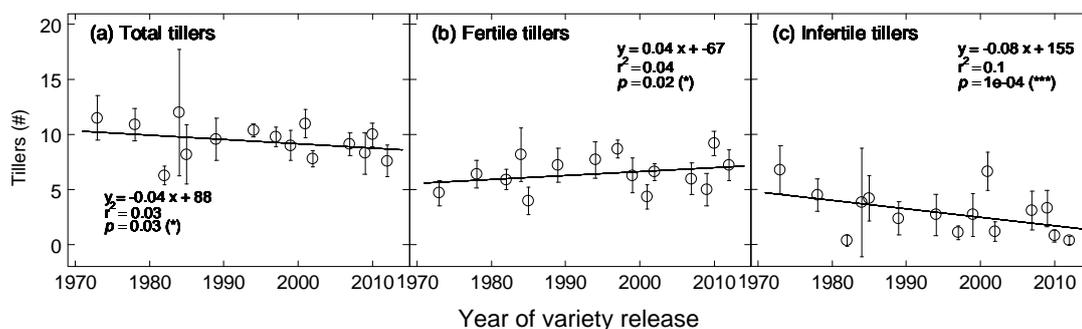


Figure 2. Change in (a) tiller number, (b) fertile tillers, and (c) infertile tillers at flowering, over year of release. Error bars correspond to 95% confidence interval (n = 10). Linear regressions were calculated on row data (individual plants). Abbreviations: ns, not significant; *, p < 0.05; **, p < 0.01; ***, p < 0.001.

Transpiration efficiency has significantly increased between 1973 and 2012.

While modern cultivars seem more efficient in partitioning their resources towards reproductive organs, they were also found to be more efficient in converting transpired water into plant biomass (Fig. 3). Plant transpiration efficiency (Fig. 3) has increased significantly with the year of release.

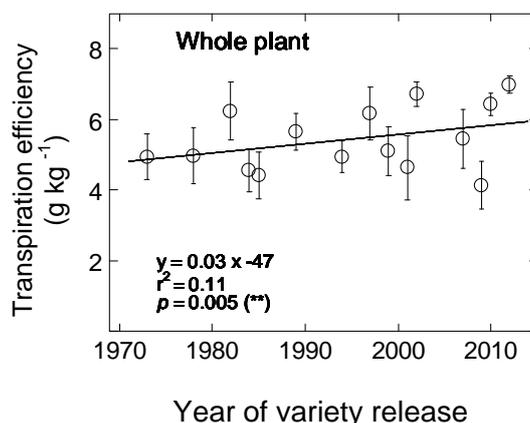


Figure 3. Change in transpiration efficiency for whole-plant dry biomass for varieties released between 1973 and 2012. Error bars correspond to 95% confidence interval (n = 10). Linear regressions were calculated on row data (individual plants). Abbreviations: ns, not significant; *, p < 0.05; **, p < 0.01; ***, p < 0.001.

Conclusion

While this study was conducted under well-watered conditions, it revealed substantial changes in traits likely to be beneficial under drought conditions. A significant trend in increasing number of fertile tillers was observed with the year of release, while the number of total tillers and infertile tillers significantly decreased. Modern cultivars had less early senescing leaves but maintained a similar plant leaf area and green-leaf biomass to older varieties at flowering. Most importantly, a significant increase in transpiration efficiency was observed for modern varieties. To put these results into perspective, during the 70s wheat varieties were producing approximately 4.8g of biomass for every litre of water transpired, while modern varieties have increased biomass accumulation to just over 5.8g per litre. Overall, modern wheat cultivars were able to use approximately 500g less water per plant up to flowering, which for a density of 100 plants m⁻² corresponds to a saving of 50 mm of water. In the Northern Region, such pre-flowering water saving would result in the field in a greater reserve of soil water for use during grain filling, thus allowing to reduce terminal drought.

Promising variability exists for transpiration efficiency and could be used to assist breeders developing lines that produce more crop per drop.

Acknowledgements

This study was funded by the University of Queensland and the ARC Centre of Excellence for Translational Photosynthesis, with some support from GRDC projects.

References

- Chenu, K., Deihimfard, R. & Chapman, S. C. (2013). Large-scale characterization of drought pattern: a continent-wide modelling approach applied to the Australian wheatbelt spatial and temporal trends. *New Phytologist* 198(3): 801-820.
- Dreccer, M. F., van Herwaarden, A. F. & Chapman, S. C. (2009). Grain number and grain weight in wheat lines contrasting for stem water soluble carbohydrate concentration. *Field Crops Research* 112(1): 43-54.
- Hunter, M., Mitchell, J. & Dieters, M. (2012). Semi-automated, non-weighing, pot-in-bucket (PIB), water management in pot plant culture. In *16th Australian Agronomy Conference* Armidale, NSW, Australia: Australian Society of Agronomy.
- Lobell, D. B., Hammer, G. L., Chenu, K., Zheng, B., McLean, G. & Chapman, S. C. (2015). The shifting influence of drought and heat stress for crops in northeast Australia. *Glob Chang Biol* 21(11): 4115-4127.
- Sadras, V. O. & Lawson, C. (2013). Nitrogen and water-use efficiency of Australian wheat varieties released between 1958 and 2007. *European Journal of Agronomy* 46(0): 34-41.
- Watson, J., Zheng, B., Chapman, S. & Chenu, K. (2015). Impact of projected climates on drought occurrence in the Australian wheatbelt. In *17th Australian Agronomy Conference*, 4 Hobart, Australian.

Contact details

Dr Karine Chenu
The University of Queensland, Queensland Alliance for Agriculture and Food Innovation (QAAFI)
203 Tor Street
PO Box 102
Toowoomba, QLD 4350
Ph: 07 4688 1357
Fx: 07 4688 1193
Email: karine.chenu@uq.edu.au

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Understanding & managing N loss pathways

Mike Bell (QAAFI), Graeme Schwenke (NSW DPI) and David Lester (DAF Qld)

Key words

Nitrate denitrification, ammonia volatilisation, N use efficiency, ¹⁵N recovery, summer sorghum

NANORP codes

01202.027; 0102.004

Take home message

- Over the past 3 years, we have had 6 experiments with isotope-labelled (¹⁵N) urea fertiliser in northern NSW and a further 11 in southern Qld, all focussed on measuring the fate of applied N fertiliser in summer sorghum. Normal fertiliser contains ¹⁴N so the use of ¹⁵N allows us to trace the fate of urea-N applied to the soil from sowing through to harvest.
- Between 56 and 100% of the applied N was found in the soil and plant at harvest, with in-season rainfall (both timing and amount) and soil C and N status having a major impact on the seasonal loss potential.
- Avoiding unnecessarily high N rates, delaying or splitting N fertiliser so that peak N availability coincides with peak crop N demand and relying on residual N from legume rotations all significantly reduced gaseous N losses from dryland sorghum, although the effectiveness of any management strategy varied with seasonal conditions.
- Nitrification inhibitor-coated urea significantly reduced nitrous oxide emissions in all studies, but did not improve grain yields enough to justify the additional cost on an agronomic basis.
- Depending on the season, delaying/splitting N applications gave either no yield benefit (dry season) or a significantly greater yield (good in-crop rainfall). Much of the unused N after a dry season remained in the soil and, provided loss events were not experienced during the fallow, significantly benefited the following crop.

Why the focus on N losses?

Fertiliser is a major contributor to crop variable costs, particularly in the northern parts of the region where soil organic matter and associated mineralisable N reserves continue to decline. This will continue to be the case unless the legume frequency in crop rotations increases substantially compared to that typically used (i.e. typically 1 legume crop in every 4-6 crops grown – Edwards *et al.* 2012).

Given the substantial investment in N fertilisers, there needs to be considerable attention to factors that affect the efficiency of use of applied N (NUE), with indices such as crop recovery of applied N (kg fertiliser N accumulated in the crop or in the grain/kg N applied) and the agronomic efficiency of N use (kg additional grain produced/kg N applied) used to benchmark NUE. Any loss of applied N will affect NUE by reducing the pool of N that a crop can use to produce biomass and grain yield. Understanding the loss pathways and how they are influenced by seasonal conditions and management strategies are an important first step in optimising NUE for a given situation.

A recent survey of advisors throughout NSW and Qld (>150 advisors in total) showed the overwhelming majority recognized that N losses exist and can be significant, with a perception of increasing risks of losses in summer compared to winter cropping. There was also a perception of greater potential N losses (as much as 20-40% of applied N) in the northern part of the region, but given the unpredictability of environmental conditions that favour losses, few advisors actually

factor those losses into fertiliser recommendations. The results from our projects conducted in the recently completed NANORP initiative, funded by GRDC and the Department of Agriculture) provide some interesting insights into these losses in summer sorghum cropping.

Where do losses occur, how big are they & what are the drivers?

Essentially, nitrogen can be lost from cropping soils via **downwards, sideways or upwards** movement. **Downward** movement of nitrate [NO_3^-] via leaching is a greater problem in lighter textured soils than in the medium–heavy clays dominating the northern grains zone, but previous research has demonstrated some N losses, albeit small on an annual scale, can occur via this pathway.

Sideways movement can occur rapidly through erosion of organic matter rich topsoil during intense rainfall events, or more slowly through lateral subsoil movement of nitrate-N in soil water. The main **upwards** N loss pathways consist of gaseous losses through either ammonia volatilisation or denitrification of nitrate.

Ammonia volatilisation losses can occur soon after fertiliser is applied to soil, primarily when that fertiliser is surface applied. In previous research on northern NSW clay soils, we found losses from broadcast urea averaged 11% (5–19%) when applied to the surface of fallow paddocks, 5% (3–8%) when applied in a wheat crop (mostly dry soils), and 27% when applied to pasture. Ammonia N loss from pastures was higher as there was little rain after spreading. Nitrogen losses from ammonium sulfate were less than half the losses from urea at 2 pasture sites and 5 out of 8 fallow paddocks on non-calcareous soils, but were higher than urea (19–34% N loss) from fallowed soils with more than 10% calcium carbonate (Schwenke 2014).

A range of factors influence the actual amount of N lost through ammonia volatilisation. Fillery and Khimashia (2015) recently published a simple model to predict ammonia volatilisation losses from fertiliser applied to moist soils. Their model starts with a maximum potential loss figure which is then discounted according to input factors including clay content, soil pH, fertiliser rate, rainfall in the week after application, presence of a crop canopy, and the placement of the fertiliser. Their model predicted the losses we measured in our fallow studies fairly accurately, but was not used on our studies in wheat paddocks where the potential for loss was deemed minimal due to the dry surface soil. In our field study we found that wind-speed after fertiliser application was also related to the amount of N lost over time.

Nitrate denitrification losses can be large, but require the simultaneous occurrence of low soil oxygen availability (an extreme examples is when soil is waterlogged for an extended period), high soil nitrate concentration (soon after soils have been fertilized) and readily available (labile) carbon to support an active microbial community. Clearly these set of circumstances do not coincide every year, but when they do, denitrification losses can be high, with rates of loss typically higher when soils are warmer in spring and summer rather than late autumn and winter. Interestingly, this is consistent with the survey information that the risk of N losses in the region was perceived to be greater in summer cropping and in the (warmer) northern cropping areas.

Unlike ammonia volatilisation, it is more difficult to quantify total N losses due to denitrification. This is because variable proportions of those losses can occur as N_2 or as N_2O , and direct measurement of denitrification losses in the field has so far only been able to quantify losses as N_2O . There are reports in the literature of the ratio of losses as $\text{N}_2:\text{N}_2\text{O}$ being anything from 1:1 to 70:1, depending on soil and environmental conditions. To put this uncertainty into perspective, this means the NANORP measurements of annual N_2O losses at fertiliser N rates delivering maximum yield of 1-2 kg $\text{N}_2\text{O-N/ha}$ could be indicative of total denitrification losses ranging from negligible to >100 kg N/ha. The use of nitrogen fertilisers labelled with the ^{15}N isotope allows the fate of applied N to be studied in greater detail, with the difference between fertiliser N applied and that recovered in the plant (tops and roots) or remaining in the soil after harvest representing fertiliser N lost to the

environment. In soils where fertiliser N has been banded below the soil surface and leaching losses are minimal (such as in the alkaline Vertosols), most of the unaccounted-for fertiliser N is presumed to have been lost via denitrification. When cumulative N₂O emissions data are available (such as in 12 of the 18 NANORP sites in Qld and NSW where ¹⁵N was used), the ratio of total N lost (from ¹⁵N results) to that lost as N₂O can be used to estimate the ratio of N₂ to N₂O for these summer cropping systems.

The impact of N source on loss susceptibility

Nitrogen for crop production can come from (a) soil organic matter, (b) crop residues—especially legumes, (c) manures, and (d) fertiliser. To minimise N losses, managers need to match zones and times of N supply with N demand (from crop production). Ideally, the N would be produced or added as the crop needs it, but it must also be available where the plant roots can access it, i.e. in soil with available moisture for active roots.

Mineralisation of organic matter, residues and manures to plant available N forms requires moist soil and warm temperatures, so rates of N produced are greater during summer than winter. How much mineral N is produced depends on the amount of organic matter in the soil, the amount of crop residues remaining and their N concentration, and the amount and type of manure applied, its N concentration and its method of application. In contrast, fertiliser N is either immediately available for plant use (in ammonium or nitrate forms) or soon available after conversion in soil (e.g. from urea to ammonium and nitrate).

Under non-waterlogging conditions nitrate [NO₃⁻] is the N form that is produced in the soil regardless of the original source, and will accumulate over time if no significant N losses occur. So, the principal impact of N source is in the timing and rate of mineral N accumulation in the soil. If a loss event occurs while mineral N is still being produced, only that already present as nitrate will be subject to loss. If a loss event occurs after all mineralisation or urea conversion through to nitrate has taken place, then the original source will have little influence on how much is lost. An advantage of mineralisation-sourced N is that its slower-release may see it progressively distributed throughout the soil profile by fallow rainfall, rather than being present in a concentrated zone if applied all at once from fertiliser.

Managing N losses from any of these sources requires matching the times-of-year the N becomes available with potential for intense rainfall events and the time-of-year that the N will be required by the crop. Since applying N fertiliser at sowing creates a pool of nitrate N in the soil that is largely not accessed by the crop during the first 2 months post-sowing, this nitrate is at risk of denitrification losses. In splitting N application between sowing and booting, we have demonstrated reductions of 58–81% in N₂O emitted (largely from denitrification), compared to urea all-at-sowing. In a dry growing season, the late-applied N may not have sufficient rainfall to enable its uptake for crop production, as we found in 2013-2014 sorghum season. However, in situations where there are no major loss events between one crop season and the next, this unused N may be available to the following crop in the rotation sequence. An example of this is discussed for unused fertiliser N from a split N application in NSW in 2013/14 season.

Use of urease & nitrification inhibitors to limit fertiliser N losses

Urease is a naturally occurring enzyme that increases the rate of conversion [hydrolysis] of urea [CO(NH₂)₂] to ammonium [NH₄⁺]. Urease inhibitors are applied with urea to delay this conversion and keep the urea in the urea form. When hydrolysis occurs it creates a localised zone of highly alkaline pH which further converts some of the ammonium to the gaseous form ammonia [NH₃], which can be lost from the soil surface by volatilisation. The greatest risk of volatilisation loss occurs when urea is broadcast onto a moist soil surface and is not incorporated into the soil via rainfall or soil covering. While there are many compounds that can inhibit the urease enzyme, the main one available for use

in Australian agriculture is NBPT [N-(n-butyl) thiophosphoric triamide], although it is actually the breakdown product of NBPT that is the inhibitor. Urea coated with NBPT has been shown to reduce ammonia volatilisation loss in a range of crop and pasture situations.

Nitrification is the process of conversion of ammonium [NH_4^+] to nitrate [NO_3^-] in the soil, so the use of a nitrification inhibitor with an applied fertiliser aims to delay this process and keep more of the nitrogen in the ammonium form. The reason for applying this inhibitor is to prevent N loss via nitrate leaching or nitrate denitrification, which occurs in anaerobic soil conditions (e.g. waterlogging). Losses from denitrification in dryland cropping are sporadic, but can result in up to 50% of the applied fertiliser N being lost to the atmosphere, mainly as di-nitrogen gas [N_2]. The greenhouse gas nitrous oxide [N_2O] is also emitted from the soil during denitrification. Unlike ammonia volatilisation, which only occurs at the surface, denitrification occurs within the soil wherever nitrate and labile carbon (as an energy source for the microbes which drive this process) are present. Denitrification gases [N_2 , N_2O] are not retained by soil adsorption, unlike ammonia [NH_3] which is easily adsorbed by soil surfaces. Some of the chemicals that can be used for nitrification inhibition include 3,4-dimethylpyrazole phosphate (DMPP), dicyandiamide (DCD), and 2-chloro-6-(trichloromethyl) pyridine. Urea coated with DMPP (commercially available as Entec[®]) has been shown in 4 northern NSW and 4 Qld trials to reduce N_2O emissions by an average of 85% (range: 65–97%) compared to uncoated urea. Despite the reductions in N_2O loss, there have generally been marginal or no benefits to grain production or gross margins from using DMPP that justified its additional cost compared to untreated urea.

Measurement of fertiliser N losses with ¹⁵N-isotope-labelling experiments (2012-2015)

During the past 3 years we have used isotope-labelled (¹⁵N) urea fertiliser to trace the fate of applied N in 6 season-long mini-plot field experiments with sorghum near Tamworth and Quirindi/Breeza in NSW, and in 11 experiments on the Darling Downs and Inland Burnett regions in Qld (Kingsthorpe, Kingaroy, Kupunn, Bongeen and Irongate). Normal fertiliser contains ¹⁴N so the use of ¹⁵N allows us to trace the urea-N applied into the harvested grain, the plant residues, large roots, and the soil profile after harvest. The difference between what we applied and the total of what was found after harvest was assumed to be the N lost by denitrification, as the urea was mixed/banded into the soil to minimise ammonia volatilisation, adjacent crop rows and soil were sampled to quantify any lateral movement and/or the mini-plots had raised steel borders to minimise surface runoff. Possible leaching of applied N was accounted for by deep coring of the mini-plots and measurement of mineral N to 150 cm depth.

Trial results

NSW sites (see Figure 1).

In 2012-13 experiments, total gaseous loss ($\text{N}_2 + \text{N}_2\text{O}$) ranged from 28–45% of applied N. At the Tamworth (drier) site, there was no effect of N fertiliser rate on the proportion lost (21%), while at the Quirindi (wetter) site, N losses were 43%, 44% and 27% from the 40, 120 and 200 kg N/ha treatments, respectively. It is likely that the proportion lost from the 200 N rate was lower because some of the excess nitrate N moved lower in the soil during the heavy rainfall period rather than being denitrified. Evidence for this was seen in the greater uptake of applied N into the grain protein in this treatment.

In 2013-14, a much drier sorghum-growing season, we used ¹⁵N either as (a) urea at sowing, (b) as urea applied at 7-leaf stage, or (c) as urea applied at sowing with a nitrification inhibitor. At the Tamworth site, there was no difference in total N lost between treatments (26%), but of the N applied only 10% was found in plant tissue at harvest when applied at the 7-leaf stage, compared to an average of 36% in the plant when N was applied at sowing. This is because there was only one rainfall event after the late-applied N fertiliser, so limited opportunity for plant N uptake after the

topdressing. At the Quirindi site, there was only 4% total N loss from the inhibitor treatment, compared to an average N loss of 20% from urea either applied at sowing or at 7-leaf stage. The main difference between the urea and the inhibitor treatment was in the extra 15% of applied N found in the soil at harvest in the treatment where the inhibitor had been used, compared to ordinary urea. Only 13% of the late-applied N was found in the plant tissue (including grain) at harvest, compared to an average of 28% in the other treatments applied at sowing.

In 2014-15, an ideal summer for sorghum growing (after a dry start), our treatments compared (a) urea added at sowing, and (b) urea split between sowing (33%) and 7-leaf stage topdressing (67%). At the Tamworth site, there were also two different N rates applied, depending on whether the previous crop was sorghum (120 kg N/ha) or soybean (40 kg N/ha).

Overall N losses averaged 29%, and were not affected by the previous crop, but were 4% greater when the N was applied all-at-sowing. The difference in N loss was an extra 4% found in the top 0-10 cm of the soil of the split N treatments; there was no difference in N recovery in the crop.

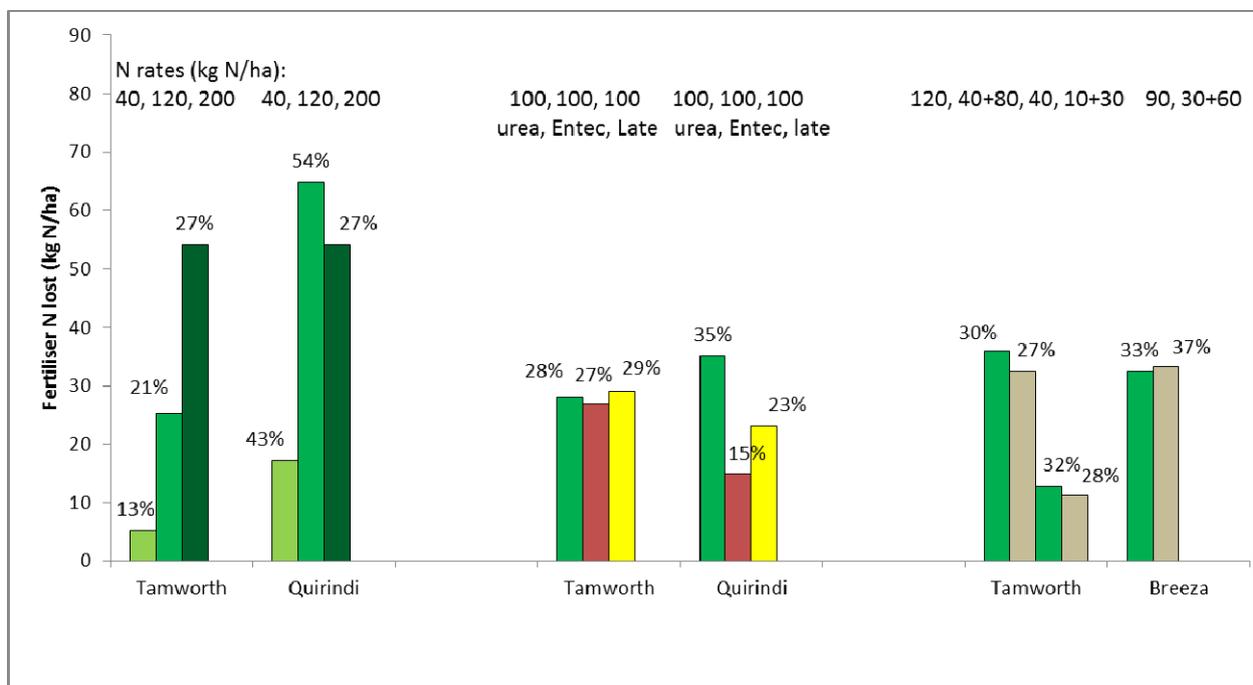


Figure 1. Losses of applied urea-N in field trials on Vertosol soils in northern NSW during the NANORP project. Losses were calculated from recoveries of ¹⁵N labelled urea in soil and plant material.

Qld sites (see Figure 2).

In a very wet 2012-13 season, total gaseous loss ($N_2 + N_2O$) ranged from 23–48% of N applied prior to or at sowing on black and grey Vertosols but was minimal with split applications on a brown Ferrosol near Kingaroy with very low soil N reserves. On the Vertosol sites at Kupunn (sown early October) and Kingsthorpe (sown late November) losses tended to increase with fertiliser N rate, representing 23%, 40% and 47% at Kupunn and 34%, 46% and 48% at Kingsthorpe for the 40, 80 and 120 kg N/ha rates, respectively. The high losses in the 80 and 160 kg N/ha rates at Kupunn emphasised the vulnerability of any excess fertiliser N supply (optimum N rate was 80N at that site) remaining in the soil during a late season wet event (block received 100mm and was flooded near physiological maturity). Conversely, the N_2O -N emissions monitored at Kingsthorpe suggested most losses occurred in response to prolonged wet (not waterlogged) soil in the 6-8 week period following

sowing and fertiliser application (i.e. before most crop N uptake occurred). For this site-season combination the optimum N rate was ~170 kg N/ha.

At the Kingaroy site the interaction between rotation history (grass or legume ley pastures) and N rate was explored, with the higher fertiliser N requirement after the grass ley (100 kg N/ha versus 70 kg N/ha after the legume ley) resulting in similar crop yields but emissions intensities (kg N₂O-N/t grain yield) twice as high as in the legume history.

The 2013-14 season was much drier, as in NSW. Experiments again looked at losses in response to urea-N rate (Bongeen), while also comparing responses to urea to those from urea with a nitrification inhibitor (Kingaroy and Kingsthorpe). The impact of the inhibitor was assessed in terms of crop performance (growth, yield and N uptake), but total gaseous N losses determined using ¹⁵N were only assessed for the urea treatments. Losses were lower at all the Vertosol sites (13-30% of applied urea-N), but slightly higher in the Kingaroy site (15-25% of applied N), with the latter requiring frequent sprinkler irrigations (totalling 160mm) to provide enough water to grow the crop. The relationship between losses and N rate evident in 2012/13 was not as consistent in 2013/14, and was perhaps most evident at the irrigated Kingaroy site, where 14%, 18% and 28% of applied N was lost in the 40, 80 and 120N rates, respectively (optimum N rate at this site was ~120 kg N/ha). In the Vertosol sites the lower yields and crop demands (and hence lower optimum N rates) did not lead to large N losses during the growing season as there were few (2 at Kingsthorpe and only one, near physiological maturity, at Bongeen) significant rainfall events and most 'surplus' fertiliser N could be found as NO₃-N in the soil profile after crop harvest.

Despite 65-70% reduction in annual N₂O emissions in the treatments with the nitrification inhibitor at both sites, there was little agronomic benefit other than a slight (10-15 kg N/ha) reduction in the optimum N rate and a slight increase in yield (the latter at Kingaroy only) with the inhibitor. These responses were not sufficient to cover the price premium charged for the commercial nitrification inhibitor product (i.e. ~20% more/kg N applied).

2014-15 turned out to be a great sorghum growing season after a dry start that caused poor crop establishment and a replant at one early-sown trial site. We ran 5 experiments, with 3 again comparing rates of urea with urea and a nitrification inhibitor. The other sites either simply looked at urea N rate (Irongate early sown) or the interaction between N rates and crop rotation history (Kingaroy). In the later sown Vertosol sites that experienced wet conditions during early growth (Irongate late and Kingsthorpe) losses again increased with N rate, although not always as a proportion of N applied. Losses ranged from 15-45% of applied N, depending on site, with the contrast between the early and late sown Irongate sites particularly interesting. Fertiliser N was applied at the same time at both sites (planting of the successful early sown block), but there was no effective rainfall after that until flowering in the early block (and re-sowing of the late block). The lower losses of fertiliser N in the early sown block were related to the strong sink present (a well grown sorghum crop near flowering) when the fertiliser N was converted to nitrate-N by in-season rainfall, compared to the late sown block where nitrate rapidly became available but there was effectively no crop uptake for a period of 4-6 weeks, during which soils remained wet.

Once again, the reduction in N₂O emissions from use of the nitrification inhibitor was much greater than any effect on crop growth or fertiliser N requirement. The effect of grain legumes in the crop rotation on fertiliser N requirement, N₂O emissions and N losses was also consistent with the ley pasture trial in 2012/13 – fertiliser N requirements were less and N₂O emissions intensity was lower (by 25%) in the legume systems compared to back to back sorghum.

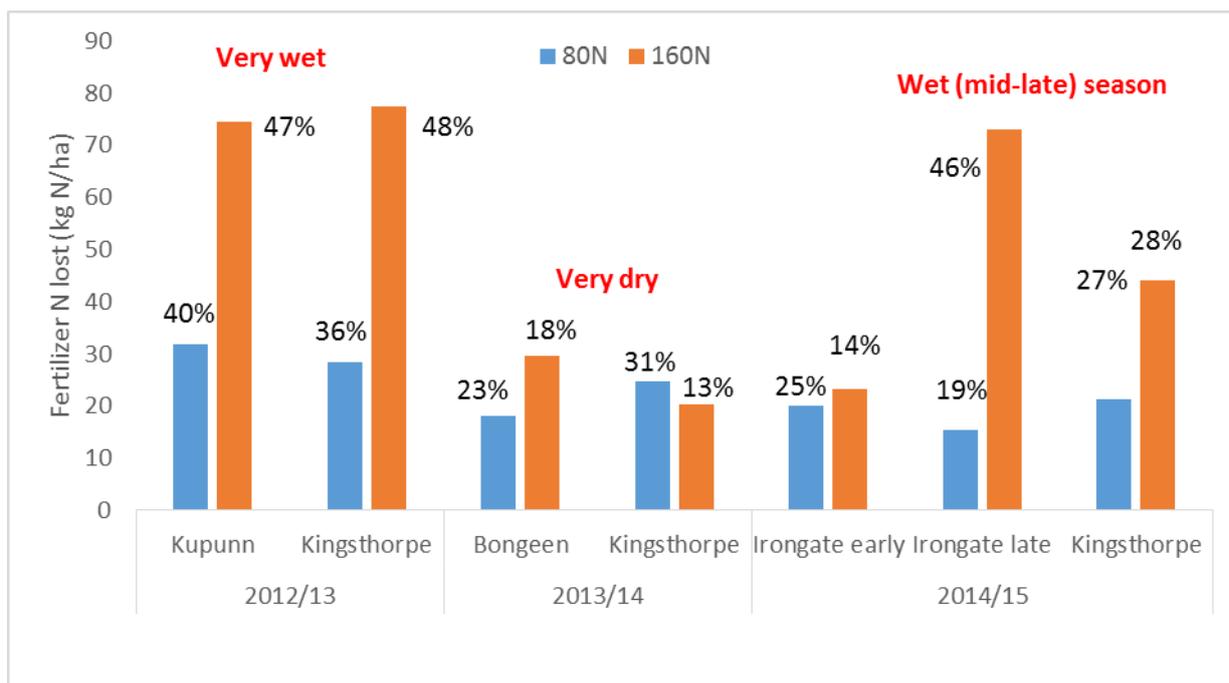


Figure 2. Losses of applied urea-N in field trials on Vertosol soils in Queensland during the NANORP project. Losses were calculated from recoveries of ¹⁵N labelled urea in either soil or plant material.

Local case studies illustrating management strategies to reduce N losses

NSW – Impact of timing of N application (Courtesy of Maurie Street and Ben O’Brien, GOA)

In 2015, two central-west wheat trials on nitrogen rate and timing of application showed poor crop N uptake by wheat when urea was pre-applied in late December 2014. At both sites (Narromine, Nyngan), the urea was drilled into sandy clay loam topsoils. The sites had already had 40-50 mm during December and another 30-40 mm followed in the week after N was applied. Another 140-180 mm of rain fell from January until sowing in early May 2015. The aim of these trials was to compare pre-applied N, at-sowing N and in-crop N applications on wheat production and grain protein. While the crop data is not yet available, in-crop sensing results (NDVI) indicated that the pre-applied N treatments were not showing the N-rate responses seen in the at-sowing N treatments.

Pre-sowing soil testing conducted in the pre-applied N plots was unable to account for 2–91% of the N applied in December, with greatest apparent losses in the 200 kg N/ha treatments at both sites. Profile results indicated little or no downward movement of mineral N below 30 cm depth in the soil. Nitrate denitrification was presumed to have caused much of these losses since the urea was incorporated into the soil. However, some ammonia may have volatilised from the soil surface of these light-textured soils. Weed N uptake and N immobilised by microbial breakdown of crop residues may also have accounted for some of the applied N.

Qld – Impact of legume N on fertiliser requirement and N₂O emissions

An experiment was established at Kingaroy to explore the impact of crop rotation (grain or grain legume pre-histories) on fertiliser N requirement and NUE during a subsequent sorghum crop in 2014/15. The pre-histories were sorghum, peanut or soybean in the 2013/14 summer, all harvested for grain. In the second summer crop year (sorghum), the fertiliser N rate required to achieve maximum sorghum grain yield (6.3 t/ha) was reduced by at least 50% after a peanut rotation (i.e. 60 kg N/ha compared to 120 kg N/ha) or eliminated totally after a soybean crop (i.e. no fertiliser N response). Fertiliser N losses determined using ¹⁵N recovery were negligible at the optimum N rate in each history (<5 kg N/ha), with 65-70% of the applied N accumulated in crop biomass at this high

yielding site. Regardless, cumulative N₂O emissions during the growing season and the emissions intensity (kg N₂O N/t grain produced) were 35% higher in the sorghum history with 120 kg N fertiliser/ha than in legume histories with 60 kg N fertiliser/ha.

Acknowledgements

This research was funded by the Australian Government Department of Agriculture, as part of the National Agricultural Nitrous Oxide Research Program (NANORP). However it was made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, and the authors would like to thank them for their continued support. In NSW, we gratefully thank Ian Carter for the use of “Connemara” and “Romney Vale” on the Liverpool Plains. Other trials were located on NSW DPI Research Stations near Tamworth and Breeza. In Qld we would like to thank Warakiri Ag Trust Manager Scott Reichelt, Andrew Ruhl and Peter Bach for the use of ‘Myola’, ‘Seacres’ and ‘Craigielee’, with other trials located on the DAF Research Stations at Kingsthorpe and Kingaroy.

Many people assisted with various aspects of field operations, sample processing and sample analyses. In NSW this included Matthew Gardner, Rick Graham, Peter Formann, Mustafa Kamal Hossain, William Keene, Kelly Leedham, Annabelle McPherson, Adam Perfrement, Peter Sanson, Zara Temple-Smith, Wayne McPherson, Guy McMullen, and Loretta Serafin (NSW DPI, Tamworth), while Leanne Lisle (UNE), Brad Keen, Stephen Kimber and co-workers (NSW DPI, Wollongbar) conducted various analyses.

In Qld the project team also included Prof Peter Grace, Dr Clemens Scheer, Dr David Rowlings and Dr Max de Antoni Migliorati (QUT), while the field program was managed by Gary Harch, Peter Want, Lawrie Smith, Peter Aegis, Rod Obel and Trish Balzer. Julie Renwick, Alice Strazzabosco, Rachael Nicholls and John Taylor (QUT) are recognized for their analytical work.

References

Fillery IRP, Khimashia N (2015) Procedure to estimate ammonia loss after N fertiliser application to moist soil. Soil Research (online early) <http://dx.doi.org/10.1071/SR14073>

Schwenke G (2014) Nitrogen volatilisation: Factors affecting how much is lost and how much is left over time. <http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Factors-affecting-how-much-N-is-lost-and-how-much-is-left-over-time>

Contact details

Mike Bell
University of Queensland
Gatton Campus, Gatton 4343
Ph: 07 5460 1140
Email: m.bell4@uq.edu.au

Graeme Schwenke
NSW DPI
4 Marsden Park Road, Tamworth
Ph: 02 6763 1137
Email: graeme.schwenke@dpi.nsw.gov.au

David Lester
DAF Qld
Leslie Research Centre, Toowoomba 4350
Ph: 07 4639 8886
Email: david.lester@daf.qld.gov.au

Nitrogen management in wheat – 2015

*Richard Daniel, Rachel Norton, Anthony Mitchell and Linda Bailey
Northern Grower Alliance*

Key words

Nitrogen, wheat, yield and protein

GRDC code

NGA00004: GRDC Grower Solutions for Northern NSW and Southern Qld

Take home message

1. The rate of nitrogen applied was the main factor impacting yield and grain quality (both positive and negative) in all trials
2. There was no significant benefit from polymer coated urea products compared to urea alone at any site
3. Urea spread immediately post sowing, and with no physical incorporation, provided equivalent crop responses to urea spread and incorporated by sowing
4. Split application of urea at 50 kg N/ha drilled preplant or incorporated by sowing followed by 50 kg N/ha spread in-crop at ~GS30 provided at least equivalent crop responses to urea at 100 kg N/ha spread and incorporated by sowing
5. Although grain protein levels increased with rate of N application at all sites, grain quality was reduced (screenings and test weight) in response to N rate at sites where yield losses occurred

In recent years, NGA have been heavily involved in projects focussed on nitrogen application strategies in wheat, particularly to assist the management of high yielding - and frequently lower protein achieving - wheat varieties such as EGA Gregory[®]. In 2015 the trial activity focussed on two main areas; 1) the impact of application timing on N responses and 2) a second year of evaluation of the fit of 'enhanced' urea products.

Method

Six trials were established in 2015 in paddocks nominated by agronomists and growers as low in nitrogen or expected to be N responsive. Unfortunately the site chosen near Billa Billa was later found to have a high variability in starting N and the trial was discontinued. EGA Gregory[®] was the test variety at all sites.

All trials were established using small plot planters with row spacings of 32cm and plot lengths of 9-12m. Five N application approaches were evaluated;

- Application A - N disc drilled preplant (late March/early April)
- Application B – N spread on soil surface on same date as Timing A
- Application C - N spread immediately before sowing and incorporated by sowing (IBS) with narrow point tynes
- Application D - N spread immediately post sowing (PSPE) and
- Application E – N spread in-crop at GS30

Table 1. Site details 2015

	Moree	North Star	Bellata	Narrabri	Macalister
Previous crop	Chickpea	Chickpea	Chickpea	Wheat	Maize
Available soil nitrogen preplant (kg N/ha)	71 (0-90cm) April 2015	41 (0-90cm) Jan 2015	68 (0-120cm) May 2015	83 (0-60cm) Feb 2015	64 (0-120cm) Feb 2015
Available soil nitrogen sowing (kg N/ha)	25 (0-30cm)	44 (0-30cm)	41 (0-30cm)	68 (0-30cm)	50 (0-30cm)
Applications A & B (preplant)	30/3/15	30/3/15	2/4/15	2/4/15	10/4/15
Timing and quantity of first rain preplant	8mm 1 DAA	74mm ~5 DAA	69mm 2-5 DAA	60mm 2-3 DAA	8mm 10-11 DAA
Applications C & D (sowing)	5/5/15	16/5/15	26/5/15	27/5/15	1/6/15
Timing and quantity of first rain post sowing	7mm 16 DAA	8mm 5-6 DAA	10mm 5 DAA	5mm 4 DAA	9mm 16 DAA
Application E (in-crop)	20/7/15	20/7/15	21/7/15	21/7/15	30/7/15
Timing and quantity of rain post in-crop application	62mm 3-5 DAA	51mm 3-5 DAA	13mm 3-7 DAA	4mm 2 DAA	4mm 26 DAA
Final NDVI assessment	10/9/15	10/9/15	15/9/15	15/9/15	7/9/15
In-crop rainfall (mm)	128	129	300	203	132

Available soil nitrogen = total soil mineral N kg/ha (to soil depth) using a bulk density of 1.3. It does NOT include any mineralisation credit. DAA= Days after application.

Urea was the main nitrogen formulation used with two polymer coated formulations also evaluated for impact on canopy management. Equivalent rates of total N/ha were applied as ESN (in a ratio of 60% ESN and 40% urea) or Agrocote N39 (in a ratio of 30% ESN and 70% urea).

Soil testing for N level was conducted twice. An initial sample for site selection but an additional shallow sample (0-30cm only) at sowing to determine whether the preplant N application had moved in the profile. The levels found at 0-30cm in the untreated at sowing were higher than expected, particularly at North Star, Bellata and Narrabri. This suggested increased levels of N mineralisation may have occurred since the initial testing and that these sites may have been less responsive to applied N.

Table 2. Treatments evaluated (rates in kg N/ha applied)

Application	Description	Urea	ESN	Agrocote N39
A	Disc drilled preplant	50, 100, 200	100	100
B	Spread at preplant timing	100	-	-
C	Spread and IBS	50, 100, 200	50, 100	50, 100
D	Spread PSPE	50, 100, 200	-	-
E	In-crop	100	-	-

NB the 200 kg N/ha rate was included in an attempt to over-fertilise.

In addition two split applications of a total of 100 kg N/ha were applied as urea to evaluate top dressing following either drilled preplant or IBS application. (50% at Timing A plus 50% at Timing E or 50% at Timing C plus 50% at Timing E).

Results

The large number of treatments were selected to allow a number of key comparisons. The three major comparisons of interest were:

1. **Nitrogen rate:** response to urea when applied at three rates and three key timing/application methods (drilled preplant v IBS v spread PSPE)
2. **Product:** all three products were drilled preplant at 100kg N/ha or applied via IBS at 50 or 100kg N/ha
3. **Timing:** urea was applied at a total of 100kg N/ha using five individual timing/application methods plus two split applications

Rainfall for incorporation of spread urea

Conditions for natural incorporation (rainfall) of urea spread at the preplant timing were considered good at all sites. Rainfall post sowing was much more limited but with 5-10mm within 5-16 DAA at all sites. Good rainfall (5-60mm within 2-7 DAA) was received at all sites except Macalister following in-crop application.

Were the trial sites nitrogen responsive?

The first objective was to determine whether the sites were actually N responsive. NDVI (Normalised Difference Vegetation Index) was used to provide an in-crop objective measurement of nitrogen response between treatments. Larger NDVI results indicate increased biomass and/or greener treatments. Figure 1 shows the NDVI results at each site from the factorial analysis of urea applied at three rates and Timings A, C and D.

Nitrogen rate comparison

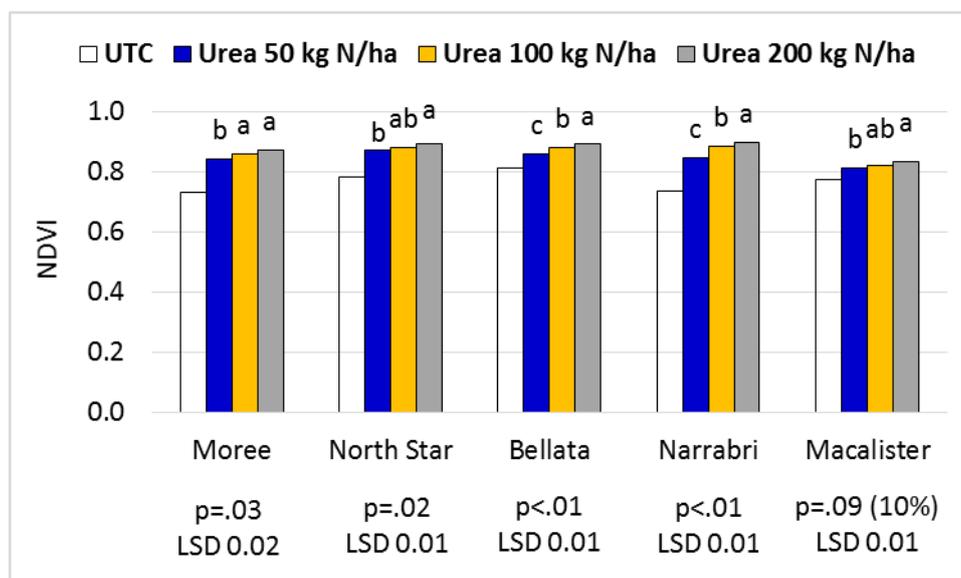


Figure 1. NDVI responses to nitrogen rate by trial site when assessed in mid-September. UTC= untreated (no additional nitrogen applied). UTC not able to be included in factorial analysis but graphed for reference. Treatments that share the same letter within each site are not significantly different at P=0.05, except Macalister where p=.10.

- **NDVI results (in mid-September) indicated all sites were responsive to added nitrogen.** This was visually apparent in 'greenness' of plots but also in increased biomass and density of crop canopy
- At Bellata it was estimated that the 200kg N/ha rate may have delayed maturity by ~10 days compared to the untreated
- The 100kg N/ha rate significantly increased NDVI compared to 50 kg N/ha at three of the five sites
- The 200kg N/ha rate significantly increased NDVI compared to 50 kg N/ha at all sites

NDVI data not presented

- **All treatments significantly increased NDVI compared to the untreated at all sites except Macalister** (12 of 19 individual treatments were significant at Macalister)
- There was no significant difference in NDVI response between the products at any site
- There was no significant difference in NDVI response between application timing or method for urea when applied at 100kg N/ha at 4 of the 5 sites
- However at Macalister, **urea drilled or spread preplant provided significantly higher NDVI response** than the IBS application
- At Macalister, **split applications of urea provided equivalent NDVI response** to IBS application
- At Macalister, **urea spread in-crop only resulted in significantly lower NDVI response** compared to IBS application

Key points

1. Significant NDVI/crop responses to nitrogen were recorded at all sites with **nitrogen rate the main factor**
2. Product differences were not apparent at the rates and timings tested
3. Conditions for ‘incorporation’ of nitrogen spread at either the preplant or IBS timings were sufficient to provide equivalent responses to the IBS application at all sites
4. Split application of nitrogen, with 50% at GS30, provided equivalent responses to IBS application at all sites

Yield

Nitrogen rate comparison

NDVI measurements provide an objective measure of crop response during the growing season but obviously yield and grain quality determine the economic outcome. Figure 2 shows the factorial analysis of yield when urea was applied at three rates and Timings A, C and D.

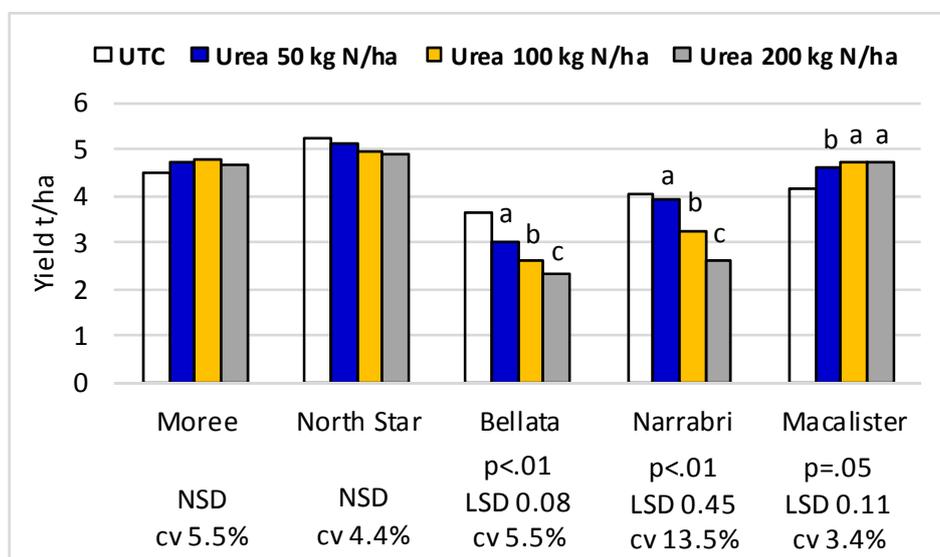


Figure 2. Grain yield responses to nitrogen rate by trial site

UTC= untreated (no additional nitrogen applied). UTC not able to be included in factorial analysis but graphed for reference. Treatments that share the same letter within each site are not significantly different at P=0.05, except Macalister where p=.10.

Despite all sites appearing N responsive when assessed for crop growth in mid-September, only one site recorded increased yields from N application, one site was unresponsive and three sites recorded reduced yields with N application

- At Moree, there was no significant difference in yield between any treatment and the untreated
- At North Star, 5 of the 19 individual treatments recorded significantly reduced yield compared to the untreated
- At Bellata, all individual treatments recorded significantly reduced yield compared to the untreated. There was a significant rate response with the 100kg N/ha rate significantly lower than 50kg N/ha, and 200kg N/ha significantly lower yielding than 100kg N/ha
- At Narrabri, 9 of the 19 individual treatments recorded significantly reduced yield than the untreated. There was also a significant rate response with the 100 and 200kg N/ha rates significantly lower yielding than 50kg N/ha

- At Macalister, all individual treatments recorded significantly increased yield compared to the untreated with 100 and 200kg N/ha significantly higher yielding than 50kg N/ha

Yield data not presented

- There was no significant difference in yield between urea and the two polymer coated formulations at any site when drilled preplant or spread and IBS
- There was no significant difference in yield from urea applied at 100kg N/ha at any timing or application method

Key points

1. Although the addition of nitrogen produced significant crop growth benefits at all 5 sites, yield benefits were only recorded at the Macalister site.
2. **Nitrogen rate was the key factor affecting yield**
3. There was no significant difference between the polymer coated urea products and urea alone
4. There was no significant difference in yield between timings and application method at any site
5. Bellata and Narrabri were both sites that recorded good levels of early rainfall in-crop but experienced a dry and hot September/October

The most likely explanation for the negative yield responses at North Star, Bellata and Narrabri is a combination of limited soil moisture during flowering/grain fill and the impact of N application on time of flowering combined with increased temperatures during grain fill in late October.

Grain protein

Nitrogen rate comparison

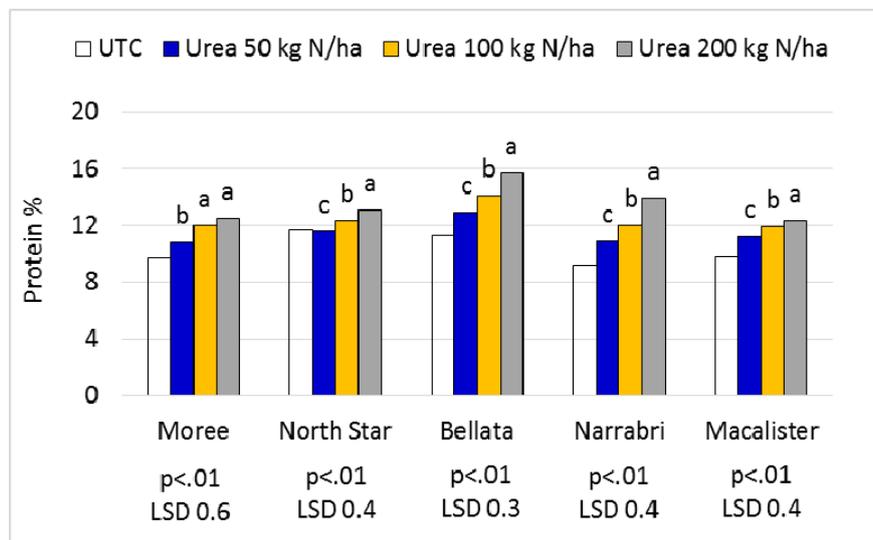


Figure 3. Grain protein responses to nitrogen rate by trial site

UTC= untreated (no additional nitrogen applied). UTC not able to be included in factorial analysis but graphed for reference. Treatments that share the same letter within each site are not significantly different at P=0.05

- **Analysis of grain protein levels showed all sites were responsive to added nitrogen**

- The 100kg N/ha rate recorded significantly increased protein levels compared to the 50 kg N/ha rate at all sites
- The 200kg N/ha rate recorded significantly increased protein levels compared to 100 kg N/ha at 4 of 5 sites

Grain protein data not presented

- There was no significant difference in grain protein levels between urea, ESN and Agrocote N39 at 3 of the 5 sites (North Star, Narrabri and Macalister)
- At Moree, there was no significant difference in grain protein levels between urea and Agrocote N39, however ESN recorded significantly lower protein (by ~0.5-0.7%) than the other products
- At Bellata, ESN and Agrocote N39 recorded significant lower protein (by ~0.3-0.4%) than urea. There was no significant difference between ESN and Agrocote N39
- There was no significant difference in grain protein levels between application timing or method for urea when applied at 100kg N/ha at 3 of the 5 sites (Moree, North Star and Narrabri)
- At Bellata, urea drilled preplant or spread at GS30 both provided significantly higher protein levels (by ~0.3-0.4%) than the IBS application
- At Macalister, urea either drilled or spread preplant, split applied at preplant and GS30 or applied PSPE all recorded significantly higher protein levels (by ~0.5-1.5%) than the IBS application
- At Macalister, urea drilled preplant recorded significantly higher protein levels than all other applications (by ~0.8-1.6%)

Key points

1. Grain protein levels in the untreated ranged from 9.2 to 11.7%
2. The addition of nitrogen resulted in increased grain protein levels at all sites with **nitrogen rate the main factor.**
3. Product differences were minor with no apparent benefit from either ESN or Agrocote N39 at the rates and timings tested
4. At sites where application differences were apparent, urea drilled preplant provided the highest protein levels
5. Urea spread PSPE provided at least equivalent grain protein levels to the IBS application at all sites
6. Split application of nitrogen, with 50% at GS30, provided at least equivalent protein levels to IBS application at all sites

Screenings

Nitrogen rate comparison

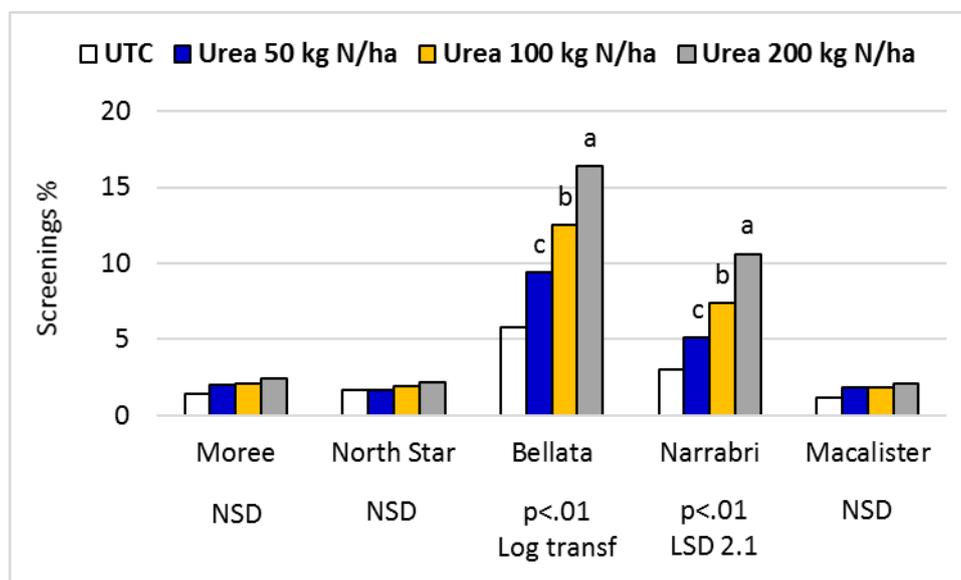


Figure 4. Grain screenings responses to nitrogen rate by trial site

UTC= untreated (no additional nitrogen applied). UTC not able to be included in factorial analysis but graphed for reference. Treatments that share the same letter within each site are not significantly different at P=0.05

- **At both Bellata and Narrabri, increasing N application rates significantly increased grain screening levels**
- Although there was no significant N rate response at Macalister, 8 of the 19 individual treatments recorded significantly higher screenings than the untreated

Grain screenings data not presented

- There was no significant difference in grain screening levels between urea, ESN and Agrocote N39 at any site
- There was no significant difference in grain screening levels between application timing or method for urea when applied at 100kg N/ha at any site

Key points:

1. **Grain screening levels significantly increased with N rate at the two sites (Bellata and Narrabri) that recorded significant yield losses to applied N**
2. There was no apparent difference between the products at the rates and timings tested
3. Application timing and method differences were minor compared to N rate, however at Macalister the three rates of drilled preplant application of N resulted in significantly increased screenings compared to the same rates spread and IBS (by ~0.7%)
4. There was no reduction in screening levels when urea was spread at preplant or PSPE compared to the IBS application at any site
5. There was no reduction in screening levels when urea was split applied, with 50% at GS30, or when 100% applied in-crop

Grain nitrogen recovery (data not presented)

- Grain nitrogen recovery (yield t/ha x protein % x 1.75) was calculated to assess the efficiency of fertiliser use
- Using the 50 kg N/ha rate, the recovery levels at Narrabri and Moree were 20 and 26% respectively
- At Macalister the recovery level from the 50kg N/ha rate was 45%
- At North Star and Bellata, there was less N recovery in fertilised treatments than the untreated

Economics

Receival grade prices at the end of October 2015 had a wide range of ~\$70/t between APH and HPS1 classifications. Figure 7 shows the net benefit/loss across all sites for rates of urea alone.

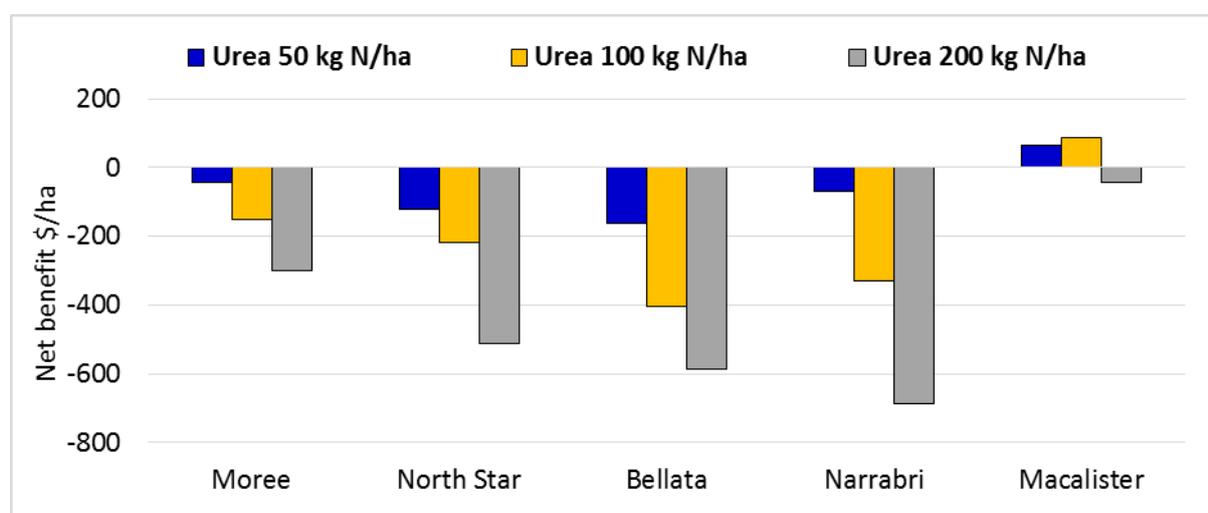


Figure 5. Net benefit responses to nitrogen rate by trial site

Assumptions: urea at \$1.30/kg N (\$600/t), spreading cost of \$25/ha/application, drilled application at \$40/ha, grain prices delivered Moree 29/10/15: APH \$267/t, H2 \$250/t, APW \$237/t, AUH2 \$227/t, ASW \$225/t, AGP \$207/t and HPS \$197/t

- **Despite all sites appearing N responsive during September, net benefits were only obtained from N application at the 50 or 100kg N/ha rates at the Macalister site**
- **The results reinforce the need to try to match N application rate with yield potential and soil moisture availability**
- At Macalister, 12 of the 19 individual treatments recorded a net benefit ranging from \$1-\$163/ha

Conclusions

The results in 2015 comparing urea with the polymer coated urea products were very similar to 2014. Despite all sites being responsive to increasing N rate for both crop growth and protein, there was no apparent benefit from the polymer coated products. However in four of the nine trials, ESN has recorded significantly lower protein than achieved with urea alone and indicates the polymer coating is clearly having an impact on N availability.

The rate of N applied has been the dominant factor affecting yield and grain quality across all nine trials in 2014 and 2015. Preplant application in 2015 appeared more vigorous in early winter assessment but only provided a significant benefit at the Macalister site.

The performance of urea spread and not mechanically incorporated has continued to provide equivalent results to incorporated urea at the same timings – unfortunately this also applied to

situations where yield losses occurred! In 2015, useful levels of incorporating rain were received at all sites following the preplant applications however rainfall levels were much lower following the PSPE application and with a longer delay from application. Although spreading urea preplant or PSPE is certainly not being promoted, the results continue to support the N volatilisation results achieved by Dr Graeme Schwenke and indicate in-crop application may be less risky than previously considered in the northern region.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support.

NGA would particularly like to acknowledge the assistance from Jason Schelberg, Ian Webster, Hugh Ball, Simon Doolin, Drew Penberthy and the Frater family for 2015 trial activity together with Kalyx staff for trial planting, maintenance and harvest. In addition we would like to thank Landmark, Impact Fertilisers and Pacific Seeds for product supply and technical support.

Contact details

Richard Daniel
Northern Grower Alliance
Ph: 07 4639 5344
Email: richard.daniel@nga.org.au

Ⓟ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994

Microwave technology for weed management

Graham Brodie

Key words

Weed management, Herbicide resistance, Microwave heating, Soil health, Crop response

GRDC code

UM00053

Take home message

Microwave heating, using a suitable device to project the microwave energy onto plants and the soil, can:

1. Kill weeds and their seeds in the field, without limitations of wind or moisture;
2. Kill dormant seeds in the soil;
3. Significantly reduce bacterial numbers in the top layer of the soil; however these populations recover to become significantly higher than their initial values within a month of treatment;
4. Not significantly affect fungi or protozoa in the soil; and
5. Significantly increase grain yields in a number of crops, including canola and wheat.

Herbicide resistance is becoming an important problem in Australia no-till farming systems. Many weed species have developed multiple resistance to different herbicide groups. Several strategies have been suggested to address this issue, including tillage, flaming, and steam treatment. Many of these strategies are not compatible with no-till strategies.

A sustained research programme has demonstrated that microwave heating, using a suitable device to project the microwave energy onto plants and the soil, can kill weed plants and their seeds. Microwave treatment is not affected by incumbent weather conditions such as wind or rain.

The following species have been tested with good success: Ryegrasses – annual and perennial; barnyard grass; barley grass; bellyache bush; brome grass; clover; feathertop Rhodes grass; fleabane; hemlock; mimosa pigra; parthenium; rubber vine; wild oats; and wild radish. The microwave energy density required to kill plants varies according to the species.

Microwave treatment significantly reduces bacterial numbers in the top layer of the soil; however their numbers rebound to a significantly higher population after one month (Table 1). Microwave treatment has no measurable effect on fungi or protozoa in the soil.

Microwave soil treatment also significantly increases the yield and maturation rate of subsequent crops grown in the treated soil (Table 2).

Table 1. Effect of microwave treatment and soil depth on total viable bacteria

Soil depth (cm)	Time from microwave treatment (days)	Estimated microwave treatment ($J\ cm^{-2}$)			
		0	150	300	600
0	1	6.20 ^d	5.57 ^d	4.73 ^d	1.78 ^d
	31	18.90 ^c	38.48 ^a	38.25 ^a	19.67 ^c
5	1	3.78 ^d	4.71 ^d	4.23 ^d	1.18 ^d
	31	18.73 ^c	24.28 ^{bc}	29.95 ^b	28.22 ^b
10	1	4.06 ^d	2.93 ^d	3.87 ^d	1.74 ^d
	31	16.93 ^c	26.13 ^{bc}	28.90 ^b	18.00 ^c
LSD (P = 0.05)					7.30

Note: entries with different superscripts are significantly different from one another

Table 2. Response of subsequent crops to growing in microwave treated soil

Microwave treatment ($J\ cm^{-2}$)	0	Hand weeded	168	384	576	LSD (P = 0.05)	Change from control
Canola pod yield (g pot ⁻¹)	0.27 ^a	0.56 ^a	0.36 ^a	1.25 ^b	1.95 ^c	0.55	550 %
Days to flowering - canola	71.4 ^a	67.6 ^{ab}	70.2 ^a	63.2 ^b	61 ^b	7.1	14.6%
Wheat grain yield (g pot ⁻¹)	0.66 ^a	0.67 ^a	0.68 ^a	0.75 ^a	1.25 ^b	0.30	90 %
Rice grain yield (g pot ⁻¹)	40.00 ^a	41.3 ^a	43.25 ^a	59.00 ^{ab}	64.00 ^b	18.90	60 %
Tomato dry shoot yield (g pot ⁻¹)	4.13 ^a	4.25 ^a	6.05 ^a	14.44 ^b	14.46 ^b	3.10	250 %

Note: entries with different superscripts are significantly different from one another

In conclusion, microwave treatment kills weeds and their seeds in the top layer of soil. Microwave treatment reduces bacterial populations in the top layers of soil, but has no effect of fungi or protozoa. Bacterial numbers recover within one month of treatment. Microwave soil treatment also enhances crop growth and yield.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Contact details

Graham Brodie
The University of Melbourne
Dookie Campus, Nalinga Rd., Dookie, Victoria, 3647
Ph: 03 5833 9273
Fx: 03 5833 9201
Email: grahamb@unimelb.edu.au