NORTHERN

7TH & 8TH MARCH 2017

GRAINS RESEARCH UPDATE

GRDC UPDATES

GOONDIWINDI

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Goondiwindi Grains Research Update

PROGRAM DAY 1 – TUESDAY 7 MARCH 2017

Time	Topic	Speaker (s)
10:00 AM	**Welcome**	John Minogue (Chair Northern Panel GRDC)
10:20 AM	**Chickpea disease management plan for 2017** • Lessons from 2016 and recommendations for 2017 • Wide rows? • Fungicide efficacy on Ascochyta and Botrytis grey mould • Virulent new Victorian asco pathotype – management implications • Dealing with high Ascochyta inoculum loads in 2017	Kevin Moore (NSW DPI)
11:00 AM	**Measuring airborne drift and factors affecting** • The impact of tank mix, nozzle type and adjuvant on drift risk • How spray operators can assess the level of risk	Andrew Hewitt (University of Queensland) and Professor Gordon Holloway (University of New Brunswick, Canada)
11:30 AM	**Herbicide volatility and spray drift.** Boom setups for different tasks; summer fallow, post-emergent graminicides, pre-emergent herbicides in stubble and late season fungicides/insecticides for canopy penetration • Quantifying boom height impact on drift • Air-assist booms - where can they assist? • Spraying without driftable fines – is it possible?	Bill Gordon (Nufarm)
12:05 PM	Lunch	
1:05 PM	**Concurrent session 1** *(See concurrent sessions for details)*	
2:50 PM	Afternoon tea	
3:20 PM	**Concurrent session 2** *(See concurrent sessions for details)*	
5:05 PM	Close	
6:40 PM	**Pre-dinner drinks, Royal Hotel 48 Marshall St(*Supported by Nufarm*)**	
7:30 PM	**Dinner, Royal Hotel Marshall St.**	

PROGRAM DAY 2 – WEDNESAY 8 MARCH 2017

Time	Topic	Speaker (s)
7:30 AM	**Early risers - Panel session on nutrition.** Informal time with key speakers (*Back room of main venue*) Mike Bell (QAAFI), David Lester (DAF Qld), Chris Guppy (UNE), Richard Daniel (NGA), James Hagan (DAF Qld), chaired by Chris Dowling (Back Paddock Co).	
8:30 AM	**Concurrent session 3** *(See concurrent sessions for details)*	
10:15 AM	Morning tea	
10:45 AM	**Concurrent session 4** *(See concurrent sessions for details)*	
12:30 PM	Lunch	
1:30 PM	**Understanding and interpreting weather and seasonal climate forecasts** - The role of the Indian dipole as a driver of weather in NNSW and Qld.	Jon Welsh (CottonInfo)
1:55 PM	**Elevation by time of sowing by frost risk** - how big is the difference in day degrees and maturity down the slope? Using this to optimise yield and better manage frost risk	Matt Gardner (AMPS)
2:20 PM	**New fungicides and developments in disease control strategies for wheat and barley**	Nick Poole (FAR)
2:45 PM	**Fungicide resistance in grain crops - what's happening and how should we respond?**	Fran Lopez (Curtin University CCDM)
3:15 PM	Close	

LOCATION & TIMING OF CONCURRENT SESSIONS

	Main auditorium	River room	Goondiwindi Training Centre
DAY 1			
Session 1 & 2	Cereal agronomy	Nutrition	A bit of everything
DAY 2			
Session 3 & 4	Disease	Weeds	Canola, organic matter and fababean

CONCURRENT SESSIONS

Cereal agronomy (Day 1, sessions 1 & 2)

Time session 1	Time session 2	Topic	Speaker (s)
1:05 PM	3:20 PM	Agronomic drivers of yield in rain-fed wheat - environment, management, variety and disease	Rick Graham (NSW DPI)
1:35 PM	3:50 PM	Optimising yield in new cereal varieties - varietal specific agronomy research	Guy McMullen, (NSW DPI)
2:05 PM	4:20 PM	A new visual lodging risk guide to assist with decision making on PGR's	Nick Poole (FAR)
2:20 PM	4:35 PM	Plant growth regulator research	Richard Daniel (NGA)
2:40 PM	4:55 PM	Discussion	

Nutrition (Day 1, sessions 1 & 2)

Time session 1	Time session 2	Topic	Speaker (s)
1:05 PM	3:20 PM	Nitrogen timing and placement - does early fallow timing provide better nitrogen use efficiency?	Richard Daniel (NGA)
1:35 PM	3:50 PM	Plant availability of reserve P and K - fertiliser type and the impact of wetting/drying cycles	Chris Guppy (UNE)
2:05 PM	4:20 PM	The economics of P nutrition	James Hagan (DAF Qld)
2:30 PM	4:45 PM	Discussion	

A bit of everything (Day 1, sessions 1 & 2)

Time session 1	Time session 2	Topic	Speaker (s)
1:05 PM	3:20 PM	**Soil water, stubble and fallow management.** • Stubble load/type impact on fallow efficiency • Kelly chain impacts in the fallow and after sowing chickpeas	Brendan Burton (NGA)
1:30 PM	3:45 PM	Maize agronomy and managing climate risk in rain-fed maize with multi cobbing hybrids	Daniel Rodriguez (QAAFI)
1:55 PM	4:10 PM	**Aphids and other little green profit suckers** • Russian wheat aphid - how big is the threat, identification and management • Aphid thresholds in canola and cereals; scouting, beneficials and population dynamics • Green peach aphids in canola • *Helicoverpa* threshold data updated in canola and pulses • Row spacing in chickpeas - implications for sampling and thresholds • Late mirid damage in fababeans • Altacor® stewardship	Melina Miles (DAF Qld) & Ken Young (GRDC)

Disease (Day 2, sessions 3 & 4)

Time session 3	Time session 4	Topic	Speaker (s)
8:30 AM	10:45 AM	Barley disease yield loss response curves. How much yield is lost in varieties with different levels of genetic resistance under different disease pressures?	Greg Platz (DAF Qld)
8:55 AM	11:10 AM	Yellow leaf spot epidemiology and why responses to fungicides can be variable	Jean Galloway (DAFWA)
9:20 AM	11:35 AM	Wheat disease update • Rust • Fusarium issues	Steven Simpfendorfer (NSW DPI)
9:45 AM	12:00 PM	Barley disease update • New barley seed treatment trial performance • Leaf rust in Compass® • Increased levels of NFNB in Commander® & Shepherd® barley • Loose smut in 2016 • Scald and other wet season diseases - what did we learn in 2016?	Ryan Fowler (DAF Qld)

Weeds (Day 2, sessions 3 & 4)

Time session 3	Time session 4	Topic	Speaker (s)
8:30 AM	10:45 AM	Managing weeds in fence lines • What's registered and works? • What does IWM on fence lines look like?	Chris Preston (Adelaide University)
8:55 AM	11:10 AM	Managing resistant wild oats • Residual herbicides • Tweaking efficacy of post-ems • Harvest weed seed capture	Mike Walsh (Sydney University)
9:20 AM	11:35 AM	New developments and understanding in resistance mechanisms and management • Avoiding false negative resistance tests - when have they occurred and why? • Temperature effects on fop, dim and glyphosate efficacy. Are there practical implications for testing or spray timing? • Group A resistance differences between the fops and dims in key weed species - its more than just which is more likely to occur first! • Resistance in *Phalaris paradoxa*	Chris Preston (Adelaide University)
9:50 AM	12:05 PM	Weed management and new technology - what's possible and what are the priorities?	Panel session with Mike Walsh and Chris Preston

Canola, organic matter and fababean (Day 2, sessions 3 & 4)

Time session 3	Time session 4	Topic	Speaker (s)
8:30 AM	10:45 AM	Managing Sclerotinia in canola - heads up on blackleg • Genetic, cultural and fungicide strategies • How fungicides compare • Crop sequencing, canola frequency and disease. What about chickpeas?	Kurt Lindbeck (NSW DPI)
9:00 AM	11:15 AM	Canola agronomy and fit in northern farming systems • How phenology changes and contributes to decision making in northern environments • Varieties and time of sowing • Nutrition (N and S) • The fit of canola in northern crop sequences	Jeremy Whish (CSIRO)
9:25 AM	11:40 AM	Fababean disease management update	Joop van Leur (NSW DPI)
9:50 AM	12:05 AM	Stabilising organic matter decline. Land use and crop management impacts on organic carbon from 1000 paired sites • Land use and farming systems impact • The role of crop type, pastures and organic supplements/compost	Jayne Gentry (DAF Qld)

Contents

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General plenary day 1

Minimising risk of disease in 2017 chickpea crops

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Key words

Chickpea, Ascochyta, Botrytis, Phytophthora, Sclerotinia, waterlogging, management

GRDC codes

DAN00176, DAN00212, DAN00172, DAN00177

Take home message

2016 conditions were very conducive to Ascochyta, Botrytis, Phytophthora and Sclerotinia diseases in chickpea crops throughout the GRDC Northern Region.

Large amounts of inoculum of these pathogens will be available to infect 2017 chickpea crops.

Strategies described in this paper will reduce the risk of these diseases; the more strategies employed, the greater the benefit for chickpea growers in 2017.

Background

Following high incidences of diseases (Ascochyta, Phytophthora, Sclerotinia and Botrytis) in 2016 chickpea crops throughout NSW and Queensland, there will be large amounts of inoculum to infect 2017 chickpea crops.

This paper describes strategies that will reduce the risk of each of these diseases. Some of these strategies are based on local and international field experiments; others are based on observations of reduced disease in 2016 crops. The more strategies employed, the greater the benefit for chickpea growers in 2017 and beyond.

Ascochyta blight, AB, Asco (fungus *Phoma rabiei* previously called *Ascochyta rabiei*)

Ascochyta inoculum will be present in four forms:

1. Ascochyta infected chickpea residue being discharged out the back of headers or spread by floods and surface water;
2. Seed internally infected by the fungus (a consequence of pod infection);
3. Seed contaminated externally with infected chickpea residue during harvest and handling;
4. Volunteer chickpea plants infected over summer and autumn.

The following will reduce the occurrence and impact of Ascochyta Blight in 2017 chickpea crops.

- Grow varieties with improved AB resistance (experiment/observation): These varieties will have less disease and require fewer fungicide sprays.
- Burn cereal stubble (this holds AB inoculum, observation): Infected chickpea residue discharged during harvest of 2016 crops blows onto paddocks that are intended for chickpeas in 2017; most of these will have had a cereal crop in 2016 (or 2015).

- Remove volunteers (observation): Volunteer chickpea plants infected with Ascochyta will provide inoculum even if the volunteer plants are killed with herbicide. Controlling volunteers early will restrict their size and limit the amount of inoculum they can produce.
- Treat all planting seed (experiment): Proper treatment of seed with a registered fungicide will control both internally borne Ascochyta and external contamination.
- Sow later in planting window (experiment/observation): This reduces the number of infection events.
- Wider rows 66cm+ (experiment/observation): Wide rows improve airflow through the crop leading to more rapid drying after a rain event or dew. They also delay canopy closure and improve penetration of fungicides later in the season.
- Tyne openers rather than disc (observation): 2016 observations of less Ascochyta where crops had been sown with tynes is thought to reflect burial and movement of Ascochyta inoculum away from the emerging seedlings.
- Double crop sorghum, cotton (experiment/observation): Stress and high biomass favour Ascochyta. 2016 crops double cropped into sorghum or cotton residue were less affected by waterlogging and did not produce the biomass of chickpeas sown into winter cereal or long fallow paddocks.
- Fungicide before 1st post emergent rain event, even PBA Seamer(Þ) (experiment/observation): 2016 crops that had an early preventative Ascochyta fungicide had less disease than crops that were not sprayed until after the disease was detected. Even though PBA Seamer(Þ) is rated resistant to Ascochyta, growers are urged to apply a preventative fungicide because: (a) the large amount of inoculum will increase disease pressure, (b) it safeguards against changes in the Ascochyta pathogen that are more aggressive or virulent on PBA Seamer(Þ) and (c) it insures against contamination of PBA Seamer(Þ) crops with plants of varieties with lower or no Ascochyta resistance eg PBA HatTrick(Þ), PBA Boundary(Þ) or Kyabra(Þ) (varietal purity is still a major issue in our chickpea industry).

Phytophthora root rot, PRR (fungus-like Oomycete *Phytophthora medicaginis*)

Phytophthora inoculum will be present in three forms:

1. Chickpea plants that had PRR in previous seasons (up to 10years back);
2. Other hosts e.g. medics, lucerne, and other leguminous plants including sulla (*Hedysarum* spp) and sesbania (*Sesbania* spp) in which Phytophthora can survive and multiply;
3. Soil and water containing PRR infected material and survival structures (oospores, chlamydospores).

The following will reduce the risk of PRR in 2017 chickpea crops.

- Avoid PRR high risk paddocks where annual or perennial medics have been a component of pastures and where PRR has occurred in the past chickpea or lucerne; the oospores of *Phytophthora medicaginis* can survive for more than 10 years.
- Avoid paddocks with areas prone to waterlogging although the conditions which induce waterlogging may not occur every year.
- Avoid paddocks exposed to water flow from previous chickpea or medics areas; PRR infected material and survival structures can be spread though water movement to neighbouring paddock/s.

- Metalaxyl-based seed dressings are registered for PPR, but they are relatively expensive and provide only 6-8 weeks protection after sowing.
- Grow a variety with the highest level of resistance, particularly in medium-high risk situations, such as where medics, chickpea or lucerne crops have been grown in the past 5-6 years.

Sclerotinia stem and basal rot (fungi *Sclerotinia sclerotiorum*, *S. minor*)

In the GRDC northern region, *Sclerotinia* spp infect chickpea plants two ways (a) Sclerotia germinate directly in or on soil and invade the plant through root or basal stem tissue, producing Sclerotia on and within the basal stem tissues, (b) Sclerotia germinate indirectly, produce apothecia at ground level and these release air borne ascospores (carpogenic germination) that infect plant parts higher in the canopy. In most seasons we only see direct germination because carpogenic germination needs cool moist conditions. In August/September 2016, Sclerotinia disease was very common in chickpea crops in north western NSW and southern QLD due to high levels of canopy leaf wetness and favourable temperatures. Importantly, every case of Sclerotinia involved carpogenic germination ie infection at mid canopy meaning that the Sclerotia formed on and inside the chickpea stems would have been captured during harvest. This led to problems at receival because the cylindrical Sclerotia formed inside the stems resembled ryegrass ergots and some loads were rejected or docked. Sclerotinia inoculum will be present in several forms:

1. Sclerotia spread by floods and surface water;
2. Sclerotia admixed with chickpea seed and introduced into 2017 chickpea paddocks during planting;
3. Sclerotia in canola residue in paddocks intended for chickpea in 2017; large Sclerotia can survive for up to 10 yr;
4. Sclerotia in weed hosts in paddocks intended for chickpea in 2017;
5. Sclerotia already present in paddocks with a history of broadleaf crops and recent Sclerotinia outbreaks.

The following will reduce the risk of Sclerotinia in 2017 chickpea crops.

- Grow varieties with lowest susceptibility: Sclerotinia basal rot was assessed in field trials at Wagga Wagga in 2014 and 2016 which led to the following tentative ratings:
- Very susceptible: PBA Maiden(Þ)
- Susceptible: Ambar(Þ), Genesis™ 090, Neelam(Þ), PBA Slasher(Þ), PBA Striker(Þ), PBA Monarch(Þ)
- Moderately susceptible: PBA Boundary(Þ), PBA HatTrick(Þ), PBA Seamer(Þ)
- Avoid paddocks with a history of Sclerotinia. Paddocks with a history of Sclerotinia will already have a population of viable sclerotia before the crop is sown and these are a disease risk. A frequent history of the disease also indicates that the environment is also most likely favourable for Sclerotinia to develop. Be aware that even adjoining paddocks can be at risk, due to movement of air-borne ascospores of the Sclerotinia fungus.
- Avoid paddocks with a history of canola. Canola is a very good host for Sclerotinia stem rot. Experience in southern NSW has shown that the number of sclerotia in the soil can build up very quickly when canola is frequent in the cropping rotation.
- Avoid paddocks with a history of broadleaf weeds. The collective host range of the Sclerotinia fungi (*Sclerotinia sclerotiorum, S. minor*) exceeds 400 plant species, mostly broadleaf plants. Weeds can be important in maintaining sclerotial populations in paddocks, even when the

frequency of broadleaf host crops in the rotation is low. Broadleaf weeds such as capeweed, shepherds purse and variegated thistle are just some common hosts for Sclerotinia.

- Sow within the planting window. Observations from field trials at Wagga Wagga suggest that early sown chickpea is more prone to developing symptoms of Sclerotinia infection; this includes both direct infection and canopy infection from air-borne spores. Plots sown within the recommended sowing window developed significantly less disease. Dense crop canopies from an early sowing also favour Sclerotinia stem rot later in the season.

Botrytis seedling disease, BSD (fungus *Botrytis cinerea*)

BSD and Botrytis Grey Mould, BGM are caused by the same fungus, *Botrytis cinerea*, but they are very different diseases. BSD is a seed-borne disease that can occur at any temperature and under any conditions. BSD can ONLY occur if pods of chickpea crops from which the seed came were affected by BGM. BSD is readily controlled with the standard chickpea seed treatments. BSD inoculum will be present in two forms:

1. Seed from pods infected with *B. cinerea* during a prior BGM outbreak.
2. Primary infections of BSD (ie from *B. cinerea* infected seed); primary infections lead to secondary infection of initially healthy seedlings through root contact.

The following will reduce the risk of BSD in 2017 chickpea crops.

- Treat all planting seed: Field trials conducted in 2011 at Moree, Narrabri and Breeza using two *B. cinerea* infected seed lots from the 2010 BGM epidemic, showed treating chickpea seed with registered seed dressings controlled BSD, improved crop establishment and increased yield but proper coverage and rate were essential.
- Avoid using *B. cinerea* infected seed: Even though seed treatment controls BSD, Botrytis infected seed will have lower vigour than non-infected seed.

Botrytis grey mould, BGM (fungus *Botrytis cinerea*)

BGM is an air-borne foliar disease active ONLY when temperatures warm up towards spring (ca 15°C). It is more prevalent in the warmer regions of the north, where significant crop losses can occur in wet winters and springs as occurred in 2016. BGM is controlled with foliar fungicides; seed treatment is ineffective. Testing chickpea seed from the 2016 harvest at Tamworth has found that half the seed lots tested to date (December 2016) are internally infected with Botrytis. Not treating this seed will lead to BSD (but will have no impact on BGM in 2017). *Botrytis cinerea* is ubiquitous, has a wide host range (over 138 genera in 70 families) and is a good saprophyte, meaning it can survive, grow and sporulate on just about any dead plant tissue. The fungus readily produces air borne spores and some isolates form sclerotia. This means that inoculum of BGM is always present and if conditions favour BGM, it will occur irrespective of what has happened earlier in the chickpea season.

The following will reduce the risk of BGM in 2017 chickpea crops.

- Paddock selection: Avoid planting chickpeas next to paddocks where BGM was an issue the previous season. As for Ascochyta blight, chickpeas should be grown as far away from paddocks in which BGM was a problem as is practically possible. However, under conducive conditions, this practice will not guarantee that crops will remain BGM free, because of the pathogen's wide host range, ability to colonise dead plant tissue, and the airborne nature of its spores.
- Sow later: If long-term weather forecasts suggest a wetter-than-normal 2017 season (La Nina) consider sowing in the later part of the planting window as this will reduce biomass production; BGM is favoured by dense canopies.

- Wider rows 66cm+: Wide rows improve airflow through the crop leading to more rapid drying after a rain event or dew. They also delay canopy closure and improve penetration of fungicides later in the season.
- Foliar fungicide: In areas outside central QLD, spraying for BGM is not needed in most years. However, in seasons and situations favourable to the disease, a preventative spray of a registered fungicide immediately prior to 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 chickpea BGM have eradicant activity, so their application will not eradicate established infections. Consequently, timely and thorough application is critical.

Waterlogging

Waterlogging (WL) and other stresses can reduce resistance and efficacy of management. Plants exposed to environmental stresses have altered architecture, metabolism and elongation; these reduce the plant's ability to maintain resistance and re-shoot post disease infection. This was evident across chickpea crops in 2016 with increased severity of AB on resistant lines (including PBA HatTrick, MR) when under WL stress. Preventative fungicide spray application on stressed, disease prone areas is critical to reducing yield loss.

There are currently no released varieties with significantly improved waterlogging (WL) tolerance; further studies are currently being carried out to exploit potential for improvement in conjunction with PRR resistance. During the 2016 season the northern growing region reported significant crop losses due to PRR. Surveying and quantitative PCR testing of soil samples collected from a number sites across this region concluded that both PRR and waterlogging were involved in plant death at various growth stages. Differentiating WL and PRR crop damage is difficult, often WL is incorrectly identified as PRR.

Distinguishing WL from PRR

- Water logging symptoms occur 1-3 days post flooding compared to a minimum of 7 days for PRR. Both WL and PRR can have similar above ground symptoms with red/yellowing, wilting, and death of plants. However, WL affected plants often succumb too quickly to have red/yellowing or lower leaf drop as always occurs with PRR. PRR symptoms may be delayed if temperatures are cool and soil moist. Waterlogging is a result of lack of oxygen to roots; PRR is the result of an organism killing roots. Waterlogging is thus more common and pronounced during warmer periods because (i) warm water cannot hold as much oxygen as cold water, and (ii) during warm weather, plants grow faster and thus need more oxygen.
- Affected whole plants need to be examined shortly after prolonged rain or flood event (1-3 days). Are the plants easy to pull out? PRR affected plants have little to no lateral roots and offer no resistance when pulled. Initially, WL affected plants have intact lateral roots and will not pull easily. Note: waiting longer than7 days to do the pull test on WL affected plants allows opportunistic soil fungi to decay lateral roots leading to misidentification as root rot.
- PRR infected plants may have dark brown or black lesions on the tap root. Often such lesions extend above ground level forming a slightly sunken canker with a distinct junction with healthy stem tissue above.
- Plants are most susceptible to WL at flowering and early pod fill unlike PRR which can occur at all growth stages.

The following will reduce the risk of waterlogging in 2017 chickpea crops.

- Avoid poorly drained paddocks and those prone to waterlogging.
- Sow later if the weather forecast for 2017 predicts a wetter-than-normal early-to-mid season. Evidence suggests that in chickpea and other crops early vigour associated with plants in the early vegetative phase will re-shoot and recover root growth more efficiently reducing plant death.

Additional Information

Further information on chickpea disease management can be found at the Pulse Australia website www.pulseaus.com.au and in the NSW DPI 2017 Winter Crop Variety Sowing Guide.

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Chickpea Ascochyta – Further evidence that varieties differ in reaction of pods

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Department of Primary Industries, NSW, Tamworth

Key words

Chickpea, Ascochyta, management

GRDC codes

DAN00176, DAN00212

Take home message

The susceptibility of pods to Ascochyta blight is important as infection can cause pod abortion and blemish or kill seed; infected seed can lead to downgrading of grain, furthermore infected seed is a future inoculum source.

A 2016 field trial confirmed that chickpea varieties differ in pod reaction to Ascochyta; varieties with higher levels of resistance to vegetative plant tissues e.g. PBA Seamer(Φ) had less disease on their pods.

However, as all varieties can get pod infection (albeit at different proportions), in Ascochyta conducive seasons pods need to be protected with fungicides.

Background

Knowing the susceptibility of chickpea pod tissue to Ascochyta blight (caused by *Phoma rabiei* formerly known as *Ascochyta rabiei*) is important because if pods get infected early in their development they will abort; if fully developed pods get infected near the peduncle (as many do because the calyx holds water), they will abort; or the seed will get infected and is killed or the seed becomes infected, but remains viable and is a potential source of inoculum to initiate an epidemic. Further, if Ascochyta lesions are detected on desi or kabuli kernels and the incidence exceeds 1% by weight, the load will be downgraded or rejected.
http://www.pulseaus.com.au/storage/app/media/markets/20160801_Pulse-Standards.pdf

Current Australian chickpea varieties and advanced breeding lines differ in susceptibility of their vegetative plant tissues to Ascochyta Blight (Moore et al, 2016). However, the chickpea industry believes that pods of all varieties are equally susceptible to Ascochyta (see http://www.grdc.com.au/GRDC-FS-ChickpeaDiseaseManagement). The 2011 Tamworth chickpea Ascochyta management trial, VMP11 suggested that may not be the case - anecdotal evidence indicated varieties with higher levels of resistance to Ascochyta e.g. Genesis™ 425 had less disease on their pods and scientific evidence was obtained by the 2014 Tamworth chickpea Ascochyta yield loss trial, VMP14. VMP14, which was inoculated before flowering, provided data on susceptibility of pods of ten genotypes consisting of released varieties and advanced breeding lines ie CICA1007, (C1007), CICA1211 (C1211), Genesis™425 (G425), Genesis™Kalkee (KAL), PBA Seamer(Φ) (SEA, coded as CICA0912 in Figure 1), PBA HatTrick(Φ) (HAT), PBA Monarch(Φ) (MON), PBA Boundary(Φ) (BOU), Kyabra(Φ) (KYB), and Jimbour(Φ) (JIM). The genotypes fell into 4 susceptibility groups with no differences between entries within a group but significant differences between genotypes in different groups. The four groups from least to most susceptible were (C1007, SEA, G425), (BOU, HAT, KAL, MON), (C1211) and (JIM, KYB) (Fig. 1).

A criticism of VMP14 is that the data could be confounded, because the plots (JIM and KYB) with the most infected pods and the greater number of lesions were also those that had the highest levels of Ascochyta in the vegetative stage. We reasoned (Moore at al., 2015) there was sufficient inoculum pressure in VMP14 that all pods of all genotypes in the trial would have been exposed to the same level of inoculum. Nevertheless, the fact remains that plants had been exposed to at least five infection events during the vegetative phase and that could have affected resistance of genotypes and/or inoculum pressure within a plot. The 2016 trial, reported here, addressed these concerns by protecting plants with foliar fungicide during the vegetative stage and by sampling pods after one post-inoculation infections event.

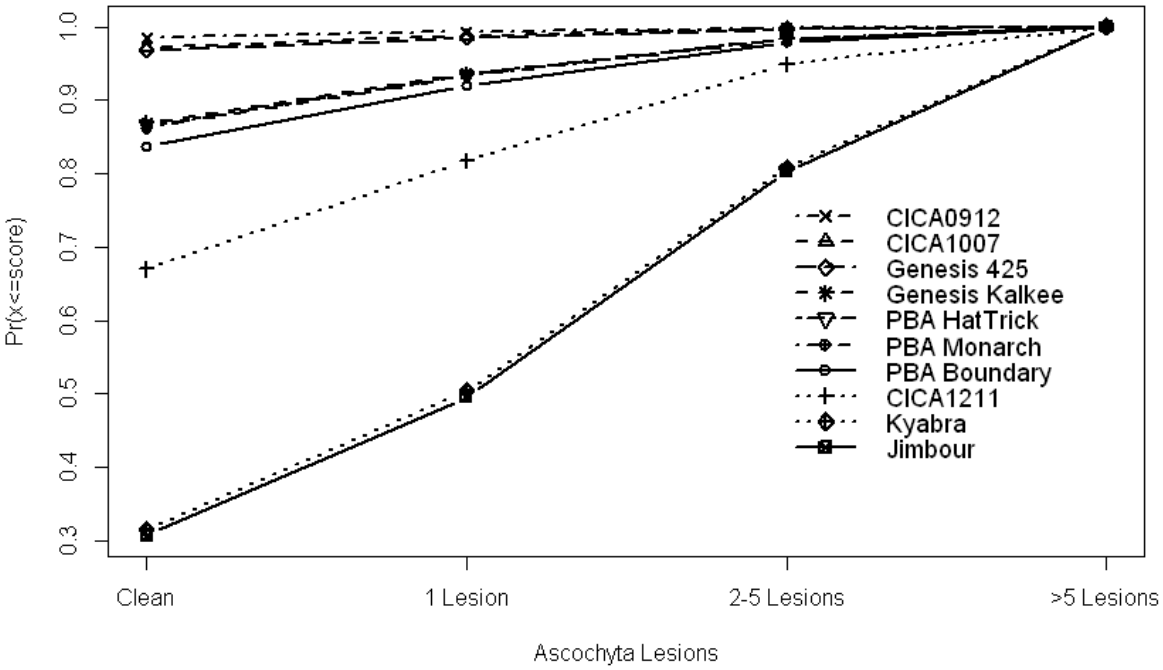

Figure 1. Predicted cumulative proportions of pods across four disease severity categories of Ascochyta lesions for the ten chickpea genotypes in the 2014, VMP14 trial

Methods

The trial (POD16) was sown into burnt barley stubble on 18 May 2016 using tyne openers on 50cm row spacing in plots 2m wide by 10m long. Granulock® Supreme Z (50kg/ha) and liquid Rhizobia were applied at sowing with Gesatop® 600 SC applied PSPE. There were five varieties PBA Seamer$^{\Phi}$ PBA Boundary$^{\Phi}$, PBA HatTrick$^{\Phi}$, PBA Monarch$^{\Phi}$ and Kyabra$^{\Phi}$ coded as above and four replications. Plants were protected from Ascochyta infection with eight applications of 1.0L/ha chlorothalonil (720g/L active) applied before rainfall, the first application on 4th July and the last on 14th October. On 30th October when the desi varieties were at 50-60% podding and PBA Monarch$^{\Phi}$ was at 40-50% podding, the trial was inoculated during a rain event with a cocktail of 20 isolates of *P. rabiei* containing 550,000 conidia/mL of water and applied at 100 L/ha; there were four application passes giving a total of 2.2million conidia/mL. From the start of inoculation (6pm) to when the rain stopped at 7am 31 October, 17mm fell. On 10th and 14th November, 16.4mm and 12.8mm were recorded, respectively, this rainfall provided two potential post-inoculation secondary infection events. On 18th November, from each plot in Reps 1-3, one branch was collected from 50 plants at random (Rep 4 was severely affected by Phytophthora root rot and was not sampled).

Ascochyta assessment and statistics

Samples were air dried in glasshouse for 1 day, pods removed and sorted into four disease severity classes based on their Ascochyta status: clean = no Ascochyta lesions; 1 lesion = pods with a single lesion; 2-5 lesions and >5 lesions. A lesion was not called Ascochyta unless pycnidia could be seen either with the naked eye or under a low power dissecting microscope. For each variety the number of pods falling into each of the four Ascochyta classes was analysed using proportional odds logistic regression, implemented using the "polr" function of the r MASS package Venables & Ripley (2002). Differences between varieties were assessed by comparing the coefficients of the model for each variety. A 95% confidence interval (CI) for each coefficient was calculated. Two varieties differ in disease severity if their respective CI's do not overlap.

Results

2016 results: To limit the potential effect of secondary infection via inoculum generated from susceptible vegetative tissue, the pod samples were harvested 18 days after inoculation. At this early time point there were large differences in pod infection among the genotypes. Only 1.3% of KYB pods were clean (no disease), whereas 22.8% of SEA pods had no Ascochyta (Table 1). Not only did KYB have a greater proportion of Ascochyta infected pods, but these pods were more severely diseased with most (63.7%) infected pods having more than five Ascochyta lesions; this compares with only 10.2% of infected SEA pods having more than five lesions (Table 1).

Analysis showed with the exception of BOU and HAT, varieties were significantly different (P = 0.05) with the ranking from least to most susceptible being SEA < MON < BOU = HAT < KYB (Fig. 2).

2014 and 2016 results: All varieties in POD16 had more pods infected with Ascochyta than the same varieties in 2014. This is believed to reflect higher disease pressure in 2016 resulting from inoculation with 2.2million conidia/mL and very conducive conditions (total 46.2mm rain in 3 rain events). Nevertheless, the ranking of varieties was the same as in 2014 (Fig. 1, Fig. 2, Table 1) and the conclusions reached were the same.

Table 1. Percentages of pods in four Ascochyta disease severity categories for five varieties in 2016 vs 2014

Genotype	%Clean	%1 Lesion	%2-5 Lesions	%>5 Lesions
SEA 2016	22.8	15.0	52.0	10.2
SEA 2014	*98.5*	*1.0*	*0.3*	*0.3*
MON 2016	16.5	12.9	51.4	19.3
MON 2014	*86.2*	*7.8*	*3.3*	*2.8*
BOU 2016	11.4	10.1	48.3	30.2
BOU 2014	*84.3*	*5.5*	*6.3*	*4.0*
HAT 2016	10.1	9.8	47.0	33.2
HAT 2014	*86.2*	*9.3*	*4.0*	*0.5*
KYB 2016	1.3	3.1	31.9	63.7
KYB 2014	*33.8*	*15.5*	*30.5*	*20.3*

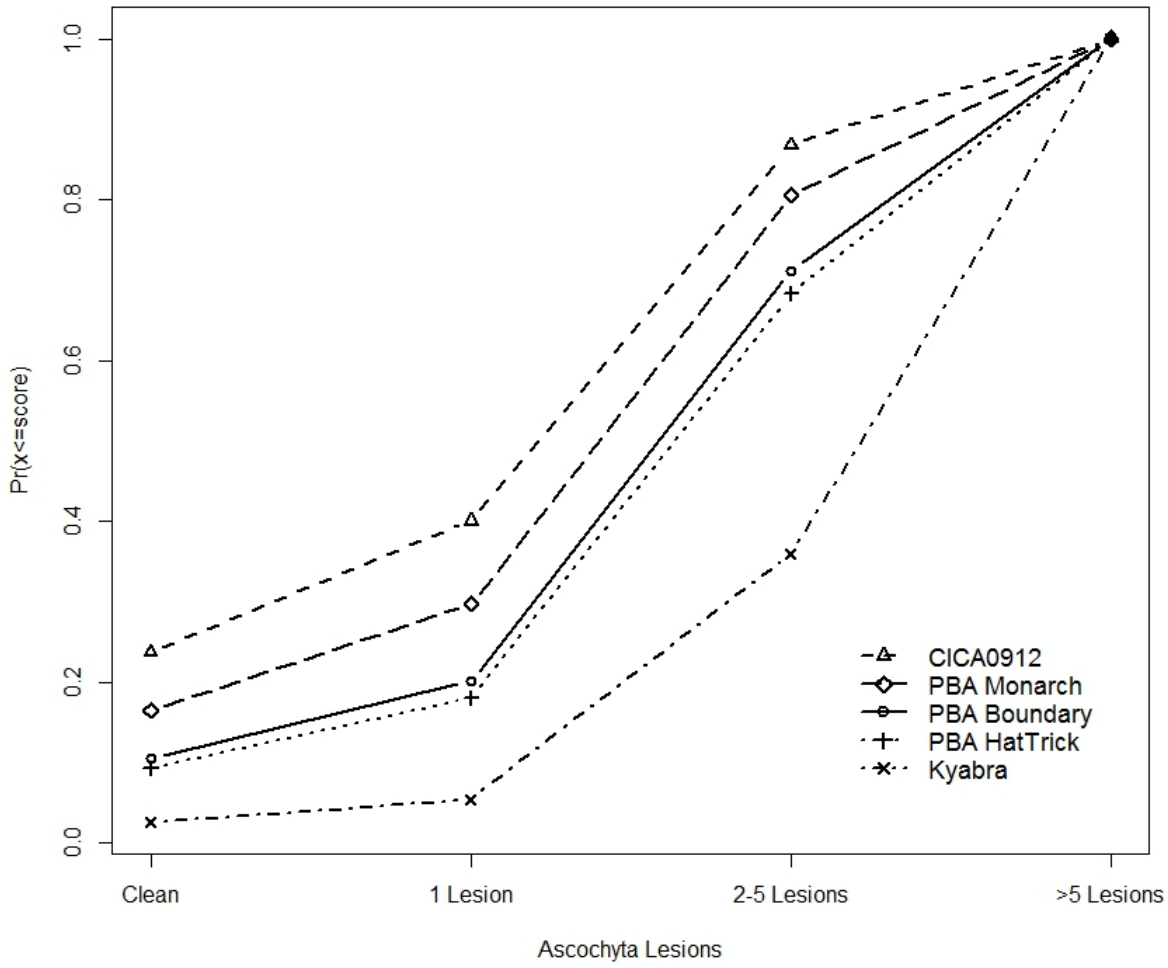

Figure 2. Predicted cumulative proportions of pods across disease severity categories of Ascochyta lesions for the five chickpea varieties in the 2016 trial. (CICA0912 is PBA Seamer(ϕ))

Key pod infection findings of POD16 were:

- Varieties differed in the relative proportion of severely infected pods 18 days after inoculation, with SEA < MON < BOU = HAT < KYB
- This ranking agrees closely with current Ascochyta variety ratings for vegetative tissues
- From a management perspective, all varieties can get pod infection (albeit at different proportions); therefore in Ascochyta-conducive seasons pods need to be protected with fungicides

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Disease risk prediction for Phytophthora root rot of chickpeas: inoculum detection problems

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Key words

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

GRDC code

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Take home message

- *Phytophthora medicaginis* (Pm) inoculum concentrations decline to low levels (within 6-12 months) of a diseased crop and the distribution becomes more uneven
- Resting populations (oospores) can be below detectable levels based on both soil DNA and isolate baiting methods
- These factors limit the ability of PreDicta B® to identify paddocks which have a significant disease risk
- The Pm test is useful for disease diagnosis when the pathogen is active and inoculum decline has not taken place

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, the cause of chickpea Phytophthora root rot (PRR) is endemic and widespread in the northern grains region. Under conducive conditions, PRR can cause 100% loss. The pathogen survives from season to season on chickpea volunteers, lucerne, native medics, sulla and as resting structures (oospores) in roots and soil. It is known that Pm inoculum concentrations is difficult to detect and quantify in paddocks when a susceptible host such as chickpeas is not present (Dale and Irwin, 1990).

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 three seasons of studies to assess the capability of this test to:

1. Detect Pm in soil from commercial paddocks
2. Predict the risk of PRR disease and potential yield losses in chickpea

Methods

Ability to detect Pm in paddock samples: Soil samples were collected during winter-spring period from fields in northern NSW and southern QLD in 2013, and from central (16) and south-western Queensland (10), and Victoria (7) in 2014. All paddocks included chickpeas in the rotation but not all had chickpeas in the previous year.

Eight sites were sampled per paddock using with 10 soil cores (15 long 1 cm wide cm AccuCore soil corer). At each site 10 cores were collected every 20 – 25 paces along a 'W' collection pattern (total

distance 200 – 250 m per sample site). If soil conditions were too dry, a 15 cm long by 6 cm wide trowel tapering to 2 cm was used to sample. Soil samples were stored in sealed plastic bags at 5°C.

After sieving (4 mm aperture), a 400 g sub sample was sent to SARDI for DNA analysis the remainder of each sample was used for baiting of the pathogen using a glasshouse based technique. Seedlings (cv. Sonali) were assessed for disease (chlorosis, stem cankers, death) three times a week. Stem 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. Isolation of Pm was attempted from all treatments that produced chlorosis followed by the appearance of Pm like stem cankers or seedlings with poor growth. After six weeks the experiment was terminated. To fulfil Koch's postulates on putative Pm isolates, seedlings of the susceptible chickpea cv. Sonali were inoculated in controlled environment experiments.

Detection capability across a range of concentrations: A Pm concentration:DNA yield series was prepared using a Pm isolate (943c-1) grown on plates of low strength V8 agar then prepared as a oospore-mycelium solution with distilled water at 1752 oospores/mL (average of five separate sample counts). The required volume of solution containing 0, 100, 500, 1000, 2000, 4000, and 8000 oospores was then pipetted into 400 g of dry sand and distilled water added to bring the total volume of each solution to 5 mL, with three replicates prepared. The samples were sent to SARDI for Pm DNA analysis.

Disease and yield loss prediction trials: In 2014, 2015 and 2016 disease and yield loss prediction trials were carried out. A range of Pm levels were established by applying, different rates of oospores (a mixture of 10 isolates) in-furrow at seedling to four row plots. At sowing or early in the season soil cores (150 mm depth cores, in row coring) were collected from the two middle rows of each plot and pooled and analysed for soil Pm concentration by SARDI. During the each season PRR disease assessments (% infected plants, or row length of severely infected plants) and grain yields were measured from the two middle rows of each plot. The trials were also soil sampled at the end of season as described previously. The 2015 and 2016 trials had four row buffer plots around each plot to limit spread between plots. Irrigation treatments were watered with dripper tape delivering between 0.6 to 0.7 mm/hr.

Ability to monitor Pm concentrations in paddocks: To develop sampling recommendations, Pm concentrations were assessed on three farms (Coonamble NSW, Moree NSW, Goondiwindi QLD) where PRR had been an ongoing problem, "Hotspots" were marked and GPS recorded.

Four samples were collected from each hotspot area following a W collection pattern (32 points along the pattern, each point 6 m apart, using a 150 mm AccuCorer). At each point cores were sampled from a single stubble row, with each core for each separate sample taken 2-3 cm apart. Low lying areas of paddocks where pooling following rainfall occurred (below contour banks, low areas of paddocks, dips) were also sampled and raised or uniform areas were also collected, these areas provided three 32 core 'low area' samples and three 32 core 'high area' samples from each field, their GPS positions were also marked. Using this method 12 paddocks were sampled in April 2016, another four paddocks were also sampled with either hotspot or low-high samples collected. In Nov and Dec 2016 all hotspot sites were resampled, all low-high sample sites were revisited and samples collected from paddocks in chickpeas in 2016 showing any disease problems.

For the April samples three soil samples from each hotspot and all low-high samples were sent for analysis to SARDI. The fourth hotspot sample was assessed for Pm in a glasshouse baiting experiment (5 reps, cv. Sonali grown in a soil:sand mix) as described previously. At the end of the baiting experiment the soil-sand media in each cup was sent to SARDI for analysis.

Hotspot sites in Coonamble and Goondiwindi were resampled in Nov to compare with April results and for paddocks in chickpeas, the low and high areas were also inspected and soil samples collected if any disease symptoms were observed.

Results and discussion

Ability to detect Pm in paddock samples: The 2013 and 2014 collected soils showed a similar pattern with most samples (which had positive DNA results also yielding Pm cultures 2014: 9/11, 82%; 2015: 8/9, 89%) and with most samples which had negative DNA results not yielding Pm cultures (2014: 36/37, 97%; 2015: 33/34, 97%). There were two false negatives, whereby the DNA method did not detect Pm, but the soil sample yielded Pm isolates. If within sample variability is high, the lack of DNA detection may be due to low concentrations in the sub-sample submitted for DNA analysis. Both sets of samples also had some cases of false positives, possible explanations for this is that more time may be required for symptoms to develop during baiting, or that the pathogen had died but some DNA had been detected.

Detection capability across a range of concentrations: The experiment showed increasing DNA yields from an increasing pathogen concentration, although the spread among replicates was quite large for the three highest concentrations (Figure 1). It was also notable that for the lowest concentration 0.25 oospores/g (100 oospore solution in 400 g sand) that yields were variable, values for the three replicates were 0, 261 and 858 copies/g sand. It is possible that the small amounts of DNA present in low concentration samples, such as these, may have degraded during transportation to SARDI for analyses and lead to the nil detection in one replicate. Further work is required in this area but this single set of results suggests that the detection of Pm DNA at low concentrations (≤ 0.25 oospores/g sample) may be variable and could deliver nil detection values.

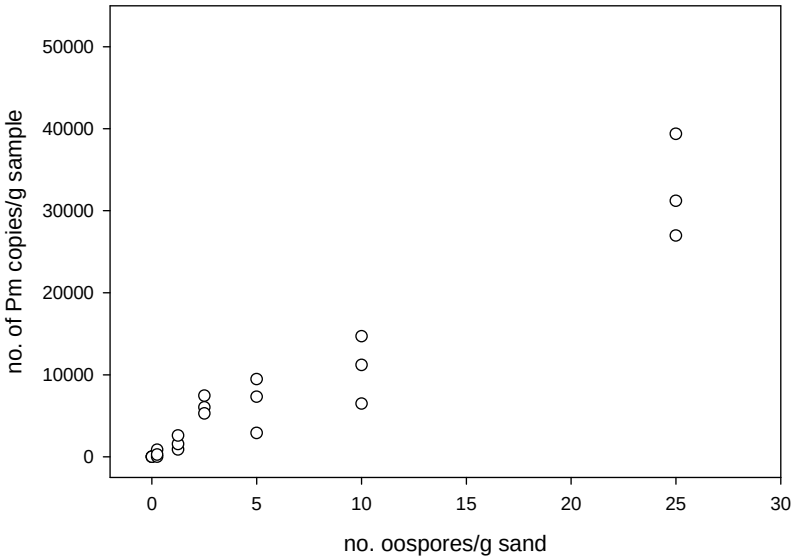

Figure 1. Plot of three replicate sample of Pm oospore-mycelium in sand at a range of concentrations against the yield of Pm copies/g of sample.

Disease and yield loss prediction trials: ability to predict average disease and average yield loss: The relationships between Pm DNA values and disease or yield correlations for the three trials are summarised in Table 1. For 2014 with cv. Sonali there were relatively weak correlations between the early season soil Pm DNA concentrations and PRR disease (r = 0.46) and chickpea yields (r = - 0.37), but for the 2015 with var. Yorker(Þ) trial Pm DNA values provided a common central relationship across data from both irrigation treatments for both disease and yield. The 2016 trial with cv. Yorker(Þ) provided a poor relationship between Pm DNA values and both disease and yield. The high

r values for PRR disease measurements and yield in each trial supported the assumption that the yield losses were principally due to PRR disease.

Table 1. Correlations r values for early season or sowing Pm DNA values, PRR disease and yield of three experiments (DNA14 (2014), HMDNA15 (2015) and HMDNA16 (2016).

Trial date	Post sowing or early season Pm DNA values		PRR disease
	PRR disease	Yield	Yield
2014	0.46	-0.37	-0.86
2015	0.82	-0.77	-0.83
2016	0.17	-0.22	-0.70

Ability to consistently detect Pm DNA in yield loss trials on a plot by plot basis: In each of the three seasons there were a number of plots where no Pm DNA was detected by the qPCR method either at sowing or early in the season or at the post-harvest sample (Table 2). The nil DNA plots included both inoculated and non-inoculated treatments each season. Of the nil Pm DNA early season or at sowing samples, across each of the three trials a proportion (2014 0.79, 2015 0.43 and 2016 0.94) of these then had PRR symptoms, in the majority of cases yield losses were high in these plots (data not presented). The 2016 trial results were unusual with the very large number of nil DNA plots, Pm control samples included for analyses with these samples gave expected DNA values. It is not known why so many 2016 samples gave negative Pm DNA results yet PRR symptoms occurred in the plots. The 2015 trial was the most successful with only 3 of 7 nil DNA plots having PRR symptoms. However, for the postharvest DNA results from 2015 trial 7 plots with PRR had nil DNA values.

Table 2. No of plots in each of three experiments (DNA14 32 plots (2014), HMDNA15 40 plots (2015) and HMDNA16 40 plots (2016)) that had nil Pm DNA results early in the season or at the post-harvest sample and the number of these plots that had PRR symptoms or not.

Time	post sowing or early season Pm DNA values			post harvest Pm DNA values		
Trial date	Total nil DNA values	nil DNA values & nil PRR symptoms	nil DNA values & PRR symptoms	Total nil DNA values	nil DNA values & nil PRR symptoms	nil DNA values & PRR symptoms
2014	14	3	11	2	2	0
2015	7	4	3	11	4	7
2016	33	2	31	-	-	-

Of individual plots with nil DNA results, based on relatively high soil sampling intensities (2.5-3.2 cores/m row length), each season a differing proportion of these then had PRR later in the season. If these findings are extrapolated to a paddock scenario where a single sample-single result from the paddock will be used to assess PRR disease risk, then the probability for nil DNA results but PRR later being observed (a false negative) will range from 0.18 to 0.83. However, as the sampling intensity per unit area of paddocks will be much lower than those of plots in field trials, it may be expected that the probability of a false negative for paddock samples may be higher than those for field trials.

Time of sampling effects on Pm DNA concentrations: The post harvest Pm DNA concentrations did not differ between treatments in 2014 and 2015 trials (not presented), 2016 post harvest results were not available. For DNA14 which include a mid-season sample, for analysis of oospore treatment (P = 0.150), time and oospore trt.*time interaction (P = 0.116), only time was a significant factor (Table 3). The concentrations of DNA at 15 Sep were very high compared to both the early August and Dec post harvest samples. Between 12 and 23 Sep there were large increases in the

number of infected plants (not presented). These results show that when the disease is active, very high soil concentrations of the pathogen are present, but relative to this active period the populations decline rapidly over a three month period.

Table 3. Time effects for Pm DNA concentrations (no. Pm sequences/g soil) for three sample dates in the 2014 Pm inoculum level trial (DNA14) (Time, P < 0.001; lsd 118,466.4)

Time	4 Aug	15 Sep	19 Dec.
Pm DNA	1,561	476,183	8,014

April 2016 paddock inoculum results, detection variability: Six of the 13 paddocks with hotspot soil samples had positive Pm DNA results, all but one of these paddocks were in chickpeas in the 2015 season (Table 4). Of the six paddocks with positive DNA results only two paddocks had all three samples test positive, for another two paddocks (10 and 11) only two samples tested positive and for the other two paddocks (3 and 13) only one of the samples tested positive.

Table 4. April 2016 hotspot sample location, paddock code, prior crop (wh, wheat, cp, chickpea), average hotspot sample Pm DNA, number of positive hotspot samples, April 2016 hotspot sample isolate baiting results (no. cankers, no. of putative Pm cultures) and post-experiment DNA results of baiting media

location	code	2015 crop	Av. Hotspot P. med DNA sequences/ g soil	Hotspot no. + samples	Av. No. Cankers / cup	total no. putative cultures	Av. P. med DNA sequences/ g media
Coonamble	1	wh	0	0/3	0	0	0
Coonamble	2	wh	0	0/3	0	0	0
Coonamble	3	cp	209	1/3	0	0	205
Coonamble	4	cp	0	0/3	0	0	0
Coonamble	5	cp	0	0/3	0	0	0
Coonamble	6	cp	0	0/3	0	0	0
Coonamble	7	cp	0	0/3	0	0	544
Coonamble	8	cp	0	0/3	0	0	0
Goondiwindi	9	cp	1389	3/3	3	6	334767
Goondiwindi	10	cp	1205	2/3	2.8	9	348014
Goondiwindi	11	cp	690	2/3	0.75	2	618706
Goondiwindi	12	cp	2881	3/3	3	7	186981
Moree	13	wh	339	1/3	0	0	0

Given the close proximity (2-3 cm apart) of the cores sampled at each of the 32 points in a hotspot area it was notable the extent of variability in positive DNA results among the three samples. The results for paddocks 10 and 11, and in particular, for paddocks 3 and 13 indicate an uneven distribution of inoculum giving differing results even for closely collected soil samples. The baiting experiment yielded characteristic PRR symptoms and putative Pm cultures for soil samples from the four paddocks with two or three positive samples (Table 4). The post-baiting media DNA results showed large increases in DNA values relative to average hotspot soil results for these four paddock, however, paddocks 3 and 7 also had positive but low value media DNA results although disease

symptoms were not observed during baiting. Conversely, paddock 13 which had one positive hotspot soil sample, had both no disease symptoms or positive post-baiting media DNA result.

The baiting experiment results supported the soil DNA results, including that Pm inoculum was unevenly distributed in these samples. The large increases in baiting media DNA values relative to soil only results, and in particular the positive media DNA results for paddocks 3 and 7 which only had negative soil results, suggest that the baiting process may be useful in raising the DNA values for soil samples which initially have very low inoculum concentrations. Various priming methods have been developed to improve the detection of oomycetes at low concentrations or where the pathogen may be dormant (Wakeham and Pettitt, 2016). However, later season survey results (see Table 6) for paddocks 1, 2, 4 and 6 which had nil disease when baited and nil Pm DNA in the baiting media had PRR symptoms and positive DNA results in Nov of 2016, showed that such a priming method does not show promise for PRR prediction.

April 2016 paddock inoculum results, sample site effects: PRR is often first seen to occur in low lying areas of paddocks where pooling of water occurs after heavy rainfall. However 2016 results showed that using local knowledge to target sampling to areas to where PRR had been observed gave a slightly better success (4/11 cases) than just targeting low areas of paddocks (3/11 cases) (Table 5). It was notable that in two of the four positive hotspot locations were not in low lying areas of paddocks, rather their location was possibly related to prior the historic presence of alternative hosts in the area of the hotspot. However if prior knowledge of a paddock is not available then it was clear that targeting low lying areas for sampling is an appropriate strategy to maximise the chances of detection. For example, another three paddocks (coded 14, 15 and 16) in wheat in 2015 were low and high area sampled in Goondiwindi in 2016 for which there was no hotspot information, for the single paddock (no. 15) with positive Pm DNA results all three low area samples were positive and no high area samples had positive results.

April vs. Nov. 2016 inoculum results, unexpected increases: Results for four Coonamble paddocks (rainfall June to Oct 2015 of 112 mm, June to Oct 2016 of 388 mm) are presented which included: increases from nil inoculum in a break crop to substantial inoculum in chickpeas including areas with PRR like symptoms (paddocks 1 & 2); increases from nil inoculum in a prior chickpea crop to substantial inoculum in chickpeas including areas with PRR like symptoms in one paddock (paddocks 3 & 5) (Table 6).

All of the Goondiwindi paddocks (rainfall June to Oct 2015 209mm, June to Oct 2016 321mm) with hotspots were in wheat the winter of 2016, but two paddocks (coded 14 and 16) with no hotspots but had low and high area sampled were sown in chickpeas. All April samples for both paddocks had nil Pm DNA values, but in Nov the low sites were positive, for paddock 14 (average Pm DNA 694 copies/g soil) and 16 (average Pm DNA 6174 copies/g soil), and for 16 the high site average value was 8587 copies/g soil. That high sites provided positive values suggests that the inoculum was resident at the samples sites, rather than due to inoculum arriving after April via the flow of storm water containing inoculum. This paddock 16 planted to a PRR susceptible kabuli variety had large areas of PRR in 2016, despite the April presowing nil Pm DNA results from four low and four high sites.

Table 5. April 2016 sample location effects, average Pm DNA (sequences/ g soil) results, number of positive samples, for samples from a single hotspot area, low areas and high areas of paddocks

Paddock code	Av. hotspot P. med DNA	Av. low P. med DNA	Av. high P. med DNA
1	0	0	0
2	0	0	0
3	209^{1*}	418^{1}	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	1389^{3}	1698^{2}	285^{1}
11	690^{2}	0	0
12	2881^{3}	2355^{3}	0

* no. of positive samples, out of three

Table 6. April and November 2016 comparison for four Coonamble paddocks (see paddock codes) April no. of positive Pm DNA samples, Nov average Pm DNA values, Nov no. of positive Pm DNA samples and no. collected (in superscript) for soil samples from a single hotspot area, low areas and high areas of paddocks

		April	April	April
code	2015 crop	Hot no. +	Low no. +	High no. +
1	wh	0/3	0/3	0/3
2	wh	0/3	0/3	0/3
4	cp	0/3	0/3	0/3
6	cp	0/3	0/3	0/3
		Nov.	Nov.	Nov.
code	2016 crop	Hot av.	Low Av.	High Av.
1	cp	0*	$13,110^{3/3}$	$4,107^{1/1}$
2	cp	$1,242^{1/3}$	$6,447^{2/2}$	$2,936^{1/1}$
4	cp	0	$6,662^{3/3}$	$13,248^{2/2}$
6	cp	$3,417^{2/3}$	-#	-#

*only dead seedlings present in hotspot area, possible death from waterlogging, two samples taken from an adjoining area were both Pm positive (av. 19,054 sequences/g soil)

#no disease symptoms observed, no soil samples collected

These results although from a small number of paddocks in a single season (albeit a high rainfall season) were unexpected, as they indicate that results taken prior to the sowing of a crop may not be indicative of future disease and associated inoculum concentrations.

Implications for growers

This work has not been able to develop disease risk categories for Phytophthora root rot of chickpeas using pre-sowing soil inoculum concentrations. There are three main reasons, Pm declines to low levels during break crops within 6-12 months, resting spore concentrations are very low and distribution across paddocks is uneven.

In wet seasons low concentrations of Pm can multiply rapidly to cause PRR. Pm can also spread to neighbouring crops in run-off water.

However the Pm DNA test may be useful as a diagnostic tool for growers and agronomists to confirm PRR diagnosis. For example, in the 2016 some chickpea paddocks in NW NSW were saturated causing some areas of the paddocks die. Pm DNA analysis of soil samples from some of these areas has allowed agronomists and growers to identify if waterlogging or PRR were the cause of the losses.

Where suspected PRR occurs in chickpea crops, confirmation through isolation of the pathogen from diseased tissue can be unsuccessful if the symptoms are advanced or the plants have died. Analysis of soil samples for Pm DNA provided confirmation of a suspected case of PRR in QLD in 2015. The key point to the use of this diagnostic tool will be the need for in-crop soil samples when the pathogen is active and inoculum concentrations are high.

In addition, the Pm DNA test is a valuable research tool as has been used to compare the resistance of breeding lines and varieties to Pm.

For detailed information on control of PRR in chickpea visit:
http://www.pulseaus.com.au/pdf/Chickpea%20Phytophthor%20Root%20Rot%20Management.pdf

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Notes

Spray application tips and tactics

Bill Gordon, Nufarm Australia

Key words

Spray application, spray coverage

Take home message

Product choice and rate, timing and total application volume will normally have the largest impacts on the efficacy achieved from any spray job. The sprayer setup and operating parameters can also have a significant effect on the outcome by affecting the spray coverage on the target, as well as the drift potential. Assessing spray coverage is a simple process that can help to improve the sprayer setup.

Introduction

Throughout the season there are a number of situations where spray applications are made to very different types of targets, often with products that have different types of translocation. This variation generally requires a change in nozzle type or orifice size and the operating parameters to achieve a change in total application volume and/or spray quality.

After adjusting the sprayer setup, being able to determine where the spray droplets are landing allows the operator to change the sprayer setup to improve the coverage for particular spray jobs. Often this requires that the operator is able to assess the impact of changes to the set up on where the droplets land.

A starting point – how many setups should the operator have?

As a general guide, the main spray jobs, application volumes and typical spray qualities required by an operator are covered in table 1. This highlights the fact that often more than 2 sets of nozzles are required to cover all situations.

For each type of spray application there may be subtle variations in the sprayer setup or operation that can be made to improve the coverage. This paper discusses some of the practical considerations the operator should take into account when choosing the set up for various spray jobs throughout a typical season, including the factors influencing spray coverage and how to compare setups and operating parameters for continual improvement.

Table 1. Typical spray quality and total application volume for different situations

Typical Application Volume	Medium Spray Quality (lower drift risk areas)	Coarse Spray Quality	Extremely Coarse Spray Quality (higher drift risk areas)
Lower range **50 -60 L/ha** **(Low stubble load)** **to** **70-80 L/ha** **(High stubble load)**	*Only where permitted on label: Fully translocated herbicides Small to medium sized targets.	Fallow Spraying Fully translocated herbicides such as Glyphosate and Group I herbicides,	Fully translocated herbicides, medium targets, Very sensitive areas or NIGHT SPRAYING
Higher range **70-80 L/ha** **(Low stubble load)** **to** **100 + L/ha** **(High stubble load/ dense crop canopy)**	*Only where permitted on label: Contact type products. Small targets. In crop spraying. Penetration and coverage in large & broadleaf crops.	Good stubble penetration. Pre-emergent's. Fully Translocated herbicides, Some contact herbicides at the higher application volumes.	Water soluble Pre-emergent's. Medium sized targets with fully translocated summer fallow herbicides. Very sensitive areas or NIGHT SPRAYING

*note, the arrows indicate that one nozzle may be able to do more than one type of application, provided the spraying speed, application volume and operating pressure are suitable

Suggestions to improve fallow applications

The following points have been included to provide a guide or starting point for the sprayer setup. Some of the important things to consider include:

Total application volume: For fully translocated products typically volumes above 50L/ha for a coarse spray quality in low stubble environments, and above 70L/ha in heavy stubble environments. Typically this volume should be increased by 10 to 20 L/ha when using an extremely coarse spray quality. For contact type products (translaminar) the total application volume should be above 70L/ha in low stubble environments, and up to 100 L/ha in heavy stubble situations.

Spray quality: For small vertical targets (grasses) operating at the small end of the coarse spectrum will normally provide good retention of droplets on a range of weed types, however using coarser spray qualities may also be useful for many broadleaf weeds. Often operating at the small end of the coarse spectrum will provide a good balance for a range of targets and products. This is normally suitable for daytime conditions, but may not reduce the spray drift potential if considering spraying at night.

Nozzle spacing: Using narrow nozzle spacings, e.g. 25cm compared to 50cm, can improve deposition into standing stubble. However before deciding to plumb the machine this way ensure that the orifice size and spray quality will be suitable if operating with nozzles that have smaller orifice sizes.

Boom Height: Operating at heights above that required for a double overlap at top of the stubble or weed (whichever is the taller) will reduce coverage and increase drift potential. Increasing boom height from 50cm above the target to 70cm above the target can increase the airborne fraction of spray by up to 4 times.

Adjuvant selection: adjuvants should always be chosen to increase efficacy, however many adjuvants have the potential to change the spray quality and drift potential in unexpected ways. Most non-ionic wetter 1000 type products can more than double the drift potential from some air

inducted coarse nozzles. For fallow spraying it is important to select adjuvants that do not increase the drift potential of the spray application.

Spraying speed: Reducing spraying speed can reduce dust and wheel tracks, will improve penetration into stubble and crop canopies and can reduce shadowing.

Nozzle design: There are a number of nozzle designs that have twin patterns, where one pattern is angled forward and the other angled backwards. Generally twin nozzles are best utilised for increasing deposition onto vertical targets, which may also increase stubble interception. Twin nozzles are best operated at lower spraying speeds, commonly less than 16 km/h.

Risk assessment: Before any spray application it is important to fully assess any risks including the weather conditions, sensitive areas and volatility risk.

Pre-emergent herbicides

Most applications of pre-emergent herbicides will benefit from using coarser spray qualities to increase penetration through stubble and by increasing the total application volume, however volumes above 150 L/a generally do not provide further significant improvements in efficacy.

For products with relatively low water solubility, such as trifluralin and pendimethalin, avoiding the tie up of product onto stubble is critical to maximising herbicide contact with the soil. When using a conventional nozzle spacing of 50cm, a VC spray quality or larger (such as XC) set to produce a double overlap at the top of the stubble can minimise retention on stubbles, however the uniformity of the spray deposit onto the soil surface will be more variable than compared to a coarse spray quality due to the lower number of droplets produced.

For reasonably water soluble products such as atrazine, simazine and metalochlor, interception by the stubble may have a smaller impact on efficacy, provided a reasonable rainfall event can wash the product back onto the soil. Where rainfall is anticipated, the more water soluble products may be applied in a lower total application volume, typically above 70-80 L/ha.

Generally reducing spraying speeds will improve the penetration into stubble and improve the evenness of the application. Narrower nozzle spacings can also be of benefit, provided the spray quality and boom height are suitable.

Alternately, many operators have plumbed machines with nozzle spacings to match the crop row width. Where nozzles are positioned in the centre of the inter-row gap between standing stubble lines, the nozzle height may be lowered to obtain an overlap close to the base of the stubble. This may improve soil contact and reduce interception by the stubble, provided spraying speeds and wind speeds do not excessive.

Early season grass sprays in-crop

Droplet retention on small, vertical grasses is usually optimised when using a medium spray quality (where permitted on label), however in a heavy standing stubble, the smaller droplet sizes tend to increase the amount of product deposited onto the stubble. Generally a spray quality at the smaller end of the coarse spectrum (towards medium) combined with total application volumes above 70-80 L/ha will provide a reasonable outcome.

Where operators typically operate at higher spraying speeds, or with larger than coarse droplets, they may notice increased shadowing of small weeds behind stubble. Where this is occurring, slowing down would help, but ensuring that each new job is driven in the opposite direction to the last can also improve overall level of control, particularly when a ‘double knock’ strategy is employed.

When using a Group A product, always ensure that an appropriate adjuvant is used, through a nozzle that will not significantly alter the spray quality with the addition of the adjuvant (see table 2). Also ensure the water quality is suitable by testing for bicarbonate levels before the application.

Table 2. Variation in the Dv0.5 (VMD) produced by selected low drift nozzles* operated at 3.0 bar, expressed as the standard deviation +/- from the Dv0.5 (VMD)[1] in micrometers (µm) for 3 spray solutions

Spray Solution	**water**	**clopyralid**	**pinoxaden + methylated oil**	**Average Standard Deviation**
Nozzles Tested (all nozzles were operated at 3.5 bar)	**Standard Deviation + / - micrometers (µm)**			
	7.33	4.69	4.45	5.49
Bellericay Bubblejet ABJ 110-015	28.62	26.01	14.52	23.05
Bellericay Bubblejet ABJ 110-02	9.60	5.11	3.54	6.08
TeeJet AITTJ60-110-02	8.40	8.72	9.78	8.97
TeeJet AIXR 110-015	5.44	10.28	9.06	8.26
TeeJet AIXR 110-02	19.63	16.40	12.80	16.28
Hypro Guardian Air 110-015	15.92	14.27	10.61	13.60
Hypro Guardian Air 110-02	6.14	8.17	8.73	7.68
Lechler IDK 120-02	4.64	6.35	4.84	5.28
Lechler IDKT 120-02	6.32	8.23	4.29	6.28
Hardi Minidrift MD-110-02	4.16	3.73	3.10	3.66
Hardi Minidrift Duo-110-02	5.23	2.30	3.53	3.68
TeeJet TTI 110-015	13.04	10.51	14.04	12.53
TeeJet TTI 110-02	5.39	8.71	12.25	8.78
Teejet TTJ60-110-02	41.71	11.69	5.83	19.74
Hypro ULD 120-015	7.75	14.11	8.54	10.13
Hypro ULD 120-02	7.63	3.39	3.89	4.97

[1]Dv0.5 or VMD is the droplet size (diameter in micrometers or µm) at which half of the spray volume produced by the nozzle will exist as droplets smaller than this size, and the other half will exist as dropets larger than this size.

*note the range of nozzles listed in this table does not include all of the nozzles tested by J Connor Ferguson

Broadleaf sprays in crop

Fully translocated products such as the Group I herbicides should be applied with a coarse spray quality or larger at application volumes above 60 L/ha. Where a product with contact activity is used the application volume should be increased to 80 L/ha or more.

Late season applications into dense canopies

Late season fungicide and insecticide applications, along with pre-harvest desiccation, typically require that the droplets are able to penetrate into the canopy. The size of the canopy and the architecture of the plants will greatly influence how far droplets can penetrate into the canopy.

Leaf type, leaf shape and leaf surface all affect how well droplets will be retained. Droplet retention on most cereals and large grass type crops will be improved by using a medium spray quality (where permitted on label), however penetration through a canopy may be increased using a coarse spray quality. Droplet retention on many broadleaf crops may allow for good retention when using coarse spray qualities.

With a standard boom sprayer there are only a limited number of things the operator can do to potentially improve the penetration into the canopy, those include:

- Reducing the spraying speed
- Increasing the application volume
- Manipulating the spray quality, and
- Utilise a narrower nozzle spacing

To make a greater impact on penetration into the canopy generally requires the use air assistance to help transport droplets into the canopy. While the addition of air into the equation can add another layer of complexity to the sprayer setup, it can also provide large improvements in canopy penetration when correctly setup and adjusted.

To assess which variations in the sprayer setup and operating parameters can actually improve the penetration into dense canopies, useful tools include water sensitive paper (WSP) and the SNAPCARD app, which can help the operator to determine where improvements are being made.

Consider assessing spray deposits to improve your spray coverage

Using tools such as water sensitive paper will allow the operator to look at where the droplets are landing and to compare various sprayer setups to see which ones provide the best coverage.

Often it is difficult to see small improvements in coverage. A tool that can measure the level of spray deposit can assist when trying to evaluate changes. The SNAPCARD app allows spray operators to measure the spray deposits onto water sensitive paper by indicating a 'percent coverage.' Taking regular measurements and recording this information allows for continual improvements in the sprayer setup for different types of spray applications.

Further reading

https://grdc.com.au/GrowNotesSprayApplication

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Cereal agronomy concurrent session

Agronomic drivers of yield in rain-fed wheat - environment, management, variety and disease

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Optimising yield in new cereal varieties - varietal specific agronomy research

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Notes

A simple visual lodging risk guide to assist with decision making on Plant Growth Regulators (PGR)

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Key words

Irrigated wheat, Plant Growth Regulators (PGR's), NDVI, Lodging

GRDC code

CSA00039

Take home messages

- Irrigation increases crop canopy biomass and supports higher yield potential; both however put greater stress on stem strength and the anchorage of the plant in the soil, leading to increased risk of lodging.
- Two of the biggest determinants of lodging (other than weather conditions during grain fill) in irrigated wheat crops are the cultivar lodging resistance rating and the inherent fertility (N supply) of the paddock.
- Background N supply to the crop can be "visualised" and quantified with reference to NDVI readouts or canopy photos comparing N deficient or N Rich strips to the remainder of the paddock.
- PGR input and N management at stem elongation represent the last opportunity to reduce lodging risk with management matched to lodging as defined by the visual appearance of the crop and knowledge of cultivar standing power under irrigation.
- These recommendations were generated from experiments and farm monitoring on vertosol soil types in the 'old' northern region (Northern NSW and QLD), and caution should be taken applying them outside of these districts.

Background

A small component of the "Better Irrigated Wheat Agronomy" project (CSA00039) led by CSIRO has been tasked with producing a simple visual guide to lodging risk. As part of the project, FAR Australia has been working on the linkages between the visual appearance of the crop at stem elongation and its subsequent propensity to lodge.

Like fungicides, managing PGR's is about risk management, adjusting the level of 'insurance' purchased against the potential risk of crop lodging. As with fungicides, one doesn't know whether the PGR insurance will pay until the end of the season, since the agrichemicals have to be applied at critical development stages before all of the climatic factors have been expressed.

The problem

Irrigation increases yield potential and lodging risk!

Lodging occurs regularly in northern region irrigated wheat crops. It reduces yield and quality as well as increasing harvesting costs. Lodging is the result of compounding factors. Irrigation increases crop canopy biomass and supports higher yield potential; both however put greater stress on stem strength and the anchorage of the plant in the soil, leading to increased risk of lodging. Therefore the irrigation that gives rise to higher yield potential, when combined with unsettled windy weather also increases lodging risk, particularly during grain fill.

How can we get clearer indication of lodging risk in an irrigated wheat crop?

With regards to crop management there are two categories of lodging risk factors, those that the grower can control and those they cannot. Of those factors that the grower has some control over, it is clear from our research results that some have a greater influence on lodging risk than others. From this work and from feedback from advisers, the following table gives an indication of some the key agronomic factors associated with lodging in irrigated crops (Table 1).

Table 1. Factors associated with lodging risk deduced from trials run in the project (Generally higher star ratings confer greater influence over lodging risk)

Factors not under the growers control	Lodging risk rating	Factors under the growers control	Lodging risk rating
1. Inherent fertility – high fertility that is long standing for that paddock in the rotation	*****	1. Cultivars' resistance to lodging – Cereal cultivars have different root architecture and stem strengths that increase or decrease lodging risk	*****
2. Windy and wet weather (ear emergence to harvest)	*****	2. Irrigation (1) – Irrigation timing in relation to expected weather conditions is a key factor in lodging risk (2) total irrigation applied increases yield potential and hence lodging risk	*****
		3. Total N rate applied – Higher N rates increase lodging risk particularly superimposed on high inherent fertility	***(*)
		4. Nitrogen (N) timing - Earlier (at sowing) nitrogen application can increase lodging risk, particularly if inherent fertility is already high.	***
		5. Sowing date – Earlier sowing dates, particularly combined with high seed rates can increase lodging risk.	**
		6. Seeding rate – Higher seed rates can increase lodging particularly combined with earlier sowing and inherent fertility.	**

These factors have different weightings and different consequences for lodging risk depending on seasonal environmental conditions, irrigation however is a very large driver of lodging risk since the size of the crop canopy and grain yields supported by the crop canopy are much larger than those achieved on dryland.

In interviews with regional agronomists other factors having influence on crop lodging were brought forward, including row orientation, basal P levels both inherent and applied giving vigorous early growth, seed depth and consolidation ensuring good plant anchorage to prevent root lodging.

Management actions to prevent lodging

Influence of cultivar on lodging risk

One of the most important factors in preventing lodging is the selection of a lodging resistant cultivar which are traditionally characterised by stiffer straw strengths and better root anchorage. The majority of germplasm screening in the northern region has been conducted under dryland

conditions but the project has also been able to rank the standing power of some of the current cultivars and conduct screening of early generation lines to assess yield potential and standing power under irrigated farming systems. Of the current cultivars that have been tested, Table 2 shows the most and least lodging resistant cultivars when grown under irrigated scenarios.

Therefore one of the simplest ways of reducing lodging risk in an irrigated wheat crop is to select a lodging resistant cultivar.

Table 2. Preliminary lodging ratings for varieties as rated using preliminary results from the 2014-2016 trials of the Better Irrigated Wheat Agronomy Project. Varieties sown early in their sowing window may not achieve the level of lodging resistance indicated. Yield potential, grain quality, maturity and disease resistance among these varieties is variable and growers should consider aspects of varietal performance when selecting a variety.

Lodging Rating	R-MR	MR		MR-MS	MS	MS-S	S
Variety	Sentinel(b) Cobra(b)	Suntop(b) Wallup(b) Crusader(b) Trojan(b)	Livingston(b) Merinda(b) Dart(b) Condo(b)** Kiora(b)**	Bellaroi(b) Caparoi(b) Mitch(b) Kennedy(b) Lancer(b) Sunmate(b)** Spitfire(b) Aurora(b)* Lillaroi(b)*	EGA Gregory(b) Suntime(b)* Flanker(b)*		Orion(b)

R-MR = Resistant to Moderately Resistant
MR = Moderately Resistant
MR-MS = Moderately Resistant to Moderately Susceptible
MS- Moderately Susceptible
MS-S = Moderately Susceptible to Susceptible
S = Susceptible
* = Preliminary rating based on one year of trial data
** = Preliminary rating based on two years of trial data

Other management options that can be adopted to reduce your lodging risk

Other factors that can reduce lodging risk but have less impact than cultivar standing power are the key components of crop canopy management. Those factors under the control of the grower and adviser can be split into two categories:

a) Measures that can be adopted at sowing

1. **Review seeding rate** – higher seeding rates increase lodging risk, particularly when they are combined with earlier sowing - plant by seed number to achieve target plant populations of approximately 100 -125 plants/m^2 with higher target where sowing is delayed.
2. **Seed depth** – Ensure that seed is planted into a consolidated seed furrow at 30-40mm depth combined with the correct plant population
3. **Review nitrogen (N) quantities at sowing** – Soil + fertiliser N at sowing is recommended to be 70-90 kg /ha in order to minimise excessive vegetative growth during tillering.

b) GS30 (Pseudo stem erect – start of stem elongation)

4. **Review N quantity and timing at the start of stem elongation** – At the start of stem elongation the crop canopy can visually signal its fertility status and therefore its propensity to lodge given conducive weather conditions.
5. **Plant Growth Regulator (PGR) application** – If cultivar lodging risk suggests a higher risk of lodging consider PGR application in the late tillering to second node window GS25-32.

"Visualising" lodging risk

How can paddock fertility and lodging risk be visualised?

One of the most influential factors giving rise to lodging in an irrigated wheat crop is the inherent fertility of the paddock. This fertility and the associated propensity of the following crops to lodge "can be visualised" in the crop canopy at the start of stem elongation and was widely experienced in 2008 in the northern region when large quantities of sowing N was applied to soils with high levels of available nitrogen, and extremely thick canopies were produced. The link between crop density in terms of shoot number and Green Area Index (GAI) are used in lodging risk tools in Europe.

In Australia, agronomists regularly assess crops visually using their experience to judge the vigour and crop canopy size as a surrogate for fertility and associated N supply at different development stages. The issue in estimating inherent fertility is complicated by the fact that northern Australian crops routinely receive N fertiliser at sowing, which can mask the visual indicators of inherent fertility in the crop. This is much less of an issue in Europe since crops are not fertilised with large amounts of N at sowing, so crop canopy images in early spring at GS30-31 are more indicative of the background N mineralisation and the inherent fertility of the paddock. This is where an "old technique" for assessing soil nitrogen availability can be a good guide to assessing lodging risk and the appropriate level of PGR management.

In order to visualise paddock fertility and associated lodging risk (independent of N fertiliser already applied), four to five N rich or N deficient strips can be set up in the paddock at planting. This is where N is either excluded (if large quantities of N are being applied at sowing), or added (100-200kg N/ha), to four or five small areas of the paddock if no N is being applied to the commercial crop. These N strip areas needn't be large, perhaps the size of trial plot or the width of the sowing rig with no N applied. The visual difference between these N deficient or N rich strips can then be compared visually to the remainder of the paddock in the spring at GS30-31 when remaining N and PGR inputs are considered.

Where fertility is very high, there will be little or no difference between the N rich/deficient strips and remainder of the paddock when assessed in the spring. In contrast where visual differences between the N rich/deficient strips and the paddock are pronounced, the fertility will be lower. Since high inherent paddock fertility has such a pronounced effect on lodging risk and irrigation serves to increase that risk, crop canopy visual appearance during stem elongation (GS30-39) is a key determinant of lodging risk and therefore also a useful predictor of the likely need for an application of Plant Growth Regulators (PGRs). The scale of this visual difference can be assessed at its simplest by visual observations of the agronomist. However it's also possible to quantify the difference using readouts from a hand held GreenSeeker® or by using a mobile phone photo.

Using a hand held GreenSeeker® to quantify lodging risk

The following table (Table 3) sets out three arbitrary categories of soil fertility on the basis of crop canopy appearance (recorded in northern region crops) at GS30-31 (visual difference between N rich strips or N deficient strips set up at sowing and the remainder of the paddock), as quantified with a GreenSeeker®. By dividing the NDVI representing the higher N status whether it be the paddock or the N Rich strip, by the No N strip or unfertilised paddock surround, gives the adviser the response index. For example 0.84 NDVI for the paddock divided by 0.83 NDVI for the N deficient strip set up at sowing, gives a NDVI response index of 0.84/0.83 = 1.012. Below three arbitrary response indices ranges have been put forward to help estimate lodging risk and subsequent PGR input when combined with cultivar lodging resistance ratings grown under irrigation with yield potential of 8-10t/ha.

Table 3. Different lodging risk scenarios based on NDVI response Index from N rich or N deficient strips set up at sowing in paddock scenarios of different fertility.

High lodging risk No visual difference Response Index Less than 1.05	**Intermediate lodging risk** Some visual difference Response Index 1.05 – 1.20	**Low lodging risk** Strong visual difference Response Index Greater than 1.20	
			**N R I C H**
NDVI 0.84 High N status	NDVI 0.86 – High N status	NDVI 0.73 High N status	
			**N D E F I C E N T**
NDVI 0.83 – No N	NDVI 0.73 No N	NDVI – 0.50 No N	
NDVI Response Index = 1.01	**NDVI Response Index = 1.18**	**NDVI Response Index = 1.46**	

Clearly the highest risk scenarios for lodging are where high inherent fertility (NDVI index at approximately 1.0), poor cultivar standing power and additional N applied at sowing combine.

Using mobile phone photos to quantify inherent fertility and potential lodging risk

Mobile phone photos can also be used to quantify the difference between N rich strips or N deficient strips set up at sowing and the remainder of the paddock. The link between crop density and lodging is used by online European websites that use mobile phone photos to quantify lodging risk. An example of such a website is the BASF CAT online which uses a mobile phone image to quantify Green Area Index (GAI), shoot number and subsequent lodging risk when combined with knowledge of the cultivar.

www.agricentre.basf.co.uk/agroportal/uk/en/tools/website_tools/gai_cereals_cat_online/cat_online.html

Although this website is very specific to the UK in terms of parameters entered e.g. calendar date, location and cultivar it can still be used to quantify the **relative (rather than absolute) differences between two mobile phone images** in just the same way as NDVI readouts can be compared. The difference is that instead of using NDVI units to quantify the difference in canopy appearance, the photos are compared in terms of GAI units and shoot number, which can then be ratioed just as the NDVI readouts in Table 3 to generate the degree of difference. The only proviso with using such a website is to ensure that the assumed surrogate details provided are the same for both images uploaded.

To show how this website uses these images to generate a lodging risk prediction based on canopy structure, Figure 1 shows a simple comparison from the Liverpool Plains comparing images of irrigated wheat crops at similar growth stages GS31 in two different rotation positions.

Figure 1. Irrigated wheat grown on the Liverpool Plains on the left a) cv Ventura following Sorghum GS31 (NDVI 0.50) and on the right b) cv Sentinel following canola GS31 (NDVI 0.69)

If image (a) were attributed the status of a weaker strawed cultivar (rated 5 for resistance to lodging) with 8t/ha yield potential the lodging resistance score would be 7 (1-9 scale where 1 has the highest potential risk of lodging). Conversely set with the same yield potential and using the image on the right the lodging resistance score decreases from 7 to 3 indicating a significant increase in lodging risk. Even without the website being adapted for Australian wheat cultivars lodging risk tools such as this give an indication of how crop canopy density (influenced by inherent fertility) relates to lodging risk. Using the same images but with a more lodging resistant cultivar (rated 8) increased the lodging resistance score to 9 (image a) and 5 (image b) respectively (Table 4).

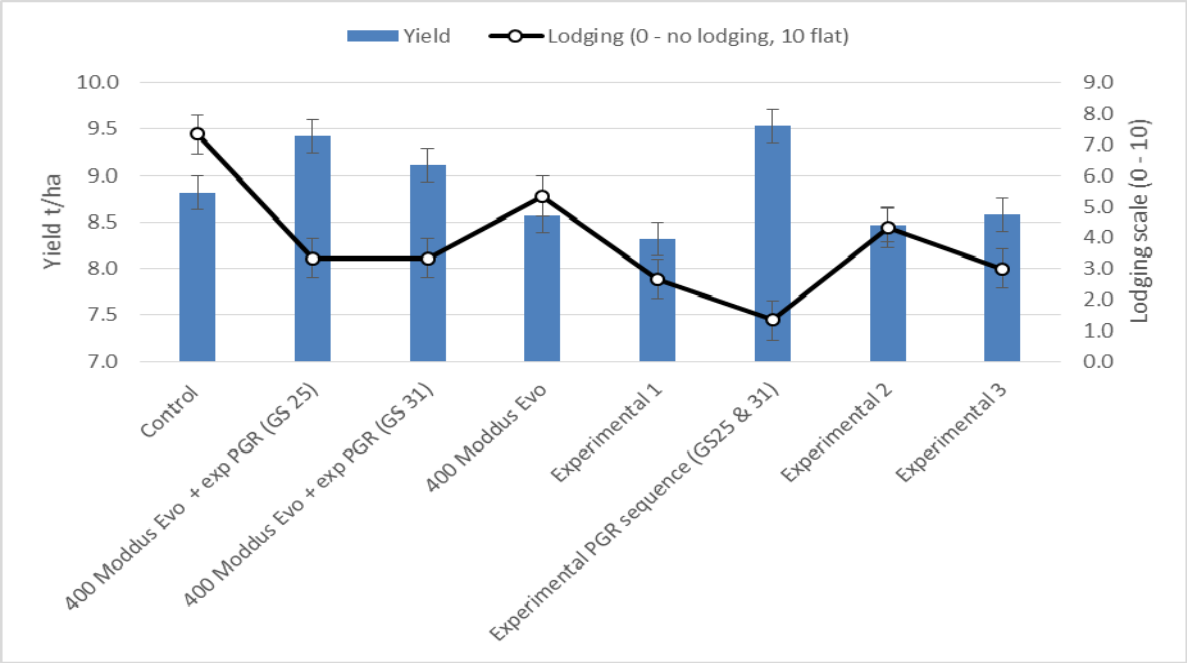
Table 4. Lodging resistance score attributed to images uploaded to CAT online (1-9 scale 1 low lodging risk resistance – **high risk**, 9 high lodging resistance risk – **low risk**) at 8t/ha yield potential

	Lodging resistance score (1 – 9 scale)	
	Image a) above	**Image b) above**
Lodging resistant cultivar	9	5
Lodging susceptible cultivar	7	3

Matching potential lodging risk to PGR insurance

Whilst there are other management actions that can be adopted to prevent potential lodging risk at stem elongation concerning N management (already discussed), there is also the potential to investigate PGR input. PGRs are very similar to fungicides in that they are insurance inputs for a potential risk that may not eventuate, but complicate matters as they can be associated with both positive and negative yield responses. Negative yield responses from PGR's frequently occur when dryland crops encounter water or heat stress later in the season following application. In other circumstances, when lodging doesn't occur and results are neutral. Clearly PGRs help reduce subsequent crop lodging in irrigated crops and this has been shown in the project, but it should be emphasised that adjustment of other crop canopy parameters can be just as important, cultivar standing power, reducing planting populations and delaying N application. Whilst irrigation increases lodging risk it does at least remove the potential for the more adverse effects of these products encountered in dryland crops. In fact the issue can be that under irrigation current PGR labels do not provide sufficient lodging prevention since labels have been generated with respect to dryland cropping. However there are clear differences in PGR performance that can be matched to label recommendations and potential lodging risk.

AMPS Research conducted some excellent field research on the interaction between PGR treatments and durum wheat yields in 2016. The data suggested that mixtures of PGRs trinexapac ethyl (Moddus Evo®) & an experimental PGR were more successful than applications of a single active ingredient such as trinexapac alone. The data also illustrated that yield increases could be generated in the near absence of lodging with irrigated crops and that there would be merit in researching PGR sequences for higher risk scenarios in irrigated crops (Figure 2a & 2b) for which there is currently no label approval in Australia. It should be noted that this experimental trial work included an application of Moddus Evo at GS25, when the earliest application on the approved Moddus Evo label is at GS30.



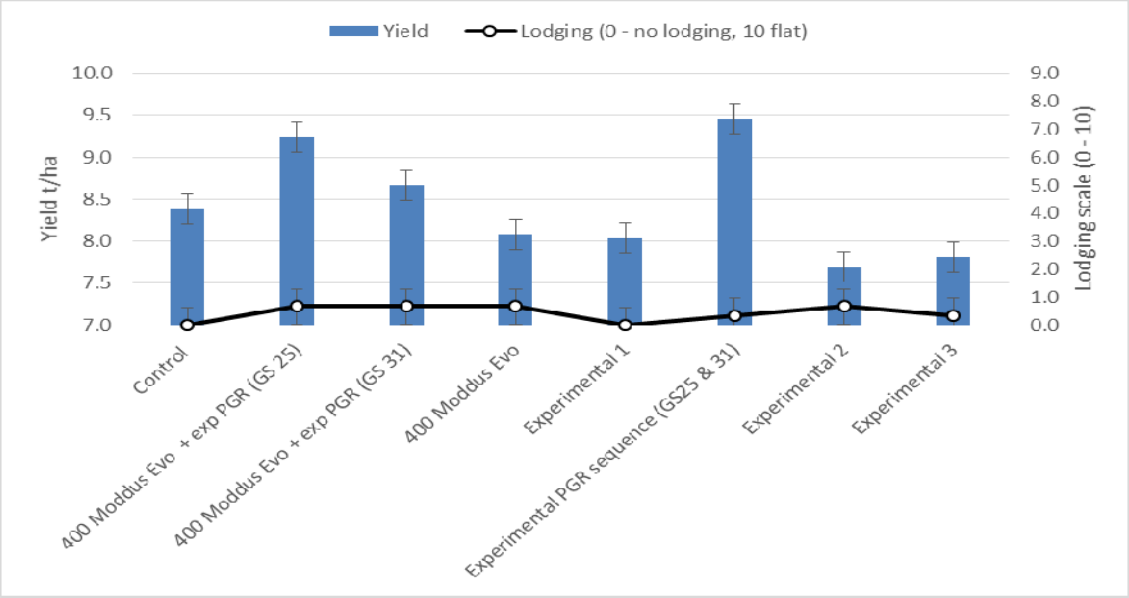


Figure 2a & 2b. Influence of PGR treatment (product & timing) on harvest lodging and final yield in the durum wheats AGT 043 (1a) and Bellaroi (bb).

The following label rates allow different levels of PGR insurance to be adopted for different levels of ldoging risk to be covered with different levels of insurance (Table 5 & 6).

Table 5. Potential PGR and N management at GS30-32 to take account of visual differences (and cultivar lodging resistance) in potential lodging risk.

High lodging risk	Intermediate lodging risk	Low lodging risk
1. PGR management Consider applying PGRs at higher rate or as label mixture (trinexapac ethyl & chlormequat chloride) applied at GS30-GS31.	Consider applying a PGR treatment at GS30-31. (lower end of the rate ranges)	No PGR Review the need for a PGR based on cultivar lodging rating and N applied to date.
2. N Rate and timing Consider reducing overall N dose planned and splitting the N application remaining between GS31 and GS33-39.	Apply the majority of the remaining N at GS31.	Apply the majority of N as soon as possible if sampling strip is representative of the paddock.

N.B. Consult with your agronomist with regard to exact PGR products and timings (see table below)

Table 6. PGR's approved for use in wheat

Product (active ingredient)	Rates approved for wheat (mL/ha)	Conc^{n}	Gibberellin inhibitor	Active applied (gai/ha)	Zadoks Growth stage
Single active products					
Stabilan® 750SL (chlormequat chloride)*	500 - 1300	582g/L	Yes	291 - 757	GS25-35
Cycocel® 750 A (chlormequat chloride)*	500 - 1300	582g/L	Yes	291 - 757	GS25-31
Errex 750 (chlormequat chloride)*	500 - 1300	582g/L	Yes	291 - 757	GS25-31
Moddus Evo® (trinexapac-ethyl)	300 - 400	250g/L	Yes	75 - 100	GS30-32
Mixtures					
Errex 750 + Moddus Evo®	1000 - 1300 + 200		Yes	582-757 + 50	GS30-32

***PLEASE NOTE CYCOCEL 750A has no label approval for use in QLD or Northern Territory, ERREX 750 has no label approval for use in QLD or Northern Territory & STABILAN has no label approval for use in Northern Territory.**

In conclusion, PGRs represent an insurance premium which the adviser does not know will pay until the end of the season, since these agrichemicals have to be applied at critical development stages before all of the environmental factors have been expressed. Visualising the crop canopy at early stem elongation and quantifying its inherent N supply enables the adviser to better match potential lodging risk with PGR and N management at this important development stage.

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 trials, along with Angus Murchison of Spring Ridge for hosting some of the trials.

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"

GRDC Goondiwindi Update Paper (2016) by Peake et al. "The effect of sowing date, variety choice and N application timing on lodging risk and yield of irrigated wheat"

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Plant growth regulators in barley 2015 and 2016

Rachel Norton, Linda Bailey, Denielle Kilby and Anthony Mitchell, Northern Grower Alliance

Key words

Barley, PGR's, lodging, Moddus® Evo, yield

GRDC code

NGA0004

Take home messages

- Plant growth regulators (PGRs) have shown inconsistent results in terms of crop responses and lodging reduction.
- Mixing partners with Moddus® Evo showed no advantage over the use of Moddus Evo alone.
- In a wet, favourable year, the use of PGRs can aid in reducing the incidence and severity of lodging in susceptible barley varieties and have positive effect on yield however, multiple applications may be required.
- PGRs can have substantial impact on crop height; however, the response in terms of crop yield can be variable.

Background

NGA have been involved in work to help validate Plant growth regulator (PGR) options in barley under northern conditions. Trial work started in 2015 from interest in their use and fit due to the potential of a higher rainfall winter season outlook. Growers and agronomists from the higher rainfall areas east of Moree were keen to see if PGRs could be tool they could use in wet years to reduce lodging in barley and improve yields and harvestability.

Use of PGRs was occurring but there was little validation on effectiveness or whether they were an economical option. A single trial was established near Moree in Commander barley in 2015 assessing Moddus Evo performance. Despite favourable conditions for lodging when treatments were applied little to no lodging occurred and there was continued interest from a number of local research groups to expand on the work in 2016.

Three trial sites were established in 2016, one each at Mount Tyson, Croppa Creek and Boggabri. The Croppa Creek and Boggabri sites both showed significant levels of lodging. The Mt Tyson site showed only low levels of lodging.

Visual lodging assessments, crop height, NDVI readings, yield and grain quality were evaluated for all trial sites.

2015

A single, four replicate trial established in a commercial paddock of Commander barley evaluated a range of Moddus Evo rates (200, 300 and 400mL) at two application timings, crop growth stages GS32 and GS37. The trial also contained two treatments where 100kg/ha of Urea was applied to enhance the lodging effect, one in combination with a Moddus Evo application.

The first application was applied on July 9 at majority GS32 or second node and the second application was on August 4 at GS37 or flag leaf just visible. The applications of urea were spread by hand over the treatment plots at GS32.

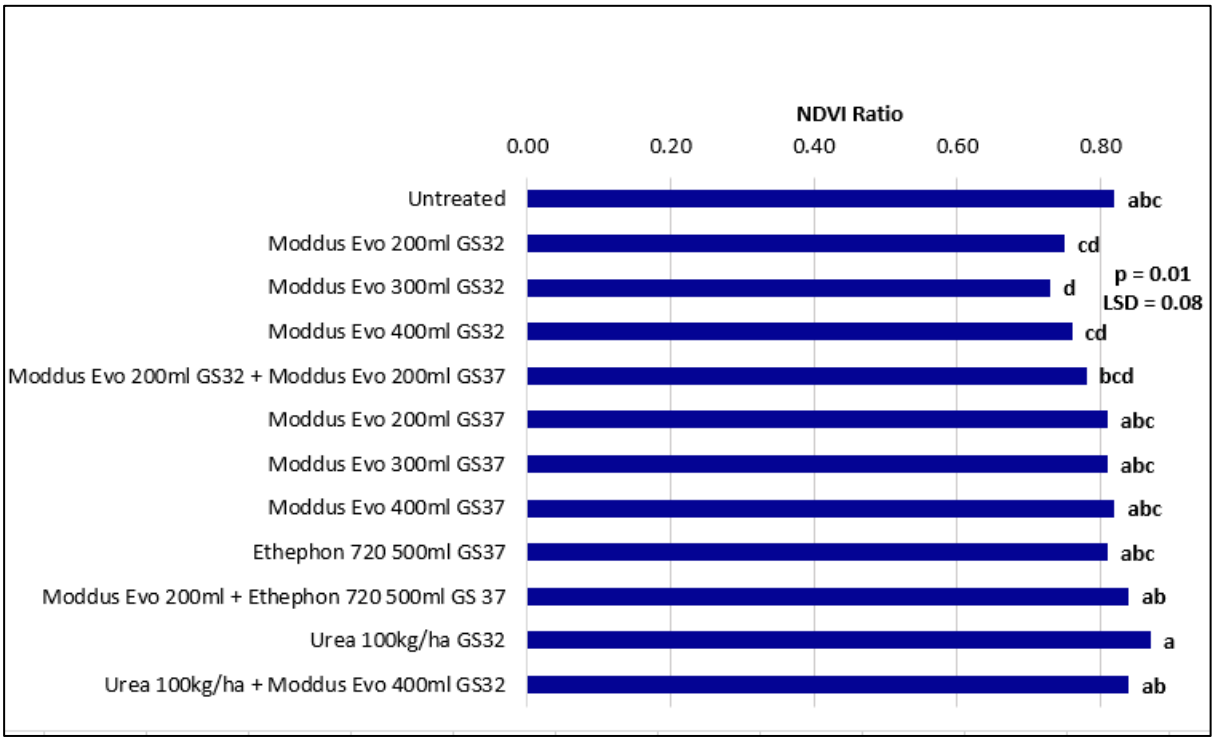

Figure 1. NDVI assessment September at Moree 2015 trial site

NDVI (Normalised Difference Vegetation Index) readings were taken on the 11th August and 10th September. No significant crop responses were found at the first timing in August. At the September assessment there was a clear trend to reduced NDVI ratios from all rates of Moddus Evo applied at GS32, however the 300mL rate was the only treatment that was significantly lower than the untreated.

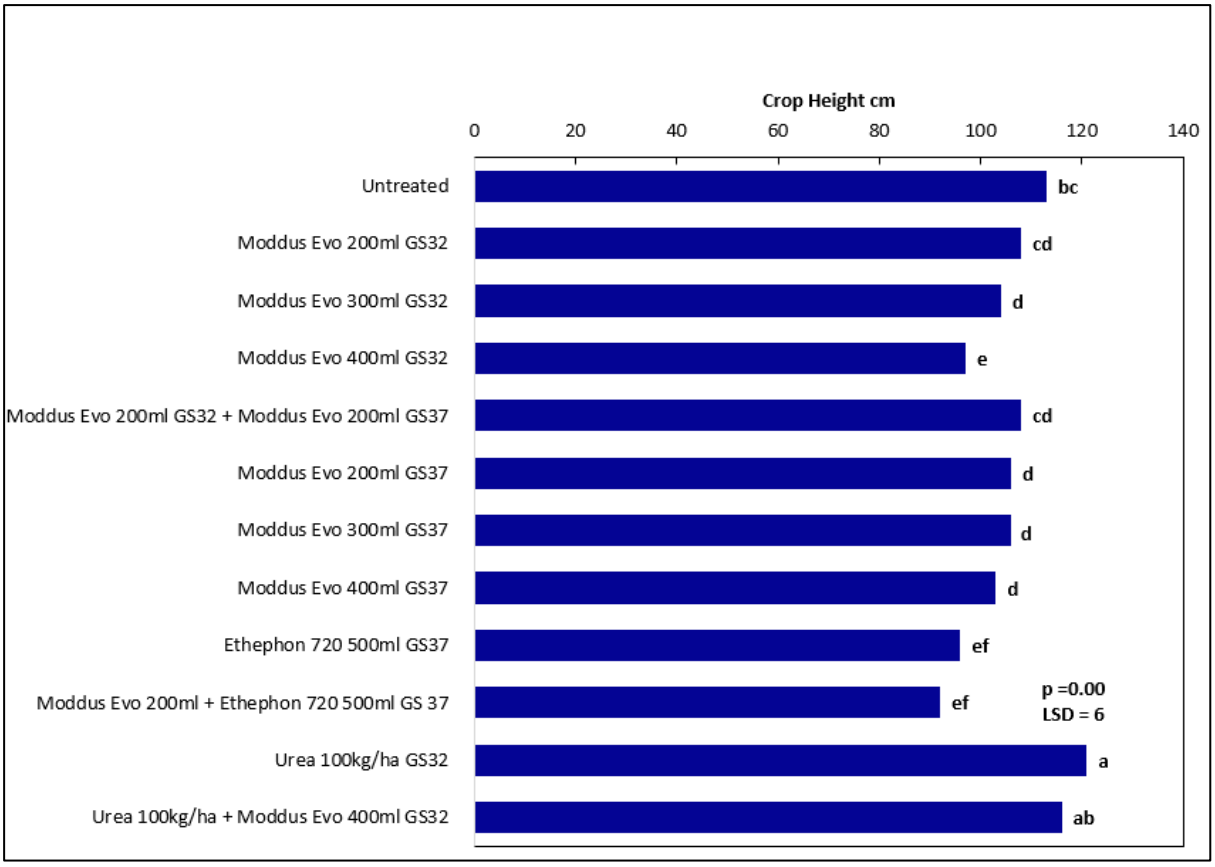

Figure 2. Measurement of crop height (cm) Moree September 10, 2015

There was a clear trend to all PGR treatments reducing height compared to the untreated. There was also a rate response in the Moddus Evo application at GS32 with the 400mL reducing crop height more than 300mL and 200mL rates. The two ethephon treatments at GS37 and the 400mL Moddus Evo rate at GS32 had the shortest crop heights.

There was no significant lodging at the site therefore an evaluation of treatments was not possible. However, the site was harvested with yield and grain quality assessed.

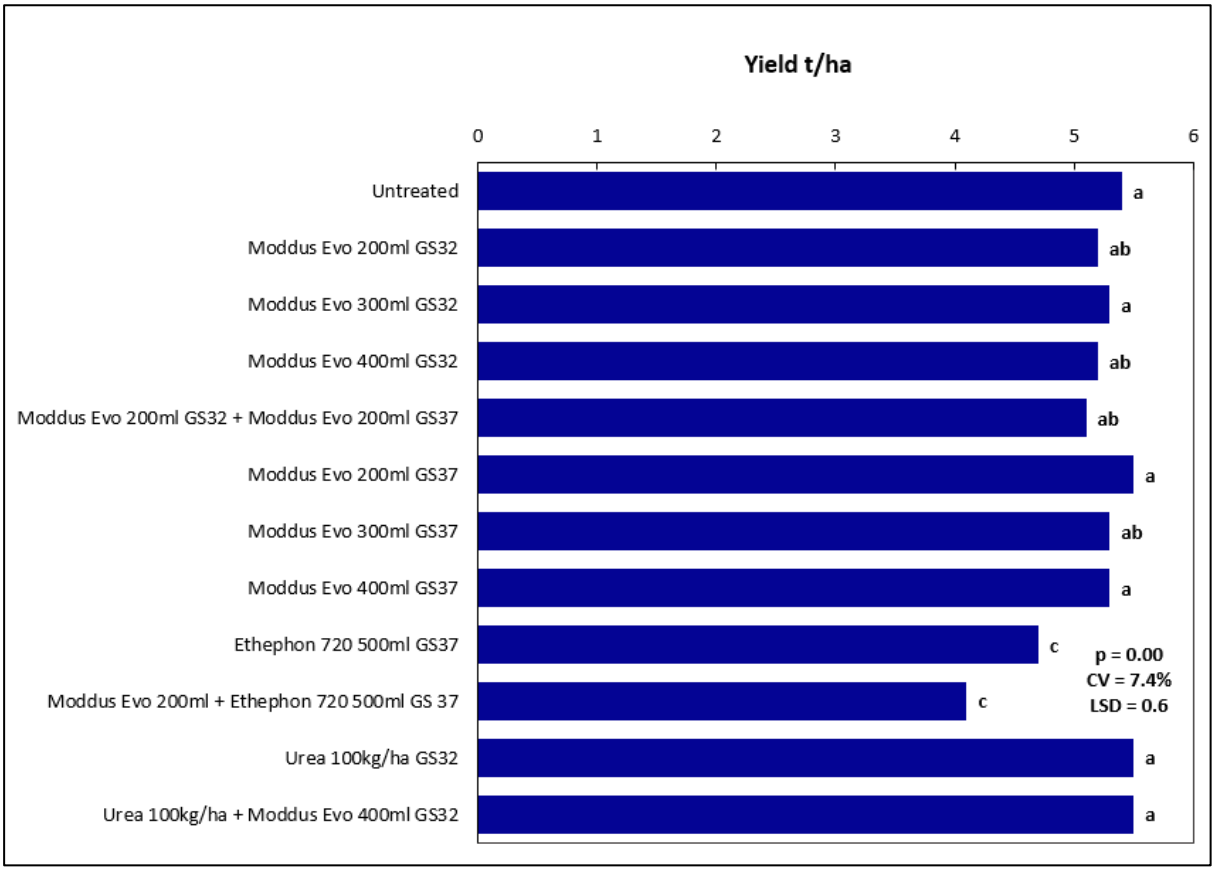

Figure 3. Yield (t/ha) from Moree 2015 trial site

Yield data shows there was no significant yield increases from any PGR treatment. The two ethephon treatments significantly reduced yield when applied at GS37.

Grain quality data showed no significant impact from the PGR treatments in terms of protein, test weight or screenings.

2016

Due to the lack of lodging in the 2015 trial, another three sites were established in commercial barley in 2016. The sites located at Mt Tyson on the Darling Downs, Croppa Creek and Boggabilla were established on three different barley varieties. The trials again primarily looked at applications of Moddus Evo at 200, 300 and 400mL rates at two timings GS30-32 and GS37 and in split applications. Four other treatments were also included, these included two PGR products either as a mixing partner with Moddus Evo or alone. These results are not shown as they are not registered for use in barley.

Also included were two treatments where urea was added at 100kg/ha to enhance the potential for lodging, one in combination with a single application of Moddus Evo.

NDVI readings, crop height, lodging score, yield and grain quality were assessed at all three sites.

Croppa Creek

This site was established in Compass barley with the first application, including the hand spreading of Urea, on the 1st July at GS30 (jointing). The second application was applied on 29th of July at GS37 (flag leaf tip visible). NDVI readings conducted on the 10th August indicated minor crop effects from the higher rates of Moddus Evo and with the mixing partner treatments.

Crop heights were measured on the 17th August (early flowering) with significant height reductions (7-10cm) seen in the 300 or 400mL Moddus Evo GS30 applications and the split application of 200mL GS30 followed by 200mL GS37.). The trial was assessed at multiple timings for lodging and scored using the percentage of crop lodged by the severity or 'angle' of lodging.

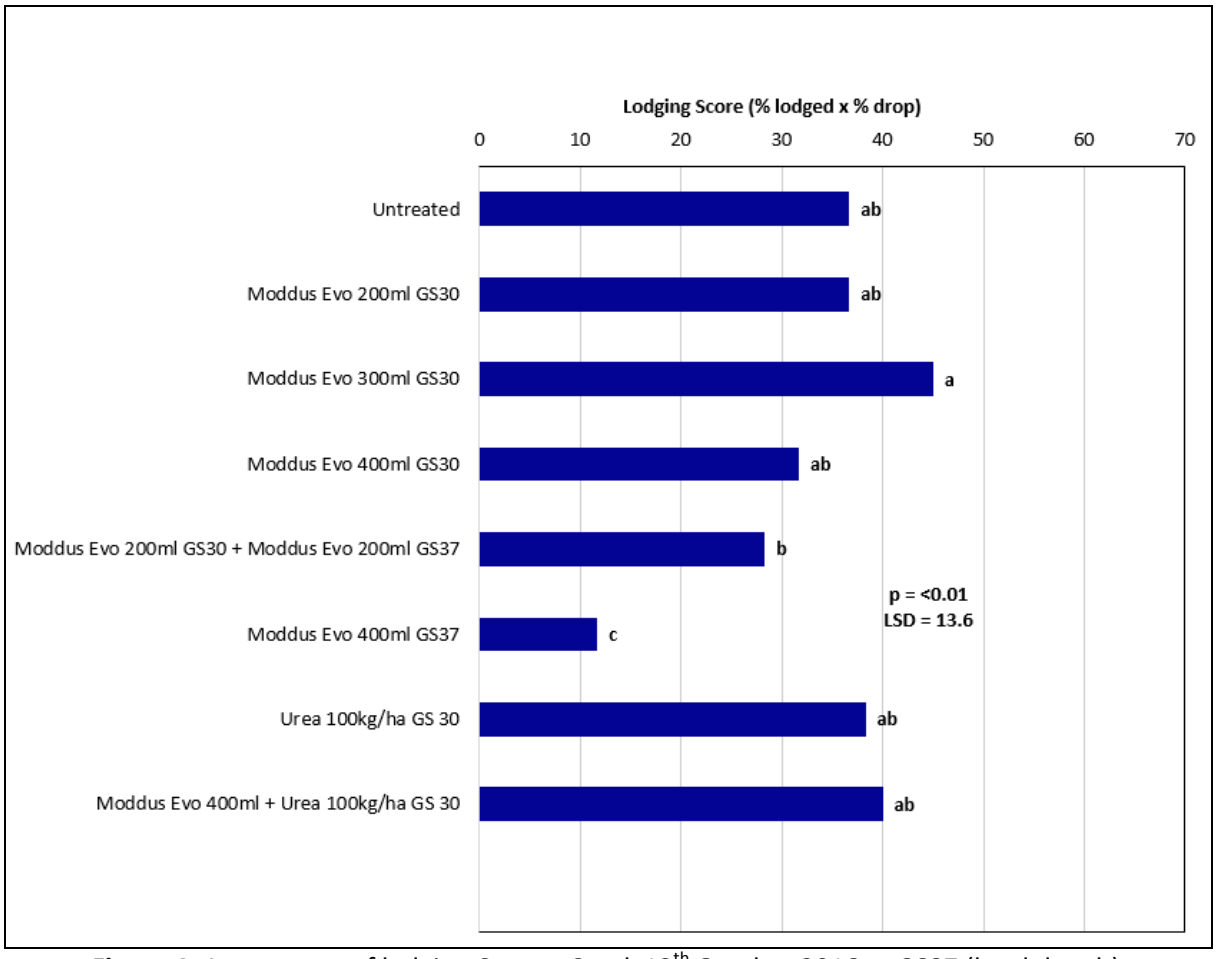

Figure 4. Assessment of lodging Croppa Creek 13th October 2016 at GS87 (hard dough)

Significant amounts of lodging were apparent by full flowering in early September and by early

October lodging was visible in all treatments.

At this late stage in the crop, the 400mL rate of Moddus Evo applied at GS37 was the only treatment that significantly reduced the levels of lodging. The split rate applied at GS30 and GS37 appear to have reduced the amount and severity of lodging but was not significant. No treatments prevented lodging completely.

While some treatments had an impact on the reduction of lodging, the impacts on yield appeared less clear.

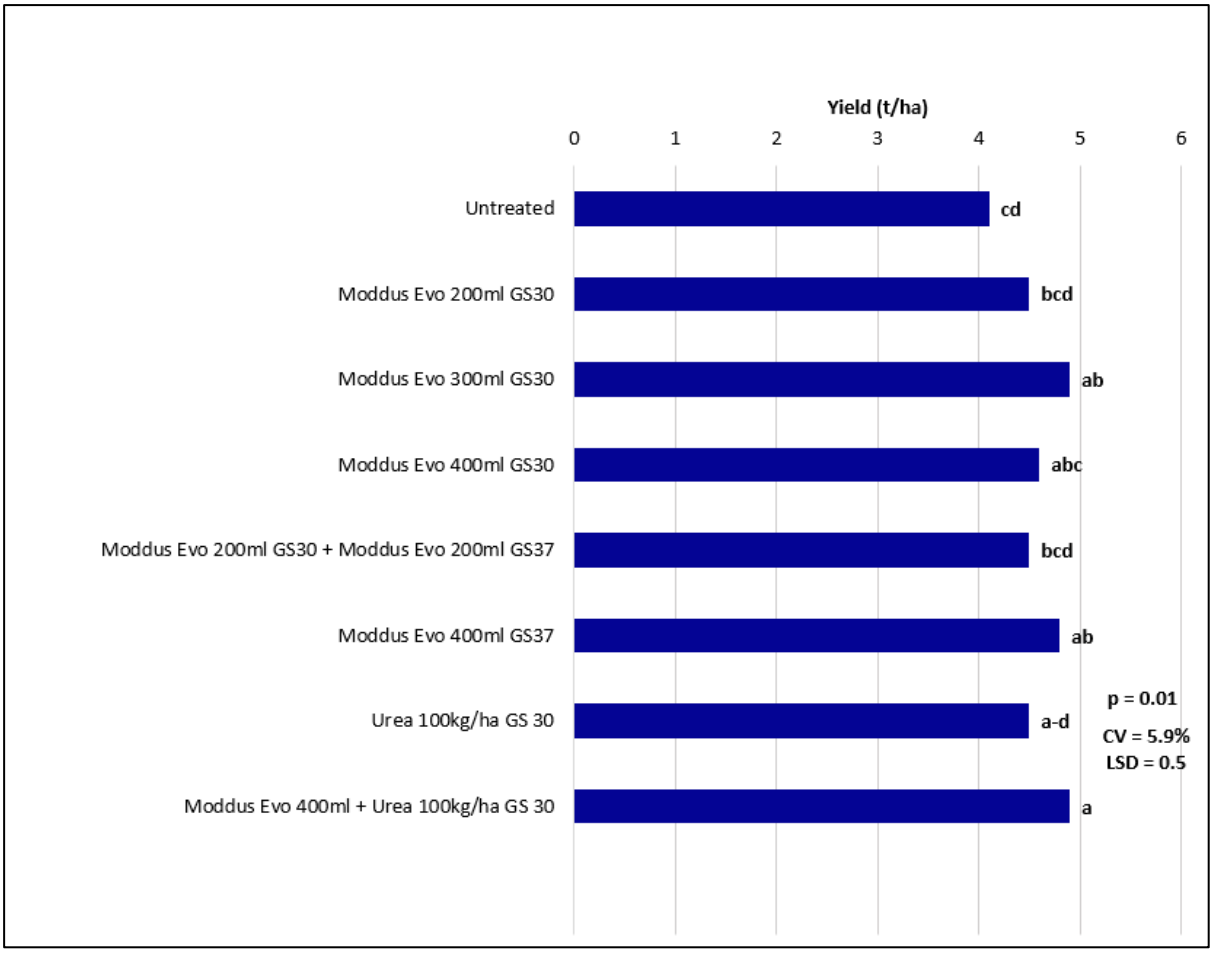

Figure 5. Yield (t/ha) Croppa Creek trial site 2016

A significant yield benefit was seen in the 300mL Moddus Evo rate at GS30 and the 400mL rate applied at GS37 when compared to the untreated. The most substantial benefit saw an 800 kg/ha increase in yield. Moddus with mixing partners (not shown) did not show any advantage over Moddus Evo applied alone.

Boggabri

A second trial site was established near Boggabri in a commercial paddock of Commander barley planted 5th May. The first treatments were applied on the 17th July at GS32 (second node) with the following treatments applied 17th August when majority of the crop was GS35-37 (tip of flag leaf visible). No NDVI was taken at this site and the first assessment was of crop height on 31st August at GS39 (full flag leaf emergence). Similar reductions in crop height were shown between this trial site and that of the Croppa Creek site with the 400mL rate of Moddus Evo having the greatest effect.

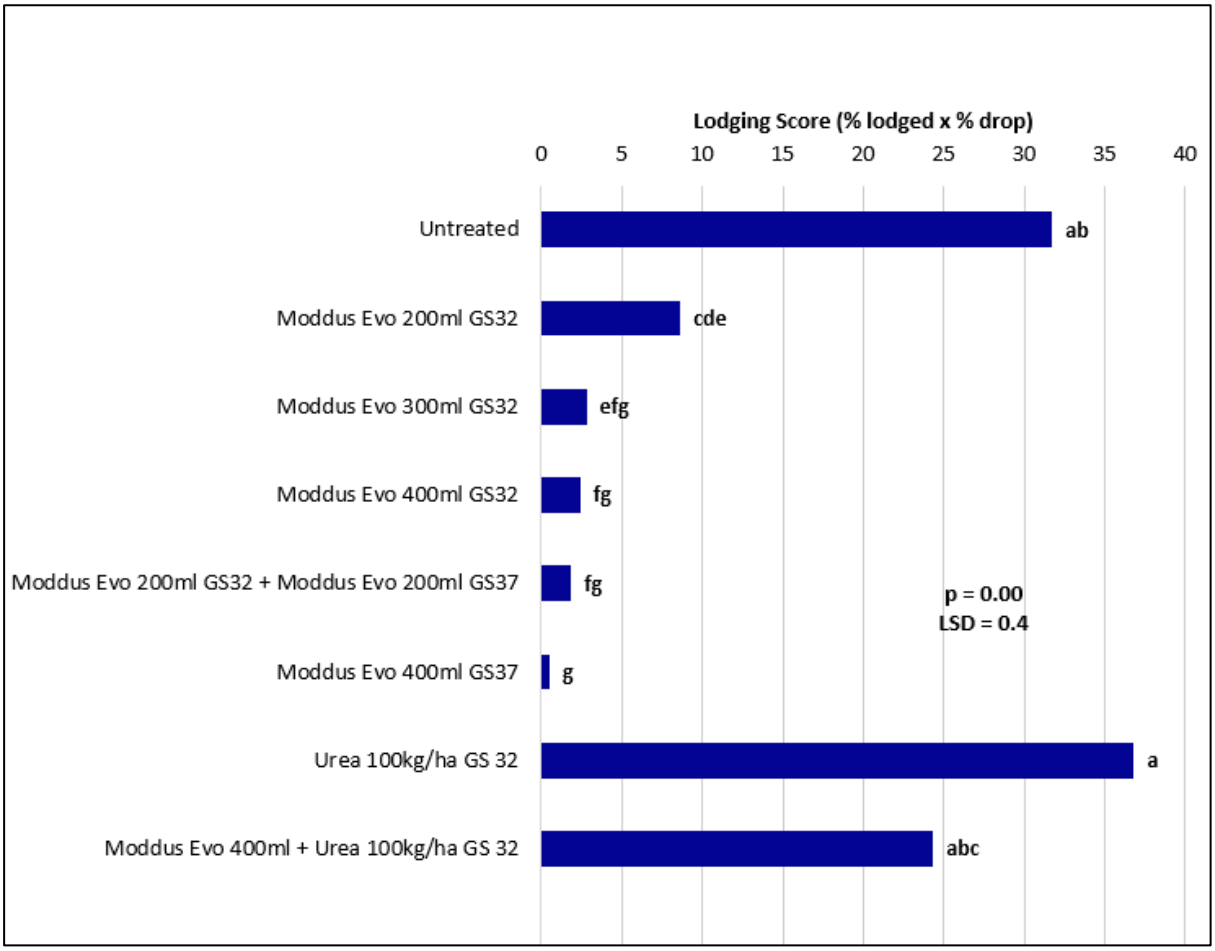

Figure 6. Assessment of lodging Boggabri trial site 2016

Though not as severe as the Croppa Creek site, the amount of lodging was still significant. A lodging score taken on the 17th November at early flowering shows a rate response in the single Moddus Evo treatments applied at GS32. As expected, the treatment of added Urea significantly increased the rates of lodging with the Moddus Evo 400mL rate only partly effective in offsetting the impact of additional nitrogen on lodging. All the PGR treatments reduced the severity of lodging when compared to the untreated.

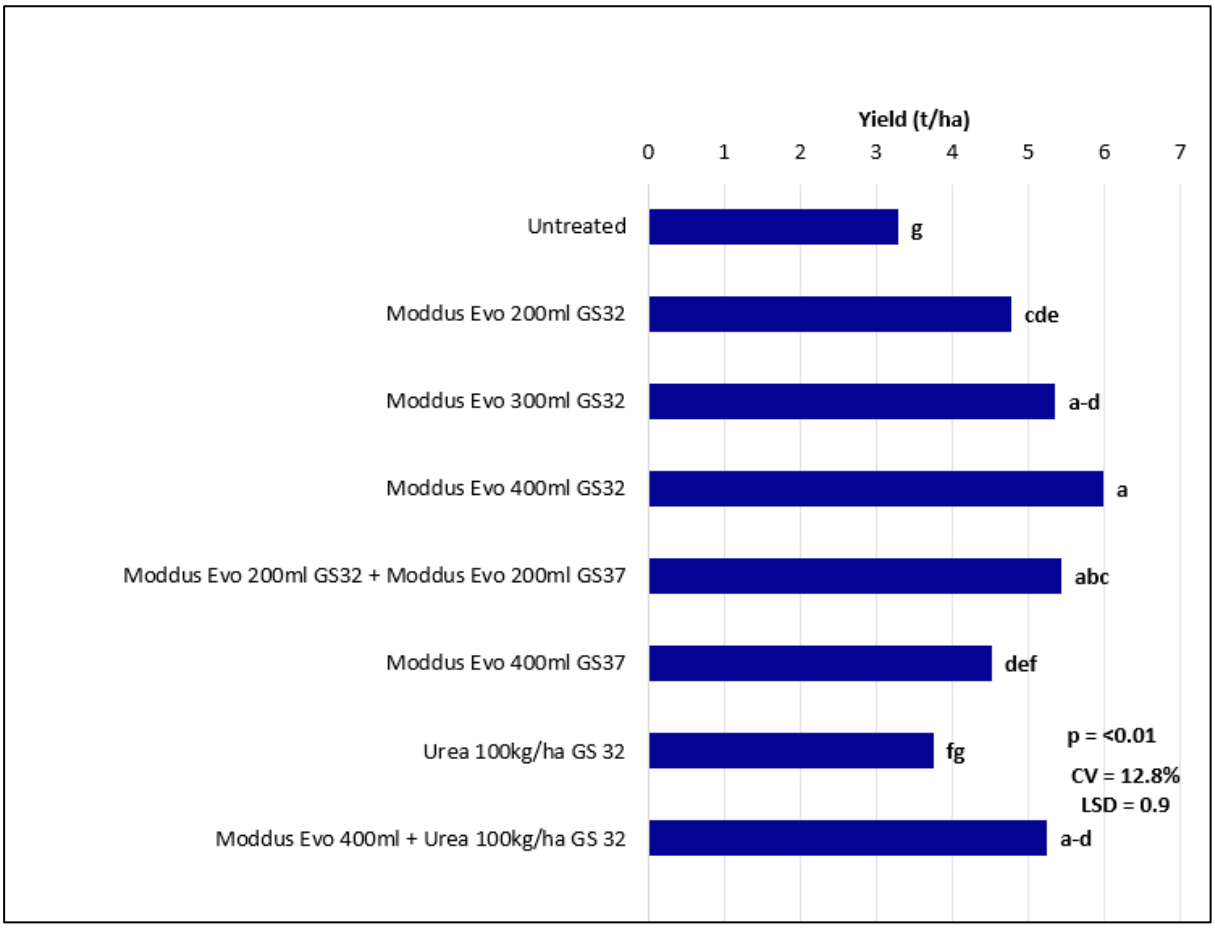

Figure 7. Yield (t/ha) Boggabri 2016

All treatments except the added Urea treatment alone provided an increase in yield when compared to the untreated. The 400mL rate of Moddus Evo applied at GS32 recorded a large increase of 2.7t/ha over the untreated.

There were no significant effects on test weight or screenings at this site. The effects on protein were minimal with the added Urea treatments recording the highest protein (10.2-10.6%) but were not significantly different to the untreated.

Mt Tyson

The third of the 2016 trials was established in commercial Oxford barley, planted 15th June at Mt Tyson on the Darling Downs. The first of the PGR applications were applied on 17th August at GS31 or first node. With the second application being at GS33-37 (third node to flag leaf tip emerging) on the 31 August. A measurement of crop height was taken on 12th October with significant height reductions (5-6cm) only observed from treatments that included ethephon. However, NDVI readings taken 19th October showed no significant difference in crop responses between any treatments.

Only a very small amount of lodging was seen at this site, which could be a reflection on the variety as Oxford is rated has having 'good' straw strength. A lodging assessment taken on 19th October showed no difference between any of the treatments. There was also no significant difference in yield or grain quality between any of the treatments.

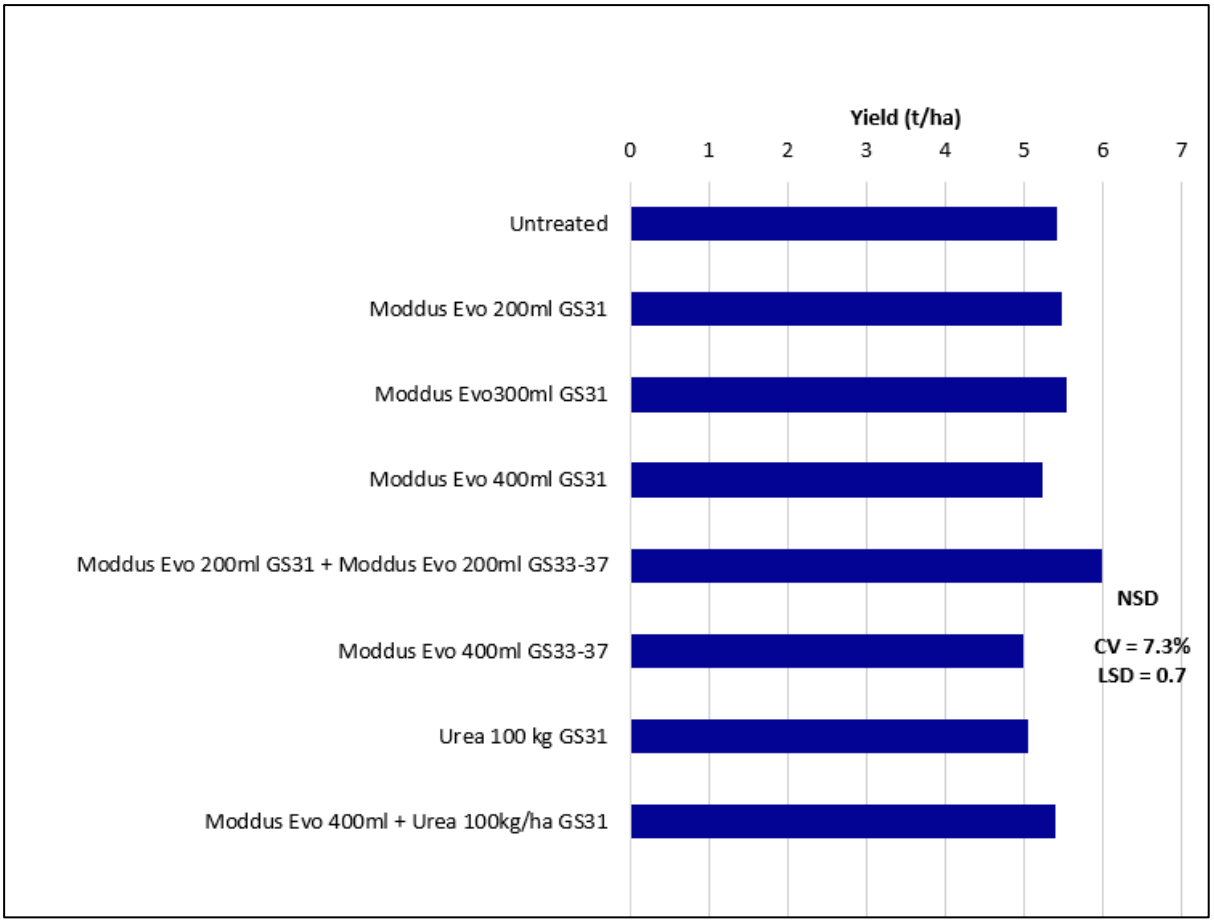

Figure 8. Yield from Mt Tyson PGR site. There was no significant difference between treatments.

Economics

While a benefit can be seen in a year such as 2016 with increased lodging for situations like those at Croppa Creek and Boggabri in terms of yield increase and improved harvestability, can these benefits outweigh the cost of product and application?

Croppa Creek

- Despite all Moddus Evo treatments recording higher yields than the untreated, only two were significant. The 300mL rate applied at GS32 gave a yield benefit of 800kg/ha and the 400mL rate applied GS37 an increase of 700kg/ha. Using 2016 feed grade barley price delivered Moree of $151/t together with application costs; these treatments achieved a net benefit of $95/ha and $74/ha respectively.

Boggabri

- While it is unclear what was driving this response, this trial saw unexpectedly high yield benefits from all Moddus Evo treatments. Yield increases ranged from 1.2 to 2.7t/ha more than the untreated. Grain quality data shows barley made malt grade at $163/t delivered Moree in 2016, a net benefit of ~$164 to $400/ha was possible.

Mt Tyson

- There was no significant difference in yield therefore or economic benefit.

Moree

- There was no significant difference in yield between treatments of Moddus Evo alone, however there was a significant yield reduction of 700 and 1300kg/ha in both applications of

ethephon at GS37. Grain quality showed barley made malt grade with the 2015 malt barley price delivered Moree of $216/t, together with product and application costs of $11/ha this gave a negative net benefit of ~ - $140 to - $270/ha.

Net benefits based on 2016 barley price delivered Moree -Oxford & Compass – feed $151/t
Commander – malt $163/t
2015 malt barley $216/t delivered Moree
Application Cost = Moddus Evo $17.79 at 300mL rate and $23.73 at 400ml rate, ethephon $2.80 at 500mL rate Cost includes an $8/ha contractor application

In a season such as the one in 2015 and at the Mt Tyson site where no positive yield benefit was seen, due little to no lodging present, there was no economic benefit in applying a PGR. In fact, a yield and economic penalty was seen in some of the treatments.

For the sites at Boggabri and Croppa Creek where positive yield benefits were seen, in a year where the lodging risk is high for a susceptible variety there appears to be some economic benefit to applying a PGR.

Conclusions

The use of PGRs in a conducive season does appear to have a mostly positive benefit in the reduction of lodging in susceptible varieties and may result in improved harvestability and yield benefits. The risk is identifying what approach to take when we cannot be certain of the forthcoming conditions for the season and whether they will lead to increased lodging in susceptible varieties. The results so far have shown large variability in all trials suggesting that the success of the PGRs is very much dependent on conditions and variety. Also included in these trials were a number of Ethephon treatments, both alone and as a mixing partner with Moddus Evo. No advantage was seen in these trials from its use either alone or as a mixing partner with Moddus Evo in reducing lodging or improving yields.

While it can be difficult to predict the outcome of a season, should conditions for lodging potential be possible, a useful tactic could be the use of multiple applications at a lower rate. In the 2016 trials the 200mL Moddus Evo treatment applied at stem elongation to second node (GS30-32) followed by another 200mL application later at early flag (GS37) proved effective at reducing lodging incidence while still having a yield improvement over untreated at Croppa Creek and Boggabri, similar to that of the higher single application rate. This approach may help to spread the risk and reduce any losses, both crop and economic, should the season change and lodging risk decrease.

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 authors would like to thank them for their continued support.

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Nutrition concurrent session

Nitrogen management in wheat 2016 – method, timing and variety

Richard Daniel, Denielle Kilby and Linda Bailey, Northern Grower Alliance

Key words

Nitrogen, wheat, yield and protein

GRDC code

NGA00004

Take home messages

1. The rate of nitrogen applied was the main factor impacting yield and grain quality in all trials.
2. Urea spread with no physical incorporation, provided equivalent crop responses to urea spread and incorporated.
3. There was no consistent impact from N application timing.

In recent years, NGA have been heavily involved in projects focussed on nitrogen (N) application strategies in wheat, particularly to assist the management of high yielding, and frequently lower protein achieving, wheat varieties such as EGA Gregory(Þ and Suntop(Þ. In 2016 the trial activity focussed on two main areas; 1) the impact of method of application of urea (spread v incorporated) and 2) the impact of timing of urea application (comparing December, February and planting application).

What was done?

Three sites were established in 2016 in paddocks identified by agronomists and growers as low in nitrogen or expected to be N responsive. Suntop(Þ was the test variety in three N method x timing trials with EGA Gregory(Þ and Lancer(Þ evaluated in three variety comparison trials. Both approaches were conducted at each trial site with urea as the only nitrogen source.

All trials were established using small plot planters with row spacings of 32cm and plot lengths of 9-12m. The N application approaches evaluated were;

Suntop(Þ timing and method trial

- Application A - N spread and then incorporated by narrow point tynes (fallow Nov/Dec)
- Application B - N spread on soil surface (fallow Nov/Dec)
- Application C - N spread and then incorporated by narrow point tynes (fallow Feb)
- Application D - N spread on soil surface (fallow Feb)
- Application E - N spread immediately before sowing and incorporated by sowing (IBS) with narrow point tynes (sowing)
- Application F - N spread immediately post sowing (PSPE) and
- Application G - N spread in-crop at GS30

EGA Gregory(b) and Lancer(b) variety comparison trial

- Application A - N spread on soil surface (fallow Feb)
- Application B - N spread immediately before sowing and incorporated by sowing (IBS) with narrow point tynes (sowing)
- Application C - N spread in-crop at ~GS30

Table 1. Site and application details 2016

	Macalister	**Billa Billa**	**Tulloona**
Previous crop	Wheat	Wheat	Chickpea
Available soil nitrogen sowing (kg N/ha)	100 (0-120cm)	118 (0-120cm)	79 (0-120cm)
Fallow (Nov/Dec)	7/12/15	30/11/15	14/12/15
Timing and quantity of next rain	25mm 5-6 DAA	11mm ~16-17 DAA	17mm 2-3 DAA
Fallow (Feb)	29/2/16	15/2/16	23/2/16
Timing and quantity of next rain	9mm 19-22 DAA	31mm 5 DAA	2mm 25 DAA
Sowing	22/7/16	10/5/16	14/6/16
Timing and quantity of next rain	9mm 12 DAA	14mm 17 DAA	22mm 6 DAA
In-crop	26/9/16	11/7/16	8/8/16
Timing and quantity of next rain	11mm 8 DAA	10mm 30 DAA	6mm 4 DAA
In-crop rainfall (mm)	178	242	280

NB Available soil nitrogen = total soil mineral N kg/ha (to soil depth) using bulk density of closest similar soil type It does NOT include any mineralisation credit. DAA= Days after application. Macalister planting was very delayed due to absence of planting moisture.

Table 2. Suntop(b) timing and method trial: key treatments evaluated

Application	**Description**	**kg N/ha**
A & C	Fallow incorporated	50, 100, 200
B & D	Fallow spread	100
E	Spread and IBS	50, 100, 200
F	Spread PSPE	100
G	In-crop	50, 100

NB the 200 kg N/ha rates were included in an attempt to over-fertilise.

Three split applications of a total of 100 kg N/ha were also evaluated. All had 50% of the N incorporated at either the fallow timings or the IBS application followed by 50% spread at GS30.

Table 3. EGA Gregory(b) and Lancer(b) variety comparison trial: key treatments evaluated

Application	Description	kg N/ha
A	Fallow spread	50, 100, 200
B	Spread and IBS	50, 100, 200
C	In-crop	50, 100, 200

NB the 200 kg N/ha rates were included in an attempt to over-fertilise.

Two split applications of a total of 100 kg N/ha were evaluated. Both had 50% of the N applied at either the fallow timing or the IBS application, followed by 50% spread at GS30.

Rainfall for incorporation of spread urea (see Table 1)

Conditions for natural incorporation (rainfall) of urea spread at the December fallow timing were considered good at Macalister and Tulloona (both >15mm within 2-6 days of application) but poorer at Billa Billa (~ 2 weeks until first rainfall). Following the February fallow timing, conditions were poor (~ 3-4 weeks until first rainfall) at both Macalister and Tulloona. Macalister and Billa Billa did not receive their first rainfall after sowing was until ~ 2-3 weeks. The Billa Billa site did not receive any rainfall after the GS30 application for 30 days.

Results

1. Were the sites actually nitrogen responsive?

When dealing with nitrogen response trials, the most basic consideration is whether the sites were actually N responsive. NDVI (Normalised Difference Vegetation Index) was used to provide an objective in-crop assessment of nitrogen response. A larger NDVI ratio indicates increased biomass and/or greener treatments. Figure 1 shows the Suntop(b) NDVI results, at each site, from the factorial analysis of urea applied at three rates and three timings.

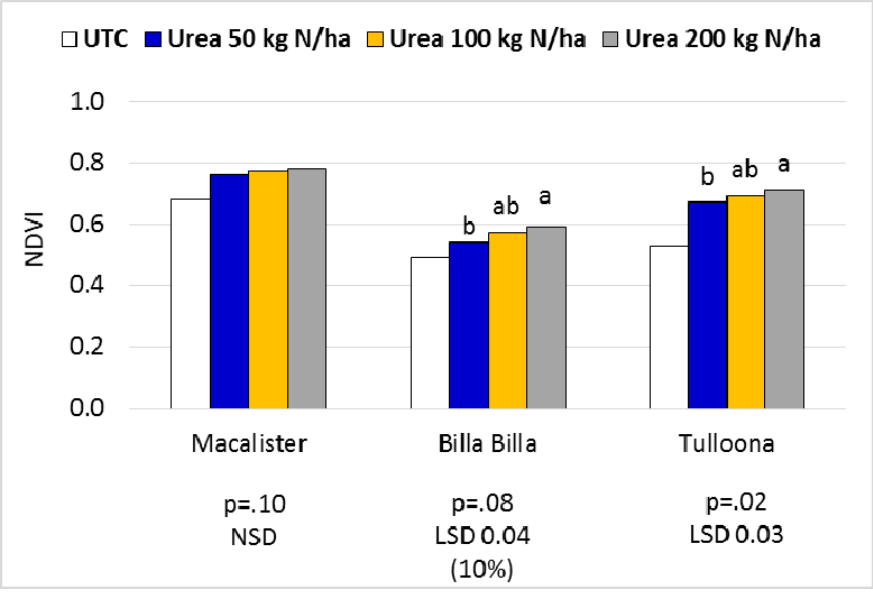

Figure 1. Suntop(b) NDVI responses to nitrogen rate by trial site when assessed in mid-September to mid-October

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 Billa Billa where p=.10.

- Although there was no significant N rate response at Macalister, all N treatments applied in the fallow or at planting provided a significant increase in NDVI compared to the UTC.
- **NDVI results indicated all sites were responsive to added nitrogen.**

Figure 2 shows the Suntop(Φ) factorial analysis of yield when urea was applied and incorporated at three rates and timings.

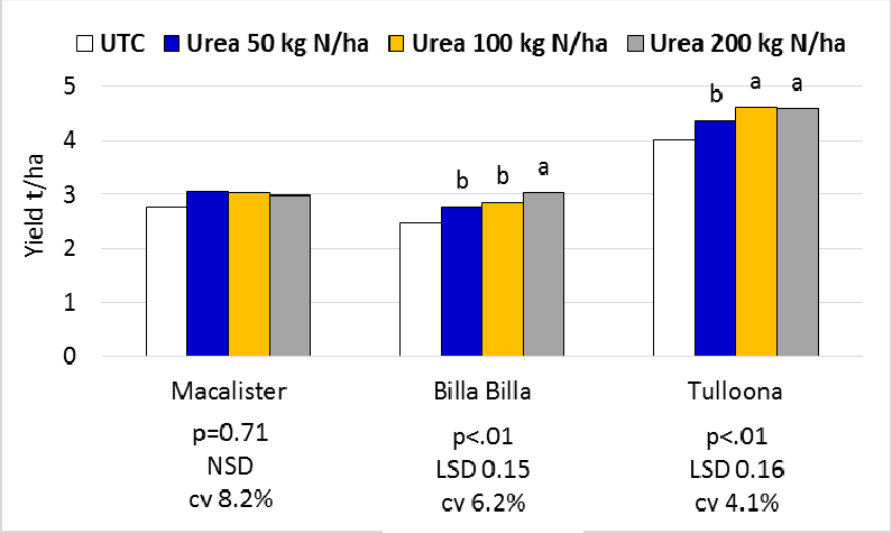

Figure 2. Suntop(Φ) yield responses to nitrogen rate by trial site. All treatments applied and incorporated at three timings.

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.

- The 200 kg N/ha rate resulted in a significant yield increase compared to the 50 kg N/ha rate at both Billa Billa and Tulloona.
- The Macalister site was less responsive to applied nitrogen than Tulloona or Billa Billa

Figure 3 shows the Suntop(Φ) factorial analysis of protein when urea was applied and incorporated at three rates and timings.

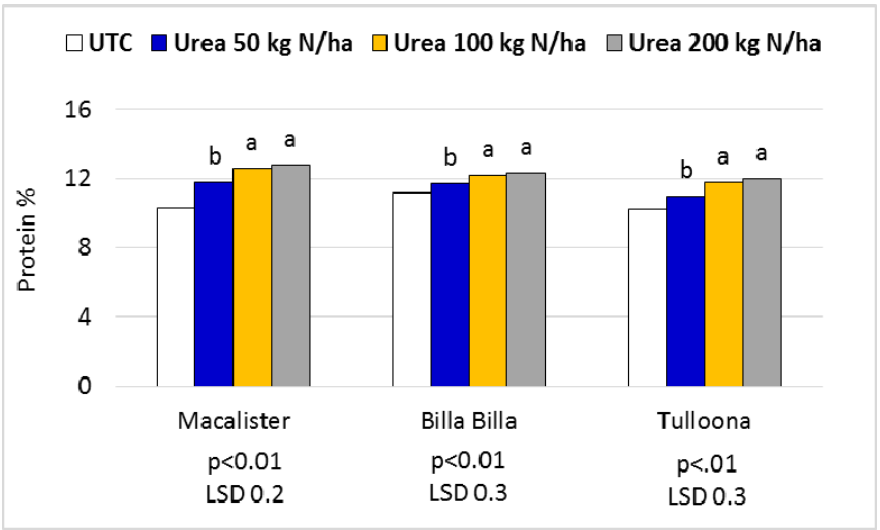

Figure 3. Suntop(Φ) protein responses to nitrogen rate by trial site. All treatments applied and incorporated at three timings.

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.

- Both the 100 and 200 kg N/ha rates resulted in a significant increase in grain protein compared to the 50 kg N/ha rate - at all sites, in both sets of trials.
- Protein level appeared to plateau at 100 kg N/ha in these trials.
- **Grain protein levels at all trial sites were highly responsive to nitrogen.**

Overall: All sites were nitrogen responsive with grain protein the most responsive followed by NDVI and yield. This was similar to results from 2014 and 2015 trial activity.

2. What were the key comparisons of interest?

Two of the key areas of focus in these trials were:

a) Method of application

b) Timing of application

a) Method of application

The Suntop® trial was designed to assess the method of application of urea. A rate of 100 kg N/ha was applied in December, February and at planting. At each timing, treatments were spread and incorporated on the same day with narrow point tynes or spread with no physically incorporation. In addition a split application treatment was included with 50 kg N/ha incorporated at each of the timings and then followed with 50 kg N/ha spread in-crop at GS30.

Figures 4 and 5 show the Suntop® factorial analysis of yield and protein when urea was applied at 100 kg N/ha using the three different methods of application.

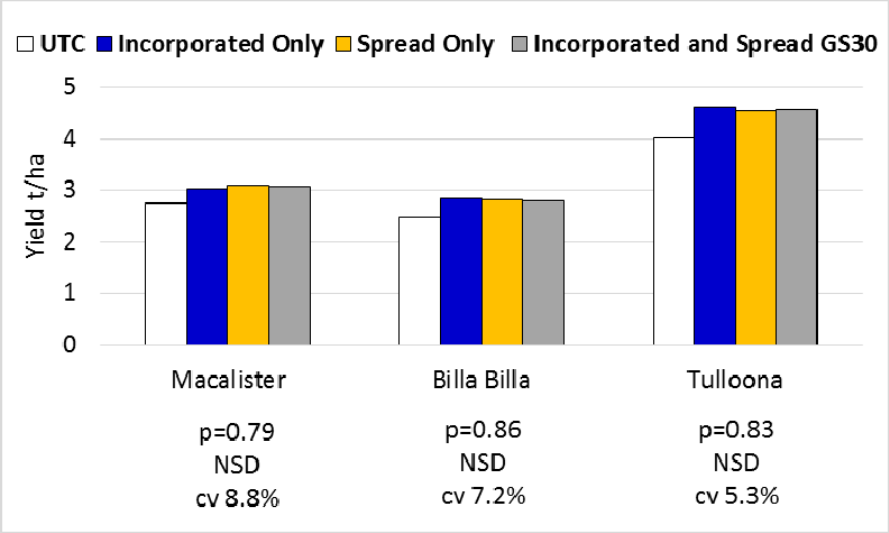

Figure 4. Suntop® yield responses to 100kg N/ha by Method of Application. All treatments were applied at three timings (December, February and planting).

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

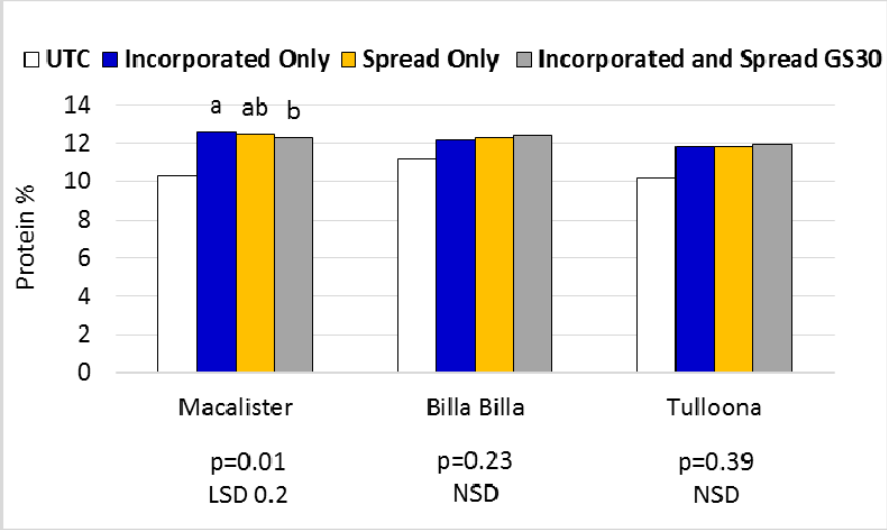

Figure 5. Suntop® protein responses to 100kg N/ha by Method of Application. All treatments were applied at three timings (December, February and planting).

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

- There was no significant difference in Suntop® yield or protein at any site between 100 kg N/ha applied and incorporated or spread only.
- The split application of nitrogen at Macalister resulted in significantly lower (-0.3%) protein levels than the same total rate of nitrogen incorporated at planting or during the fallow.

b) Timing of application

Figures 6 and 7 show the Suntop® factorial analysis of yield and protein when urea was applied and incorporated at 50, 100 or 200 kg N/ha at all three timings.

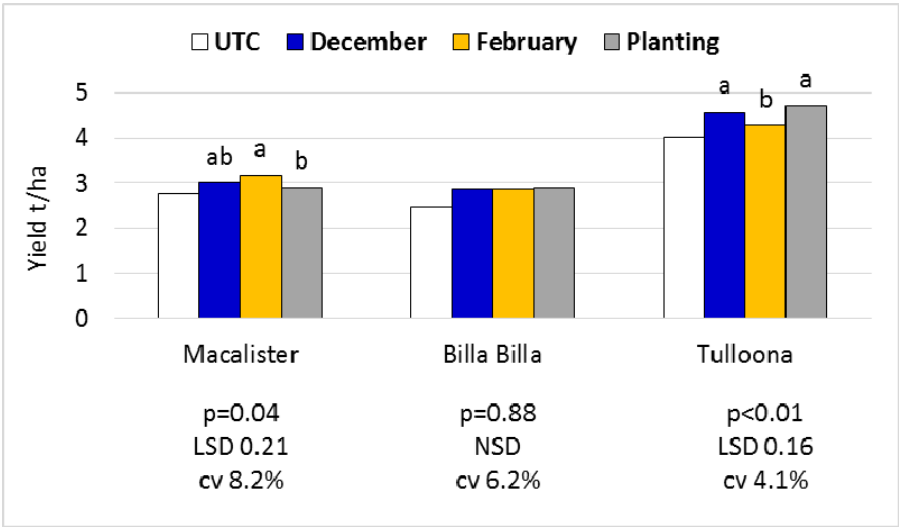

Figure 6. Suntop® yield responses to Timing of Application. All treatments incorporated and applied at three rates.

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

Urea treatments applied at planting in the Macalister trial resulted in significantly lower yield than the same treatments applied in February. This was a site with a high cereal stubble load from 2015 which resulted in some planting difficulties. Crop establishment in treatments where an

incorporation event occurred during the fallow were significantly higher (13-19%) than from planting treatments, in a late sown situation.

Urea applied and incorporated in February in the Tulloona trial resulted in significantly lower yield than the same treatments applied in December or at planting. However, where urea was spread without any incorporation in February, yields were equivalent to the same rate of urea applied at planting (see Figure 8).

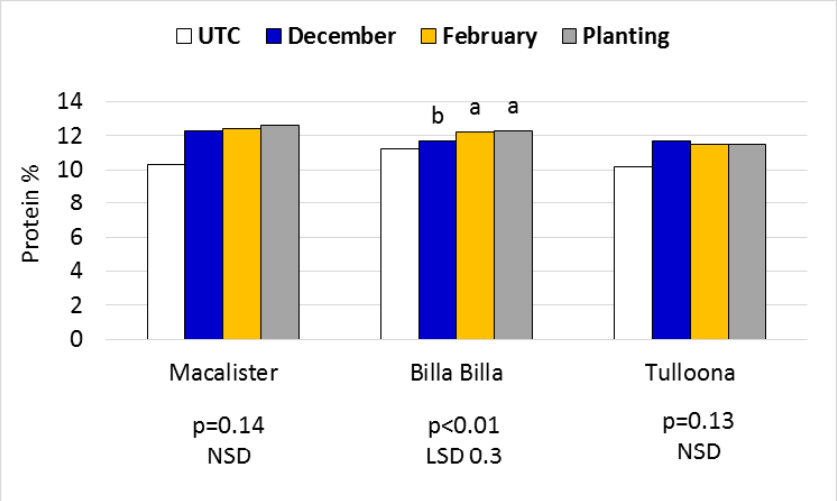

Figure 7. Suntop® protein responses to timing of application. All treatments incorporated and applied at three rates.

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

Figures 8 and 9 show the EGA Gregory® and Lancer® factorial analysis of yield and protein when urea was applied at 50, 100 or 200 kg N/ha at all three timings.

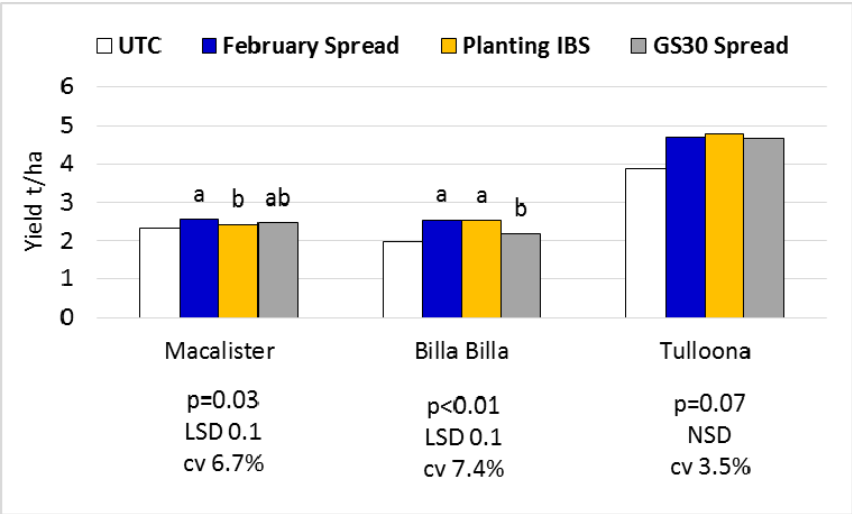

Figure 8. EGA Gregory® and Lancer® yield responses to timing of application. NB February and GS30 treatments spread only.

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

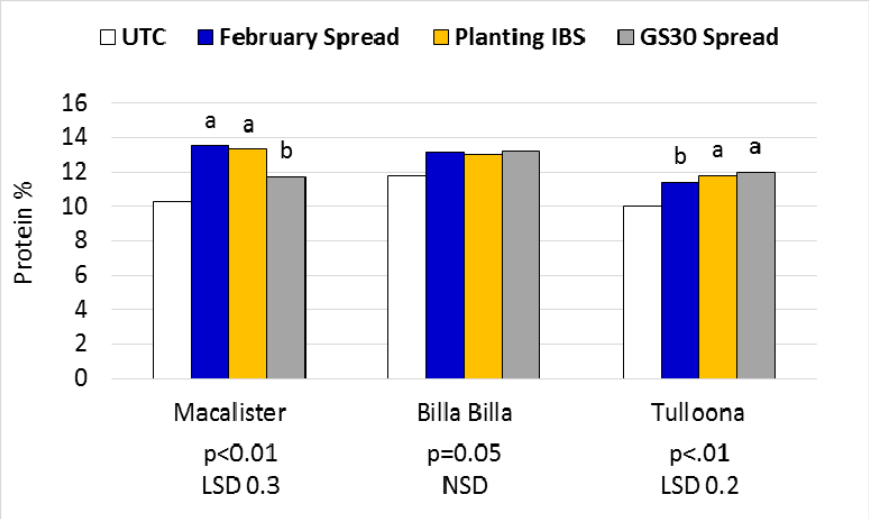

Figure 9. EGA Gregory$^{\Phi}$ and Lancer$^{\Phi}$ protein responses to timing of application. NB February and GS30 treatments spread only.

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

- Similar patterns of impact from timing of application were seen in both sets of trials at all sites
- The GS30 only application of urea at Billa Billa was significantly lower in yield than February or planting application. This site did not receive any rain for 30 days after the in-crop application.
- The impacts from timing of application of urea appeared minor compared to the rate of nitrogen applied. Similar results were seen in 2015 comparing February/March timing to a planting application.

Grain quality

Table 4. Suntop grain quality when all urea was incorporated and applied at three timings

Macalister			
N Rate	**Protein %**	**Screening %**	**Receival grade**
UTC	10.3	7.2	GP
50 kg N/ha	11.8 b	9.9 b	AUH2
100 kg N/ha	12.6 a	10.9 a	HPS1
200 kg N/ha	12.8 a	10.8 a	HPS1
	p<0.01, LSD 0.2	P=0.02, LSD 0.7	
Billa Billa			
N Rate	**Protein %**	**Screening %**	**Receival grade**
UTC	11.2	3.3	APW
50 kg N/ha	11.7 b	3.0	H2
100 kg N/ha	12.2 a	3.0	H2
200 kg N/ha	12.3 a	3.0	H2
	p<0.01, LSD 0.3	P=0.98, NSD	
Tulloona			
N Rate	**Protein %**	**Screening %**	**Receival grade**
UTC	10.2	5.2	GP
50 kg N/ha	11.0 b	5.5	GP
100 kg N/ha	11.8 a	5.2	AUH2
200 kg N/ha	12.0 a	5.3	AUH2
	p<0.01, LSD 0.3	P=0.72, NSD	

UTC= untreated (no additional nitrogen applied). UTC not able to be included in factorial analysis but added for reference.
Treatments that share the same letter within each site are not significantly different at P=0.05.

Tables 5-7 show the grain quality results when EGA Gregory(Þ) and Lancer(Þ) were compared with all applications at three timings.

Table 5. EGA Gregory(Þ) and Lancer(Þ) grain quality at Macalister

Macalister- EGA Gregory(Þ)			
N Rate	**Protein %**	**Screening %**	**Receival grade**
UTC	9.8	5.4	GP
50 kg N/ha	11.5 d	7.4 bc	AUH2
100 kg N/ha	12.6 c	9.8 a	AUH2
200 kg N/ha	12.6 c	8.5 b	AUH2
Macalister- Lancer(Þ)			
N Rate	**Protein %**	**Screening %**	**Receival grade**
UTC	10.8	3.0	APW
50 kg N/ha	12.5 c	3.6 e	H2
100 kg N/ha	13.5 b	5.2 d	AUH2
200 kg N/ha	14.3 a	6.4 cd	AUH2
	P=0.02, LSD 0.4	P=0.06, LSD 1.2 (10% level)	

Treatments incorporated at planting but spread only at February and in-crop.

UTC= untreated (no additional nitrogen applied). UTC not able to be included in factorial analysis but added for reference. Treatments that share the same letter are not significantly different at P=0.05.

Table 6. EGA Gregory(Þ) and Lancer(Þ) grain quality at Billa Billa

Billa Billa- EGA Gregory(Þ)			
N Rate	**Protein %**	**Screening %**	**Receival grade**
UTC	11.2	4.4	APW
50 kg N/ha	12.0 c	4.2 a	H2
100 kg N/ha	12.4 b	4.0 a	H2
200 kg N/ha	12.7 a	4.0 a	H2
	p<0.01, LSD 0.2		
Billa Billa- Lancer(Þ)			
N Rate	**Protein %**	**Screening %**	**Receival grade**
UTC	12.4	3.0	H2
50 kg N/ha	13.4 c	2.4 c	APH2
100 kg N/ha	13.8 b	2.8 b	APH2
200 kg N/ha	14.2 a	3.2 b	APH1
	p<0.01, LSD 0.2	P=0.01, LSD 0.4	

Treatments incorporated at planting but spread only at February and in-crop.

UTC= untreated (no additional nitrogen applied). UTC not able to be included in factorial analysis but added for reference. Treatments that share the same letter for protein are not significantly different at P=0.05, within each variety. Treatments that share the same letter for screenings are not significantly different at P=0.05, across varieties.

Table 7. EGA Gregory and Lancer grain quality at Tulloona

Tulloona- EGA Gregory			
N Rate	**Protein %**	**Screening %**	**Receival grade**
UTC	9.3	5.5	GP
50 kg N/ha	10.3 c	4.7	ASW
100 kg N/ha	11.2 b	4.5	APW
200 kg N/ha	12.1 a	4.0	H2
	p<0.01, LSD 0.2		
Tulloona- Lancer			
N Rate	**Protein %**	**Screening %**	**Receival grade**
UTC	10.7	5.4	GP
50 kg N/ha	11.3 c	4.7	APW
100 kg N/ha	12.4 b	4.7	H2
200 kg N/ha	13.1 a	4.4	APH2
	p<0.01, LSD 0.2	P=0.11, NSD	

Treatments incorporated at planting but spread only at February and in-crop.

UTC= untreated (no additional nitrogen applied). UTC not able to be included in factorial analysis but added for reference. Treatments that share the same letter for protein are not significantly different at P=0.05, within each variety.

- Lancer had significantly higher protein levels (plus ~1%) than EGA Gregory at all sites, despite also having significantly higher yields at two of the three sites
- Lancer had significantly lower screening levels than EGA Gregory at Macalister and Billa Billa.

Grain nitrogen recovery (data not presented)

Grain nitrogen recovery (yield t/ha x protein % x 1.75) was calculated to assess the efficiency of the applied urea. In addition, soil sampling at planting and harvest enabled a grain nitrogen recovery calculation for the UTC. This figure assessed the 'efficiency' of recovery of the available soil NO_3 and NH_4, as determined by soil tests to 120cm depth. Grain nitrogen recovery in the UTC was calculated by dividing the amount of grain nitrogen removed by the amount of soil N depleted eg at Macalister, 50 kg N/ha was removed in the grain from a depletion of 87 kg N/ha in soil N level (soil tests at planting indicated 100 kg N/ha with only 13 kg N/ha remaining at harvest).

In the Suntop trials:

- With all urea incorporated, the grain nitrogen recoveries averaged 23%, 18% and 10% from the 50, 100 and 200 kg N/ha application rates respectively. This is similar to results from 2014 and 2015.
- The grain nitrogen recoveries from soil derived N ranged from 57% at Macalister to 101% at Billa Billa and 128% at Tulloona (for values >100%, it is assumed that additional mineralisation occurred during the cropping period). This is similar to results from 2014 and 2015.

In the EGA Gregory(Þ) and Lancer(Þ) trials:

- Lancer(Þ) had significantly higher grain nitrogen recoveries than EGA Gregory(Þ) at all sites (range from 4-12 kg N/ha)

Economics

Net benefits were calculated using grain receival prices for delivery Moree in mid November 2016. There was a large spread of >$60/t between APH and APW classifications. Figure 10 shows the net benefit/loss across all sites for the Suntop(Þ) trials where all urea was incorporated.

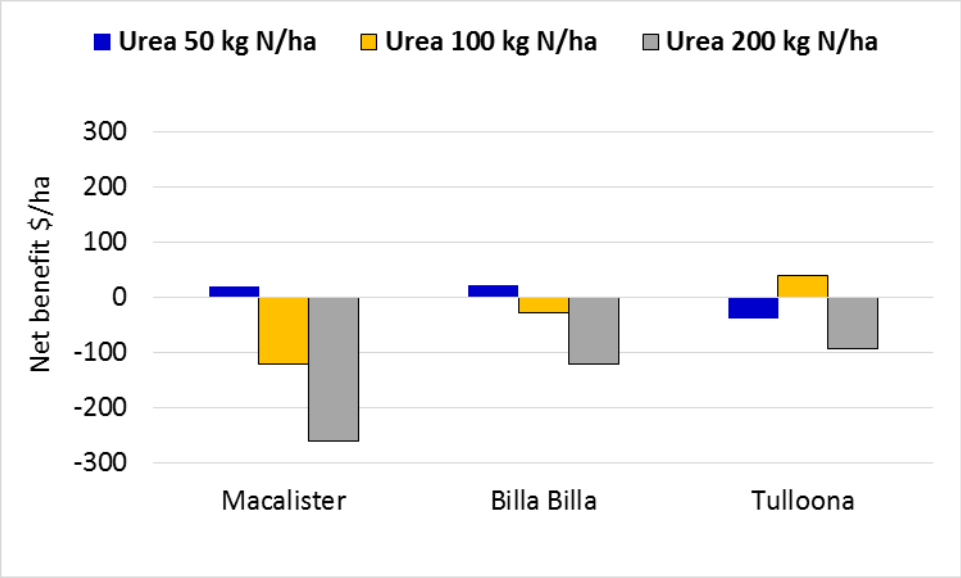

Figure 10. Suntop(Þ) net benefit from applied nitrogen rate by trial site. All treatments applied and incorporated at three timings.

Assumptions: urea at $1.30/kg N ($600/t), spreading cost at planting $25/ha, fallow incorporation at $40/ha, grain prices delivered Moree mid Nov 2016: APH2 $237/t, H2 $202/t, AUH2 $194/t, APW $177/t, ASW $172/t, AGP $172/t and HPS $171/t

Figures 11 and 12 show the net benefit/loss across all sites for EGA Gregory(Þ) and Lancer(Þ) trials.

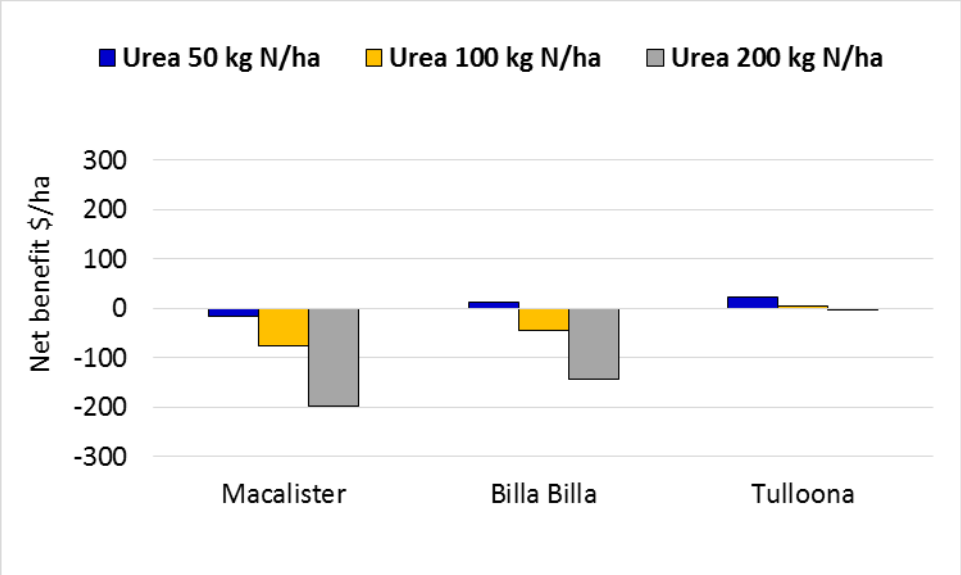

Figure 11. EGA Gregory(Þ) net benefit from applied nitrogen rate by trial site. Treatments incorporated at planting but spread only at February and in-crop.

Assumptions: urea at $1.30/kg N ($600/t), spreading cost $25/ha, grain prices delivered Moree mid Nov 2016: APH2 $237/t, H2 $202/t, AUH2 $194/t, APW $177/t, ASW $172/t, AGP $172/t and HPS $171/t

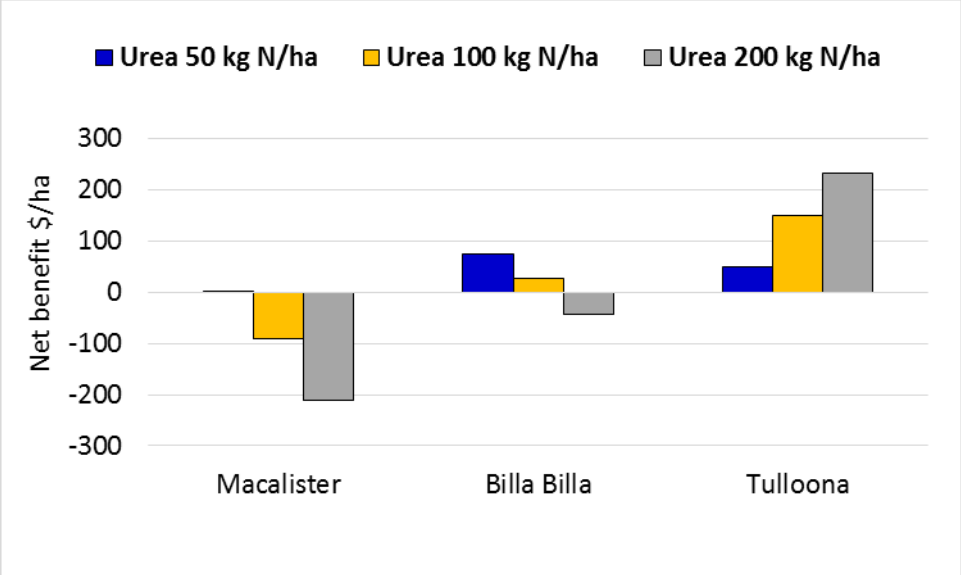

Figure 12. Lancer(b) net benefit from applied nitrogen rate by trial site. Treatments incorporated at planting but spread only at February and in-crop.

Assumptions: urea at $1.30/kg N ($600/t), spreading cost $25/ha, grain prices delivered Moree mid Nov 2016: APH2 $237/t, H2 $202/t, AUH2 $194/t, APW $177/t, ASW $172/t, AGP $172/t and HPS $171/t

- At Macalister and Billa Billa (yields ~2.5-3.0t/ha), the 50 kg N/ha rate was the most economic rate evaluated although net benefits were $20/ha or less for five of the six comparisons.
- At Tulloona (yields >4t/ha), higher rates of N were economic, resulting from both increased yield and improved grain quality.
- Lancer(b) provided the highest net benefits at both Billa Billa and Tulloona, with similar results from all varieties at the Macalister site.

Key points 2016

1. **Nitrogen rate was the key factor impacting yield in both series of trials.**
2. There was no significant impact on yield from method of application.
3. There were significant differences from application timing but these appear to be associated with other agronomy impacts rather than N availability.

Conclusions

The results in 2016 are in line with earlier project activity.

1. The rate of N applied has been the dominant factor affecting yield and grain quality in all twelve trials.
2. The performance of urea spread and not mechanically incorporated has continued to provide equivalent results to urea incorporated at the same timings.

The February fallow application at Tulloona provided the longest interval in the trial series between spreading and first rainfall, with only 2mm at 25 days after application. This data continues to support the N volatilisation results achieved by Dr Graeme Schwenke and indicates that spreading of urea is less risky than previously considered in the northern region. These results are not suggesting there are no N losses. However the losses were small enough that we were unable to measure a difference in the following crop, despite significant N rate responses at each site.

Application of N in the fallow was compared to at planting in 2015 and 2016. The hypothesis tested was that application prior to planting may allow N to distribute more deeply in the profile and provide a 'canopy management' benefit compared to a shallow N concentration at planting. In the eight trials, there has been no consistent difference between application timings in crop yield or grain quality response.

A concern from these trials is that despite all sites recording significant grain protein increases with added N, actual net benefits have only been achieved from EGA Gregory[b] in 4 of the 12 trials.

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, George Picton and Peter Butler for 2016 trial activity together with Kalyx staff for trial planting, maintenance and harvest. In addition we would like to thank AGT and Pacific Seeds for product supply.

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

Plant availability of reserve P and K - fertiliser type and the impact of wetting/drying cycles

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Notes

A summary of the economics of deep P nutrition trials in the northern grains region: where have current trials provided economic benefits?

James Hagan, Dr David Lester, Dr Andrew Zull, Queensland Department of Agriculture and Fisheries

Key words

Deep phosphorus, deep-P, economics, sub-soil nutrition, nutrition, economics

GRDC codes

UQ00063, DAQ00194, CSA00036

Take home messages

- Yield increases of 10% or more in 21/43 site observations, whilst 30/43 observations had responses of 5% or more to 20P.
- There does not appear to be a significant difference in response to P rate, with the average yield increase across 20P, 30 and 40P (combined), and 60 and 80P (combined) rates all being approximately 10%.
- The majority of treatments did not create a positive return in the first two years, with 7 of 21 sites having currently returned a net benefit.

Background

Phosphorus (P) requirements for early crop development are well known in the Northern Grains Region, (QLD and Northern NSW) with critical limits defined and the use of starter P fertilisers well adopted. However, sub-soil P requirements are not so readily understood.

Later season P has traditionally come from native subsoil P reserves, but as we deplete this P in harvested grain the need to introduce fertiliser sources to replenish these reserves is becoming more urgent, as stratification occurs.

Nutrient stratification occurs when there is a redistribution of non-mobile nutrients such as P from the lower parts of the profile (10-30cm) and then being released through stubble breakdown into the top 10cm of the profile, is an increasing issue across the Northern Region.

Table 1. Critical P values and their relationship to P fertiliser decisions in northern vertosols

	COLWELL P	BSES P	FERTILISER DECISION
DO I NEED TO APPLY DEEP P? (10-30CM DEPTH)	>10 mg/kg	NA	No
	<10 mg/kg	30-100 mg/kg	Possibly
	<10 mg/kg	<30 mg/kg	Highly Likely

The values shown in Table 1 are the estimated subsoil P critical limits required for vertosols in the northern grains region prior to trials and case studies being commenced. (Bell, 2014)

As P is an immobile nutrient replacing it in this subsoil layer requires it to be either placed there or moved there mechanically after being placed on the surface. In order to fit in with current no-till farming system it was decided placing the nutrients at depth via less intensive tillage would be preferable to inversion for the aims of this project and more likely to be adopted across the northern grains region.

Treatments

Trial sites were setup across the Northern Grains Region from summer 2011 onwards (Figure 1), with the first crops harvested in 2013. All sites were initially treated with background levels of 80 units nitrogen (N), 50 units potassium (K), 20 units sulphur (S) and 0.1kg of zinc (Zn) in order to ensure that the sites were unconstrained by other nutrients, these treatments are outlined in Table 2.

Each of the sites selected had a 10-30cm Colwell-P of less than 10, and were chosen with the expectation that they would be responsive. Only 3 of the sites had a 10-30cm Colwell-P of greater than 6.

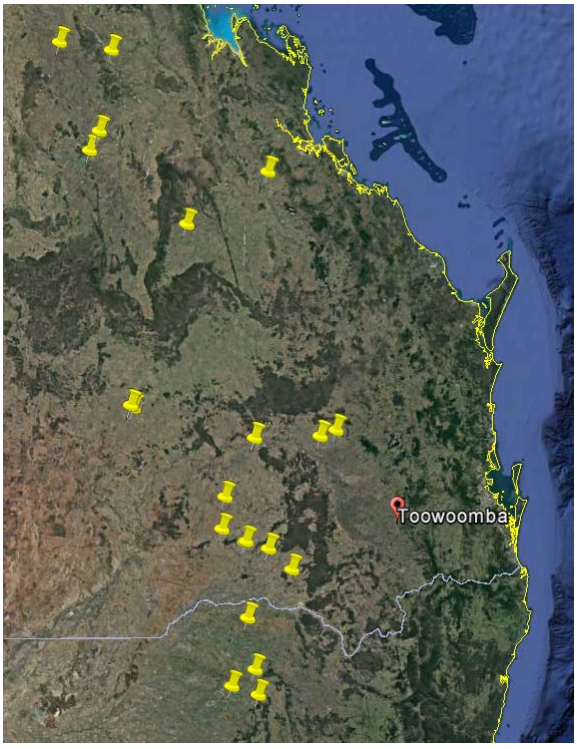

Figure 1. Trial site distribution across northern region

Rates of P ranged from 0 – 80kg, every site had a 0 and 20kg P rate, whilst the upper end luxury rates were either 40 and 80kg, or 30 and 60kg. The analysis in this paper merges the results from 30 and 40kg, and 60 and 80kg, whilst keeping costs separate. The sites also had a farmer reference treatment, which was the farmer's normal fertiliser treatment of that paddock without any tillage as a baseline.

The fertiliser makeup varied across trial sites as would be expected for farm based implementation, with choices driven by nutrients required and the price of different fertiliser mixes to achieve these nutrients eg MAP vs DAP, NPK mixes etc. The analysis in this paper will use the examples of Urea for N, Monoammonium Phosphate (MAP) for P and Sulphate of Potash (SOP) for K and S, with Zn applied as Trace Zn.

Table 2. Trial nutrient makeup and cost ($/t)

NUTRIENT	TREATMENT (KG/HA)	APPLIED AS	PRICE ($/T)
NITROGEN (N)	80	Urea (46N)	$400
PHOSPHORUS (P)	Variable	MAP (22P, 11N)	$800
POTASSIUM (K)	50	SOP (41.5K, 18S)	$800
SULFUR (S)	20	SOP (41.5K, 18S)	$800
ZINC (ZN)	0.1	Trace Zn (93Zn)	$2000

Note i: 80N background rate was total N applied to site pre seeding, as MAP rate increased Urea application was lowered by ~25%, Likewise SOP applied for 50 units of K would also supply ~20 units of S.

Costs for the application of deep- P when applied with current commercial farm equipment has ranged from $15 - $40 /ha, the analysis in this paper will use a flat rate of $30 /ha.

Table 3. Estimated trial treatment costs by P rate ($/ha)

	APPLICATION ($/HA)	UREA ($/HA)	MAP ($/HA)	SOP ($/HA)	ELEMENTAL ZINC ($/HA)	TOTAL TREATMENT COST ($/HA)
0P	$30	$69	$0.00	$96	$0.22	$196
20P	$30	$61	$73	$96	$0.22	$260
30P	$30	$57	$109	$96	$0.22	$292
40P	$30	$52	$145	$96	$0.22	$324
60P	$30	$43	$218	$96	$0.22	$388
80P	$30	$35	$291	$96	$0.22	$452

Note i: K and S were applied as backgrounding to ensure unconstrained soil for scientific results, Grower implementation may be able to remove this cost depending on soil test status.

As noted above K and S were applied to ensure measured responses were to P and that the size of the responses would not be constrained by lack of some other element. In practice if a paddocks K and S levels were not deficient then it would be reasonable to remove this treatment and its $96/ha cost.

Average crop prices (Table 4) are used in order to avoid the large fluctuations in chickpea and mungbean prices that occurred during trial period, to ensure that a percentage change in crop production in 2013 is equivalent to the same change in 2015. The use of average prices also gives a more realistic indication of the long term economics of deep P.

Table 4. Average crop prices used in deep P analysis

CROP	PRICE ($/T)
BARLEY	230
CHICKPEA	500
MUNGBEAN	750
SORGHUM	250
WHEAT	250
DURUM	300

Results

Positive yield responses greater than 5% to the 20P rate were witnessed in 30 of 43 observations, whilst 21 of 43 observations had responses of 10% or more. There does not appear to be a rate response between the rates of P used with rates from 20 – 80P providing a very similar range of responses across the 16 sites.

A number of sites appear to have had a positive response to the background K, N, S and Z treatments, with the 0P treatment having an average yield response of 4%, and 9/46 responses being greater than 10%. The data (not shown) suggests that the sites with highest 0P responses were heavily influenced by K.

Three crop types dominate the dataset, with 42/43 observations being one of chickpea (15), sorghum (14) or wheat (13). Chickpea yield responses were lower than both wheat and sorghum on average, however had a similar distribution as shown in Figure 2.

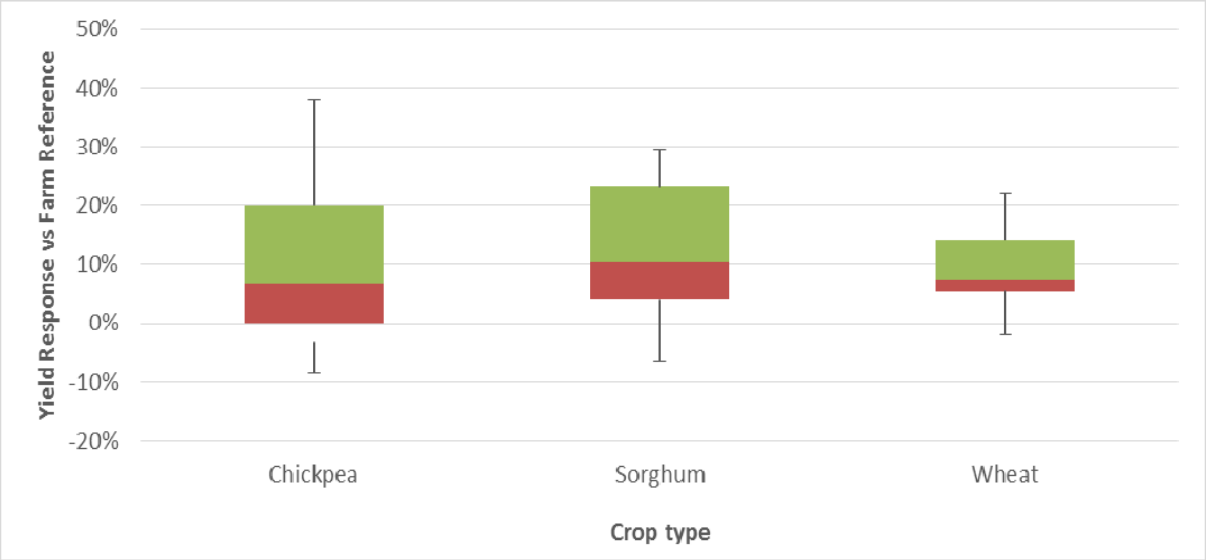

Figure 2. 20P yield distribution vs farm reference by crop type.

There is a strong similarity in the responses between the different P rates as illustrated in Figure 2, because of this further analysis in this paper will focus on the 20P rate, which is most likely to have provided net positive returns over a shorter time period given its lower upfront costs.

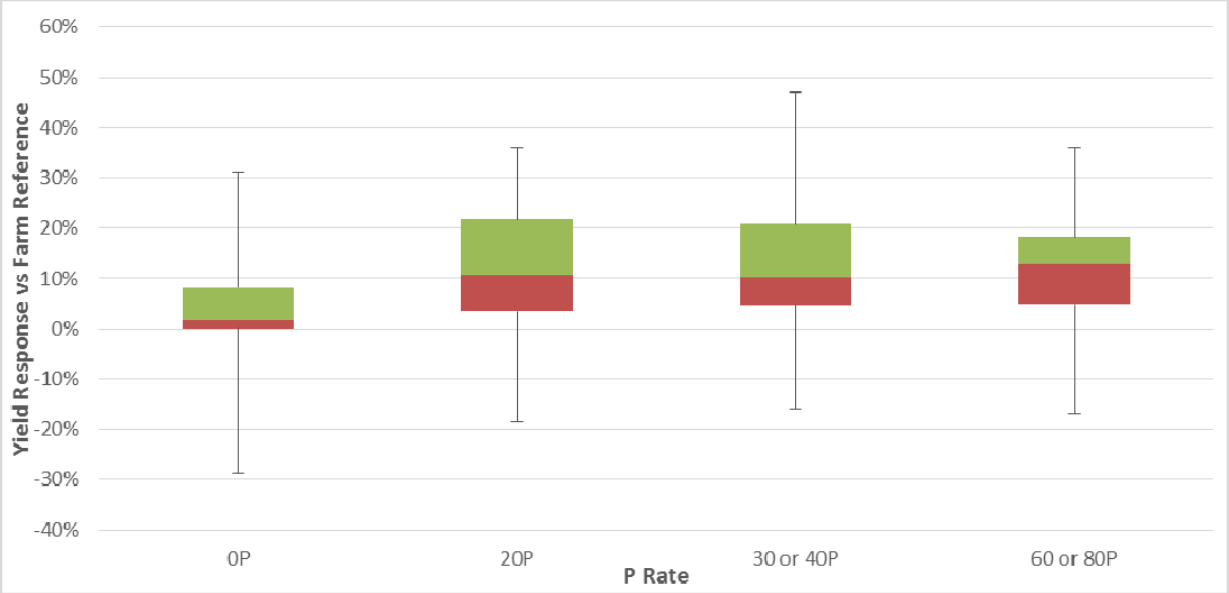

Figure 3. Distribution of yield responses across 46 observations per treatment vs farm reference

It should also be noted that despite the background treatment of N in year 1 in all trials, some extremely low sorghum proteins have been recorded in following years, suggesting that a number of sites may have been N constrained, which would mask any P response.

Only one of the 21 sites achieved a positive return in the first year as shown in Table 5. This is typical of longer term decisions with large upfront costs and returns expected over a number of following years. If the K and S treatments were assumed to not take place then the 20P treatment would have generated a benefit at 5 of the 21 sites in the first year.

Table 5. Cumulative Net Benefit generated over time by 20P treatment

	YEAR 1	YEAR 2	YEAR 3
NUMBER OF SITES	21	15	7
AVERAGE CUMULATIVE NET BENEFIT	-$160 /ha	-$77 /ha	-$67 /ha
MAX NET BENEFIT	$10 /ha	$126 /ha	$235 /ha
NUMBER OF POSITIVE SITES	1	5	3

The average first year result for the 20P treatment generated an income of $100/ha more than the farm reference treatment, however this was not enough to offset the $260/ha upfront cost. Five of the 15 sites generated profits in the second year, with the average income increase being approximately $80/ha.

If it was assumed that these sites had sufficient K and S thus did not require additional treatment, then 9 of 15 sites that we have 2 or more years of data for would have returned a positive net benefit in the second year.

Table 6. Cumulative net benefit to 20P assuming no additional K or S required

	YEAR 1	YEAR 2	YEAR 3
NUMBER OF SITES	21	15	7
AVERAGE NET BENEFIT	-$73	-$5	-$11
MAX NET BENEFIT	$106	$222	$331
NUMBER OF POSITIVE SITES	5	9	3

Unfortunately 4/7 sites for which three or more years of data exist were largely unresponsive and removing the K and S cost is not sufficient for these sites to generate a profit. There was no correlation between the sites that were unresponsive and their starting Colwell-P test results.

The data from these trials has been used to assist in the development of a deep-P calculator which will be available soon.

Conclusion

The majority of sites achieved positive yield responses to deep-P application, however the majority of sites have not generated additional profits in the first two years. Additional monitoring will be required to determine what the difference in duration of response is between the rates used and whether the higher rates can prove economical over time.

Responses to P have varied by year, with season type being an important factor, it is believed that in-season rainfall will allow plant access to P in the 0-10cm layer, reducing the reliance on sub-soil P, thus reducing the potential benefits. Seasons where there is minimal in-season rainfall are expected to obtain greater benefit from deep-P.

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 across a number of projects, UQ00063 / DAQ00194 / CSA00036 the author would like to thank them for their continued support.

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"A bit of everything" concurrent session

Groundcover and stubble type impact on fallow efficiency

Brendan Burton, Northern Grower Alliance

Key words

Soil water, fallow efficiency, groundcover, stubble type, plant available water

GRDC code

NGA0004

Take home message

The impetus for this trial work came following three consecutive dry seasons from 2013-2015 where little to no winter crop was planted in the Walgett district. Growers and consultants wanted proof of concept that going beyond current no-till farming practices to increase the percentage groundcover can improve fallow efficiency and safe guard soil moisture against evaporative losses.

Current soil water models show upper most limit at 100% groundcover. NGA set out to determine how much additional soil water could be accumulated by going beyond 100% groundcover, by applying additional straw to the system and hence increasing the thickness layer of straw on the soil surface.

Small plot trials initiated by NGA in both 2014 and 2015 indicated that the addition of extra ground cover can increase the depth of accumulated soil water by up to 50-60cm when compared to standard standing stubble, with reduced evaporation losses considered the most likely cause.

While stubble load is important for accumulating soil water, the type of stubble appears to have a major impact on fallow efficiency. Results from a trial site at Macalister demonstrated that barley stubble had double the fallow efficiency compared to faba bean stubble given the same length of fallow period and rainfall.

Background

Following two consecutive years of drought during 2013 and 2014, with little to no winter crop planted in the western districts of northern NSW, growers and consultants from the Walgett area made maximising soil water accumulation their top priority during the NGA's local research group meetings. Consequently, two small plot trials were established in 2014 to begin looking at the effect of applying additional groundcover to the current standing stubble in an attempt to quantify how much additional soil water could be gained by applying additional groundcover in the form of baled straw.

In addition to the small plot stubble cover trials, there was interest from the Liverpool Plains Local Research Group in comparing the fallow efficiency of different stubble types. Consultants believed that stubble type had a major impact on how quickly the soil moisture profile could be refilled after harvest. Consequently, NGA evaluated a range of different stubble types following harvest to determine their fallow efficiency.

2014 small plot trials

Two trials were established in 2014. Both trials had the same six treatments with four replicates. Each treatment plot was 2m x 2m in size with a 2m x 2m buffer area between each treatment plot. Chicken wire was used to hold additional straw in place during the trial period.

Table 1. 2014 small plot trials

Trt	Product	Bullarah		Walgett	
		% Groundcover	Mulch layer thickness (cm)	% Groundcover	Mulch layer thickness (cm)
1	UTC. Standing stubble.	33 4.4t DM/ha	0	31 4.6t DM/ha	0
2	Bare ground. Stubble removed	7	0	7	0
3	Additional 5t/ha straw added to existing stubble	94	1	88	1
4	Additional 10t/ha straw added to existing stubble	99	3	98	2
5	Additional 20t/ha straw added to existing stubble	100	9	100	4
6	Additional 40t/ha straw added to existing stubble	100	11	100	5

One of the trial sites was setup at Bullarah on the 13th January 2014, where the paddock had already been fallowed for a period of 14 months, following wheat in 2012. Initial gravimetric soil samples (to 120cm depth) were taken at trial initiation to ensure soil moisture across the trial site was uniform. Starting soil water was calculated as 11mm of plant available water (PAW). Final gravimetric soil samples were taken in May 2015, approx. 16 months after trial initiation. Total rainfall received during this period was 551mm.

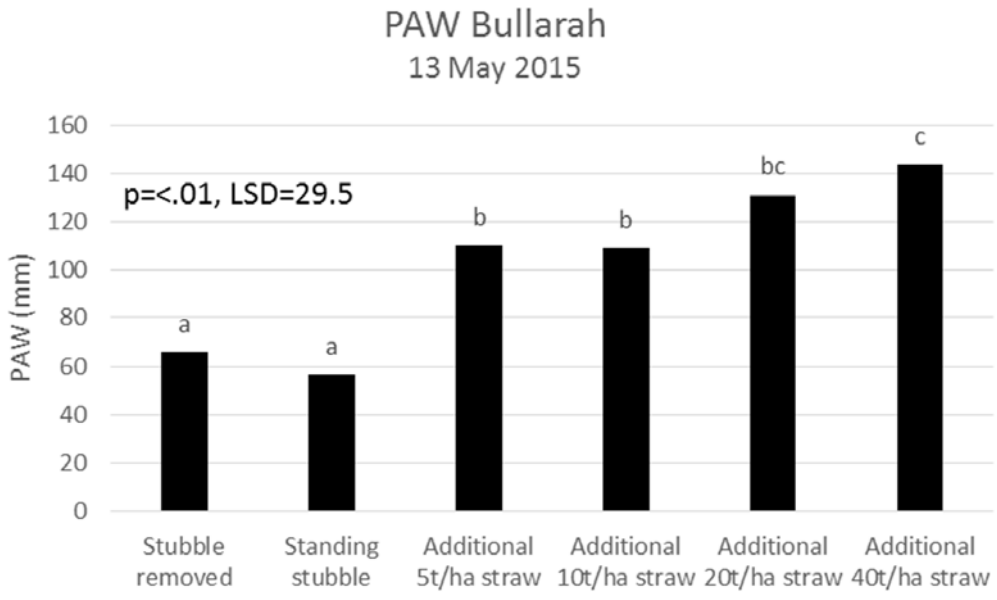

Figure 1. An additional 53mm of PAW was stored where 5t/ha of straw was applied compared to standing stubble alone. Additional 40t/ha straw resulted in extra 87mm PAW compared to the standard standing stubble. Based on water use efficiency (WUE) (wheat) of 15kg/mm/ha, an extra 87mm of PAW could result in an additional 1.3t/ha of grain.

The second site was setup up on the 15th January 2014, 5km east of Walgett, and similarly was fallowed for a period of 14 months from wheat in 2012. Initial gravimetric soil samples were taken to confirm soil moisture uniformity across the trial site. Final gravimetric soil samples were taken in January 2016 with a total rainfall of 640mm received during the trial period. Interestingly, only six significant rainfall events (>25mm within 24hr) occurred during the two year trial period.

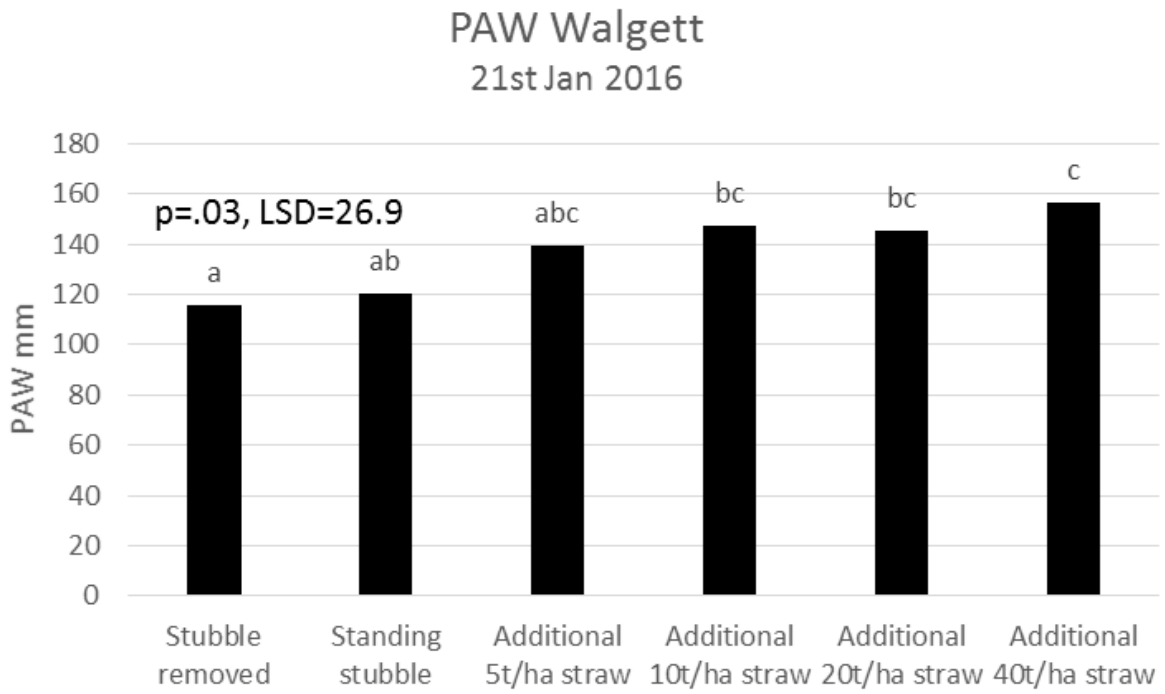

Figure 2. An extra 19mm of PAW accumulated where additional 5t/ha straw added, compared to the standing stubble. Where 40t/ha straw was applied, an extra 37mm of PAW stored compared to standing stubble. Based on WUE for wheat this could equate to an extra 550kg/ha of grain.

2015 small plot trials

An additional two small plot trials were established in 2015 following the promising initial results. The 2015 trials had eight treatments in total by four replicates. Each treatment plot was 2m x 2m in size with a 2m x 2m buffer area between each treatment plot. Sheets of galvanised mesh were placed on top of those plots where additional straw was added to keep the mulch layer in place during the trial period.

Table 2. 2015 small plot trials

Trt	Product	Bullarah		Mungindi	
		% Groundcover	Mulch layer thickness (cm)	% Groundcover	Mulch layer thickness (cm)
1	Stubble removed, surface left rough/cracked	9 5.4t DM/ha	0	8 3.1t DM/ha	0
2	Stubble removed, surface raked level & smooth	5	0	3	0
3	Standing stubble, stubble cut to 50% height	28	0	24	0
4	UTC. Standing stubble	34	0	37	0
5	Additional 5t/ha straw added to existing stubble	89	0.5	97	3
6	Additional 10t/ha straw added to existing stubble	100	1	100	5
7	Additional 20t/ha straw added to existing stubble	100	3	100	11
8	Additional 40t/ha straw added to existing stubble	100	5	100	18

Capacitance probes were also installed at both sites in two reference plots to monitor water infiltration and soil water accumulation over time. The capacitance probes were installed in a single plot of treatment four (standard standing stubble), and treatment eight (additional 40t/ha of straw added to the existing standing stubble).

One of the 2015 trials was established on the same property from the previous year at Bullarah, but in a different paddock on the 9th Nov 2015, some two weeks after the wheat harvest on the 25th Oct 2015. Initial gravimetric soil water samples were taken to confirm soil water uniformity across the trial site. Stubble height was ~25-30cm.

Total rainfall of ~550mm was received during the trial period from Nov 2015 until the 27th Oct 2016. There was no significant treatment affect at this site. The site received 42mm of rainfall during the fortnight between harvest and trial initiation. Capacitance probe results, following an early January rainfall of ~100mm, indicated that soil moisture had reached a depth of >40cm in both the standing stubble and 40t/ha straw treatments. There were no differences observed between treatments in subsequent assessments using moisture probes, EM38 or in final gravimetric soil water.

The second 2015 site was setup up on the 10th Nov 2015 approx. 30km north west of Mungindi, and similar to Bullarah had recently been harvested. Initial gravimetric soil water samples were taken to confirm trial site uniformity. Stubble height was recorded at 30-35cm. A total of 544mm of rainfall was received during the trial period from the 10th Nov 105 until the 11th Oct 2016.

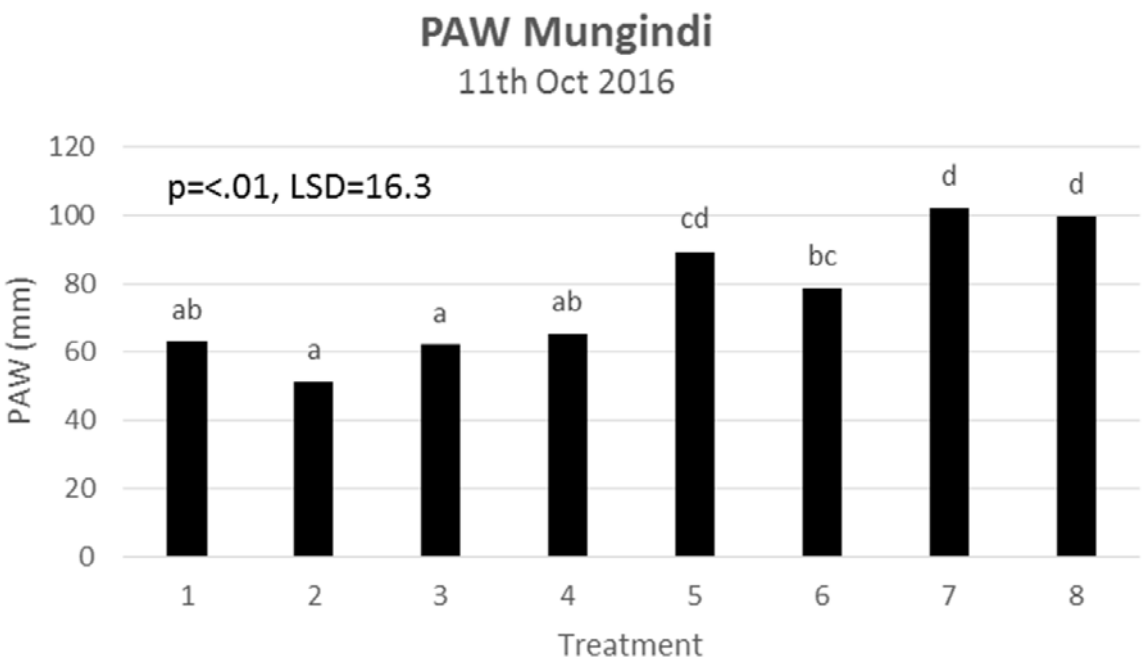

Figure 3. An additional 24mm of PAW was stored where an extra 5t/ha of straw had been added to the standing stubble. I.e. Treatment 4 versus Treatment 5.

Assumptions for soil bulk density and crop lower limits have been made for this particular site to calculate plant available water. Values for bulk density and crop lower limits were taken from the nearest soil-characterised site at Thallon. While the absolute figures may not be correct, the relative treatment differences remain.

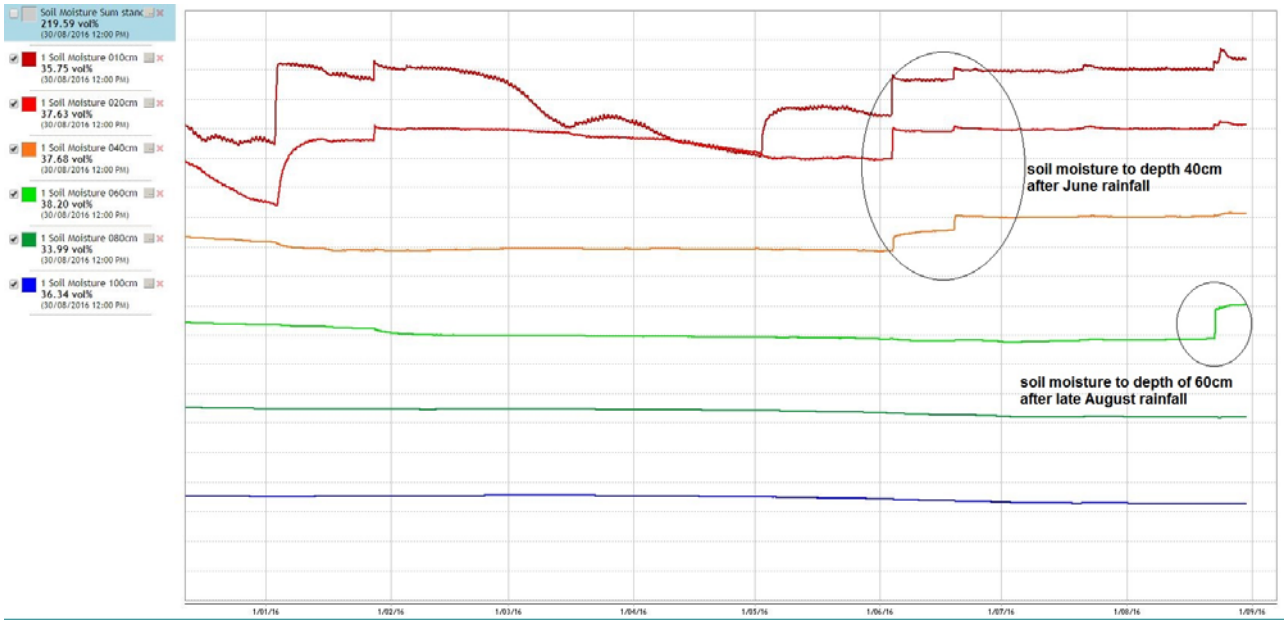

Figure 4. Standing stubble. January rainfall wet the top 20cm, but was rapidly lost due to evaporation during a drier March/April. An extra 100mm of rainfall was required in the standing stubble compared to 40t/ha straw to get the same moisture level down to 60cm.

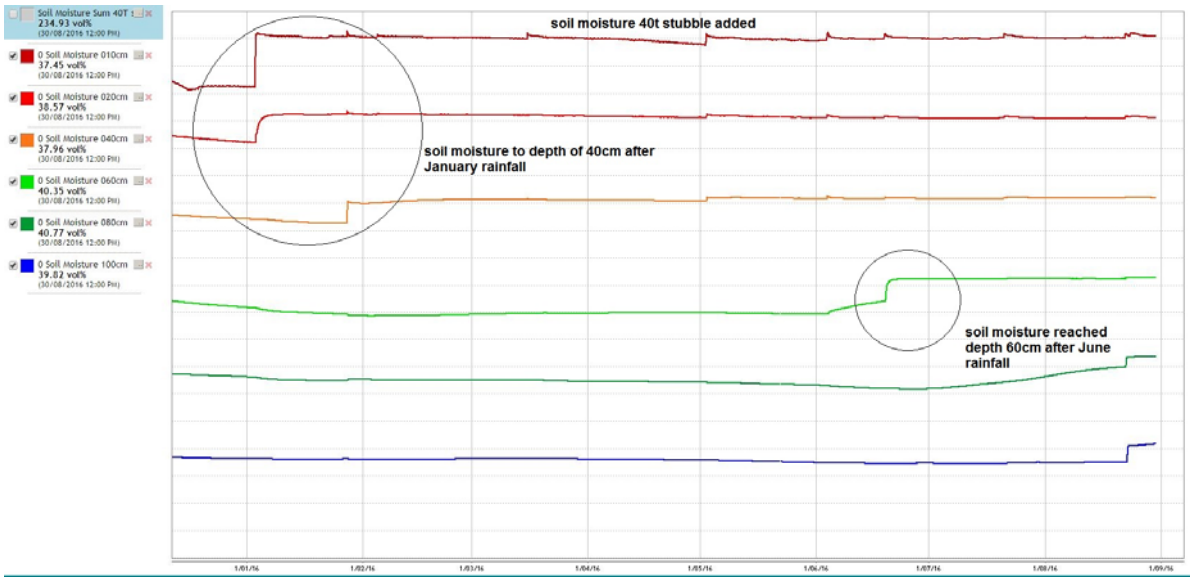

Figure 5. Standing stubble plus an extra 40t/ha straw added. Following the January rainfall, the surface moisture layers remained wet. The mulch layer appeared to reduce evaporative losses, and consequently the soil profile filled more quickly.

Fallow efficiency x stubble type

Following the harvest of winter trials in 2015 at a *P thornei* trial site at Macalister, NGA collected Dual EM data on 27th Nov 2015 from plots recently harvested. Data was collected with a minimum of four readings per plot (6m long x 2m wide plot dimensions). Dual EM data was recorded at four separate depths: 50cm, 100cm, 150cm and 300cm. During data collection, the Dual EM emitter/receiver was suspended approx. 30cm above ground level naturally altering the depth to which the Dual EM measured. The corresponding depths of measurement were now 20cm, 70cm, 120cm and 270cm.

In order to convert the Dual EM data into millimetres of plant available water a calibration curve had to be developed. Fortunately, the paddock had a previous soil characterisation carried out so figures for bulk density and crop lower limits were used. Specific plots within the trial area that were known to have different water contents were initially measured using the Dual EM and accurately marked for later soil sampling. Physical soil samples were taken from the identical location to the Dual EM readings to obtain the gravimetric soil water percentage. The appropriate bulk density and crop lower limits were applied to the calculation to determine the PAW down to a depth of 120cm.

Following the first Dual EM run, data for each plot was collected and averaged for later analysis. This data provided an indication to the differences in soil water remaining in the profile following each crop, and differences within the same crop type when moving from low to high *Pt* levels.

A second Dual EM run on the 1st September 2016 determined the quantity of soil water accumulated during the fallow period. A total of 342mm of rainfall was received during this ten month fallow period. Further reference points were recorded with the Dual EM and sampled to add additional points to the calibration curve.

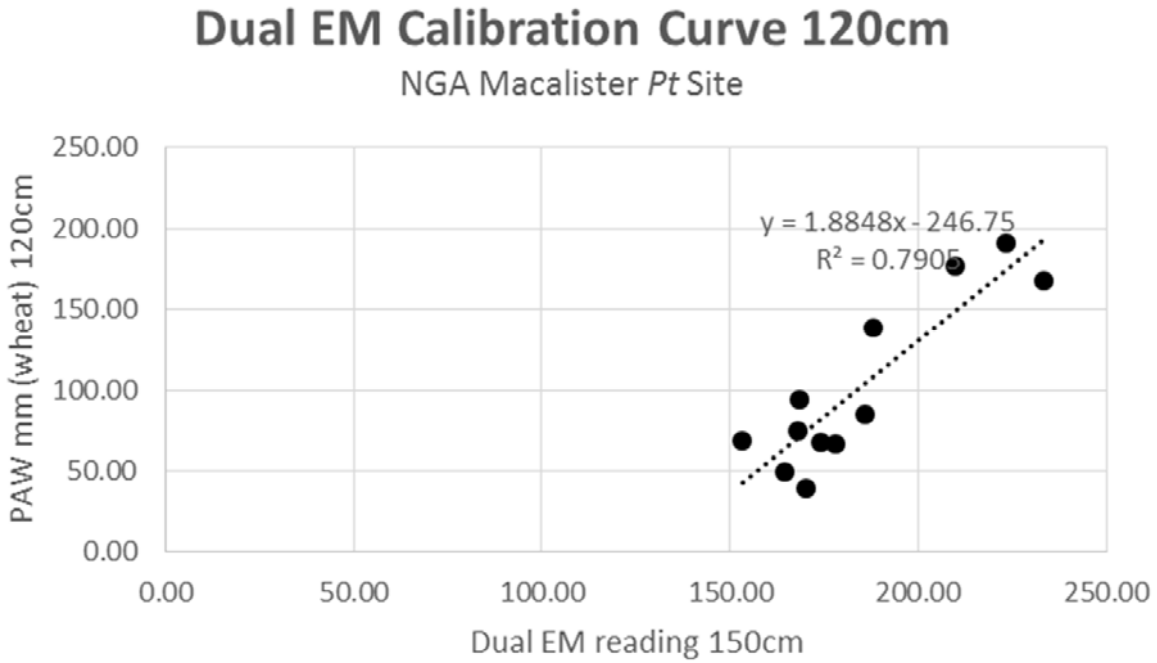

Figure 6. Accuracy of converting dual EM data into PAW is highly dependent on sampling a range of points with different soil moisture levels, and having good soil characterisation data.

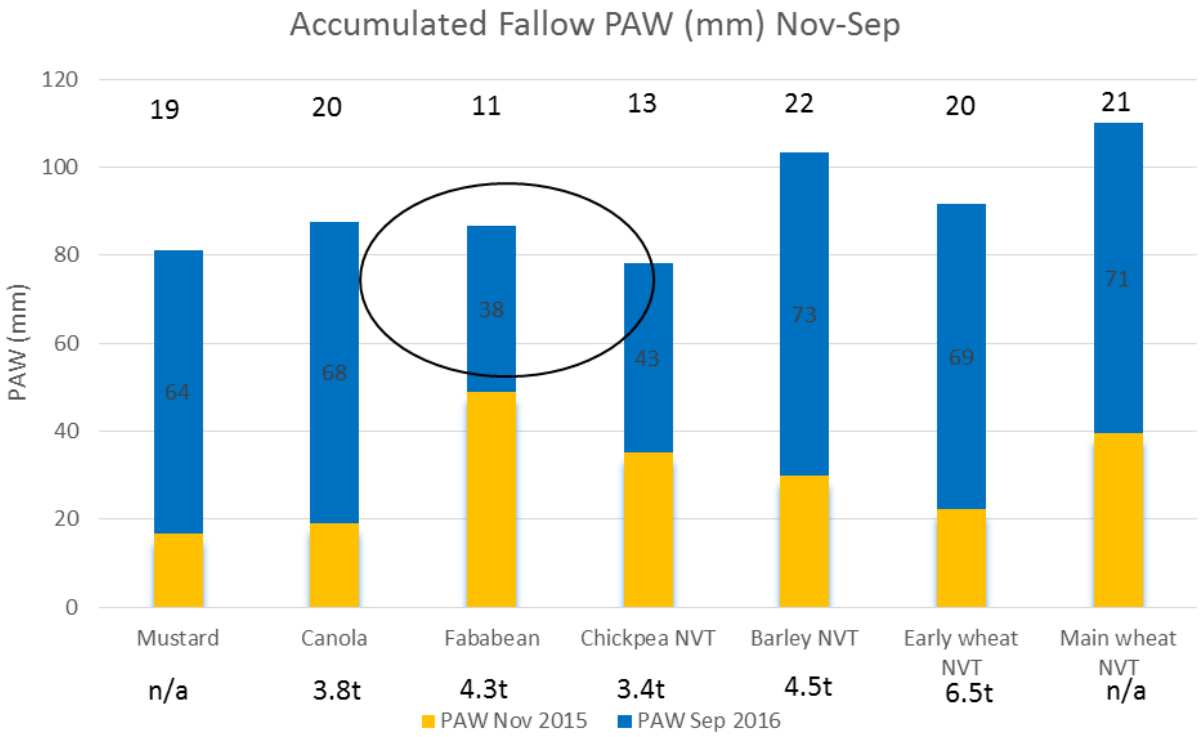

Figure 7. Stacked column graph indicates the PAW at the two dual EM timings for each stubble type. The yellow column illustrates the PAW remaining in the soil after harvest, i.e. start of fallow PAW. The blue column represents the PAW at the end of the fallow, with the number inside the blue column representing the gain in mm of PAW during the fallow period. The number above the blue column is the fallow efficiency percentage for each stubble type. A total of 342mm of rainfall was received during the fallow period.

It appears the range in fallow efficiency figures are influenced by stubble type, the amount of stubble, how easily the stubble is broken down, and whether the stubble is standing or lying flat on the soil surface. For example, both the faba bean and chickpea stubble began the fallow period with 4.3t and 3.4t DM/ha respectively, but by the end of the fallow period very little stubble remained. The low C:N ratio of these legume stubbles allow rapid microbial breakdown, which may be a possible cause of the relatively low fallow efficiency compared to the cereal and canola stubbles.

Conclusion

Accumulating groundcover to beyond 100 % appears to offer significant benefits in both capturing and retaining soil water. NGA's trial work has demonstrated that real benefits in the accumulation of soil water can occur once 100 % ground cover is reached, which generally coincides with approx. 10t of dry matter per hectare. Trial results have demonstrated that the amount of soil water is related to the amount of groundcover, with significant gains occurring once 100 % groundcover is reached and the thickness of mulch layer on the soil surface accumulates. These gains are most likely the result of reduced evaporation losses from the soil surface, particularly the top 20cm.

The challenge for growers now is how to achieve such levels of stubble cover and still maintain the ability to plant the following crop through high levels of trash. Further work needs to be done to determine whether the same benefit is achieved depending on whether the stubble is standing or lying flat on the ground. Consequently, a large scale trial was initiated in the Walgett district in December 2016 evaluating the impact of stubble height and standing versus lying flat on soil water accumulation.

The use of Dual EM technology has provided an efficient and cost effective way of providing an objective measure of soil water. However, in order to obtain meaningful results from EM soil water monitoring devices accurate soil characterisation data, and a good spread of soil water contents are required to produce a useful calibration curve.

Following the Dual EM results from our Macalister *Pt* site, it would appear that canola/mustard are extremely efficient in extracting soil moisture from the profile during the growing season. This can explain the difficulty growers face in trying to refill the profile following such crops.

In terms of fallow efficiency of different stubble types, legume based stubble appears to be less efficient in capturing soil water compared to cereal/canola stubble. The type, amount and whether the stubble is standing or lying flat appears to effect the overall fallow efficiency of each stubble type.

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.

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Maize agronomy: managing climate risk in rainfed maize with multi cobbing hybrids

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Queensland Alliance for Agriculture and Food Innovation (QAAFI) The University of Queensland

Key words

Corn, prolificacy, drought tolerance, low plant population, maize tillering

GRDC code

UQ00075

Take home messages

- Prolific multi cobbing hybrids planted at low plant population 2-3pl/m^2 can compensate yield during good seasons and save on seed costs.
- There are important differences between hybrids, environments and managements on the expression and benefit of the multi cobbing trait. In early plantings, or when planted in cooler environments at low plant densities tiller cobs can contribute up to 48% of the total grain yield. In warmer environments (Central Queensland) tillers are less likely to develop a grain-bearing cob, and are considered to be a waste of resources.
- Even though tiller cobs may contribute to yield, they are half as efficient as main stem cobs at producing grain (low tiller harvest index), and tillers can develop grains outside the husk leaves and these cobs have poor grain quality. Seed companies should consider these as undesirable traits that should be bred out of current hybrids.
- Given the diversity of maize growing environments, there is need for eco-physiology work to develop better-adapted maize plant ideotypes in close collaboration with seed companies.

Background

Increases in maize yield are the result of improvements in breeding (G), agronomy (M), the farming system, and their interactions. For example, over the last 70 years in the USA, the interaction between crop improvement and management, such as increased plant population, have doubled maize yields from under 6t/ha to just below 12t/ha (Fig 1a). These results contrast with those in Australia, particularly for the Northern Grains Region where maize is mostly grown under rainfed conditions at very low plant populations (Fig 1b). In the Northern Grains Region, the uncertainty of rainfall around flowering, heat stress and high seed costs, force rainfed (but also irrigation) farmers to sow maize at low plant populations (20-40K pl/ha), missing out on GxM interactions observed in in the USA using modern hybrids. Multi cobbing or prolific maize hybrids i.e. hybrids that develop a second or longer cob in the better seasons, have been proposed to compensate yield when sown at low plant populations.

To understand how Australian commercial hybrids and management interact when maize is sown across diverse environments in Queensland, we run two years of replicated trials including five sites, up to twelve hybrids per site, three to four plant densities, and solid (1m) and wide (1.5m) configurations.

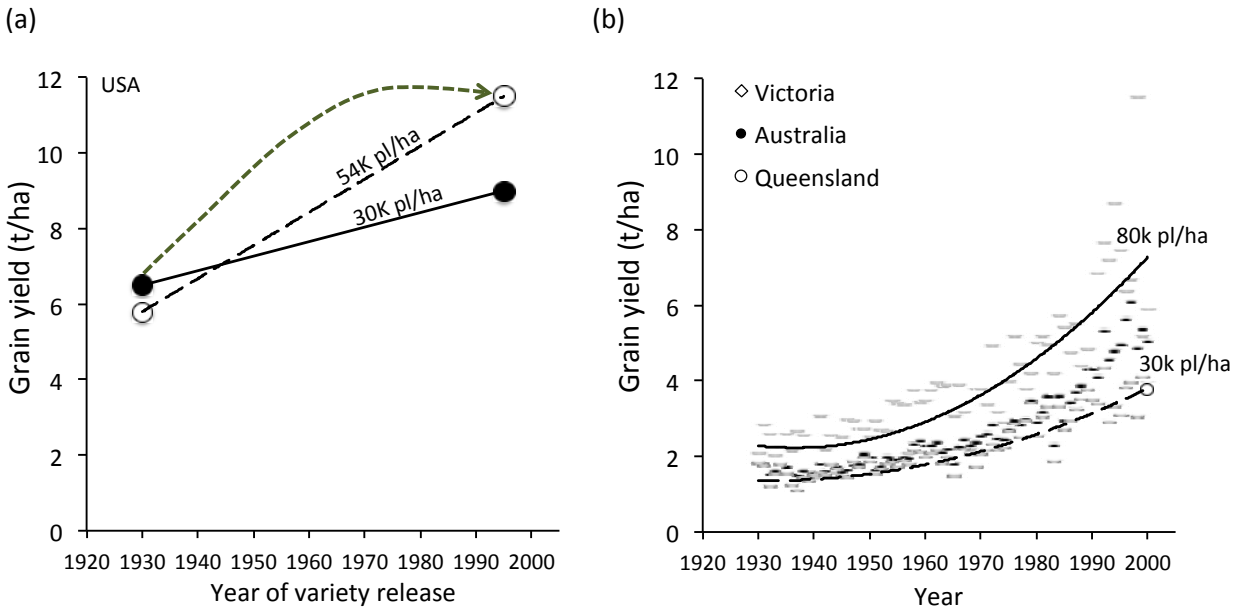

Figure 1. (a) Maize yield for old and new hybrids sown at old (30k pl/ha) and modern (54k pl/ha) plant populations in the USA (Adapted from Fischer, 2014). The dotted green line shows the combined benefit (interaction) from using new hybrids sown at higher densities. (b) Time series of maize yields for Victoria – mostly irrigated (open diamonds), Australian average (filled circles), and Queensland – mostly rainfed (open circles), (Source ABS, 2015).

Results in Figure 2a show that the difference between the lowest and highest treatment yields (combination of hybrid x density x configuration) was up to 70% (Fig 2a); representing a 2.4 fold change in water use efficiency (WUE; from 7 kg/mm/ha to 17 kg/mm/ha) (Fig. 2b).

These two graphs are important as they indicate that:

(i) yield in maize is not all about agronomy or hybrid selection alone; what really matters is that we understand how to match hybrid type and management across the different environments of the Northern Grains Region;

(ii) identifying the optimum combination of hybrid and management can increase water use efficiency by up to a 2.4 fold; and

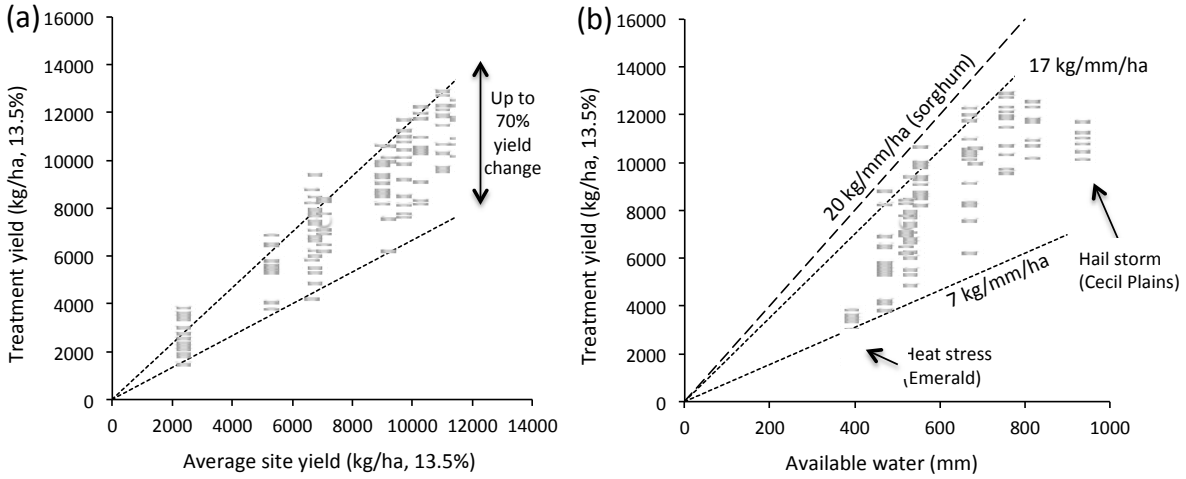

Figure 2. (a) Treatment yields (kg/ha) versus average site yields (kg/ha); and (b) Treatment yields (kg/ha) versus soil available water (mm) across NSW and Qld sites.

(iii) even though yields were has high as 13t/ha at the best sites, maximum maize yields and water use efficiencies appear to be lower than those observed with sorghum; note the dashed

maximum 20 kg/mm/ha line obtained with sorghum across similar environments, versus the 17 kg/mm/ha line for maize in Fig 2b. This suggests that genetic improvement in maize in Australia might be lagging behind that of sorghum, or that the hybrids available in the market are not able to yield optimally when grown at the typically low plant densities of the mostly dryland cropping systems of the Northern Grains Region (Fig 1b).

We also found that when planted at low plant populations multi cobbing hybrids can compensate yield in high productivity environments or good seasons (Fig 3.). This provides opportunity to (1) use lower populations to reduce water use early during canopy development and save water for the critical stages of kernel set around flowering in average and poor seasons; (2) maintain the capacity to produce extra cobs and yield in the better seasons; and (3) save up to 50% in seed costs, ca. $130/ha. Increasing plant population though, will rapidly reduce multi cobbing in maize (Fig 3).

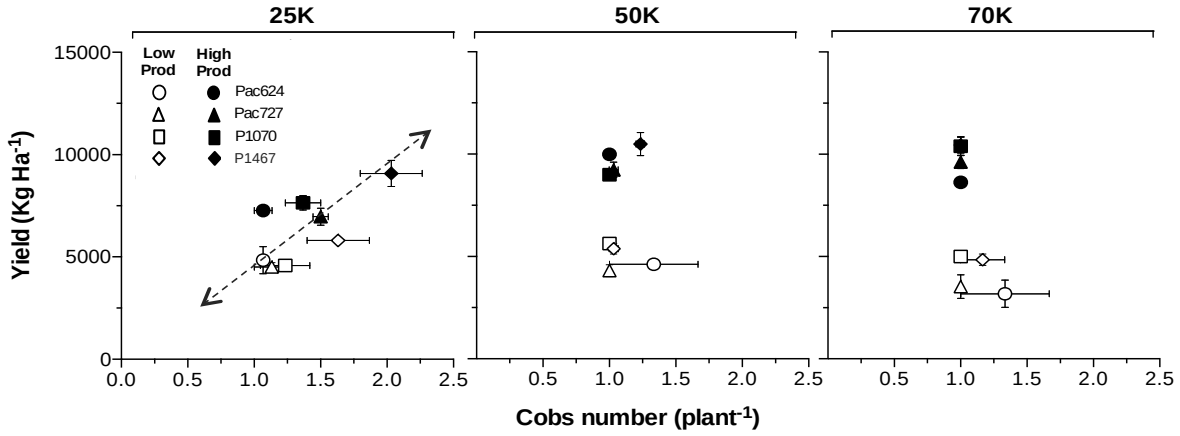

Figure 3. Maize yields versus cob number per plant for four hybrids showing contrasting degree of multi cobbing sown at three plant populations, 25,000, 50,000 and 70,000 pl/ha, in Gatton, Qld during the 2014/15 season. Open and closed symbols are for low (rainfed) and high productivity (irrigated) treatments, respectively.

Australian commercial hybrids show different types of yield formation characteristics, for example the capacity of plants to increase kernel numbers in good environments or seasons is called prolificacy (Fig 4.). Multi cobbing hybrids are one of these types. We found that very few hybrids will develop a secondary cob on the main stem (main stem prolificacy); while most hybrids will produce tillers (suckers), some of which may develop fertile cobs (we call this tiller prolificacy). Farmers consider tillering an undesirable trait, though under some circumstances tiller prolificacy can contribute up to 48% of the final grain yield (Table 1).

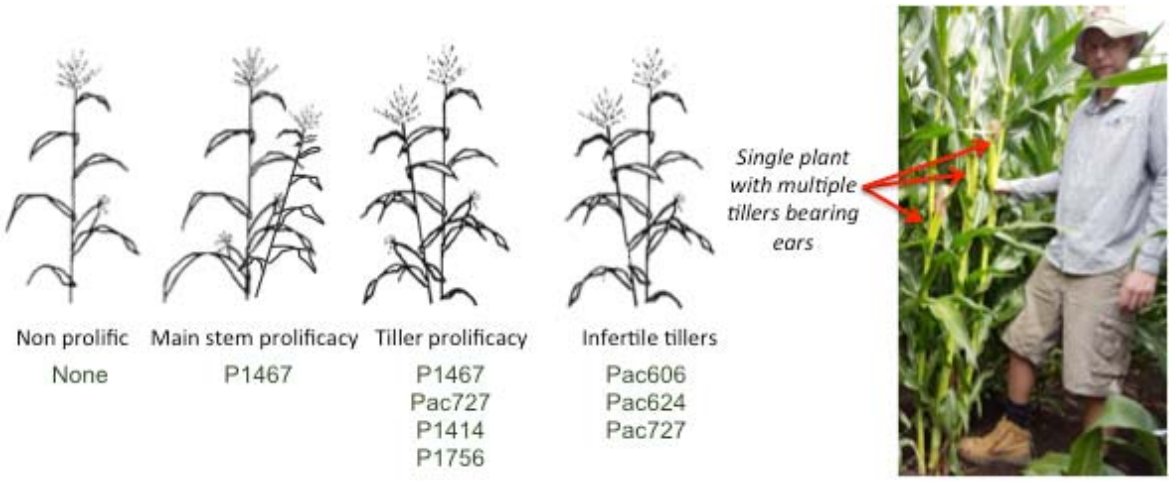

Figure 4. Conceptual representation of most common hybrid types available in the Northern Grains Region. Hybrid x Management x Environment interaction may change hybrid's expression of the prolificacy trait.

We also identified so-called flex types, where under good conditions some hybrids will set more kernels on main stem cobs i.e. usually having more kernel rows. Table 1 summarises the characteristics of some commercial hybrids in terms of their potential contribution from main stem prolificacy (multiple cobs on the main stem), tiller prolificacy (multiple cobs on multiple stems), and flex (main stem primary cobs with more kernels in good conditions). For example P1467 and P1070 were found to be the only hybrids that produced a secondary cob on the main stem that contributed up to 30% to the total yield. P1467, and Pac727 have the potential to produce a large proportion of the yield (up to 50%) on tiller cobs; while Pac606 and P1070 showed the largest capacity to set more kernels on longer primary cobs under good conditions. All tested hybrids tend to produce infertile tillers.

Table 1. Characteristics of some commercially available maize hybrids in terms of prolificacy, defined as the capacity of some hybrids to increase kernel number under good conditions. Main stem and tiller prolificacy refers to hybrids that produce multiple cobs on the main stem, or on multiple stems, respectively. Primary cob flex refers to the maximum kernel number on the main stem cob. All hybrids will produce tillers.

Hybrid	Main stem prolificity (Potential contribution to yield %)	Tiller prolificity (Potential contribution to yield %)	Infertile tillers	Primary cob flex (Maximum primary cob kernel number)
P1070	31	18	Yes	1016
P1467	29	48	Yes	975
Pac606	6	5	Yes	1022
Pac727	4	37	Yes	674
Pac624	3	2	Yes	769

Conclusion

- Prolific hybrids planted at low plant population 2-3pl/m^2 can compensate yield during good seasons; reduce water use early in the season; and save on crop establishment costs.
- There are important differences between hybrids, environments, managements and GxExM interactions on the expression of different types of prolificacy.
- In early plantings, or when planted in cooler environments at low plant densities tiller cobs can contribute up to 48% of the total grain yield. In warmer environments (Central Queensland) tillers are less likely to develop a grain-bearing cob.
- Even though tiller cobs may contribute to yield, they are half as efficient as main stem cobs at producing grain, and should be considered an undesirable trait by seed companies.
- Given the diversity of maize growing environments, there is need for eco-physiology work to develop better-ada*p*ted maize plant ideotypes in close collaboration with seed companies.

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Insect pest management research update 2017

Melina Miles, Adam Quade, Richard Lloyd, Paul Grundy and Jamie Hopkinson, DAF Qld

Key words

Green peach aphid, thresholds, canola, faba beans, green mirid, helicoverpa

GRDC code

DAQ00196

Take home messages

- Canola is most susceptible to yield and oil loss with infestations of aphids from bolting. This is earlier than previously thought, but still requires at least 10-14 days of infestation to significantly impact on the crop.
- Preliminary thresholds are proposed for helicoverpa in canola.
- Initial observations on helicoverpa feeding behaviour in faba beans suggest a crop loss rate of approx. 2.4g/larva.

Aphid thresholds in canola

Over the past 3 years, DAF entomologist Paul Grundy has been undertaking research to determine the susceptibility of canola to cabbage aphid infestations during flowering and seed set. The initial work, simulating late infestations on the terminals of filling/maturing racemes, showed that canola was compensating for terminal damage and/or the affected terminal pods were not contributing significantly to yield. Recent trials (2016) have shown that cutting stimulates atypical compensation, and that bagging better simulates aphid impact, which is to prevent normal development of racemes (Table 1).

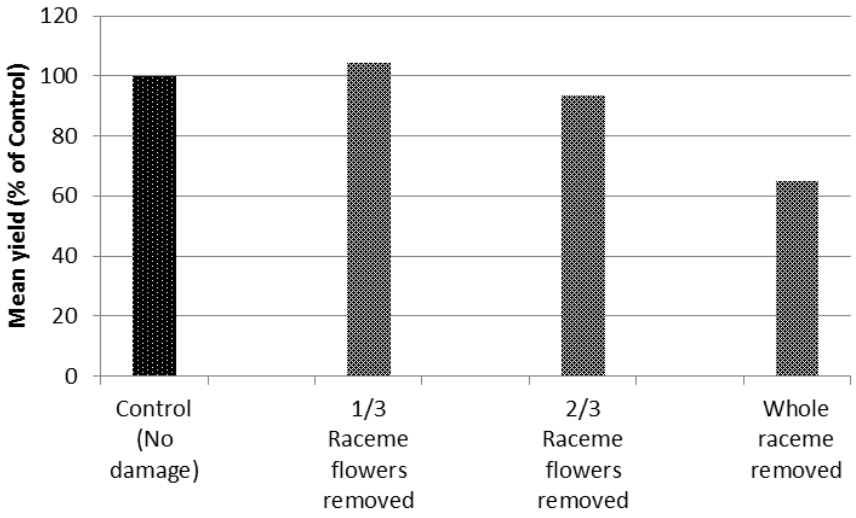
Table 1. Differences in the plant response to simulated aphid damage. Cutting racemes vs constraining growth by bagging racemes. Trial conducted in dryland canola at Allora, SE Qld, 2013.

Cutting to simulate aphid damage		Bagging racemes to simulate aphid damage	
Treatment	**Yield (t/ha)**	**Treatment**	**Yield (g/plot)**
Control	2.07 a	Control (unbagged)	1293 a
10% of terminals removed	1.93 a	1. Raceme covered first flower	988 b
50% of terminal removed	1.98 a	2. Raceme covered first flower +7 days	989 b
90% of terminal removed	2.01 a	3. Raceme covered first flower +14 days	949 b

Treatments followed by the same letter are not significantly different ($P<0.05$).

In 2014, trials at 8 locations on the Liverpool Plain produced similar results, with significant yield loss only occurring when the plant was forced to replace all the reproductive structures removed at early flowering (**Figure**).

Figure 1. Aggregate treatment yields across 8 sites near Spring Ridge NSW, 2014, expressed as a percentage of the control.



The conclusion of this research was that the widely used best-bet threshold, of 10-20% of racemes infested during late flowering-pod set, is probably conservative and could be revised up. The compensatory ability of the crop allows time for biological control by aphid parasitoids, lacewings, hoverflies and ladybeetles to take place during the first weeks of flowering without significant crop loss. If natural enemies were ineffective in supressing aphid populations, spraying on increasing level (20-25% of racemes infested) would be unlikely to result in irrecoverable crop damage. Very late infestations of aphids have very limited damage potential as the associated disruption mainly affects flowers/pods that are unlikely to contribute to final yield.

In 2016, replicated trials at Wellcamp near Toowoomba were undertaken with infestations of aphids, rather than simulated damage. This approach provided an opportunity to examine both the impact of aphids on crop growth and oil content. Conditions for crop compensation were excellent with approx. 300 mm of rain between June and September. Plots were infested with aphids prior to bolting to get racemes infested as early as possible. In the early sown trial (sown 9 April, infested 16 July) the infestations did not establish before bolting, but were well established through flowering. Infestation in the later sowing (sown 17 May, infested 10 August) resulted in successful early infestation so flowering racemes were heavily infested from early flowering. Infestations resulted in every plant having some aphids established in each treated plot. Greater impacts on both the yield and oil content were observed in the later sown trial (Figure 2).

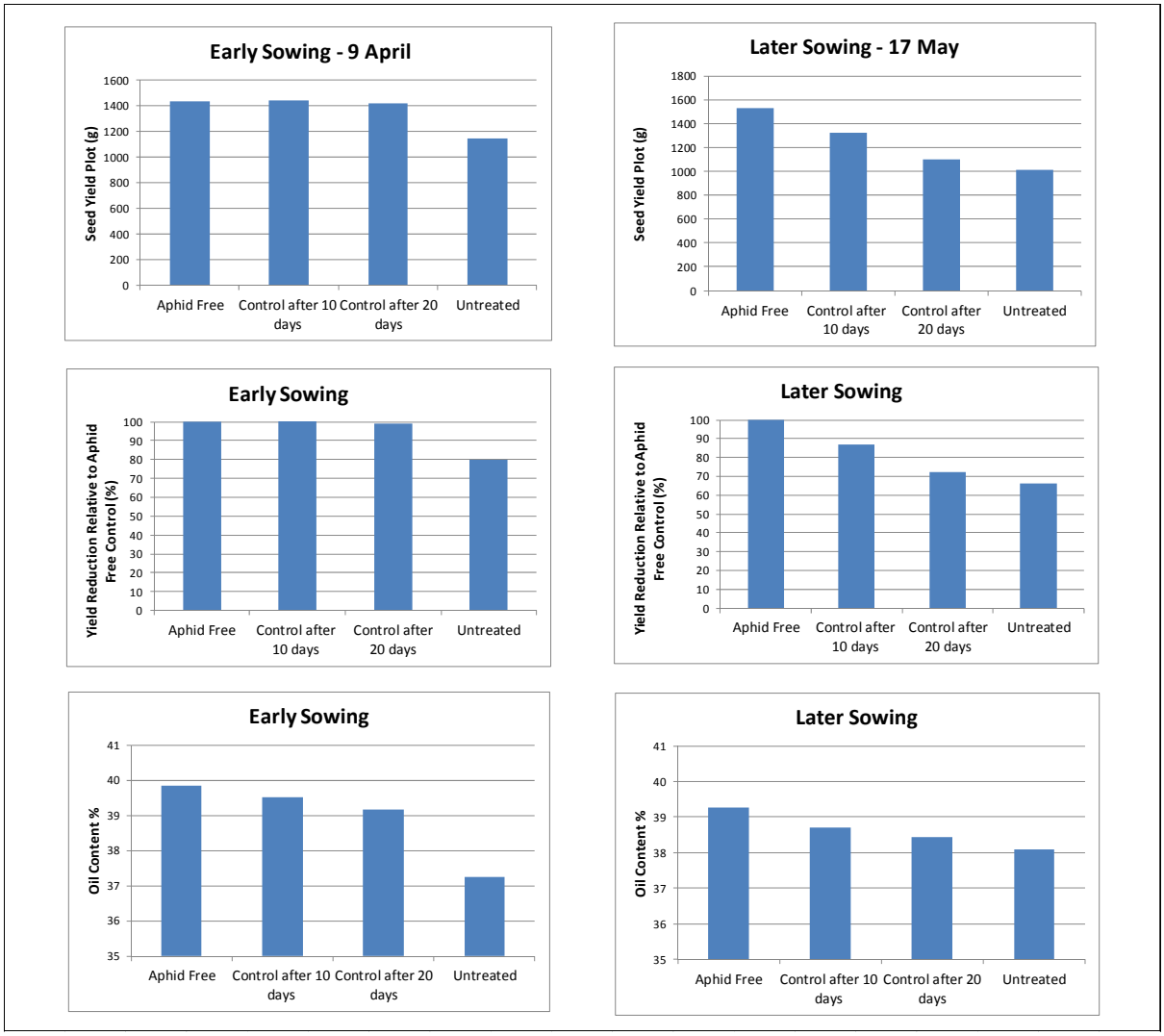


Figure 2. Very early infestation of flowering racemes with cabbage aphid for a 10 day period can reduce both yield and oil content. Result of replicated trials, Wellcamp 2016.

What the 2016 trial results mean for canola aphid management recommendations

The series of trials over the past 3 years have indicated that infestations in early flowering result in greater impacts than later infestations, and this work reinforces this.

The most susceptible period is the 2-4 weeks in which the plant is bolting and starting to flower; this is when crop monitoring for aphids should start – and which is probably earlier than it is done currently. To simplify sampling, assess aphid infestation in terms of % plants infested, rather than % racemes infested.

As significant yield and oil content declines did not occur with infestations of 10-14 days, there is time to assess the rate at which the aphid infestation is growing, and the potential impact of natural enemies and weather on infestations.

At this stage, a threshold of 20% of plants infested is proposed. Further work is required to validate this approach.

Helicoverpa threshold in canola and faba beans

Canola

To date, thresholds available for managing *Helicoverpa* in canola have been based on 'best guesses'. In 2015 we conducted a replicated trial to determine the consumption rate of *Helicoverpa* 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.

In summary, results of the trial are:

i) The consumption rate of a *Helicoverpa* 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.

Table 2. Calculating potential yield loss and economic thresholds

Potential yield loss (t/ha) per larva = D x P x V	**Economic threshold (larvae/m^2) = C / (V x D)**
Where	Where
D = estimated yield loss per larva (t/ha)	C = cost of control ($/ha)
P = pest density per sampling unit (e.g. per m^2)	V = crop value ($/t)
V = crop value ($/t)	D = estimated yield loss per larva (t/ha)

These consumption rates are preliminary. Two further trials were conducted to assess consumption rates. This data is not yet fully analysed. It is expected that we will have greater confidence and firm thresholds within 1-2 seasons.

Faba beans

Two replicated cage trials were conducted in 2016 to quantify the damage potential of helicoverpa in faba beans. Whilst this data is not yet fully analysed, the research has provided some insight into the feeding/damage behaviour of helicoverpa in faba beans. Here is a summary of some of the outcomes:

- Each helicoverpa larva damaged 4 seeds. On average, one seed was damaged per pod; and each larva damaged 4 pods.
- The majority of damaged seed (70% in Kingaroy and 100% in Billa Billa) had significant damage to the cotyledon. There was relatively little seed that was only superficially damaged (quality rather than yield impact).

At this stage we can only tentatively propose a crop loss rate for helicoverpa in faba beans, based on broad and, as yet untested, assumptions. For example, if each larva causes significant damage to 4 seed in its lifetime, and we assume each of these is lost to feeding and/or at harvest, then in a crop of Warda (seed weight around 0.6g/seed) each larva would cause a yield loss of 2.4g (or 24 kg/ha for every larva per square metre). We can compare the threshold calculated from this rate of yield loss (ET=C/(VxD), see equation above) to the nominal 2 larvae per sqm commonly used.

ET = 5.0 if using $30 insecticide application and $250/t for grain.

Working with an ET =2, the potential yield loss for grain at $250/ha = $12

Clearly this challenges the perception that even at 2 larvae/sqm significant damage is occurring in faba beans. This is why the quality (partial grain damage, with grain retained at harvest) is important to investigate. Also of importance is effective sampling (method and timing).

In 2017 we will be assessing the potential of damaged seed to be shed, or retained in the harvested grain sample. This will be a key factor in determining the level of impact helicoverpa are having on yield and quality. We also plan to review sampling effectiveness as previous work suggested potential to underestimate larval numbers with current methods.

Late mirid damage in faba beans

In 2016, mirid densities were very low in late winter – early spring; consequently further work on thresholds was not possible this season, but it is a priority for 2017.

To summarise the findings to date:

A replicated trial that caged mirid adults or 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.

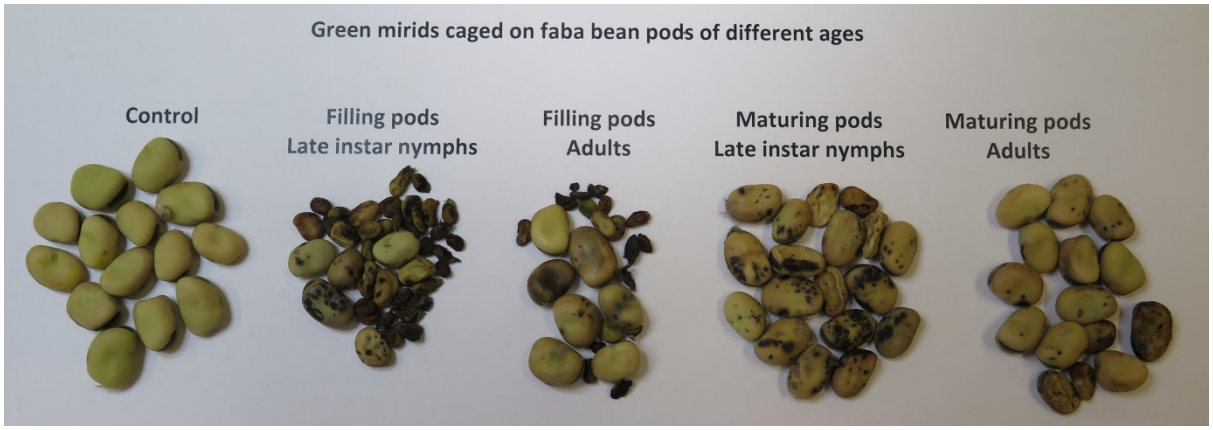


Figure 3. Effect of green mirids caged on faba bean pods of different ages

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 as opportunities arise.

Green peach and canola – overview of the issues

In 2013, the Green peach aphid (GPA) outbreak in canola in southern Australia caused significant concern in the industry. In particular, the transmission of barley yellow dwarf virus (BYDV) and insecticide resistance to multiple modes of action.

Whilst GPA is relatively uncommon in the northern half of the Northern Grains Region, it worth being aware of the impact and potential issues that the use of insecticides may have in promoting GPA populations and/or resistance.

High levels of resistance to carbamates and pyrethroids are now confirmed to be widespread across Australia. Moderate levels of resistance to organophosphates have been observed in many populations, and there is evidence that resistance to neonicotinoids (e.g. imidacloprid) is evolving (Umina et al. 2015)

Resources

http://ipmguidelinesforgrains.com.au/wp-content/uploads/Science-behind-the-Resistance-Management-Strategy-for-GPA.pdf

Umina P, McDonald G and de Little S. 2015. Green peach aphids: insecticide resistance, role in the transmission of beet western yellows virus and managing risk in 2015. GRDC Update Wagga Wagga.

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.

Support for the field trials was provided by Liz Williams, Trevor Volp and Hugh Brier. The field staff at the Kingaroy research station and the Farming systems trial site at Billa Billa made sure the trial plots were planted and maintained.

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Russian wheat aphid – what do we know?

Ken Young[1] Lauren Du Fall[1] and Craig Ruch[2]

GRDC Canberra Office[1], GRDC Adelaide Office[2]

Key words

Russian wheat aphid (RWA), economic thresholds, insecticides, population dynamics, varietal resistance

Take home message

- Russian wheat aphid (RWA) is likely to be a significant pest of Australian cereals
- Overseas economic thresholds (20 aphids per plant then 10 aphids per tiller) need confirmation in Australia
- Rain event significantly affects RWA populations particularly if weather allows for entomopathogenic fungal development
- Beneficial insects are a major management mechanism overseas and have shown effects in Australia
- Insecticides will also be a major management tool to be used in conjunction with beneficials
- The biology and ecology of RWA in Australia is still being determined including likely survival in sub-tropical climates of the northern region
- Plant genetics is not the be all and end all in management

Russian wheat aphid occurrence in Australia

Russian wheat aphid (*Diuraphis noxia*, RWA) was first reported in paddocks in Tarlee SA in May 2016. After initial incursion management under the Exotic Plant Pest Response Deed, determined that RWA had spread over considerable areas of South Australia and Victoria, it was deemed as a management issue and not feasible to eradicate on 8 June 2017.

RWA has since spread across Victoria into southern NSW and has recently been identified in Tasmania. As the occurrence of RWA has been widespread, it is thought that it has been Australia for at least a year if not longer but has gone unnoticed. It is still spreading and its final distribution could be across the whole of the Australian wheat belt.

RWA occurs in all other major grain-growing regions of the world, originating from southern Russia, the Middle East and Central Asia.

Work commissioned by GRDC

Since the declaration that RWA can't be eradicated, the GRDC has commissioned several projects to enable grower's better management of this pest this coming season and for the long term. These projects included biology & ecology; economic thresholds, insecticide efficacy and plant resistance options. Also a communications plan has been implemented which includes presentations at Updates and provision of a best bet management guide for growers.

Biology and ecology

Whilst RWA has originated from colder areas, it is associated with warmer drier climates preferring temperatures in the range 18 – 21^{o}C, with low survival when temperatures exceed 25^{o}C. In many

areas, only females are present and reproduction is asexual, and this is what has been so far observed in Australia.

The primary hosts are wheat and barley but RWA also lives on triticale, oats and rye and can survive on a range of grass species including pasture grasses and wild genera including *Poa*, *Bromus*, *Hordeum*, *Lolium*, and *Phalaris*. The full extent of the role of these other species on the invasion potential and survivability of RWA over summer and between crops is still to be determined under Australian conditions.

Symptoms and effects

Large populations in autumn can severely affect crop establishment. Based on last years' experience where management practices were taken, crops can recover and yield normally. Currently recommendations are to use the threshold levels of 20 aphids per plant up to tillering, then 10 aphids per tiller after that. It was expected that the populations of RWA would increase in spring last year as this occurs elsewhere overseas. However the wet spring conditions in the south in 2016 caused a large decrease in population levels through displacement of aphids, but also due to beneficial fungal aphid attack. Last season weather hampered testing of the above thresholds under Australian conditions. The estimated yield losses in Colorado are 0.5% per each 1% infested wheat tiller and 0.8% per 1% infested barely tillers (Peairs 2017).

Infected leaves can be seen to have white to purple striping on leaves. Leaves can be rolled, and later on, heads a can be trapped by a rolled flag leaf and can appear bleached.

The aphid releases a toxin during feeding causing the effects only on the infested leaf. So once controlled, new leaves do not show symptoms.

The GRDC commissioned SARDI to conduct population studies across 16 sites in South Australia and Victoria during late winter and spring 2016 and this continued over summer to determine the survival of RWA.

Management

Green bridge

Maintaining a summer fallow clear of grasses will decrease the numbers of aphids surviving the summer months. Due to the wide host range, it is not only volunteer cereals that need to be managed, but grass weeds and possibly also in pasture grasses that are adjacent paddocks intended for cereals.

Insecticides

The current Emergency Use Permit APVMA PER82792 is for chlorpyrifos and pirimicarb and is in place until June 2018. A range of other foliar insecticides registered for use in cereals have also been assessed in Victoria and South Australia. The results of these trials are included in both the best management practices guide and presented at the Adelaide Update. The summary of these trials was that chlorpyrifos was the most efficacious, but that pirimicarb also performed strongly and had the added advantage of being less harmful to beneficials.

Water rate did affect efficacy with high water volumes (100 L/ha) performing better than 60L/ha. Adhere to spray volumes stated on PER82792. A medium coarse spray quality is recommended. The addition of adjuvants had variable results dependant on the insecticide used. There was an advantage in adding Hasten® or BS1000® to pirimicarb and Uptake® and SACOA Biopest® to chlorpyrifos at some sites. Adhere to adjuvant recommendations stated on PER82792 and the insecticide labels.

Information from 2016 indicated that the various seed dressings that include insecticides do have an effect on RWA. Trials are currently underway in controlled environments to determine the length of control seed dressings will provide in RWA management. Permit PER82304 (valid to March 2021) allows for seeds to be treated with seed dressing products containing 600 g/L imidacloprid.

Plant genetics

GRDC has previously invested in pre-emptive pre-breeding activities associated with varietal resistance to this pest in a partnership led by Murdoch University and involving national and international collaborators. While no resistance to RWA was identified in a screen of major Australian wheat and barley cultivars conducted several years ago, encouragingly the project did develop some material where resistance genes were introgressed into Australian cereal backgrounds.

Unfortunately, RWA has many biotypes and can develop new biotypes in new environments which make plant breeding more difficult. Currently, the GRDC has commissioned several studies with SARDI and NSW DPI to determine the biotype present in Australia and levels of resistance in current varieties and elite germplasm.

A cautionary tale comes from the USA, where resistant varieties where developed to the original biotypes with >25% uptake by growers until a new biotype was found in 2003. While germplasm was available, no commercial lines were developed (Peairs 2017).

Communication

The GRDC in conjunction with Plant Health Australia and state agencies have provided continual updates on the distribution, spread and management advice since the incursion. The GRDC have commissioned a best practice guide to be released around the time of this Update. The information from the various projects commissioned by the GRDC will be included in this best practice guide. For the southern updates, GRDC has hosted Prof. Frank Peairs from Colorado State University to provide information from Colorado's 30 years' experience in living with RWA to growers, advisers, entomologist and GRDC staff and panels. Some of Frank's information is presented here, but is also available from the Adelaide Update website.

References

Peairs 2017 – Adelaide Update paper

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.

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GRDC Russian wheat aphid update- breeding

Jules Dixon and Lauren Du Fall, GRDC

In May 2016, an incursion of Russian Wheat Aphid (RWA, *Diuraphis noxia*) was discovered in the state of South Australia. This new pest that is now endemic to Australia has the potential to be highly damaging in cereal crops such as wheat and barley.

Following the incursion GRDC have invested in both a crop protection/management and breeding (biotyping/identification of resistance etc.). This has been done to establish the here and now answers 'what does this mean for me on my farm now' and the longer term solutions 'do we have/can we breed for resistance in Australian germplasm'. This paper refers to progress made in largely the potential longer term solutions.

Global expert Janine Vitou was commissioned to Australia by GRDC in October 2016 to build capacity in design and capability in the field of RWA assessment. The following three trials were the first of their kind in Australia and have been achieved using the latest global knowledge.

Key messages

Approach

GRDC have invested in three key experiments that have been undertaken by the South Australian and Research Development Institute (SARDI, Greg Baker/Maarten van Helden and colleagues). All experiments were undertaken in a controlled glasshouse environment (or plant accelerator room where quarantine of imported wheat and barley germplasm was required).

1. RWA susceptibility of current commercial varieties: 85 Australian commercial lines were screened for RWA susceptibility at the seedling to tillering stage. Scoring was done in a glasshouse design using large infestations in a controlled environment. This was completed by testing separate aphid populations sampled from across South Australia and Victoria to ensure a representative area was sampled.
2. Biotype Discovery: To determine the biotype of aphid and therefore the plant resistance that is likely to be effective, 15 aphid clones were tested against a differential set of 24 wheat and barley lines with different resistance genes. Results were compared to the known profile of American and South-African biotypes.
3. Assessing sources of resistance: A third glasshouse experiment was conducted with the aim of this experiment to determine potential sources of resistance to RWA Australia that might be utilised in breeding new varieties.

Findings

The RWA populations collected in Australia are most likely closely related to a single North American biotype suggesting only one incursion.

A range of symptom expression was observed in a selection of current commercial bread wheat, barley and durum wheat varieties. This indicates that there may be a range of effective resistances present in current commercial cultivars however further data would be required to assess the impact on yield and to provide rankings of these varieties.

Through assessing sources of resistance and the biotyping work it appears we have access to germplasm with potential genetic resistance that could be developed through breeding to deliver Australian grain growers with new resistant varieties.

Acknowledgement

The following have been instrumental in the experimental work and findings to date including design, biotyping, germplasm importation and assessment of susceptibility of commercial varieties and potential sources of resistance: Janine Vitou (French expertise), Greg Baker/Maarten van Helden and his team at SARDI, Alison Kelly and her team at SAGI (Statistics for the Australian Grains Industry), Scott Haley (breeder Colorado), Owain Edwards at CSIRO, Brett Lobsey at NSW DPI and the Australian Grains Gene bank.

Disease concurrent session

Barley disease yield loss response curves
How much yield is lost in varieties with different levels of genetic resistance under different disease pressures?

Greg Platz, Lisle Snyman & Clayton Forknall, Dept. of Agriculture and Fisheries Queensland

Key words

Response curves, disease, epidemics, resistance, yield loss, management

GRDC code

DAW00245

Take home messages

- Losses in yield to a given disease epidemic vary with the levels of resistance in the varieties affected.
- The GRDC funded project "Yield loss response curves for host resistance to leaf, crown and root diseases in wheat and barley" is gathering data on yield losses of varieties with different levels of resistance under epidemics of different severities for a range of pathogens of wheat and barley.
- The barley foliar disease module of the project is being led by DAFQ, with experiments conducted nationally to explore the impact of leaf rust, net blotch (spot form and net form), scald and powdery mildew on current commercial barley varieties.
- NVT disease resistance ratings categorize varieties into 9 resistance categories (R – VS). Data collected from the project will add precision to assignment of these resistance categories.
- Growers and agronomists will be able to make better informed and more accurate decisions on disease management by implementing information gathered from the yield loss response curves project in their calculations.

Background

Disease control measures and the economics of chemical intervention are often based on potential yield losses – a worst case scenario e.g. disease "X" can cause yield losses in excess of 50%. That may be true in a very susceptible variety under a prolonged and severe epidemic; so the decision to spray to protect yield is automatic.

However, are we always likely to incur a worst-case epidemic or is it going to be somewhere between nil and severe? Clearly it will be somewhere in-between. Furthermore, are we likely to suffer the same potential yield losses under a lesser epidemic? The answer is NO.

Similarly are the varieties we are growing all in the very susceptible (VS) category? If not, are we likely to suffer the same potential yield losses in varieties that have some resistance to disease "X"? NO, again. Therefore, when growing a variety of intermediate resistance under an epidemic that is less than severe, what is the loss likely to be – 40%, 25% or 10%? We simply don't know.

We need to be able to predict these losses under variable epidemics so that an agronomist or a grower can more accurately determine the risk from disease and the profitability of disease management strategies. Knowledge and predictability of the yield and quality losses that varieties of different resistance levels might incur under different epidemics, is crucial to these calculations.

Losses to diseases are a factor of:

- Susceptibility of the variety
- Severity of infection
- Duration of the epidemic and
- Environment

If we were able to quantify yield losses in terms of varietal resistance level and severity of the epidemic then we would have a much more accurate predictive tool to guide decisions on disease control measures. This is the basis of the GRDC funded Yield Loss Response Curves project.

Response curves relate a measure of productivity (yield), to a measure of disease (area under the disease progress curve) and are being constructed for a range of varieties of different resistance levels across a number of locations and years. The yield responses of varieties are measured by exposing them to different levels of disease severity under the same environment. Through the manipulation of disease severities, an epidemic continuum is established, allowing the yield response **due to disease** to be estimated for each variety across a wide spectrum of disease epidemics.

Data collection

The value of the yield response curves is directly correlated to the quality of the data used to generate them. Field experiments have been conducted annually since 2014 and will continue until 2018 to generate the raw data. A typical experiment consists of six varieties with different resistance levels as assigned by the NVT disease rating system, avoiding resistant to moderately resistant varieties. Varieties are then exposed to epidemics ranging from no disease to high disease. Typical epidemics are nil, very low, low, medium and high where epidemics are manipulated using different levels of initial inoculum, fungicide applications or combinations of both to give stepwise differences in grain yield for each variety.

As the crop and epidemics develop, a minimum of 5 disease assessments are taken on every plot and this information is expressed as area under the disease progress curve (AUDPC) for each treatment. AUDPC is a quantitative summary of disease severity over time i.e. the period over which assessments were taken.

Trials are taken through to maturity and harvested, yields recorded and grain quality parameters measured.

Results

Yield losses

Yield data is generated with the prime objective of developing yield response curves for the type variety of specific resistance categories; however, it also serves to demonstrate the relative yield losses across resistance categories. The figures below summarise the yield responses of trials in 2014 to investigate barley leaf rust (Figure 1) and net form net blotch (Figure 2) and in 2015 to investigate spot form net blotch (Figure 3).

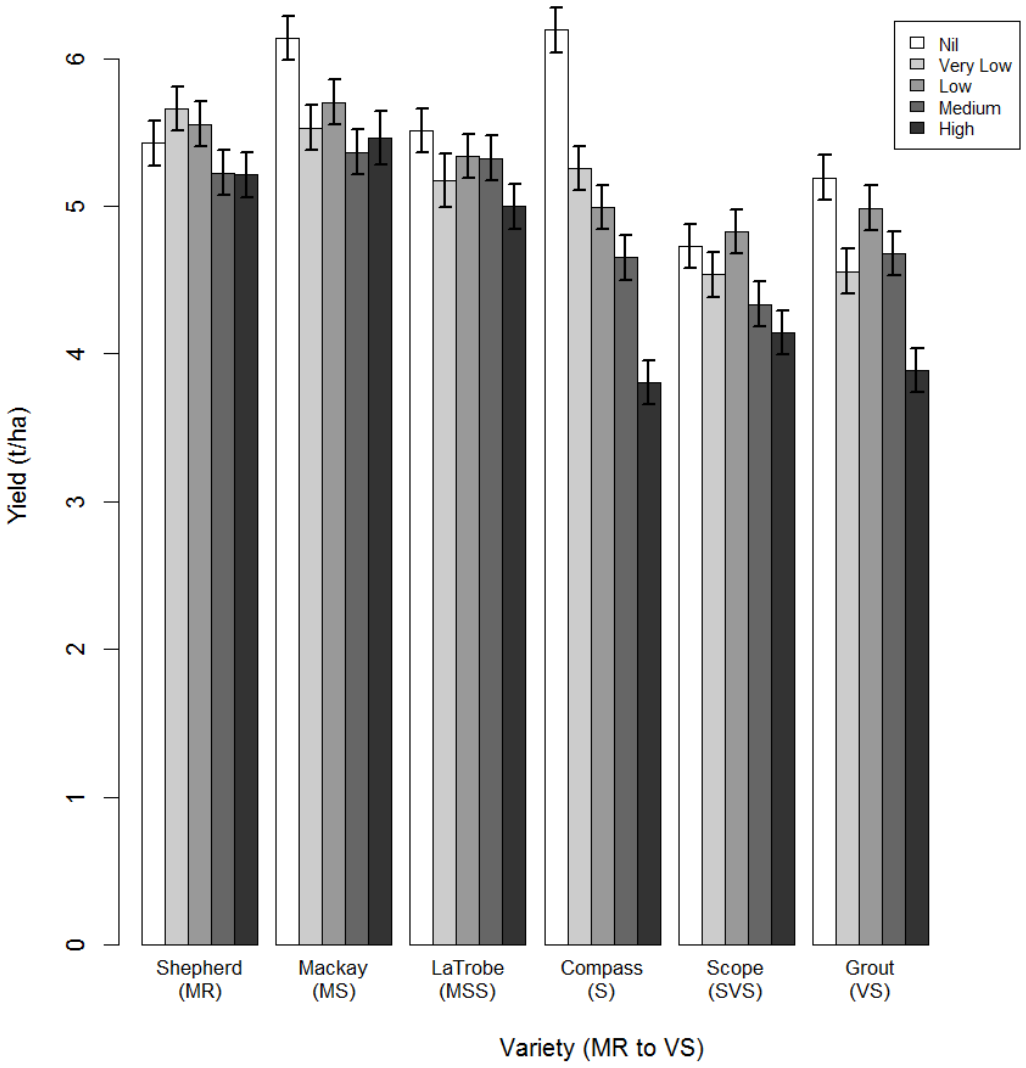

Figure 1. Comparative yields of 6 barley varieties with differing resistance categories under epidemics of leaf rust in 2014. This data corresponds to that presented in Figure 1 using response curves.

Barley leaf rust 2014

In this experiment the percentage loss in yield between the nil and high diseased plots and the resistance ratings of the varieties were Grout (VS) 25.1%; Scope (S) 12.3%; Compass (S) 38.5%; La Trobe (MSS) 9.4%; Mackay (MRMS) 11.0% and Shepherd (MR) 3.9%. The choice of varieties in this experiment was based on 2013 NVT resistance ratings where Compass was rated S. This trial demonstrated that Compass was misclassified as susceptible (S) and was clearly VS to leaf rust. It also demonstrated that a little resistance can make a big difference to yield loss under some epidemics e.g. the yield loss in Scope (S) was about half that of the VS Grout and less than one third of Compass.

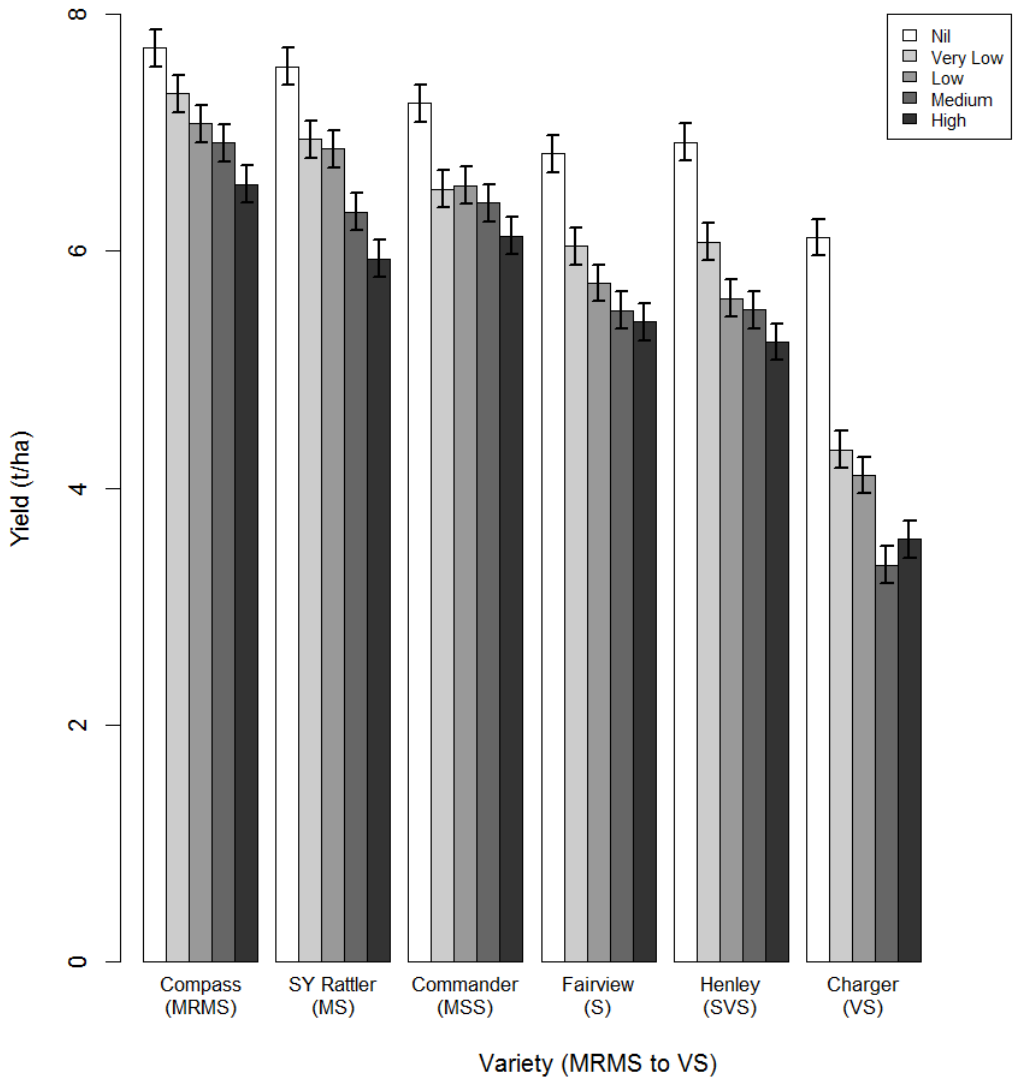

Figure 2. Comparative yields of 6 barley varieties with differing resistance categories under epidemics of net form net blotch in 2014.

Net form net blotch (NFNB) 2014

As seen in the leaf rust experiment, the VS variety – Charger(Þ) in this case - suffered the greatest yield loss (41.7%) under the high epidemic and still lost 29.3% under the very low epidemic (no inoculum applied) when compared to the nil disease treatment. This contrasted with the S variety Fairview(Þ) that lost 20.8% and 11.5% respectively and Compass (Þ) (MRMS) which lost 14.9% and 5% respectively under the same levels of inoculum applied. Compass(Þ) has good adult plant resistance to the pathotype of NFNB used in this trial; but is susceptible in the vegetative stages. The losses recorded in Compass(Þ) could have occurred from early infection of NFNB but are likely to have been exaggerated by late natural infection with leaf rust.

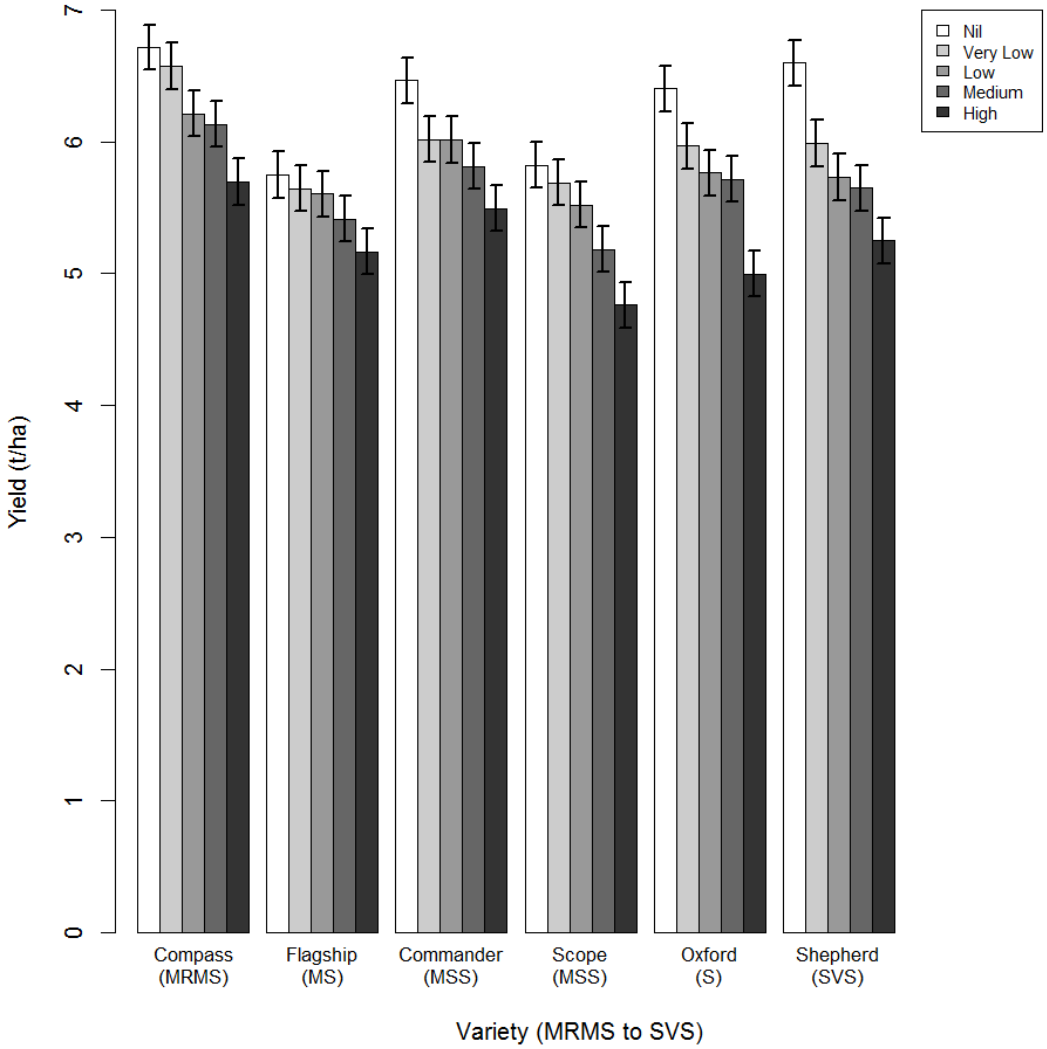

Figure 3. Comparative yields of 6 barley varieties with differing resistance categories under epidemics of spot form net blotch in 2015.

Spot form net blotch (SFNB)

The yield losses between the nil disease and high disease treatments in this experiment were 22.0% for Oxford, 20.4% for Shepherd, 18.2% for Scope, 15% for Commander, 10.1% for Flagship and 15.4% for Compass. Again, the losses in Compass (MRMS) may have been exaggerated by a late infection with leaf rust.

While the data presented here is only preliminary, it clearly demonstrates increasing losses with increasing susceptibilities. It also shows differences in yields from the different levels of inoculum applied; but the real value of this data is in generating **yield response curves** that provide additional information to the bar charts shown above.

Yield response curves

Yield response curves are derived by analysing yield and quality data using random regression techniques to estimate the yield potential (intercept) and yield response (slope) of each variety in the trial. Yield potential provides an estimate of the ability of a variety to yield in the absence of

disease, while the yield response demonstrates the rate at which yield is lost per unit increase in disease pressure.

The yield response curves of six barley varieties subjected to a range of leaf rust epidemics in the 2014 experiment are presented in Figure 4. The resistance categories of varieties in the experiment ranged from moderately resistant (MR) to very susceptible (VS). The measure of leaf rust pressure was determined by combining the assessments conducted on the two leaves directly below the flag leaf using the AUDPC. Although described as "curves" the relationship between grain yield and disease was linear in this case.

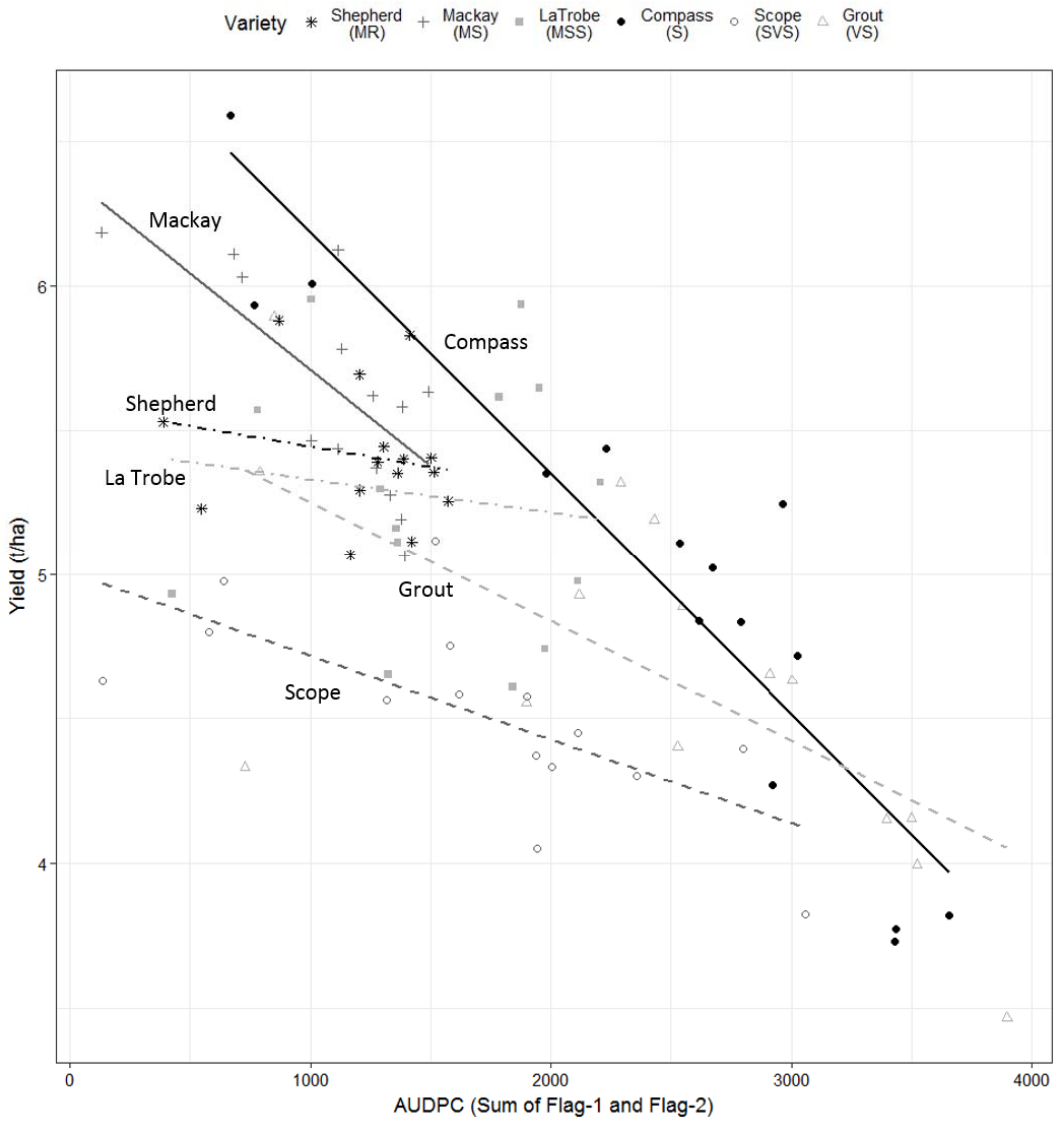

Figure 4. Yield response curves for six barley varieties of different resistance categories under a continuum of leaf rust epidemics developed in 2014.

What do the yield response curves tell us?

From Figure 4, it can be seen that the curve of each variety varies in length and slope. A comparison of how far the curves stretch along the x-axis provides a measure of the susceptibility of the varieties to leaf rust; the greater the AUDPC, the more susceptible the variety. In this case, the varieties Grout Þ and Compass Þ exhibit the greatest amount of disease, closely followed by the variety Scope Þ. This ranking of varieties is roughly consistent with the resistance categories assigned by NVT; however in 2014, Compass Þ was still rated as a susceptible variety (S) yet in terms of disease

severity (AUDPC) and yield loss, it clearly displays a very susceptible (VS) response (resistance rating updated in 2015). Conversely, the moderately resistant (MR) and moderately susceptible (MS) varieties Shepherd and Mackay show the least amount of disease.

Also demonstrated by Figure 4 is the difficulty in maintaining true nil disease treatments in the presence of leaf rust. Nil disease treatments were sprayed twice; however leaf area disease measurements still revealed loss of leaf area from the disease. This lack of a true nil disease control makes the estimation of the varieties yield potentials difficult, as extrapolation is required beyond the range of the data.

A comparison of the responses (slopes) of the varieties also proves useful in determining the rate of change at which yield is lost due to leaf rust for each variety. In this case, Figure 4 shows that the varieties Shepherd and La Trobe demonstrate near to equivalent responses to leaf rust, with flatter slopes than the other varieties. This indicates that with an equivalent unit increase in disease, these varieties lost less yield than the other varieties in the experiment. On the other hand, the variety Compass exhibits the largest slope, demonstrating that per unit increase in disease pressure, the yield lost by this variety is greatest.

Warning

The data presented in this paper come from 3 trials, each conducted at one location in one year and should be regarded as preliminary. Further trials are being undertaken and data from these will be used to validate and complement the above improving the confidence and precision of the resultant yield response curves.

Conclusion

The yield response curves project is a national initiative of GRDC coordinated by the Department of Agriculture and Food Western Australia. It is generating data on yield losses in cereals relative to varietal resistance and severity of disease epidemics. This data will be used to develop yield response curves for varieties within specific resistance categories under a continuum of disease pressures.

These curves will be much more informative than a yield loss bar chart or an NVT resistance rating. They will provide a quantitative summary of yield loss in varieties or resistance categories over a range of disease severities. This will assist in choosing varieties and in planning disease management strategies. Through this project, growers and agronomists will have quantitatively based decision support to guide the adoption or disadoption of varieties and to more accurately formulate disease control budgets and application strategies to minimize the effects of diseases. Furthermore, the trials will help validate the NVT disease resistance ratings in terms of loss of yield and quality and not just disease severity.

In terms of applying the information presented in the response curves into disease control strategies, the curves in Figure 4 reveal that a grower could rely on the host resistance of Shepherd alone to control leaf rust. The loss in yield of this variety would not warrant application of fungicide for leaf rust control. On the other hand, the curves demonstrate that Compass has the highest yield potential but also exhibits the greatest potential loss in yield under leaf rust epidemics. This information can help growers decide (a) if they want to risk growing a VS variety (b) the level of disease control required to match the yields of a more resistant, lower yielding variety and (c) the likely return on application of fungicide.

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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 valued support.

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Yellow leaf spot trials and the economics of spraying

Lislé Snyman, Greg Platz, Clayton Forknall Dept of Agriculture and Fisheries Queensland

Key words

Wheat, yellow spot, yield loss, fungicide

GRDC code

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

Take home message

- Crop rotation and reducing surface stubble decrease inoculum levels
- Do not sow susceptible wheat varieties into wheat stubble
- Economic response to fungicide application is a factor of varietal susceptibility, severity of the epidemic, product choice and timing of application.
- Increasing moisture periods increase the incidence and severity of yellow spot

Introduction

Yellow spot is a stubble-borne fungal disease caused by the pathogen *Pyrenophora tritici-repentis*. It causes yield loss and reduced grain quality. Yield loss depends on varietal resistance and severity of the disease.

Symptoms include tan-coloured oval lesions becoming darker in the centre with a yellow margin, often observed in young seedling leaves from where the disease moves up the plant under suitable conditions. As lesions merge and coalesce, they produce large areas of necrotic tissue, causing leaf death and reducing photosynthetic area.

The fungus survives as small, black fruiting bodies on stubble. From there, fungal spores are released after rain events and spread onto nearby seedlings, resulting in primary infection. Secondary spread occurs when asexual spores are produced on leaves and dispersed by wind, infecting new leaves and neighbouring crops.

At least six hours of leaf wetness with temperatures of 15-28^{o}C are required for the successful infection of leaves from stubble. Secondary infection (leaf to leaf) is favoured by leaf wetness, high humidity and optimum temperatures between 15^{o}C and 25^{o}C.

Successful management requires an integrated disease management approach including crop rotation (i.e. avoid wheat on wheat), timely application of fungicides to protect the money leaves (flag and flag-1), removal of stubble and using resistant varieties. Crops deficient in nitrogen and/or potassium have been shown to be more vulnerable to infection. Stubble of susceptible varieties harbours more inoculum, hence avoid sowing a susceptible variety into stubble from a previously infected susceptible crop at all cost.

Yield loss associated with yellow spot

The impact of yellow spot on grain yield of a susceptible variety under conditions favourable for disease development was demonstrated in the variety Banks, where yield losses reached 60%. Most of that could be attributed to a reduction in grain size (Rees & Platz, 1989).

In an attempt to quantify yield losses caused by yellow spot in current varieties, a trial was conducted in 2013 with four varieties ranging from moderately resistant (MR) to susceptible (S) to

yellow spot. Varieties included were Leichhardt (MR), Kennedy (MSS), Kidman (S) and EGA Gregory (S).

Treatments applied included a full fungicide treatment, early spray (GS31), late spray (GS39), early+late spray and a nil fungicide treatment. The full fungicide treated plots were sprayed on three occasions, approximately 2-3 weeks apart, with the first spray 14 days before the early application.

Results indicated significantly higher yield loss in the varieties EGA Gregory and Kidman, rated susceptible to yellow spot. In both these, the full spray application yielded significantly higher than all the other treatments. The full spray was significantly higher than the late spray and the nil spray only for Leichhardt (MR). In the variety Kennedy (MSS), the full spray was significantly higher than the nil spray, the late spray and the 2 sprays (early+late).

Another trial conducted in 2015 included five varieties, ranging from MRMS to SVS and a range of disease levels i.e. nil disease (full sprayed treatment), very low disease, low disease, medium disease and high disease levels. The yield response of the different varieties at different disease levels are displayed in Fig. 1.

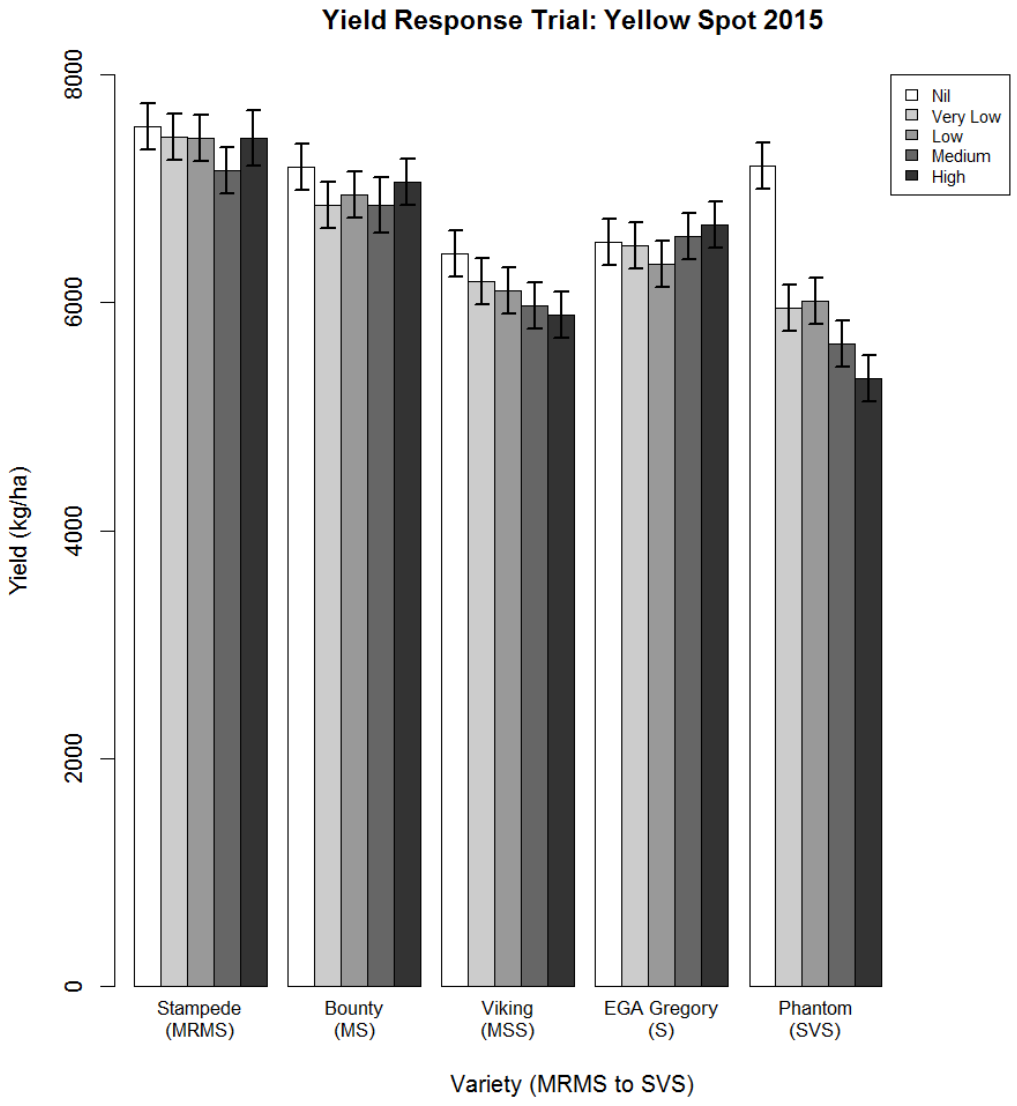

Figure 1. Yield response of wheat varieties to different levels of yellow spot in 2015

No significant differences were observed between any of the treatments in the varieties Stampede (MRMS), Bounty (MS) and EGA Gregory (S), with very little yield loss observed across treatments. The nil disease treatment yielded significantly higher than the high disease treatment in Viking (MSS), with no significant differences between the diseased treatments. The biggest yield loss was observed in Phantom (SVS), with a 25.9% yield increase in the nil disease over the high disease treatment. The high disease treatments only delivered a moderate epidemic.

Similar results were observed in the variety Bounty (MS) in 2016 under heavier epidemics with no significant difference in yield between any of the treatments and very little yield loss. Variable results were obtained in the varieties Suntop (MSS), Wallup (S) and EGA Gregory (S) where the nil disease treatments yielded significantly better than some of the diseased treatments, but not all of them (Fig. 2). The high disease treatment of EGA Gregory suffered a yield loss of 13.2% when compared to the nil disease, higher than yield loss measured in the varieties Suntop (9.5%) and Wallup (9.3%). A significant yield advantage of 22.5% was evident in Scout (SVS) and 18.2% in Phantom (VS) when comparing the nil disease and high disease treatments.

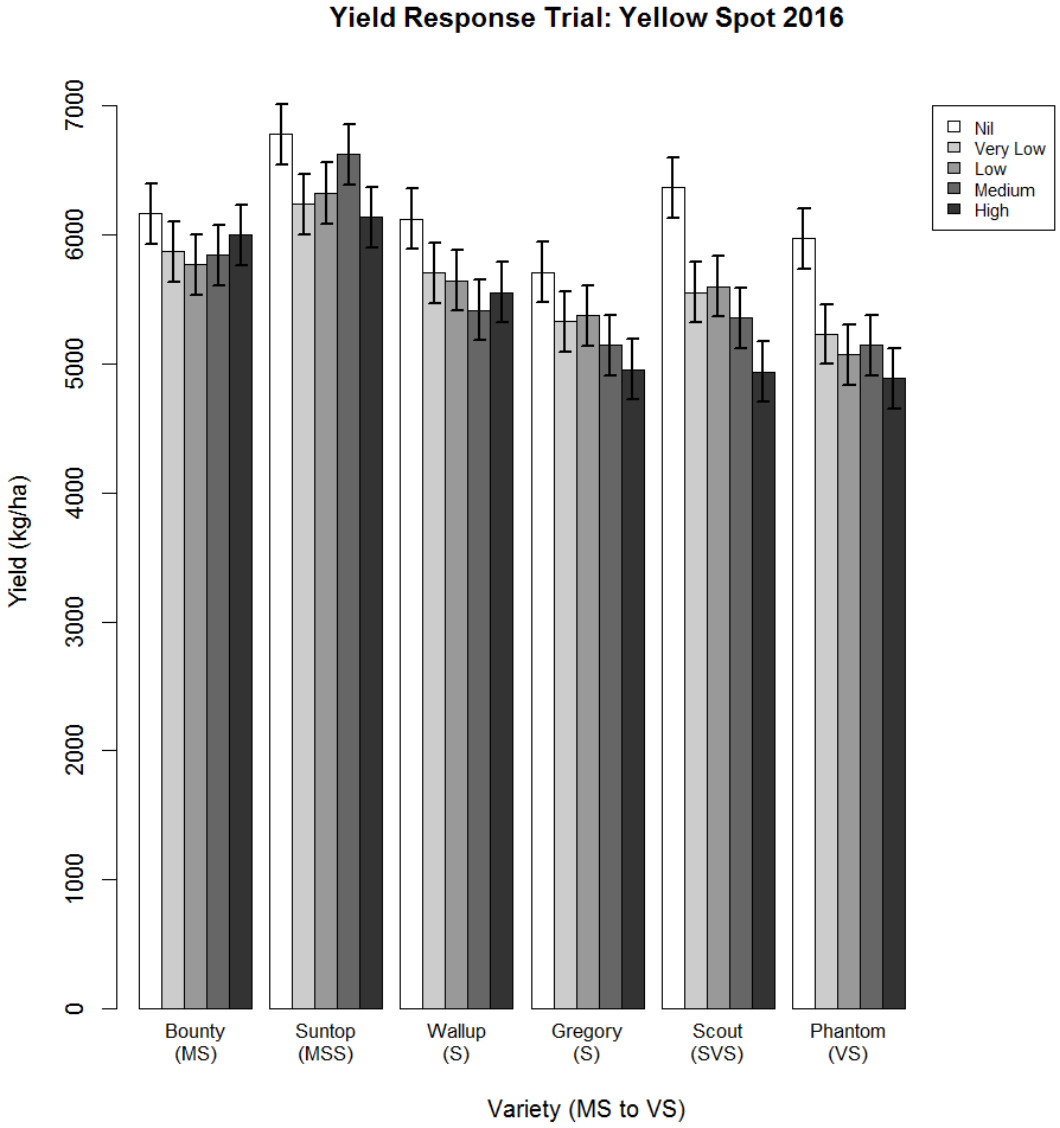

Figure 2. Yield response of wheat varieties to different levels of yellow spot in 2016

Implications

Results obtained varied between varieties and seasons. Over the three years, varieties with higher levels of resistance to yellow spot were less impacted by the disease, whereas bigger yield loss occurred in varieties rated as S or worse. Variable results were obtained across years in EGA Gregory and could possibly be attributed to differences in disease pressure, environment and the maturity of the variety. It was noted by Rees & Platz (1989) that disease levels on later maturing varieties were generally lower than on earlier varieties at any given time.

Yield losses of approximately 20% were observed under moderate disease pressure in varieties rated S to VS with Phantom ranging between 18.2% in 2016 and 25.9% in 2015 whereas yield loss in Kidman was 23.1% in 2014 and 22.5% in Scout in 2016.

In looking at the economics of fungicide application (Table 1) for the control of yellow spot, it is evident that fungicide application is more profitable in more susceptible varieties. It is however important to note that the differences quoted here were a result of three sprays used in the full spray/nil disease treatment and the same level of control may not be possible with a single fungicide application. The timing of a single fungicide application will be crucial in minimizing yield loss. These results support earlier findings that a single fungicide application can be very economical on susceptible varieties in high yielding, high disease pressure years (Colson, 2004).

Table 1. Economics of fungicide application in 2016 yield response trial

Variety	Treatment	Fungicide cost (3 sprays) ($/ha)*	Yield (t/ha)	Yield increase (%)	Income ($/ha)**	Extra net ($/ha)
Bounty (MS)	High disease	0	6.00	0	1500	0
	Nil disease	60	6.16	2.60	1540	-20
Suntop (MSS)	High disease	0	6.14	0	1535	0
	Nil disease	60	6.78	9.44	1695	100
Wallup (S)	High disease	0	5.55	0	1387.5	0
	Nil disease	60	6.12	9.31	1530	82.5
EGA Gregory (S)	High disease	0	4.96	0	1240	0
	Nil disease	60	5.71	13.13	1427.5	127.5
Scout (SVS)	High disease	0	4.93	0	1232.5	0
	Nil disease	60	6.36	22.48	1590	297.5
Phantom (VS)	High disease	0	4.89	0	1222.5	0
	Nil disease	60	5.97	18.09	1492.5	210

*$20/ha/application
**$250/t APH1/APH2 Goondiwindi

Conclusion

These results confirm previous reports that yield and quality losses as a result of yellow spot infection, are greater in more susceptible varieties than in varieties with some level of resistance to the pathogen (Colson *et al*., 2003; Rees & Platz, 1989). Consequently, it is important to consider the economic benefit in applying fungicide to a variety with good levels of resistance, unless disease pressure is very high and the environment conducive to further disease development.

Management of yellow spot is best achieved with an integrated approach of varietal resistance, stubble management, crop rotation and timely fungicide application if required. Disease control will be easier in varieties with some level of resistance even though responses to fungicide application

may not be as impressive as in a VS variety. Always be aware that fungicides are more effective if applied prior to infection events.

A much greater proportion of our wheat cropping area is sown to varieties with useful levels of resistance to yellow spot than a decade ago; therefore it is worthwhile to consider the economics of fungicide application in relation to varietal resistance and epidemic potential before spraying. The preliminary data shown above suggests that application of fungicides to varieties that are rated less than MSS may not always be profitable. Yield loss response curves for the wheat/yellow spot system are being developed under a national GRDC project and will aid in making these critical management decisions.

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Yellow spot of wheat: epidemiology studies and how they have helped us understand what we observe in the paddock

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Key words

Yellow spot, wheat diseases, ascospores, decision support tools, modelling

GRDC code

DAW00228

Take home message

The fungus that causes yellow spot survives from one season to the next on infected wheat stubble. In the Western Australian (WA) Grainbelt yellow spot fruiting bodies mature and ascospores are released from the previous season's stubble earlier in the southern coastal cropping areas (Albany and Esperance) compared with central (Northam) and northern (Eradu) cropping areas. The timing of fruiting body maturation is influenced by environmental factors, predominantly rainfall and temperature.

The early maturation of the yellow spot fungus in the southern coastal cropping area, usually before crops have emerged, results in limited primary infection opportunities. This, combined with cooler temperatures, can limit yellow spot impact in most years in this region. The later maturation of the yellow spot fungus in the central and northern cropping areas is often after crop emergence and can result in multiple primary infection opportunities. These multiple primary infection opportunities, coupled with warmer winter conditions which favour secondary spread, result in continuous wheat crops in the northern and central areas having a high risk of developing yellow spot.

The timing of the onset of yellow spot ascospore release from stubble does vary from year to year. In years when the stubble has been exposed to several summer rainfall events the fruiting bodies mature earlier in the autumn compared with years that have had limited rainfall events between harvest and the autumn break. Progress has been made towards developing and validating a decision support tool (DST) that predicts the timing of yellow spot ascospore release. This is being developed and tested with data from WA, SA and Victoria. This DST will assist wheat growers, advisors and researchers make informed decisions about yellow spot management.

Background

The fungus that causes yellow spot (*Pyrenophora tritici-repentis*) survives from one season to the next on wheat stubble. Sexual spores, called ascospores, develop in fruiting bodies on this stubble and when released infect the following season's wheat crop; this is the primary infection process. Once the wheat crop is infected, yellow spot lesions on the leaves produce abundant asexual spores, called conidia, causing further infection within the crop canopy; this is the secondary infection process. Both the primary and secondary infection processes are facilitated by rainfall, with disease being more problematic in years with regular growing season rainfall.

In WA we noticed three things about yellow spot. Firstly, we observed that in the southern coastal cropping areas around Albany and Esperance yellow spot was generally not a yield limiting disease. We attributed this observation to it being 'too cold' for disease development in this area. Secondly, we knew that yellow spot was more severe in the central and northern cropping areas. Thirdly, we

found that in time of spraying trials that the time of disease onset was not consistent and we got variable results from tillering or stem extension sprays.

To gain a better understanding of yellow spot we began detailed epidemiology work to determine how and when spores were released from infected stubble and how this might influence time of disease onset in wheat crops grown over infected stubble.

What we did

We began quantifying the effect of environment on the development of yellow spot fruiting bodies on wheat stubble at Northam in WA in 2008. From 2011-2016 we used a range of locations in the southern coastal cropping area (Albany and Esperance), southern inland cropping area (Katanning), central cropping area (Northam) and northern cropping area (Eradu) of WA. Recently (2014-2016) our locations have been extended to include stubble weathered in SA (Waite and Hart) and Victoria (Horsham).

Stubble infected with yellow spot during the growing season was collected immediately after harvest each year from a single location and in December sub-samples of this stubble was placed on the soil surface at the various locations described above. The stubble was allowed to weather under natural environmental conditions at these locations over the following summer, autumn and winter each year.

Stubble was inspected at fortnightly intervals from the beginning of autumn for fruiting bodies. The maturation stage of the sexual spores (ascospores) within these fruiting bodies was rated using a microscope. From this data the time of onset of maturation and the incidence of fruiting bodies that contained mature spores with the potential to cause primary yellow spot infection was determined.

What we found

Ascospores produced on the previous season's wheat stubble are the source of primary inoculum that initiates yellow spot outbreaks in WA.

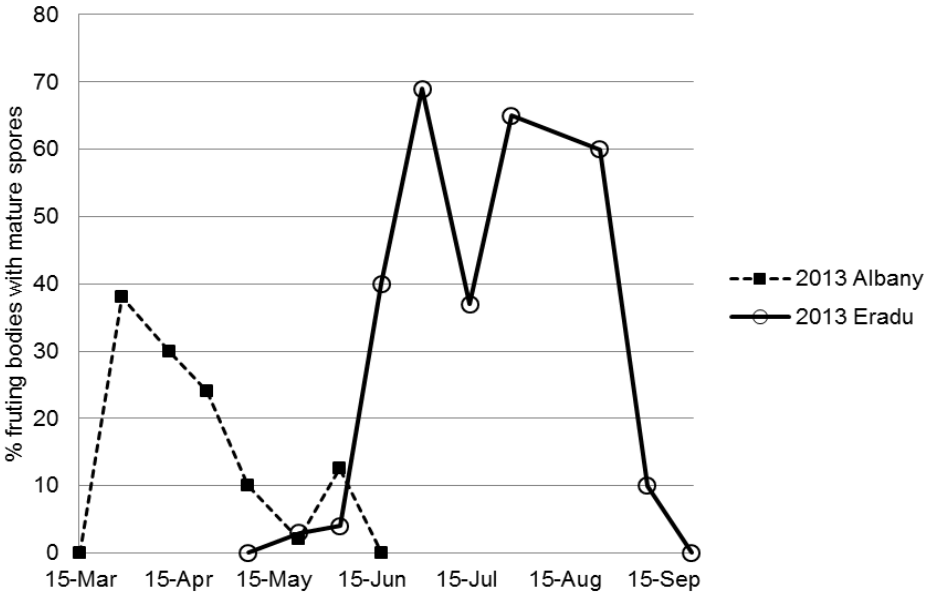

Figure 1. Maturity progress of yellow spot fruiting bodies on wheat stubble at two locations in the WA Grainbelt, Albany (south) and Eradu (north). In the southern coastal cropping area of Albany maturation occurred earlier than in the northern cropping area at Eradu.

In all years we observed that in the cooler, wetter autumn of southern coastal cropping areas yellow spot ascospores mature earlier on the previous season's stubble compared with the drier, warmer autumn of central and northern cropping areas of the WA Grainbelt (Figure 1).

The ascospore maturity information as shown in Figure 1 above has given us knowledge of when the primary infection windows are occurring. The relationship between the timing of the primary infection window and growth stage of the wheat crop helps explain the timing of observed onset and subsequent severity of yellow spot in various seasons and locations. We can use this to help interpret the results of yellow spot fungicide management trials that were conducted in similar locations. As an example, we can use the 2013 ascospore maturation data from Eradu in the northern cropping area (Figure 1) to interpret the results of a replicated fungicide timing trial conducted in the same cropping region at Eneabba (125 km away) in the same year. This comparison shows that in 2013 the primary infection window for yellow spot at Eradu began in mid-June and covered most of the growing season (Figure 1) and would have allowed for multiple infection opportunities, starting from soon after the crop had emerged. Disease severity data from Eneabba (Table 1) showed that by July 2013 yellow spot was already apparent and that by September high levels of disease had developed in the unsprayed crop.

Table 1. Yellow spot disease progress (% leaf area affected) in the northern cropping area of WA (Eneabba) in 2013.

Fungicide treatment	**Yellow spot disease severity (leaf area diseased)**		
	Z31 (17 July)	**Z59 (7 August)**	**Z71 (3 Sept)**
Nil fungicide	2.2 a	12.7 a	58 a
In-furrow + Z59 spray	0.8 b	9.2 b	41 b
Z31 spray + Z59 spray	2.2 a	8.3 b	39 b
Z59 spray	2.2 a	12.7 a	43 b
LSD (5%)	0.9	3.3	13.2

Values followed by the same letter are not significantly different

Where an in-furrow treatment was applied at sowing on 23 May, this significantly reduced the level of yellow spot compared with the nil fungicide treatment (Table 1). By comparing the disease progress data with the maturation progress (Figure 1) we can see that the in-furrow treatment was present at a perfect time in 2013, the fungicide was active as ascospores were being released from the seedling stage onwards and was able to significantly reduce the number of successful primary infection events. A similar effect can be seen with the tillering (Z31) fungicide spray which significantly reduced the level of yellow spot that developed in the crop compared with the nil fungicide treatment (Table 1). In years where ascospore release is prior to crop emergence or is delayed significantly until later growth stages then early fungicide treatments are less likely to be effective.

The timing of fruiting body maturity and the onset of yellow spot ascospore release does vary significantly from year to year within a location (Table 2). In years when the stubble has been exposed to several summer rainfall events the fruiting bodies mature earlier in the autumn compared with years that have had limited rainfall events between harvest and the autumn break. There is a complex relationship between moisture and temperature associated with fruiting body maturation. Summer rainfall effectively 'primes' fruiting bodies but until temperatures reach suitable levels ascospore development within the fruiting bodies is delayed.

Table 2. Timing of onset of yellow spot fruiting body maturity at 8 locations in Australia assessed as number of years in which maturity onset was recorded in each time period. Maturity onset is the first occurrence of one or more fruiting bodies containing mature ascospores capable of initiating primary yellow spot infection.

Site	Time Period											
	Late Mar	Early Apr	Mid Apr	Late Apr	Early May	Mid May	Late May	Early Jun	Mid Jun	Late Jun	Early Jul	Mid Jul
Albany	1	1	1	0	0	1	0	1				
Esperance	2	0	0	0	0	1	0	0	1			
Katanning			1	0	2	0	0	1				
Northam				1	0	0	1	1	1	3	0	1
Eradu							1	0	1	2	1	
Waite							1	0	0	0	1	
Hart								1	0	0	0	1
Horsham							1					

How can you work out if you are having an early or late fruiting body maturity season?

A mathematical model of yellow spot ascospore maturation has been developed and tested for accuracy of prediction using the quantitative data obtained from these epidemiology trials. The ascospore maturity model uses actual weather data obtained from weather stations and epidemiological parameters from the literature to predict when the fruiting bodies of the yellow spot fungus will contain ascospores that are sufficiently mature to be released and initiate yellow spot infection. We have compared the observed ascospore maturation dates (actual stubble samples) with the predicted ascospore maturation dates (model prediction) to test the accuracy of this model for all of the locations and years shown in Table 2.

Within the 'National pathogen management modelling and delivery of decision support' project, a yellow spot fungicide decision support tool is being developed that will provide the economic potential for a wheat crop based on location, variety and cost of fungicide application. This yellow spot decision support tool will be linked to the yellow spot ascospore model described here.

Conclusions

Ascospores produced on the previous season's wheat stubble are the source of primary inoculum that initiates yellow spot outbreaks in WA. Moisture determines when the fruiting bodies form and temperature determines the rate at which the ascospores mature within the fruiting bodies. The wetter, cooler autumn conditions in the southern coastal cropping area of WA (Albany and Esperance) favour earlier spore maturation compared with the central and northern cropping areas. When ascospore release coincides with the presence of a susceptible crop and favourable weather, then disease development is most likely.

It was originally thought that yellow spot was not a consistently yield limiting disease of wheat in the southern costal cropping area because it was "too cold". These epidemiology trials have shown that in these areas a high proportion of the spores are released from the fruiting bodies before wheat crops are sown or have emerged and hence the primary infection opportunities are limited; this combined with cooler temperatures which do not favour secondary spread, can limit the impact of yellow spot.

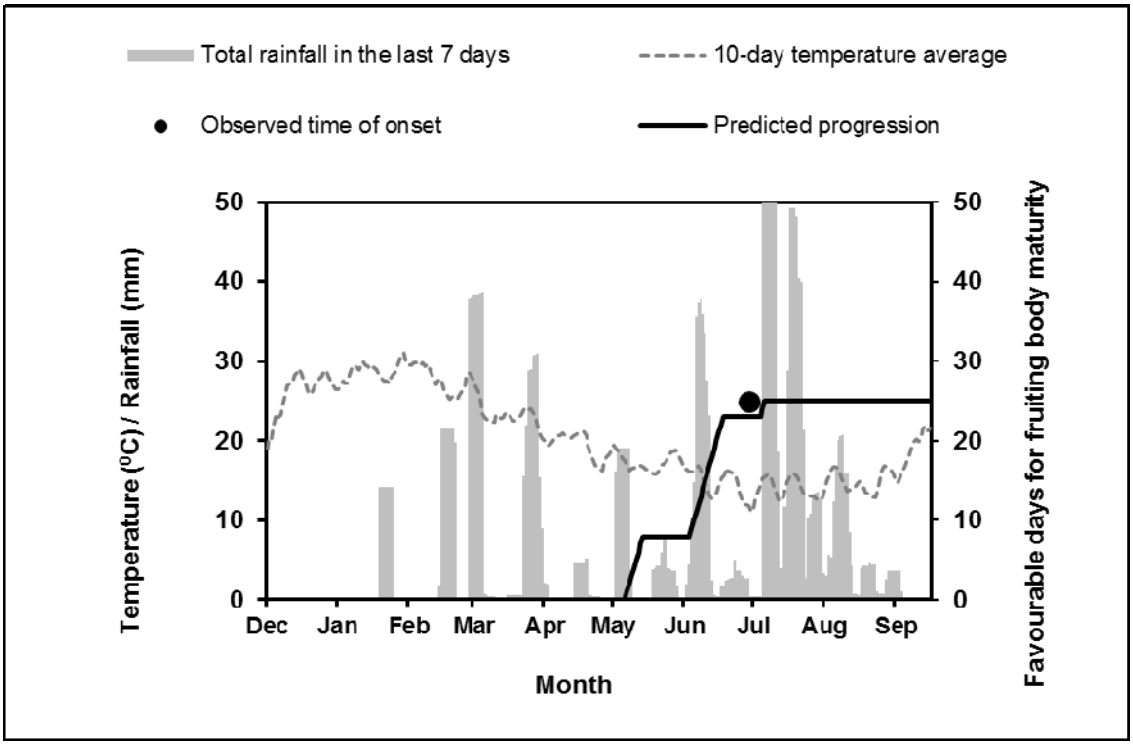

Figure 2. An example of the yellow spot spore maturity model output for Eradu in 2015. The observed time of onset and the predicted time of onset are within seven days of each other. Note the predicted progression 'flat lines' after the onset of maturation in the spore maturity model as this is the point at which this model will interface with the secondary spread model.

The temperature and moisture conditions in the central and northern cropping areas of WA usually favour yellow spot ascospore development after the wheat crop has been sown. In these areas spore release from stubble coincides with the growth of the crop and multiple primary infection opportunities occur. This, coupled with warmer conditions which drive secondary spread provides an explanation as to why yellow spot is often more prevalent in young crops in the northern agricultural regions compared with the southern agricultural regions.

Some years early season fungicide treatments (in-furrow or tillering/Z31 sprays) reduce the development of yellow spot while in other years, these early fungicide applications show little to no efficacy in reducing the development of this disease. Knowing the primary infection window has helped understand timing of disease development in continuous wheat crops and clarified some of the factors surrounding why fungicide trials can give variable results between seasons. In years when yellow spot maturation occurs early in the season, early fungicide applications may reduce the number of successful primary infections and potentially reduce the level of disease which develops during the season. In years when yellow spot maturation occurs later in the season these early fungicide applications are 'ineffective' as they are providing protection before the window of infection has opened.

The ascospore maturity model will help growers and agronomists predict the timing of yellow spot spore maturity for different locations. This information should assist in helping make decisions about which seasons might be suitable to use early fungicide treatments versus seasons in which only later applications should be considered.

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Low levels of Fusarium head blight in 2016 – where did it come from and what does it mean?

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Key words

Crown rot, Fusarium head blight, seedling blight, seed infection, melanism

GRDC codes

DAN00176

Take home messages

- Low levels of Fusarium head blight (FHB) observed in central and northern NSW in 2016 were predominantly caused by *Fusarium pseudograminearum* (*Fp*).
- This was the crown rot fungus (*Fp*) reminding growers that it does not disappear in a wet season.
- FHB infection caused by *Fp* has reduced risk for mycotoxin accumulation in infected grain but could have detrimental impacts on crop establishment if retained for planting in 2017.
- Planting *Fusarium* infected grain can also introduce seed-borne crown rot infection into clean paddocks, undoing rotational benefits associated with growing non-host crops.
- Growers are urged to test both their crown rot inoculum levels in paddocks prior to sowing and ensure their 2017 planting seed has no or low levels of *Fusarium* infection if they observed FHB in 2016, especially if considering durum production.

Background

Above average rainfall was experienced in many parts of northern NSW in the 2016 winter cropping season. While this was great for increasing crop yield, unfortunately these conditions also favoured the development of a range of diseases. Of particular concern were low levels of head infections in durum and bread wheat crops and other concerns around black point and weather damaged grain. Fortunately these issues had a relatively low incidence in crops and were quite restricted in their distribution across the cropping region. However, during the actual flowering and heading stage of crop development misdiagnosis and associated unnecessary panic was not uncommon.

A survey of symptomatic heads and grain samples was conducted in 2016 to determine the various causes and to address concerns around Fusarium head blight (FHB) infections. FHB relates to the symptoms of head infection resulting in premature ripening of infected spikelets, generally caused by two fungi *F. graminearum* or *F. pseudograminearum*, following wet weather during flowering and/or grain-fill. White grain disorder, caused by *Eutiarosporella* spp. (formerly *Botryosphaeria*), produces similar visual symptoms that are not easily distinguished from FHB. These diseases are not uncommon in the northern grains region with the last widespread occurrence in northern NSW and southern Qld in 2010. NSW DPI conducted a similar study in 2010 with implications for mycotoxin production based on identification of causal species, issues with sowing infected grain and potential role of seed treatments presented at previous GRDC Updates. Some of this information will be covered in this paper as it is still very relevant to the situation that occurred in 2016.

Research in 2016

NSW DPI with the assistance of agronomists and growers conducted a survey of wheat crops with visible head infections or with discoloured white grains at harvest to determine the causal fungi. Head and grain symptoms were consistent with Fusarium head blight or white grain disorder so

laboratory techniques were concentrated on recovery of these causal pathogens. Grain samples from seed sources targeted for sowing in 2017 were also assessed to determine the incidence of *Fusarium* and/or *Eutiarosporella* infection. Representative isolates collected from symptomatic heads or grain were identified to the species level using molecular techniques. Determining the exact causal pathogen has potential consequences for the risk of mycotoxin contamination and end use of affected grain.

What did we find and what does it mean?

Shot and sprung wheat

There were only limited reports of shot and sprung grain from the 2016 harvest in northern NSW. Damaged grain is usually downgraded to feed quality with no associated mycotoxin risks unless the grain goes mouldy which can occur if moisture content is above 12.5%. Feed value of shot and sprung grain can be reduced with bulk density being a good guide. Generally wheat with a bulk density <70 kg/hL, barley <60 kg/hL and triticale <67 kg/hL has around 60% the metabolised energy of good grain (Nourishing News, 2010).

Black point

Black point, which appears as a dark discolouration at the germ end of grain, is favoured by high humidity during the late stages of grain development. Hence, there were some instances in 2016 crops. Debate continues as to the actual cause of black point but definitive Australian research demonstrated that it is a physiological process related to the production of enzymes and not due to fungal infection. Either way, grain affected by black point is usually downgraded once above receival standards but is not associated with the production of mycotoxins as long as grain moisture content is maintained <12.5% to prevent the growth of moulds post-harvest. Black point is not desirable in durum wheat as it can result in undesired black specks in the pasta product but its impact on the quality of bread wheat is as debatable as its cause. Rees *et al.* (1984) in a study of the quality of black point affected grain stated “as the changes in quality detected were very slight, the condition had little effect on the value of the grain for bread making”.

Melanism

Initially FHB symptoms in wheat appear as small brown lesions on the glumes of infected spikelets within heads. Melanism (false- or pseudo-black chaff), is related to the overexpression of a brown pigment called melanoid under conditions of high humidity. The pigment concentrates in the glumes of wheat varieties (e.g. Suntop(Φ), Spitfire(Φ), Sunmate(Φ), Trojan(Φ)) which carry the stem rust resistance gene Sr2 and was widespread in 2016. Unfortunately this physiological condition was sometimes misdiagnosed as early FHB infections. Melanism occurs on all glumes within a head and only discolours one side of the rachis (stem in head) so that when viewing from one side only every second segment is brown. Melanism can also cause the stem directly below the head to go brown and can even discolour stems in some varieties, with browning always extending downwards from a node. Initial FHB infections usually occur as point infections on one or two glumes within a head and when the infection progresses to the rachis it produces browning on both sides at that point. *Fusarium* infection can cause browning of the stem but crown rot symptoms generally extend up the stem from the tiller bases and when node infections do occur the browning always extends upwards not downwards from a node as with melanism.

Head infections

Head or grain samples were collected from a total of 80 paddocks from central and northern NSW in 2016 and causal pathogens identified to species. In 66% of cases FHB was caused by *F. pseudograminearum* (*Fp*) only, 4% by *Fusarium graminearum* (*Fg*) only, 19% were a mixed

infection of *Fp* + *Fg* and 1% (one paddock) had a mixed infection from *Fp* and *F. cerealis* (*Fcer*)(Figure 1). A total of 4% paddocks had white grain disorder with recovery of *Eutiarosporella* (*Eut*) only with a further 4% having a mixed infection of *Fp* + *Eut* and 2% (2 paddocks) having mixed infection by *Fp* + *Fg* + *Eut* (Figure 1). Given the increased susceptibility of durum wheat to *Fusarium* infection, both FHB and crown rot, there was a slight dominance of samples coming from durum crops but plenty of infected bread wheat samples were also received.

Fusarium pseudograminearum (*Fp*) is the main species usually causing crown rot. Hence it appears that the low levels of FHB in 66% of paddocks surveyed in 2016 have come from *Fp* producing spore masses (macroconidia) on the lowest nodes of tillers infected with crown rot. Rain-splash then disperses these spores up the canopy to infect heads at flowering and cause low levels of FHB symptoms in a wet year.

There are two other main species of *Fusarium* which can cause FHB, being *F. graminearum* (*Fg*) and *F. culmorum* (*Fc*). *Fg* has more commonly been associated with FHB in the northern region and has a life stage (perithecia) which is produced on maize, sorghum, grass weeds and winter cereals. The perithecia are full of smaller spores called ascospores which are air-borne and hence more easily dispersed into wheat heads during flowering. Fortunately, *Fp* does not readily produce perithecia in the paddock and does not host on maize and sorghum. A total of 23% of paddocks had FHB infection associated with *Fg* which was most commonly in a mixed infection with *Fp.* Although *Fc* was not identified in any of the samples another species *F. cerealis* was identified in a durum sample from Terry Hie Hie in a mixed infection with *Fp* (Figure 1).

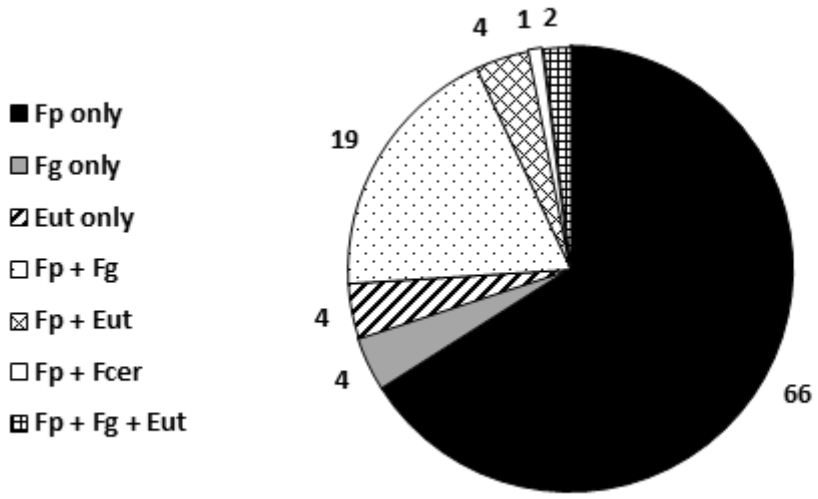

Figure 1. Fungal pathogens associated with head and grain infections in 2016
Fp = Fusarium pseudograminearum, Fg = F. graminearum, Eut = Eutiarosporella, Fcer = F. cerealis

Why is identifying the exact causal pathogen important?

In wetter seasons with frequent rainfall during flowering, which favour FHB infection, if it is *Fp* causing the infection then the incidence is usually considerably lower than if *Fg* is the causal pathogen. This is due to that lack of an air-borne spore stage (ascospore) with *Fp*, with prolonged wet weather required for *Fp* to first produce spore masses (macroconidia) around lower nodes on infected stems. The macroconidia, although still microscopic, are considerably heavier than ascospores hence they require splash dispersal to infect heads during flowering. This limits the dispersal of *Fp.* In contrast the ascospore stage in the life cycle of *Fg* is not as reliant on moisture for initial maturation of perithecia which contain the ascopsores. Rainfall during flowering is simply then required for the ascospores to be released, which then more readily are dispersed into heads during

flowering by wind. This was consistent with the very low incidence of infected heads in paddocks in 2016 with most having well below 1% of heads visually infected.

Identification to species also has implications for potential mycotoxin issues within infected grain. The main mycotoxins produced by *Fusarium* are deoxynivalenol (DON) and nivalenol (NIV), with NIV being around 10 times more toxic than DON. DON is commonly called vomitoxin in the USA, with regulated limits of 1 ppm (1 mg/kg) in grain for human consumption, 5 ppm for pig feed and 10 ppm for beef/sheep/poultry feed. With *Fg,* DON levels are closely linked to the incidence of visually infected white and pink grains at harvest as mycotoxins are concentrated in these damaged seeds (Sinha and Savard, 1997). However, grain infected with *Fp* has been shown to accumulate much lower mycotoxin levels than that infected with *Fg* under laboratory conditions (Blaney and Dodman, 2002). This is supported by analysis of field samples from a previous occurrence of FHB in Australia in 1984 with Burgess *et al.* (1987) finding that grain with 38% *Fp* infection only accumulated 0.6 ppm of DON. There are also two different forms (chemotypes) of DON, with 3ADON being half as toxic as the 15ADON form. Similar research NSW DPI conducted following an FHB outbreak in northern NSW and southern Qld in 2010 determined that 92% of 137 *Fp* isolates examined were the 3ADON chemotype, 1.5% were 15ADON, 6.5% were 15 + 3ADON and none were NIV producers. In contrast 93% of the 88 *Fg* isolates examined were 15ADON, 3.5% were 3ADON and 3.5% were the NIV chemotype. Hence, determining which species of *Fusarium* is causing FHB is important as *Fg* generally produces larger quantities of more toxic forms of mycotoxins (NIV and 15ADON). Conversely, *Fp*, the main cause of FHB in 2010 and again in 2016 in this region, produces considerably lower quantities of a less toxic form of DON (3ADON) only.

Eutiarosporella spp. also cause a head infection with symptoms appearing as premature bleaching of spikelets and production of white grains. These symptoms are hard to distinguish from FHB. However, it has been shown that there are no mycotoxins associated with this pathogen and that grain infected with *Eutiarosporella* caused no issues when fed to weaner pigs for four weeks (Kopinski and Blaney, 2010). Hence, distinguishing *Eutiarosporella* infection from FHB has important consequences for the potential end use of affected grain.

Are there issues of retaining infected seed for sowing in 2017?

The issue with grain infection by *Fusarium* is that if it is sown the next year it can cause seedling death which reduces emergence. Crown rot infection can also be introduced to the base of surviving plants with infected grain also being an inoculum source for the infection of seedlings arising from uninfected grain. Grain infection with *Fusarium* only occurs as a result of FHB, which is favoured by wet conditions during flowering. Crown rot alone cannot directly result in grain infection, as the fungus does not grow up the entire stem and into heads within a season.

Additional trial work at Tamworth in 2011 investigated the effect of grain infection with *Fusarium* on emergence, and causing crown rot infection in surviving plants (seed-borne crown rot infection). Four seed lots naturally infected with varying levels of *Fusarium* (19 to 73%) during an outbreak of FHB in 2010 were used in the study.

Grain infected with *Fusarium* had lower emergence (only 15 to 55%) as it caused severe infection of the seedlings and many died, which is commonly called seedling blight. However, the trial also showed that plants which survived past the seedling-blight stage had also been infected with high levels of crown rot (average 35%). Seed-borne crown rot affects yield in the current crop and introduces infected stubble back into the paddock. Sowing *Fusarium* infected seed, therefore, undoes any break-crop benefits that may have been obtained from growing non-host crops (such as chickpea, canola, faba bean, sorghum) in the previous season.

Some seed treatments were shown to improve emergence of *Fusarium* infected grain by 10 to 30%, but had limited effect on reducing levels of seed-borne crown rot in surviving plants. Ideally growers should plant wheat seed that is free of *Fusarium* infection by targeting crops which were not

infected with FHB in 2016 as their seed sources for 2017 plantings. Grain infected with FHB is usually white and, if prolonged wet conditions occurred during grain-fill, infected grains will take on a pink appearance. However, it should be noted that if any white or pink grains are evident, then the levels of *Fusarium* infection can be significantly higher than what may be indicated by visual inspection. This is because FHB infections that occur later during grain-fill may not cause any visual discolouration of the seed.

Implications

The low levels of FHB which occurred in bread wheat and durum crops across central and northern NSW in 2016 was predominantly related to infection by *Fp.* These infections arose from spore masses produced around lower nodes of tillers infected with crown rot which were then rain-splashed into heads during flowering. Mild conditions during Spring prevents the expression of crown rot as whiteheads. Consequently, crown rot infections often go unnoticed in wetter years. The low levels of FHB evident in 2016 could be viewed as the crown rot fungus (*Fp*) reminding growers that it does not go away in a wet season. Fortunately, the generally low incidence of FHB infection only resulted in a few instances where issues with the quality of harvested grain occurred in 2016. Hence, the overall economic impact of FHB was relatively minor in 2016. However, if Spring conditions in 2016 had been more stressed with limited rainfall and warmer temperatures during grain filling, then significant and widespread losses to crown rot are likely to have occurred. Growers need to not be complacent about potential crown rot inoculum levels leading into 2017. Avoid sowing winter cereals into paddocks which had FHB in 2016 as they are likely to represent a high risk for crown rot infection in 2017. All durum wheat varieties have increased susceptibility to *Fusarium* infection, both FHB and crown rot, hence durum production should be targeted to low risk paddocks preferably based on stubble or PreDicta B testing.

Growers who noticed or suspect that they had FHB or white grain disorder in 2016 should get their planting seed tested to determine infection levels prior to sowing in 2017. This information can be used to guide appropriate seed treatment options and to source cleaner seed with lower infection levels if required. This should be the preferred option compared to sowing seed of unknown *Fusarium* levels, which if moderate will result in poor establishment and introduce significant crown rot levels into paddocks. This will compromise rotational benefits that may have been achieved by growing a non-host crop in 2016.

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Evaluation of fungicide management strategies to control spot-form of net blotch in barley

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Key words

Systiva®, scald, yield, green leaf retention, SFNB, fungicide management

GRDC codes

DAN00176, GOA00002

Take home messages

- Spot-form of net blotch (SFNB) caused at least 18-21% yield loss in the susceptible barley varieties La Trobe and Spartacus CL in trials conducted at Tamworth and Dubbo in 2016. Note Dubbo also had another leaf disease, scald develop late in the season.
- Foliar fungicides provided effective suppression of SFNB + scald with associated yield benefits when applied at both GS31 and GS49.
- The seed treatment Systiva® provided useful levels of SFNB suppression post GS49 under moderate disease pressure at Tamworth but activity appeared to have waned by this growth stage under higher disease pressure at Dubbo.
- Systiva® basically had similar efficacy to the GS31 application of foliar fungicides when both strategies were backed up by a second foliar application at GS49.
- Product Z, an experimental foliar fungicide, appears to have improved SFNB activity compared to Amistar Xtra® which was then slightly better than Tilt®250 in these experiments.
- Barley growers are still urged to use integrated disease management (IDM) strategies to limit losses from SFNB and scald, with fungicides being only one component. IDM of barley leaf diseases will reduce disease pressure and the reliance on fungicides as the sole management tool but importantly also delays the development of resistance to these valuable chemical options.

Background

Spot-form of net blotch (SFNB), caused by the fungus *Pyrenophora teres*, is a common foliar disease of barley in the northern grains region. The pathogen survives between seasons in barley stubble so risk is elevated with both stubble retention and barley-on-barley rotations. Barley grass can also be an inoculum source. SFNB lesions reduce green leaf area (photosynthetic area) which can reduce both yield and grain quality. Losses to SFNB are most likely in wet seasons which favour infection and when greater than 10% infection occurs on the top four barley leaves during grain filling (Jayasena *et al.* 2007).

Avoiding barley-on-barley rotations, growing varieties with improved levels of resistance and application of foliar fungicides are currently the most effective management options for limiting losses to SFNB. Unfortunately, many of the common barley varieties grown in the northern grains region and recent releases have limited levels of resistance to SFNB so there is a tendency towards reliance on foliar fungicides in wetter seasons. A new fungicide seed treatment, Systiva® (fluxapyroxad) was recently registered by BASF for the control of SFNB but there is limited data from the northern grains region. Growers in the region were also interested in the relative efficacy of some of the registered foliar fungicide options against SFNB and a new Bayer CropScience fungicide (Product Z) which is in the advanced stages of evaluation and registration.

Research in 2016

Two replicated experiments were conducted in 2016 with one site at Tamworth and the second near Dubbo. The Dubbo site was established into standing stubble of a SFNB susceptible (cv. Hindmarsh) barley crop grown in 2015 whilst the Tamworth site was inoculated at the 2-3 leaf growth stage with a low level (100 kg/ha) of locally sourced infected cv. Urambie stubble.

Two SFNB susceptible barley varieties La Trobe and Spartacus CL were used in both experiments at a target plant population of 100 plants/m^2 with seed treatments evaluated being:

1. Dividend M® (difenoconazole 92 g/L + metalaxyl-M 23 g/L) at 260 mL/100 kg seed
2. Systiva® (fluxapyroxad 333 g/L) at 150 mL/100 kg seed

Dividend M® is NOT registered for the control of SFNB but was included to represent a commonly used seed treatment for bunt and smut control and as the base seed treatment for evaluating the efficacy of foliar fungicides. All seed was further treated with Emerge® (imidacloprid at 240 mL/100 kg seed) to prevent early aphid feeding and the potential transmission of Barley Yellow Dwarf Virus (BYDV) compromising the experiments. The experiment at Dubbo was sown on the 20th May whilst the Tamworth trial was sown on the 16th June 2016.

Foliar fungicide treatments and application timings were:

1. Nil control where no foliar fungicide was applied
2. Tilt®250 (propiconazole at 500 mL/ha) applied at GS31
3. Amistar Xtra® (azoxystrobin + cyproconazole) applied at GS31
4. Product Z (experimental) applied at GS31
5. Tilt®250 applied at GS31 + GS49
6. Amistar Xtra® applied at GS31 + GS49
7. Product Z applied at GS31 + GS49

In addition the efficacy of a fungicide management strategy using Systiva® for early SFNB control in combination with a later (GS49) application of each of these three foliar fungicides was investigated. The full treatment combinations examined are outlined in Table 1 with four replicates of each treatment in the Dubbo experiment and six at Tamworth. The GS31 application of foliar fungicides occurred on the 9th August at Dubbo and 30th August at Tamworth; whilst the GS49 treatments were applied at Dubbo on the 13th September and at Tamworth on the 27th September.

Visual assessments of the severity of SFNB (and scald at Dubbo) were recorded after GS49 for each plot on a 0-10 scale related to the estimated leaf area infected with lesions where 0 = no lesion and 10 = 100% of leaf area infected. At each assessment the top three leaves and the bottom of the canopy (lower leaves) were scored separately. The retention of green leaf area (GLR) within the whole canopy was also visually assessed in each plot late in the season on a 0-10 scale, where 0 = no remaining green leaves and 10 = 100% of canopy still green. Both experiments were harvested using plot headers and grain samples retained for quality assessments which were unfortunately not available at the time of writing this paper.

Results

Seasonal conditions were very conducive to the development of SFNB at both sites in 2016 with frequent rainfall events and mild temperatures through Spring. Although La Trobe is rated susceptible (S) to SFNB whilst Spartacus is rated susceptible-very susceptible (S-VS) this difference in resistance level did not result in any signifcant interaction between variety and fungicide treatments at either site. Hence, throughout this paper results are presented as the average of these two SFNB and scald suscpetible barley varieties.

Tamworth 2016

The Tamworth experiment was inoculated at the seedling stage with stubble collected from SFNB suspectible barley crop (cv. Urambie) grown in 2015. This avoided any issues with establishment but created a more moderate build-up of disease pressure from SFNB throughout the season compared to the Dubbo experiment. Scald was not evident in this experiment throughout the season with SFNB being the only leaf disease observed.

The use of the seed treatment Systiva® alone provided a visual reduction in the severity of SFNB in both post GS49 assessments compared with the base seed treatment (Dividend M®) with a corresponding slight increase in GLR late in the season (Table 1). The levels of disease control and GLR provided by each of the three foliar fungicides when applied at GS31 only, were largely comparable with that achieved with the Systiva® alone treatment.

The severity of SFNB in the later assessment was further reduced with each foliar fungicide product when applied at both GS31 and then GS49, compared to application at GS31 only. Two applications of each product provided better disease control and GLR than the use of Systiva® alone with efficacy generally Product Z>Amistar Xtra®>Tilt®250 (Table 1).

Levels of disease control and GLR achieved in the second assessment (3rd November) with Systiva® were all improved when followed by a GS49 application of a foliar fungicide and were comparable to that achieved with two applications (GS31 + GS49) of each respective foliar fungicide (Table 1). Again efficacy of foliar fungicide products was generally Product Z>Amistar Xtra®>Tilt®250 when applied at GS49 following seed treatment with Systiva®.

Table 1. Effect of fungicide treatments on the severity of SFNB in the whole canopy in October, in the bottom and top of barley canopies in November and green leaf retention scores – Tamworth 2016

Seed treatment	In-crop fungicide	Score 7.10.16[A]		Bottom 3.11.16[B]		Top 3.11.16[B]		GLR 3.11.16[B]	
Dividend M	Nil	5.6	f	9.1	g	7.3	h	2.0	h
	Tilt GS31	3.8	e	7.8	f	5.6	g	3.0	g
	Amistar Xtra GS31	2.3	b	7.2	ef	4.7	ef	3.7	def
	Product Z GS31	2.5	bc	6.9	e	4.3	e	3.8	de
	Tilt GS31 + GS49	3.4	de	5.1	d	3.0	d	4.4	c
	Amistar Xtra GS31 + GS49	2.3	b	3.1	bc	1.6	bc	5.3	b
	Product Z GS31 + GS49	1.4	a	1.8	a	0.8	a	7.0	a
Systiva	Nil	3.0	cd	7.5	ef	4.9	ef	3.2	efg
	Tilt GS49	3.0	cd	5.3	d	2.8	d	4.2	cd
	Amistar Xtra GS49	3.0	cd	3.4	c	1.8	c	5.8	b
	Product Z GS49	2.6	bc	2.5	ab	1.0	ab	6.9	a

Values followed by the same letter are not significantly different (*P*=0.05).

[A]Assessment was 113 days after application (DAA) for Systiva®, 38 DAA for GS31 foliar fungicides and 10 DAA for GS49 foliar fungicides.

[B]Assessment was 140 DAA for Systiva®, 65 DAA for GS31 foliar fungicides and 37 DAA for GS49 foliar fungicides.

Yield outcomes in the Tamworth experiment predominantly corresponded to levels of SFNB control achieved and the retention of green leaf area late in the season. Although there was no "true" nil

disease control in the experiment, the yield difference between the highest treatment and the nil control represented 18% yield loss (Figure 1).

The use of the seed treatment Systiva® alone provided a 7% (0.27 t/ha) yield benefit over the base seed treatment (Dividend M®) in the absence of foliar fungicide application which was equivalent to the levels of benefit provided by the GS31 only applications of each foliar fungicide product (Figure 1).

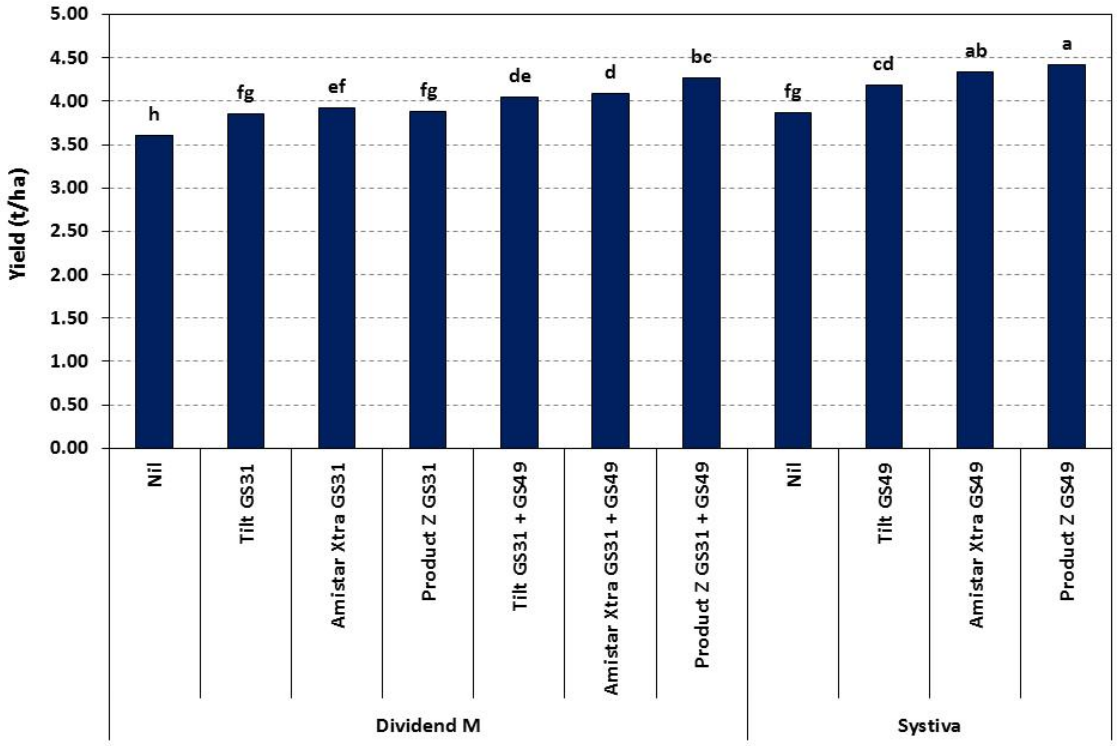

Figure 1. Effect of fungicide treatments on barley yield (average of La Trobe(1) and Spartacus CL(1)) in the presence of SFNB infection – Tamworth 2016

Bars with the same letter are not significantly different (*P*=0.05).

The yield benefit increased with two applications of each foliar fungicide product compared to the GS31 only equivalent treatment by between 12% (0.44 t/ha) with Tilt®250 up to 18% (0.66 t/ha) with Product Z at GS31 + GS49 (Figure 1). Yield benefit with two in-crop foliar applications was Product Z>Amistar Xtra® = Tilt®250.

The yield benefit associated with the seed treatment Systiva® was improved when followed by the application of a foliar fungicide at GS49. Yield in the Systiva® + Tilt®250 at GS49 treatment was equivalent to the application of Tilt®250 at both GS31 + GS49. However, with the other two foliar fungicide products the yield benefit was increased when used in combination with Systiva® compared to two applications of that product. Systiva® followed by Amistar Xtra® at GS49 provided a 0.74 t/ha (20%) yield benefit while Systiva® followed by Product Z at GS49 provided a 0.81 t/ha (23%) yield increase over the nil control treatment (Figure 1).

Dubbo 2016

The Dubbo experiment was established into a relatively heavy stubble load of a SFNB suspectible barley crop (cv. Hindmarsh) grown in 2015. Unfortunately, this resulted in patch establishment within plots but created severe disease pressure throughout the season from SFNB with another stubble-borne leaf disease, scald (*Rhynchosporium secalis*) becoming evident later in the season.

The use of the seed treatment Systiva® alone did not provide any visual reduction in the severity of SFNB in either the top or bottom of canopies compared with the base seed treatment (Dividend M) in either post GS49 assessment (Table 2). However, Systiva® alone did provide a slight reduction in the severity of scald.

Application of the three different foliar fungicides at GS31 only provided modest reductions in the severity of SFNB in the first assessment but were less pronounced in the later assessment with no clear diffence between products. However, all three foliar fungicides when applied at GS31 roughly halved the severity of scald late in the season (Table 2). Note: Amistar Xtra is not registered for control of scald in barley.

The severity of SFNB was further reduced with each foliar fungicide product when applied at both GS31 and then GS49, with the level of control achieved with Tilt®250 and Amistar Xtra® generally being equivalent, but Product Z having improved efficacy (Table 2). Two applications of each foliar fungicide product nearly eliminated the presence of scald late in the season. Levels of disease control achieved with Systiva® were all improved when followed by a GS49 application of a foliar fungicide. However, efficacy was generally lower than that achieved with two applications (GS31 + GS49) of each respective foliar fungicides (Table 2).

Table 2. Impact of fungicide treatments on the severity of SFNB in the bottom and top of barley canopies at two dates, scald* severity in top of canopy and green leaf retention scores – Dubbo 2016

Seed treatment	In-crop fungicide	Bottom 28.9.16[A]	Top 28.9.16[A]	Bottom 20.10.16[B]	Top 20.10.16[B]	Scald 20.10.16[B]	GLR 27.10.16[C]
Dividend M	Nil	8.0 h	6.1 e	8.3 h	7.8 f	6.6 d	1.8 gh
	Tilt GS31	5.8 efg	4.9 cd	7.4 fgh	6.3 de	3.6 b	2.5 fg
	Amistar Xtra GS31	4.6 cd	4.0 c	7.1 efg	6.0 d	3.3 b	2.8 f
	Product Z GS31	3.8 bc	4.3 cd	8.3 h	7.0 ef	3.1 b	2.3 fgh
	Tilt GS31 + GS49	4.8 cde	3.0 b	5.5 cd	3.9 bc	0.5 a	4.5 de
	Amistar Xtra GS31 + GS49	3.5 b	2.5 b	4.6 bc	3.4 b	0.0 a	5.8 bc
	Product Z GS31 + GS49	2.4 a	1.5 a	3.1 a	1.6 a	0.0 a	6.9 a
Systiva	Nil	8.0 h	6.3 e	7.6 gh	7.3 f	5.4 c	1.5 h
	Tilt GS49	6.3 g	4.6 cd	6.4 def	4.5 c	0.3 a	4.3 e
	Amistar Xtra GS49	6.6 g	4.5 cd	6.1 de	4.4 c	0.5 a	5.1 cd
	Product Z GS49	5.1 def	3.0 b	4.1 ab	2.1 a	0.5 a	6.4 ab

Values followed by the same letter are not significantly different (*P*=0.05).

[A]Assessment was 100 days after application (DAA) for Systiva®, 50 DAA for GS31 foliar fungicides and 15 DAA for GS49 foliar fungicides.

[B]Assessment was 122 DAA for Systiva®, 72 DAA for GS31 foliar fungicides and 37 DAA for GS49 foliar fungicides.

[C]Assessment was 129 DAA for Systiva®, 79 DAA for GS31 foliar fungicides and 43 DAA for GS49 foliar fungicides.

* Amistar Xtra is not registered for control of scald in barley

Treatment trends in the retention of green leaf area (GLR) largely reflected the level of leaf disease control (SFNB + scald) achieved. In regards to foliar fungicide products, GLR was higher in treatments with two fungicide inputs with GLR generally being Product Z>Amistar Xtra®> Tilt® (Table 2).

Unfortunately, patchy establishment resulting from sowing into a heavy stubble load from the previous season increased the variability of yield outcomes in this experiment. Hence, differences apparent in the levels of leaf disease control and GLR did not necessarily translate into significant yield outcomes (Figure 2). Significance was only achieved at the 83% (*P*=0.17) confidence level so

yield findings from this site should be interpreted with caution. Although there was no "true" nil disease control in the experiment, the yield difference between the highest treatment (Systiva® + Product Z at GS49) and the nil control (Dividend M® with no foliar fungicide application) represented a 0.95 t/ha difference or 21% yield loss (Figure 2). Fungicide strategies that used two inputs (Systiva® + GS49 foliar fungicide or GS31 + GS49 foliar applications) provided the most consistent yield benefits over the nil control of between 0.47 t/ha (13%) with Systiva® + Tilt®250 at GS49, up to 0.95 t/ha (26%) with Systiva® + Product Z at GS40 (Figure 2).

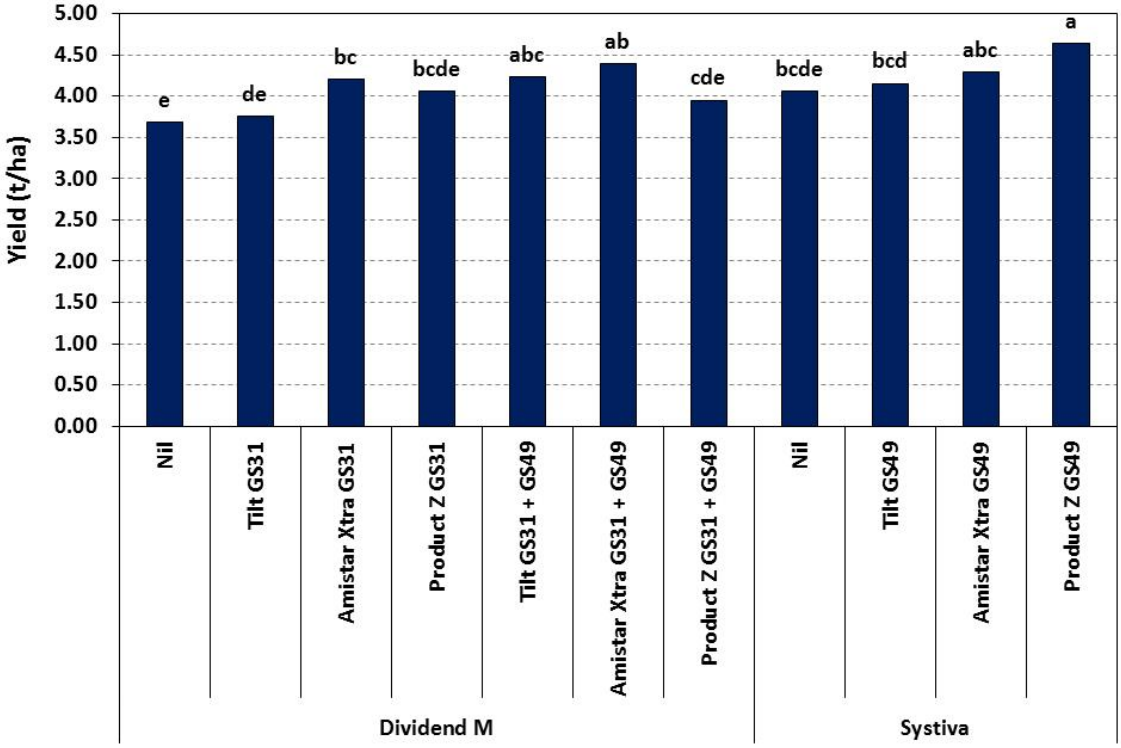

Figure 2. Effect of fungicide treatments on barley yield (average of La Trobe(1) and Spartacus CL(1)) in the presence of SFNB and scald infection – Dubbo 2016

Bars with the same letter are not significantly different (*P*=0.17).

Implications

SFNB caused significant yield losses in the susceptible barley varieties La Trobe(1) and Spartacus CL(1) at both sites under the wet seasonal conditions experienced in northern NSW in 2016. Combined application of foliar fungicides at both stem elongation (GS31) and awn emergence (GS49) provided good suppression of SFNB in both experiments and also provided effective control of scald in the Dubbo trial. While all three foliar fungicide products examined reduced the severity of SFNB, efficacy was generally Product Z>Amistar Xtra®>Tilt®250. Product Z, an experimental fungicide from Bayer CropScience appears a quite promising option for improved management of SFNB. Each of the foliar fungicides examined also provided good control of scald late in the season although Amistar Xtra not registered for the control of scald.

The seed treatment Systiva® provided useful suppression of SFNB in post GS49 assessments under moderate disease pressure at Tamworth but activity appeared to have waned by this later growth stage under higher pressure at Dubbo. However, disease suppression was improved at both sites when combined with a foliar fungicide application at GS49. In management strategies which involved two fungicide inputs, Systiva® was competitive with GS31 foliar fungicide applications at both sites when each option was backed up by a GS49 foliar fungicide application. Both of these

strategies provided significant increases in grain yield under both moderate (Tamworth) and high (Dubbo) pressure from SFNB.

Although the fungicide strategies examined in these experiments provided significant yield benefits it should be stressed that no treatment provided complete disease control. Hence, some level of yield loss is still likely to have occurred. These experiments were also either inoculated (Tamworth) or sown into a high stubble load (Dubbo) of a SFNB susceptible barley variety with only SFNB and scald susceptible varieties examined in this study. This represents a high risk scenario for the development of these stubble-borne leaf diseases and places considerable pressure on disease management strategies which rely solely on the use of fungicides and is likely to accelerate selection for fungicide resistant strains of these pathogens. Stewardship with the seed treatment Systiva® involves only using this product every second year to delay the development of resistance and under high disease pressure monitor infection levels then apply a late foliar fungicide (ideally non SDHI) beyond GS31 if needed.

The results presented here should not be interpreted as the ideal production system for barley in the northern grains region, even though significant disease suppression and yield benefits were evident. Rather growers are urged to consider an integrated approach to barley disease management incorporating rotation with non-host crops (avoid barley-on-barley), stubble management and growing varieties with improved levels of resistance to reduce disease pressure. Fungicide strategies are then placed under less pressure in terms of both control and development of resistance. Additionally the economics of planned fungicide strategies needs to be considered given the higher costing of some products and marginal returns, especially with current barley prices.

References

Jayasena KW, van Burgel A, Tanaka K, Mejewski J, Loughman R (2007). Yield reduction in barley in relation to spot-type net blotch. *Australasian Plant Pathology* 36: 429-433.

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Seed treatments – Systiva® performance in northern trials

Greg Platz, Lisle Snyman, Ryan Fowler, Dept of Agriculture and Fisheries

Key words

Systiva, SDHI, net blotch, spot form net blotch, seed treatment

GRDC code

DAQ00187 – National Barley Foliar Pathogens Variety Improvement Program (NBFPVIP)

Take home messages

- Systiva® is a new seed treatment fungicide registered by BASF for the control of several foliar diseases of barley, smuts in barley, bunt in wheat and suppression of Rhizoctonia root rot in both.
- Systiva gives very good control of most foliar diseases for about 8 weeks of crop life.
- One or more supplementary sprays may be required for whole of season foliar disease control.
- Systiva is registered for loose smut control in barley but is ineffective against covered smut.
- Early season disease control slows disease epidemic development and increases yields where conditions after flag leaf emergence do not favour disease development.
- In 2017, seed treatment with Systiva is likely to cost approximately $15/ha or $30/100kg of seed.
- Systiva is a Group 7 fungicide and introduces new chemistry to seed treatment. Responsible use of the product is encouraged to prevent breakdown of efficacy.

Background

Systiva® gained APVMA approval for registration as a seed treatment fungicide in 2015. The active ingredient is fluxapyroxad - a Group 7 fungicide - and the first succinate dehydrogenase inhibitor (SDHI) registered for use on cereals in Australia. The product has had extensive trialling pre-release across Australia but there has been relatively limited product development in the heavier soils of the northern region.

Reports on the efficacy of Systiva from southern Australia have been very favourable with outstanding disease control in many situations. It is reported that across 80 trials Systiva gave a positive yield benefit of 350kg/ha (Pers. comm. R. Holzknect BASF).

Foliar diseases have a propensity for rapid epidemic development from low levels of inoculum, given suitable conditions for infection and spread, with the frequency and duration of leaf wetness a major driver of epidemic development. Differences in environmental conditions between southern Australia and the northern region during late crop development may influence the benefits of early season control.

Here we report the results of replicated trials conducted in 2014 and 2016 and a farm demonstration conducted in 2016 to determine the benefits of Systiva in the control of spot form net blotch. Further work needs to be done to determine the benefits of seed treatment with Systiva in controlling other diseases.

Trial results

Hermitage 2014

A replicated trial comparing the use of fluxapyroxad as either a seed treatment and/or spray was conducted at Hermitage in 2014. Systiva (fluxapyroxad) with and without a late foliar spray was compared to a popular commercial seed treatment and combinations of current commercial foliar fungicides for the control of spot form net blotch in Shepherd barley. Foliar applications were made at growth Stages 31 (early) and 41 (late) while nil disease treatments received 4 applications of Prosaro® at 300mL/ha. (Note that the Prosaro label limits use in commercial crops to a maximum of two applications per season.) There was a moderate to heavy epidemic of spot form net blotch present for the duration of the trial.

A summary of the yield results is shown in Figure 1.

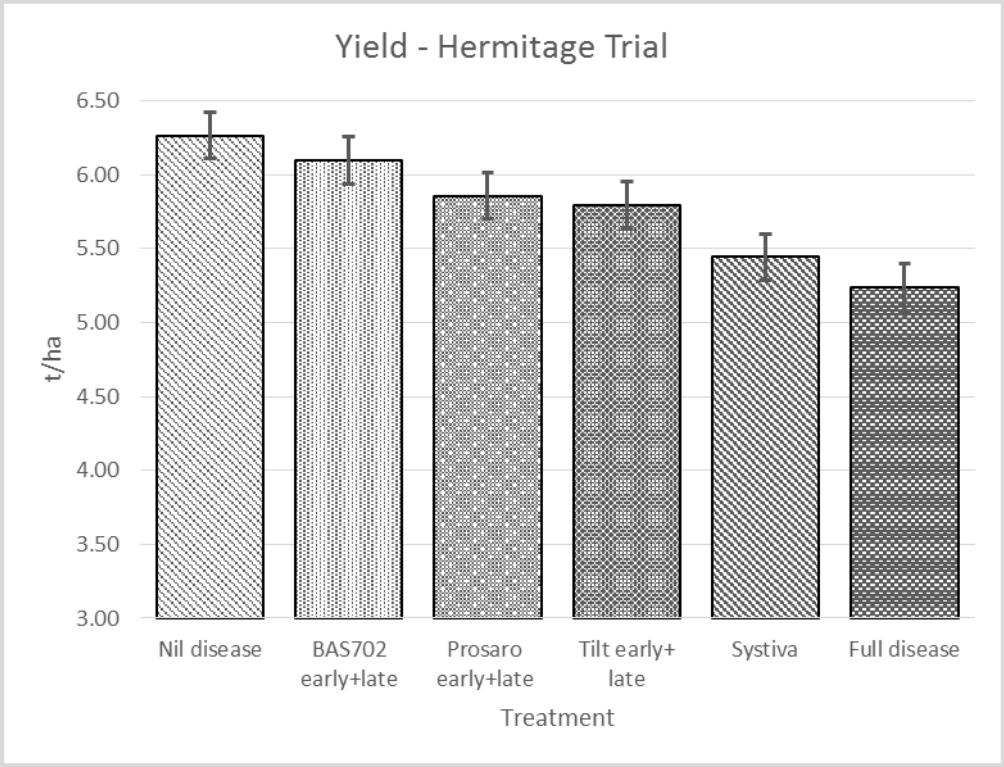

Figure 1. Yields of Shepherd barley under different fungicide treatments to control spot form of net blotch.

Four applications of Prosaro did not give absolute disease control in the Nil disease treatments; yet still resulted in a significant yield increase of 19.6% over the full disease. The yield of the Systiva treatment alone resulted in a 4% increase in yield which was not significantly different from the full disease control. However, Systiva did give positive significant differences in test weight, retention, screenings and grain size over the full disease control treatment. In a malting variety the improvement in test weight and retention would have taken the classification from feed to malting quality.

Four assessments of leaf area diseased (LAD) were conducted between 5th September (8 weeks after sowing) and 24th October. At the first assessment it was obvious that Systiva (heavy dotted line) was having an effect on disease development (Fig. 2). The three Systiva treatments had an average of 13% LAD compared to the average of the foliar spray treatments (23.5%), which at that time had not had a spray applied. However, over subsequent assessments it was obvious that the foliar sprays

were controlling the disease better than the Systiva treatment, which had %LAD levels increasing to nearer those of the full disease control (dark dotted line).

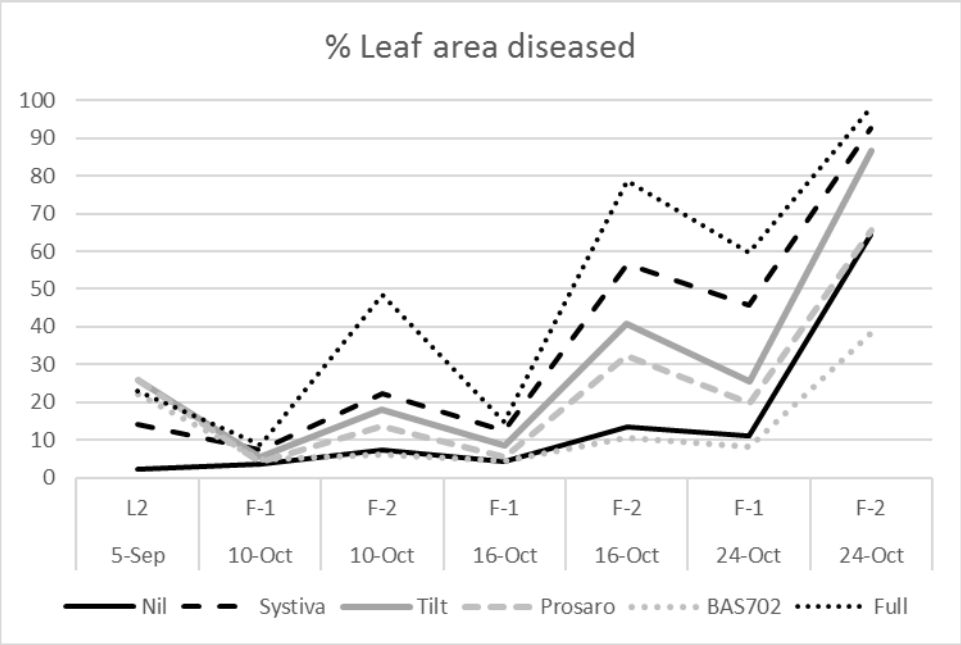

Figure 2. Percent leaf area diseased of six selected treatments.

It appeared that the effect of Systiva was waning as the crop was filling grain.

The leaves that contribute most to grain fill in barley in environments with sufficient soil moisture are the flag sheath, flag-1 and flag-2. Under conditions where epidemics of SFNB continue developing after heading, it appeared that Systiva applied without a follow-up treatment, was inferior to the application of foliar fungicides in controlling the disease and protecting grain yield.

GOA/ NSW DPI trial 2016

Systiva was evaluated for spot form net blotch control in a replicated trial conducted by Steven Simpfendorfer (NSW DPI) and Maurie Street (GOA). Data was not available in time for inclusion in this paper but is presented in the paper by Simpfendorfer and Street in these proceedings.

Farmer demonstration 2016

A broadacre comparison of Systiva and Phoenix® (triadimenol) seed treatments for spot form net blotch control in Gairdner barley was conducted at Garah (Note: Phoenix not registered for spot form net blotch). The demonstration also incorporated stubble burnt vs unburnt. DAFQ personnel attended the field day in mid-July to compare disease control in the four treatments when the crop was at mid-tillering. Assessments were done on the last fully expanded leaf showing disease and the preceding leaf.

The lowest levels of disease were in the burnt treatment with little difference between seed treatments. The difference between the Systiva and Phoenix treatments in the stubble unburnt area was almost threefold, with Systiva having 11 and 14% LAD and Phoenix 32 and 40 % LAD (Figure 3).

It was visually obvious that the area treated with Systiva had much less disease than the Phoenix treatment.

The crop was harvested in October, but unfortunately yields were unavailable at the time of writing.

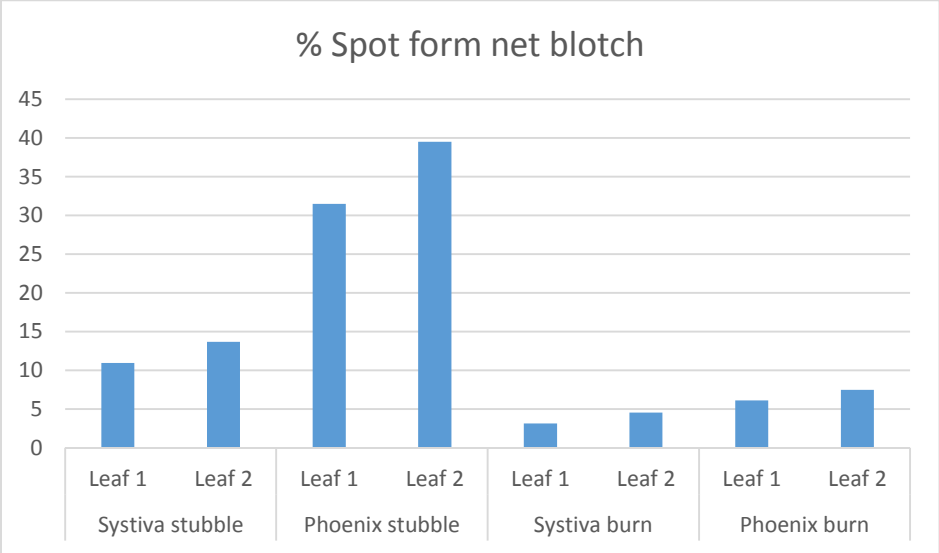

Figure 3. Percent leaf area diseased in Gairdner barley in response to seed and stubble treatments.

Conclusion

It appears that Systiva is quite effective in controlling spot form net blotch (and presumably other foliar diseases) for about 8 weeks after sowing based on results in these trials. Under conditions where disease epidemics continue to develop beyond this window, it is unlikely that Systiva will be persistent enough to provide adequate protection to the main yield contributing leaves of the flag sheath, flag-1 and flag-2. From observations and results from the limited trialling of the product in this region, it would be wise to budget at least one foliar spray in any disease management strategy using Systiva.

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The authors thank Richard Holzknect (BASF), Dr Steve Simpfendorfer (NSW DPI), Maurie Street (GOA) and Rob Long (B&W Rural) for their input into this paper.

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.

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Leaf rust in Compass®

Lislé Snyman, Clayton Forknall and Greg Platz, Department Agriculture and Fisheries Queensland

Key words

Barley, leaf rust, resistance, yield response

GRDC code

DAW00245

Take home messages

- Compass® is very susceptible to leaf rust and crops should be closely monitored for the disease.
- Barley varieties differ in yield response to leaf rust across resistance ratings.
- Resistance ratings of current commercial varieties are available on the NVT website.
- Growing resistant varieties is the most practical and economical way of controlling barley leaf rust.
- Varieties characterised as S to VS are impacted most by disease and also contribute to inoculum increase, leading to pathogen mutations putting available resistance genes at risk.
- The use of resistant varieties forms part of a bigger disease management plan, which also includes green-bridge control, regular crop monitoring and the timely application of fungicides.

Introduction

Leaf rust of barley is widely distributed and occurs regularly in the northern region. It is considered one of the five major barley diseases in Australia and can cause significant yield loss and a reduction in grain quality (Murray & Brennan, 2009). Barley leaf rust was widespread in Queensland in 2016 on Compass and other vulnerable varieties. In most instances, timely fungicide sprays were able to avoid epidemic infection levels.

The disease is caused by the obligate parasite (*Puccinia hordei*), spreading by means of airborne spores that have the ability to travel long distances. The pathogen spreads rapidly when conditions are favourable and large areas are planted to susceptible varieties, creating favourable conditions for epidemics to develop. 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, more virulent pathotypes.

Why the concern about Compass®?

Compass® is a high-yielding, broadly adapted, mid-season maturing variety expected to complete Barley Australia malt accreditation by March 2018. In Queensland, it is rated VS to pathotypes virulent for the *Rph3* gene. This virulence is present in all major production areas.

Compass® currently accounts for 15-20% of barley production in Australia. Due to the high yielding ability over a range of environments, the area sown to Compass® in 2016 was estimated to be approximately 20 000ha in WA, 400 000ha in SA, 120 000ha in VIC, 60 000ha in NSW and 20 000ha in QLD, totalling at 620 000ha of the barley production area (Seednet – pers. comm.). Widespread cultivation of a variety as susceptible as Compass® to barley leaf rust ensures a continuous supply of rust inoculum and contributes to the breakdown of valuable resistance genes.

Some of the major factors contributing to the barley leaf rust epidemic in Queensland in 2010 was the widespread sowings of susceptible varieties, which in turn led to an increase in the inoculum load and conditions favourable for disease development. High inoculum pressure and application of

fungicides after establishment of the disease contributed to mixed results from the application of foliar fungicides.

The area sown to Compass® (VS) is expected to increase across production areas in 2017. Large areas sown to a VS variety across a range of environments almost ensures that leaf rust will be a problem in some areas contributing to high inoculum levels causing epidemics whilst adding selection pressure on the pathogen to mutate and acquire new virulences.

Yield response curve trials

Since 2013 trials have been conducted by DAF QLD in an effort to quantify losses caused by barley leaf rust. A pilot study in 2013, on barley varieties ranging in resistance levels from MR to VS, showed the benefits of fungicide application on susceptible varieties. Results indicated that the more susceptible a variety, the more benefit can be gained by foliar fungicide application.

Following the 2013 results, more detailed trials were performed annually from 2014. The relationship between yield and disease severity was examined in six varieties, with resistance levels ranging between MR and VS. Plots were inoculated to represent infection levels ranging from nil disease (fungicide treated) to high disease levels.

After the 2014 trial, Compass® (included in S category) was clearly a VS type based on yield loss (38.5%) when compared to Grout® with a 25.1% yield loss. Similarly, the biggest yield loss (28.8%) was observed in Compass® in 2015 (Figure 1).

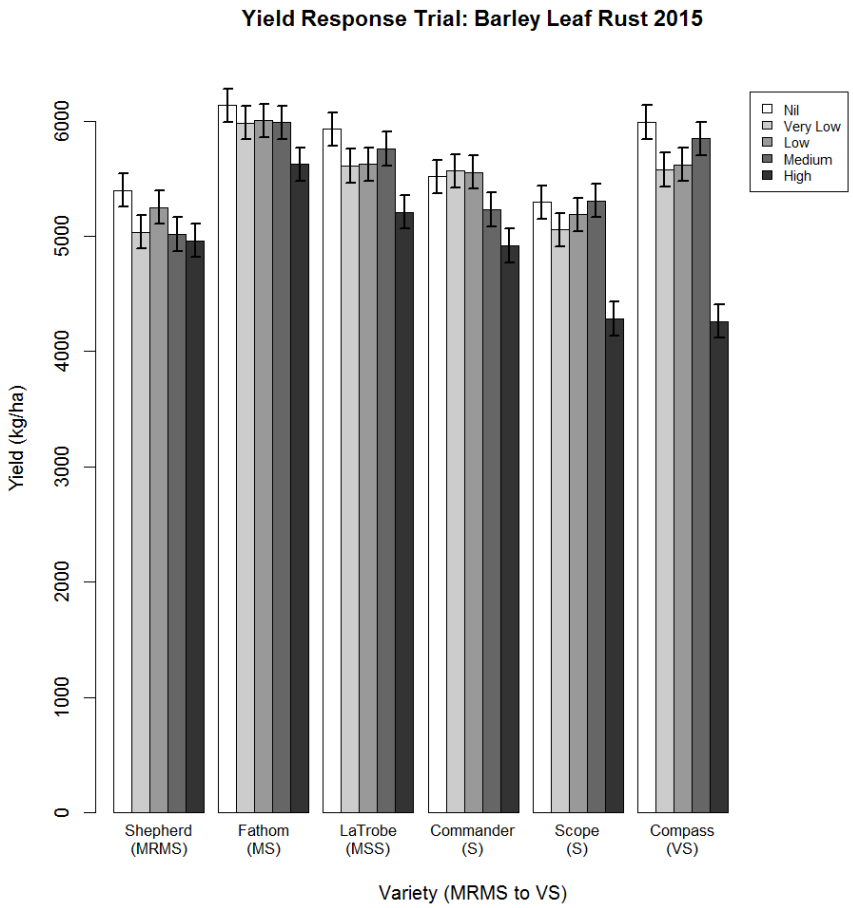

Figure 1. Yield response of barley varieties to different disease levels in 2015. (Shepherd®, Fathom®, La Trobe®, Commander®, Scope® and Compass® are all protected under the Plant Breeders Rights Act 1994.)

In 2016, yield loss of 45.6% was recorded in Compass® (VS) and 57.6% in Bass® (SVS) (Figure. 2). Yield losses in Shepherd® (MRMS) were 8.1% and 10.5% for the two years respectively and Fathom® (MS) 8.3% and 7.7%.

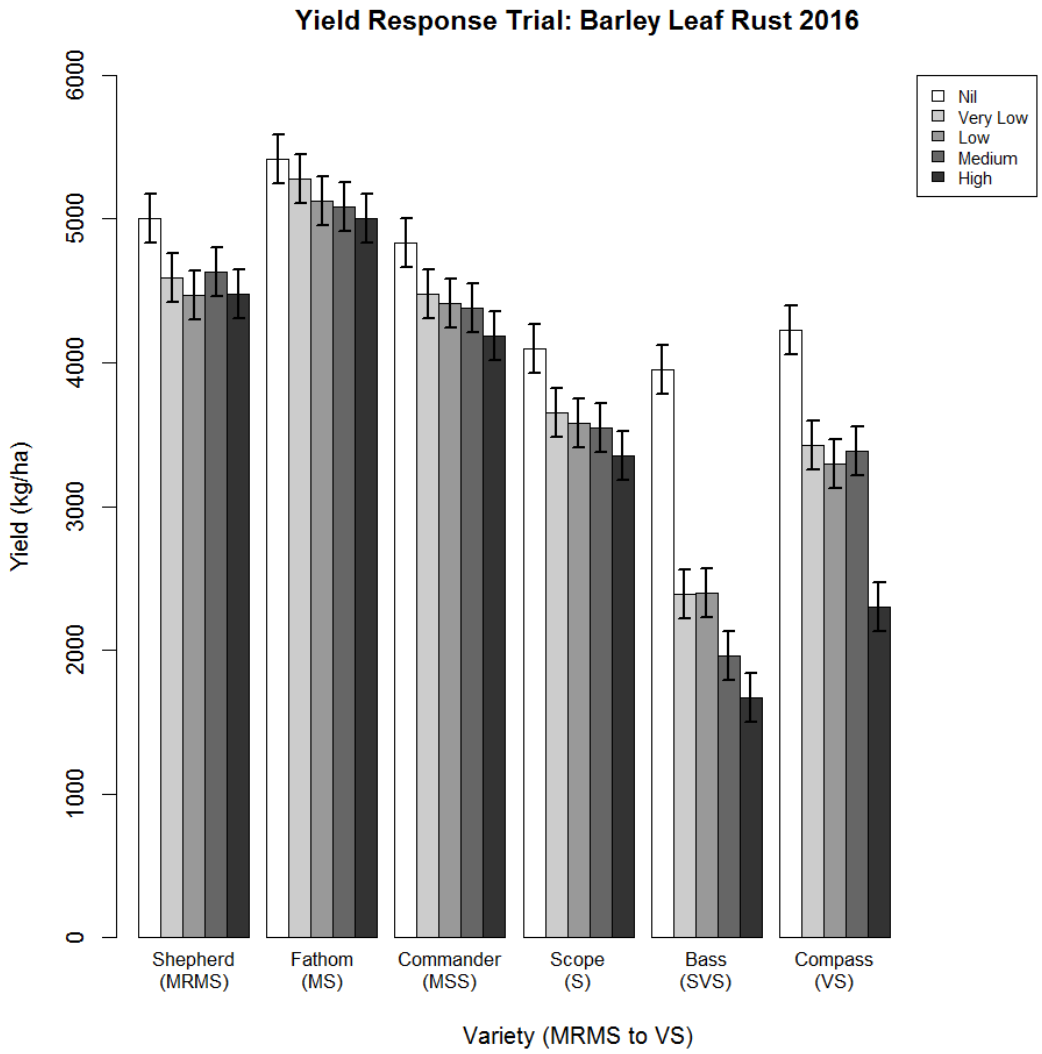

Figure 2. Yield response of barley varieties to different disease levels in 2016. (Shepherd®, Fathom®, La Trobe®, Commander®, Scope®, Bass® and Compass® are all protected under the Plant Breeders Rights Act 1994.)

Results from these trials confirmed earlier reports that barley leaf rust infection can result in quality losses. From the retention results displayed in Figure 3 it is obvious that susceptible varieties suffered huge losses in terms of quality. Retention in all six varieties were significantly better in the nil disease treatment than in all other treatments. In the varieties Commander®, Scope® and Compass®, the high disease treatment had a significantly lower retention percentage than the other diseased treatments (medium, low and very low). For the malting variety Commander®, retention percentages in all treatments were higher than 58%, whereas none of the treatments in Scope® and Bass® would be acceptable as malt quality. For Compass® only the nil treatment would qualify for malt quality when accredited. Similar observations were made with regards to other quality characteristics such as test weight.

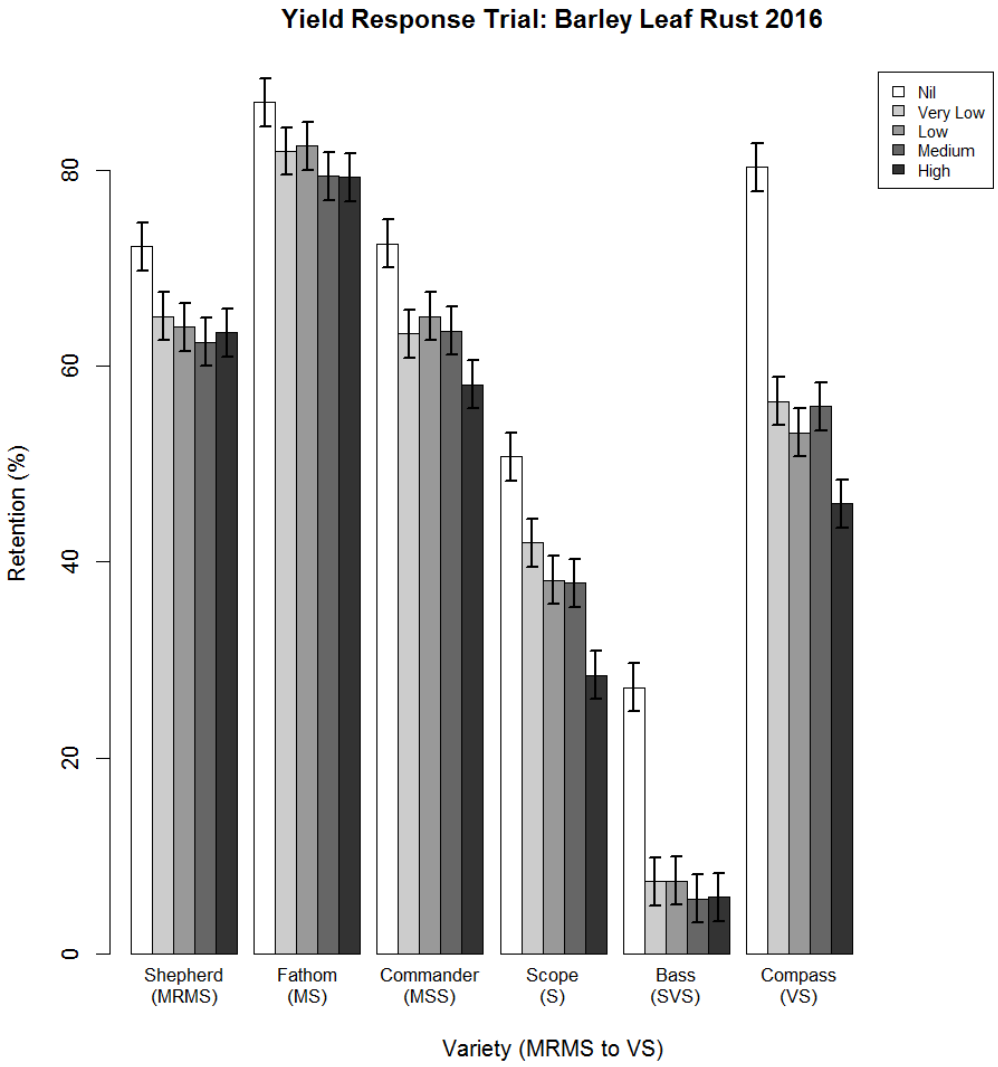

Figure 3. Response in retention percentage of barley varieties to different disease levels in 2016. (Shepherd®, Fathom®, La Trobe®, Commander®, Scope®, Bass® and Compass® are all protected under the Plant Breeders Rights Act 1994.)

Conclusions

Results from the yield response curve trials conducted between 2014 and 2016 indicated that disease has a significantly bigger impact on the yield and quality characteristics of varieties in the S to VS categories, than on more resistant varieties. In all three years, Compass® suffered significant losses ranging between 28.8% and 45.6%. The only variety tested to suffer bigger losses was Bass® in 2016.

Therefore it can be concluded that the more susceptible a variety, the bigger the yield and quality losses due to leaf rust. The area planted to Compass® is expected to increase in 2017 and with the increase in area of susceptible, especially very susceptible varieties grown, the risk of epidemics increase, particularly if conditions are favourable for disease development.

The best strategy for barley leaf rust control is to grow resistant varieties and if not, to remain vigilant with crop management decisions. It is important to ensure that there are no green bridge for the rust pathogen to over summer on. Regular crop monitoring is essential for timely fungicide control and to decide if follow-up applications are needed.

From these results it can be concluded that growing a susceptible variety such as Compass♁ increase the risk of yield and quality loss and requires dedicated effort towards persistent monitoring and decision making.

Reference

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

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

Increased levels of net form of net blotch in Commander[Φ] and Shepherd[Φ]

Ryan Fowler and Greg Platz, Dept of Agriculture and Fisheries

Key words

Barley, net form of net blotch, NFNB, disease resistance, virulence, seed treatment

GRDC code

DAQ00187 – National Barley Foliar Pathogen Variety Improvement Program (NBFPVIP)

Take home messages

- Prolonged and widespread sowing of Commander[Φ] and Shepherd[Φ] barleys has allowed net form net blotch (NFNB) to adapt to these varieties.
- Pathotypes able to infect Commander[Φ] and Shepherd[Φ], that were once rare, have increased in prevalence in recent years.
- NFNB can be spread via the sowing of infected seed that has not been treated.
- Sowing barley on barley or more specifically, sowing a variety back into stubble of that same variety, causes the disease to increase within paddocks over time.
- Environmental conditions play a major role in the development of NFNB, with wet conditions favouring infection and spread of the disease, like the spring of 2016.
- NFNB is best controlled by crop rotation, sowing of varieties with a disease rating of MS or better, treating seed prior to sowing, monitoring crops for NFNB during the season and timely application of a registered foliar fungicide before disease becomes conspicuous in an S to VS variety.

Background

Net form of net blotch is widespread throughout Australia and is found in most areas of the Northern Region. The disease persists in crop residues and infected seed between seasons. Frequent wet periods and mild temperatures favour disease development. Many different pathotypes of NFNB are present in the Northern Region and are able to infect most varieties, producing low to moderate disease symptoms on varieties rated as RMR to MSS. A very susceptible disease response occurs when a pathotype and a variety are fully compatible. NFNB has been an intermittent problem in the Northern Region, with some unusually wet years resulting in heavy epidemics on varieties such as Binalong[Φ] and Skiff in New South Wales and Gilbert and Grimmett in Queensland.

Net Form Net Blotch in the Northern Region

GRDC fund national, annual pathotype surveys of NFNB and this work is conducted under the National Barley Foliar Pathogens Variety Improvement Program from The Hermitage Research Facility. These surveys have identified at least four distinct groups of isolates - across Australia (Fig.1 and Fig. 2). Collectively, these Isolates are able to successfully infect most varieties, though the level of disease development varies depending on the isolate/variety combination (Fig. 1).

Groups are assigned by the varieties on which they show a susceptible infection type.

Group 1 isolates are highly virulent on:

- Binalong[Φ], Cowabbie[Φ], Fairview[Φ], Grimmett, Skiff, Tantangara and Yambla

Group 2 isolates are highly virulent on:

- Gilbert and Grimmett

Group 3 isolates are highly virulent on:

- Commander$^{\Phi}$, Grout$^{\Phi}$, Keel$^{\Phi}$, Mackay$^{\Phi}$, Navigator$^{\Phi}$ and Prior

Group 4 isolates are highly virulent on:

- Beecher, Maritime$^{\Phi}$ and Roe$^{\Phi}$

Shepherd$^{\Phi}$ and Granger$^{\Phi}$ and Fleet$^{\Phi}$ are susceptible to isolates that fall outside these groups; yet isolates that are virulent on Shepherd$^{\Phi}$ and Granger are avirulent on Fleet$^{\Phi}$ and vice versa.

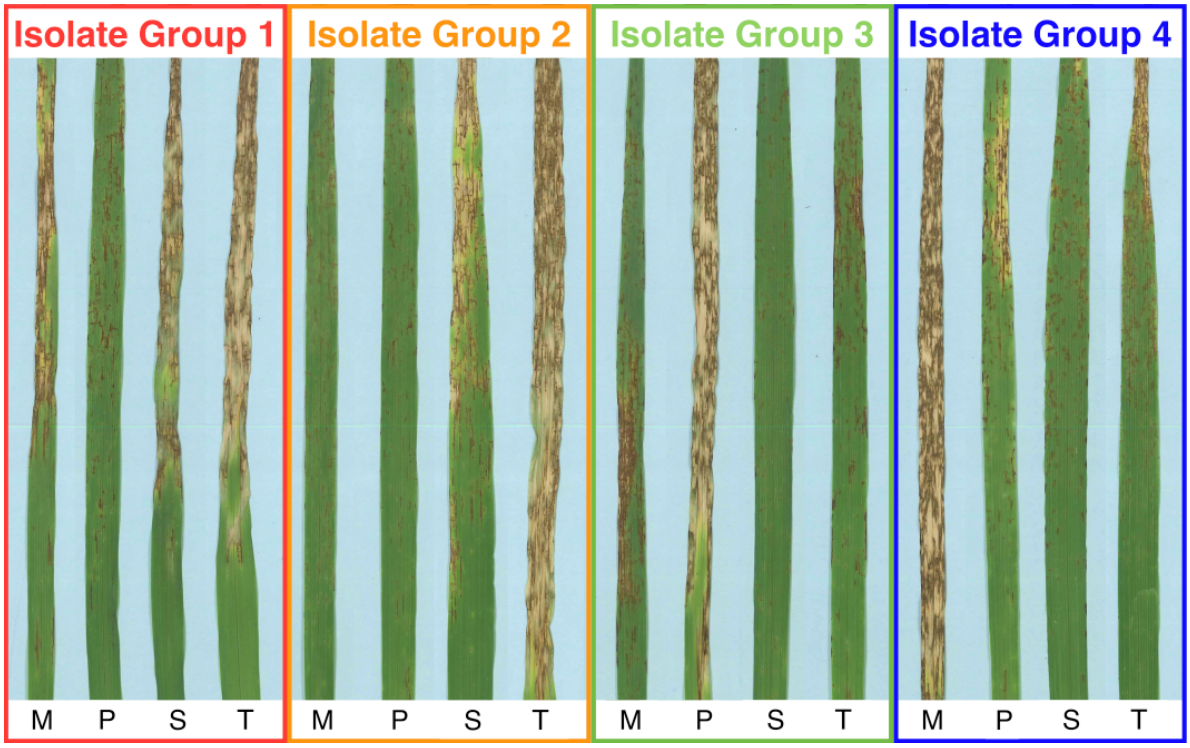

Figure 1. Disease expression of the four main isolate groups on four key varieties. M = Maritime$^{\Phi}$, P = Prior, S = Skiff and T = Tallon. Fowler *et al.* 2017.

Pathotypes from Isolate Groups 1, 2 and 3 are present in the Northern Region (Fig. 1). The most prevalent pathotypes in the Northern Region are from Isolate Group 1 (Fig. 2).

Commander$^{\Phi}$ is quite susceptible at seedling growth stages to most pathotypes, yet does expresses a useful level of adult plant resistance to the predominant pathotypes (Isolate Group 1) found in the Northern Region. However, at adult growth stages Commander$^{\Phi}$ is quite susceptible to pathotypes that attack Prior, Corvette and Mackay$^{\Phi}$ (Isolate Group 3) see Table 1. These isolates are common in Queensland and appear to be increasing in NSW (Fig. 2).

Shepherd$^{\Phi}$ is susceptible to two pathotypes that fall outside these groups.

Commander$^{\Phi}$ and Shepherd$^{\Phi}$ have been the leading malt and feed varieties in the “old” Northern Region over the past five years. Large scale plantings have placed great selection pressure on the pathogen, resulting in increased virulence for their resistance profiles which has led to greater incidence and severity of NFNB in crops of these varieties. Selection pressures that have caused an increase in disease on Commander$^{\Phi}$ and Shepherd include:

- Adaptation of the pathogen for increased virulence
    - Sowing any one variety over a prolonged period places selection pressure on the pathogen to adapt to that variety for its own survival and reproduction. Net blotches

are sexually reproducing organisms and progeny of crosses that carry increased virulence for a variety are likely to increase over time. This means that virulence genes are gradually accumulated allowing the pathogen to better infect and colonise plants of that variety.

- Increased prevalence of existing or rare pathotypes
    - Pathotypes that are highly virulent on Commander$^{\phi}$ are common in Queensland and higher disease levels observed in NSW suggest that this pathotype is increasing farther south. See "Prior" pathotype in Table 1. The continued cultivation of Commander provides a selective host for Prior virulent pathotypes to increase.
    - Two pathotypes that are highly virulent on Shepherd$^{\phi}$ are present in Queensland.
        - Shep 1 was detected in 1995 and has increased in prevalence in recent years (Table 1)
        - Shep 2 was detected in 2015 and is now widespread over the Darling Downs. This pathotype has subtle differences from Shep 1 (Table 1)

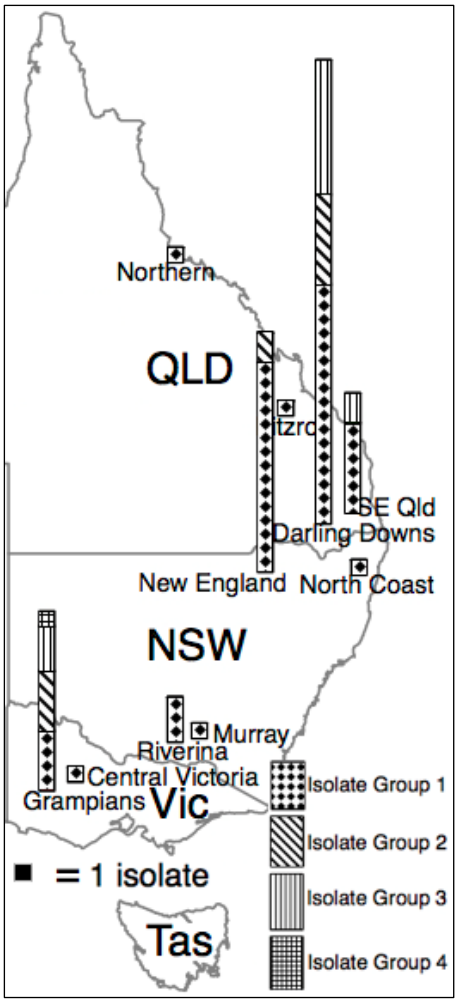

Figure 2. Distribution of four NFNB isolate groups in eastern Australia. Fowler *et al*. 2017.

Table 1. Seedling response of 15 barley genotypes to 10 NFNB isolates collected from Compass[b] and Shepherd[b] in 2016 and three routine screening isolates (NB50, NB73, NB85) used at Hermitage Research Facility. Scores ≥6.5 indicate a susceptible response.

Isolate	NB50	NB73	#16031a	#16051NFa	#16033a	#16083a	#16027a	#16025a	#16043a	#16041a	#16026a	#16024a	NB85
Pathotype	Skiff	Shep 1	Shep 1	Shep 1	Shep 2	Shep 2	Shep 2	Shep 2	Comp-Nav	Comp-Nav	Comp-Nav	Comp-Nav	Prior
Test GS	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling	Seedling
Collected	26/7/94	16/6/95	6/9/16	16/9/16	7/9/16	24/9/16	2/9/16	2/9/16	13/9/16	8/9/16	2/9/16	5/9/16	22/9/95
State	Qld	Qld	Qld	Qld	Qld	Qld	Qld	Qld	Qld	SA	NSW	NSW	Qld
Location	Gatton	Tansey	Junabee	Warrill View	Yangan	Mt Colliery	Pittsworth	Cecil Plains	Hermitage	Freeling	Tamworth AI	Croppa Creek	Gatton
Name Host	unknown	Gilbert	Shepherd	Shepherd	Shepherd	Shepherd	Shepherd	Shepherd	Compass	Compass	Compass	Compass	Cape
BS89-4-3	**10.0**	**10.0**	**10.0**	**10.0**	**8.5**	**10.0**	**10.0**	**10.0**	**10.0**	**8.5**	**9.5**	**9.0**	5.5
Gilbert	**9.5**	**10.0**	**10.0**	**9.5**	**9.0**	**10.0**	**10.0**	**9.5**	**9.0**	**6.5**	**9.0**	4.5	3.5
Westminster[b]	**8.5**	**8.5**	**6.5**	**7.5**	5.0	**8.0**	**8.5**	**7.0**	4.0	2.5	3.0	2.0	2.0
Shepherd[b]	3.5	**10.0**	**9.5**	**10.0**	**9.0**	**10.0**	**10.0**	**9.5**	2.5	1.0	2.5	1.0	3.0
CIho 11458	3.3	**7.5**	**7.5**	**8.5**	3.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Oxford	**8.0**	5.0	5.5	**7.0**	3.5	1.0	1.0	1.0	3.0	1.0	4.0	3.5	2.0
Skiff	**9.2**	3.0	3.5	3.5	2.5	1.0	1.0	1.0	1.5	1.0	1.0	1.5	1.0
Compass[b]	**7.5**	3.5	4.0	2.5	2.0	3.0	3.5	3.0	**9.5**	**9.0**	**9.0**	**9.0**	**8.5**
Navigator[b]	5.6	4.5	6.0	5.5	3.5	5.5	5.5	5.5	**7.5**	**9.5**	**9.0**	**9.5**	**10.0**
Prior	2.4	1.0	1.5	1.0	1.5	2.0	1.5	2.5	1.5	1.5	1.5	2.5	**10.0**
Fleet Aust.[b]	4.9	4.5	5.0	4.5	3.5	4.0	3.5	3.0	1.0	1.5	1.0	1.0	1.0
Rosalind[b]	4.5	1.0	1.0	1.0	1.0	1.0	1.5	1.0	3.0	2.0	2.5	3.0	2.0
Scope CL[b]	3.9	3.0	2.0	2.5	1.5	3.5	2.5	3.0	3.0	2.5	1.5	1.0	1.0
Maritime[b]	3.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.0	2.5	2.5	3.0	1.5
PSR#167	3.0	3.5	4.0	missing	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Net form net blotch control

Appropriate stubble management

Infested stubble is a source of inoculum for the following season. Avoid planting barley into barley stubble particularly if the crop that produced that stubble had conspicuous NFNB. It is best to follow a non-host crop like wheat, canola, chickpea etc. If you must plant barley on barley then removing the stubble by baling, incorporation by cultivation or even burning will reduce inoculum levels.

Resistant varieties

Sowing varieties with a resistance rating of MS or better is the most economical and convenient form of disease control. Resistance ratings are available on the NVT website or alternatively contact your agronomist or regional pathologist for further information.

Seed and in furrow treatment

During favourable conditions at flowering, the seed can become infected with NFNB. Seedlings from diseased seed can become infected with NFNB before they emerge. If planting seed was sourced from a crop that had significant NFNB then it should be treated with a systemic seed dressing containing active ingredients such as carboxin + thiram and difenoconazole to disinfect seed. Fluxapyroxad is reported to give systemic protection up to middle of heading (GS55). In furrow treatment of fertiliser with azxoxystrobin + metalaxyl-M is claimed to supress NFNB infection for up to 90 days.

Fungicides

Control with foliar fungicides should aim to protect the top two leaves and flag leaf sheath. Good results can be achieved with a single spray when a registered product is applied at around GS49 and before the target leaves become infected. Even better control can be achieved with a two spray strategy, one at GS31 and another at GS49. It is generally not economically worthwhile to apply fungicides to varieties with NFNB disease ratings of MS or better.

Crop monitoring

Fungicides are more effective if applied before NFNB becomes established. This demands regular crop monitoring from about mid tillering. In seasons that are particularly favourable for disease development more frequent monitoring may be necessary.

Conclusion

Net form net blotch is likely to continue to increase on Commander® and Shepherd®, necessitating an integrated approach to disease management for these varieties. Both varieties should still be able to be grown successfully with appropriate crop rotation, application of seed dressings, close monitoring of crops and timely fungicide application.

We are currently pathotyping samples collected in 2016 and a more comprehensive picture of the NFNB population in the Northern Region will be available by June.

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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.

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Loose smut in 2016

Greg Platz, Lisle Snyman and Ryan Fowler, Department of Agriculture and Fisheries, Queensland

Key words

Loose smut, seed treatment, fungicides, seed-borne

GRDC code

DAQ00187

Take home message

- Annual seed treatment with an effective fungicide is the best means to control loose smut.
- Loose smut infects heads at flowering and survives inside the seed.
- Some varieties are more susceptible to loose smut than others.
- Fungicides differ in their efficacy against loose smut and 100% control is difficult to achieve.
- Resistance to loose smut is not considered a high priority of barley breeding programs in Australia and control relies on the use of effective seed treatments.
- Effective seed treatment depends on choice of product, thorough application of fungicide and treatment of planting seed annually or not less than biannually.

Background

Loose smut (*Ustilago nuda*) was detected in a number of barley crops in the northern region in 2016.

Low levels of infection were reported in several varieties with crops of the Hindmarsh(Þ) lineage e.g. Hindmarsh(Þ), La Trobe(Þ) and Rosalind(Þ), often infected.

Loose smut is most conspicuous at around flowering when infected heads bearing a mass of dark brown to black sooty spores are visible among the green heads of unaffected plants. This stark contrast in colour can lead to exaggerated estimates of infected heads. Losses in yield equate to the percentage of infected heads and the detection of greater than 0.1g of loose smut particles in a half litre harvest sample will result in rejection of grain deliveries.

Several fungicides are registered for the control of loose smut; but the levels of control vary among products.

Smuts of barley

In Australia, barley is host to two species of smut – loose smut and covered smut (*Ustilago hordei*) - where infection results in florets producing thousands of spores in individual florets instead of grain. In both species the resultant spore masses are encased in a membrane. This membrane is quite fragile in loose smut but much more persistent in covered smut.

In plants infected with loose smut, the membrane ruptures soon after heading, releasing spores which are carried on the wind to infect surrounding florets. Infection occurs under moist conditions at temperatures around 16 – 22°C. Florets are susceptible to infection from flowering to about one week after pollination.

Germinating spores infect the ovary and the fungus then survives as mycelium within the embryo of the infected seed. It can persist for extended periods in this state. Once infected seed is sown, it

germinates and carries the fungus in the growing point of the plant until it manifests as the symptomatic black spore masses at head emergence. Loose smut is well adapted for survival in that infected plants are usually slightly earlier than healthy plants, ensuring an adequate supply of inoculum when the bulk of the crop is flowering.

Loose smut is exclusively internally seed-borne while covered smut is either externally seed-borne or survives in the soil. The life cycle of loose smut in barley is the same as in wheat; however barley loose smut will not infect wheat and vice versa. See Figure 1.

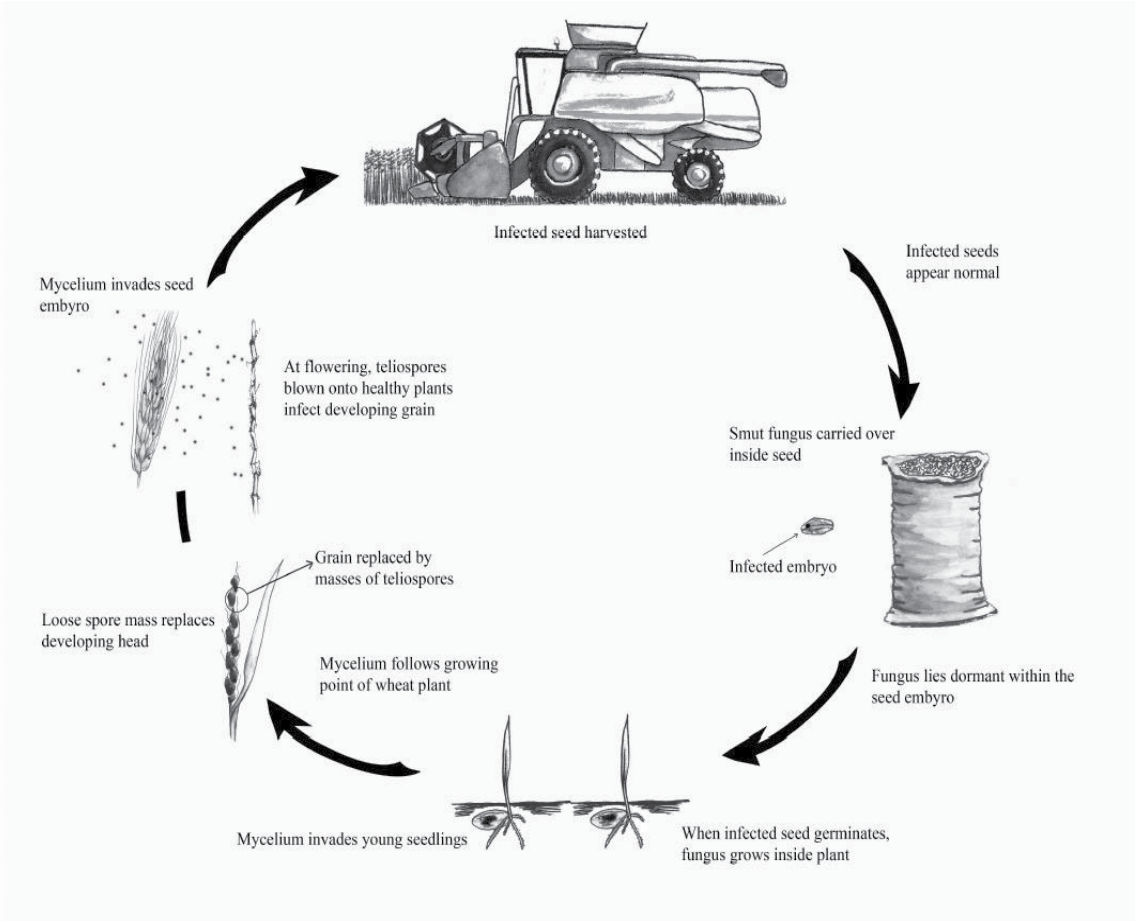

Figure 1. Life cycle of loose smut of barley (and wheat). (Image Courtesy of CropPro).

Control

The level of loose smut in a crop is a function of

- Varietal susceptibility
- The number of grains infected in the previous seed crop
- The efficacy and rate of the seed treatment applied and
- The precision of the seed treatment process

Resistance to loose smut is available; but has never been viewed as a priority objective of Australian barley breeding programs. Seed treatment has provided economical control of the disease for the past 50 years and is likely to continue to do so. As the loose smut fungus is internally seed-borne, systemic fungicides are necessary for control. Products containing carboxin, difenoconazole, flutriafol, fluxapyroxad, ipconazole, penflufen, tebuconazole and triticonazole are registered for the control of loose smut; but their efficacies against the disease vary.

A selection of smuticides was evaluated by the Department of Agriculture Western Australia and Bayer Australia in 2013 and demonstrated superior control by EverGol®Prime (penflufen), Jockey® Stayer® (fluquinconazole) + Raxil®T (tebuconazole) and Vibrance® (difenoconazole+metalaxyl+sedaxane). Their results are summarised in Table 1.

Table 1. Loose smut control from a range of fungicides

Product name	L/tonne seed	Active ingredient	$ at 50kg/Ha	% control (DAFWA)		% control (Bayer)	
				Gibson	Wongan Hills	Regans Ford	Wubin
EverGol®Prime	0.4	penflufen	2.86	100a	100a	100a	97a
Vibrance®	1.8	difenoconazole + matalaxyl + sedaxane	2.67	NA	NA	97a	86a
Jockey® Stayer® + Raxil® T	3 + 1	fluquinconazole + tebuconazole	7.68	99a	99a		
Raxil T	1	tebuconazole	0.93	93a	77b		
Vitaflo® C	2.5	carboxin	3	93b	99a		
Zorro® (discontinued)	4	imidacloprid + triadimenol	4.95	87c	85b		
Rancona® C	1	ipconazole	1.55	85c	78b		
Jockey Stayer	3	fluquinconazole	6.75	76d	61c		
Baytan® T	1	triadimenol	2.18	NA		75b	64b

Source: Hills (2015) Controlling loose smut in 2016.

The precision of seed treatment can also impact on fungicide performance. Application machinery must be well calibrated, fungicide suspensions continuously agitated and seed mixed thoroughly to ensure even distribution of chemical on the seed.

Conclusion

The reappearance of loose smut in barley in 2016 is a reminder to maintain effective fungicide treatment of planting seed. If seed is sourced from a crop known to have been infected with loose smut, it would be wise to treat seed at the higher recommended rate. The increased incidence of loose smut may be due to good infection conditions during flowering in the parent seed crop; it may be due to application of lower rates of fungicide or it may simply be that new varieties are more susceptible. Whatever the cause, vigilance in routine, quality seed treatment should continue to provide effective control of the disease into the future.

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Scald and other wet season diseases - what did we learn in 2016?

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Key words

Scald, head blight, environment, crop monitoring, disease control

GRDC code

DAQ00187 – National Barley Foliar Pathogens Variety Improvement Program (NBFPVIP)

Take home messages

- Disease epidemics are a function of presence of a virulent pathogen, availability of a susceptible host and environmental conditions favourable to the pathogen.
- Environmental conditions that are optimal for a particular pathogen signal potential for that pathogen to develop into an epidemic.
- Foliar diseases have a propensity for rapid increase where there are widespread sowings of susceptible varieties and environmental conditions are favourable for pathogen infection, sporulation and dissemination.
- Mild, wet seasons should trigger more frequent crop monitoring to detect unexpected increases in disease.
- Good disease control can usually be achieved by application of an appropriate fungicide before diseases become well established.

Background

Scald (*Rhynchosporium commune*) and other wet weather diseases like Fusarium head blight (*Fusarium* spp.) and white grain (*Eutariosporella* spp.) are considered minor diseases of the traditional GRDC northern region (north of Dubbo). Minor because the annual economic impacts of these diseases when averaged over time, is relatively minor. However in seasons when environmental and epidemic conditions are particularly favourable for these diseases, their economic impact can be quite serious.

Scald has been detected at levels that reduce yield as far north as Toowoomba but this is a rare occurrence. It was present at damaging levels in several crops in the Tamworth area in 2003 and at interest levels in 2005 and 2006. It is essentially a disease of barley in southern and Western Australia where ambient temperatures and frequent rainfall events favour the disease.

Both head blights were recorded but in Queensland were mostly confined to the western Downs. They did not reach epidemic proportions in 2016.

As scald was the most conspicuous of the minor diseases to pose a problem in 2016, this paper will focus on that disease to demonstrate the principles of why a minor disease can become a major disease in some areas and seasons and what can be done to prevent such diseases becoming a similar problem in future seasons.

Why did scald become a problem in 2016?

Three factors are essential for any crop disease to occur:

1. A susceptible host
2. A virulent pathogen and

3. A favourable environment.

In plant pathology this trinity is often referred to as the disease triangle which encapsulates the basics of disease epidemiology. If we dissect the scald "epidemic" in 2016 in terms of the disease triangle, it will provide a better understanding of why it reappeared as a problem last season and forewarn us of the potential for it and other diseases to create epidemics in future seasons.

Susceptible host

Most varieties of barley developed for the northern region are susceptible (S) to very susceptible (VS) to scald, because resistance to the disease in this region is not seen as a breeding priority. This not only provides a susceptible host in areas where scald might over-season and infect any one variety; but it also provides large areas of other susceptible varieties, making an easy target for spores to be deposited and infect. Therefore a high proportion of spores released by the pathogen will find a target host, infect and establish the disease in new areas.

Virulent pathogen

Scald is a highly variable fungus and many pathotypes have been identified. It is claimed that numerous pathotypes can be isolated from just one square metre of infected crop. Consequently, virulent pathotypes are omnipresent.

The pathogen survives on barley stubble, on barley grass (*Hordeum leporinum, H. glaucum*) and can be seed-borne. Barley stubble is most likely the major source of inoculum in 2016. The disease has probably been present in crops at low levels in most seasons and has persisted over summers on crop residues. Winter environments in recent years have not suited the development and spread of scald in crop; so it has persisted at only low levels. It is unlikely that seed-borne infection played a major role in the recent epidemic.

Once infection occurs scald can proliferate at an alarming rate. A single scald lesion can produce up to 1 million conidia (Mathre 1997).

The over-seasoning phases have implications for future disease management. Stubble from crops of barley, heavily infected in 2016, will be a major source of inoculum in 2017. Stubble could be removed but if this is not an option, do not sow barley back into those paddocks for at least 2 seasons. Stubble has been shown to support sporulation over a 10 month period.

Furthermore if growers harvested seed from heavily infected crops in 2016 intending to save some for planting seed in 2017, it is recommended that they either buy in seed from non-infected crops or alternatively treat seed with a recommended fungicide. Transmission of scald from infected seed to seedlings can be as high as 86%.

Favourable environment

The authors believe that this was the key to the 2016 scald epidemic. Scald requires free moisture for sporulation and infection and relies on rain splash to move spores up the plant and within the crop. Frequent rain periods therefore promote sporulation, disseminate conidia and favour infection. These conditions also promote crop growth; so that in dense crops leaf tissue can remain wet for 24 hours per day. Serious losses to scald occur in seasons with frequent rain (Wallwork 2000).

The optimal temperature for spore production is 15 – 20°C which also favours infection. No doubt environmental conditions that promoted spore production, spore dissemination and infection occurred repeatedly in the problem areas in 2016 and played a major role in the development of epidemics.

Control

Unusually wet weather should trigger alarm bells for disease control. If you are in an area that has experienced diseases like scald before, then be suspicious that these diseases may reappear. Monitor crops for the presence of the regular diseases but also with a purpose to detect other diseases that have appeared in previous wet seasons.

Be proactive! Usually minor diseases do not command routine procedures to control the disease. Although once detected in a favourable season, they demand close monitoring and timely fungicide intervention to minimize yield losses. Foliar fungicides are quite effective on scald and will give protection for 3-4 weeks depending on product and rate applied. In a season like 2016, application of fungicide at GS31-32 and again at GS39-41 may have been required to give an adequate level of control.

Conclusion

It has been over a decade since scald occurred at damaging levels in the northern region, north of Dubbo. While the 2016 experience is unlikely to be a frequent occurrence, it is a reminder that given the right conditions, minor diseases can rapidly increase and cause significant yield loss.

The reappearance of scald was a "new" experience for many growers and agronomists. Consequently, it was easy to overlook the disease early in the season and later to underestimate the potential for epidemic increase. By the time scald was recognized as an issue, the optimal time for fungicide application had passed. No doubt the disease reduced yield in heavily infected crops.

So what did we learn in 2016?

Minor diseases can become major diseases when very susceptible varieties are grown under environmental conditions very favourable to the disease. Unseasonal wet weather should signal "look out" warnings. Look out for the common diseases favoured by wet weather but also look out for diseases that are less common and have been a problem in the past. This demands more frequent - and more careful monitoring to detect the diseases less encountered. If in doubt, consult your agronomist or regional pathologist for assistance in the identification of "different" leaf, head or stem symptoms and what options are available should control be warranted. Where application of foliar fungicides is one of those options, spraying too early is much better than spraying too late.

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Managing weeds in fencelines

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Key words

Glyphosate resistance, crop margins, bromacil, flumioxazin

GRDC code

UA00124

Take home messages

- Persistent use of glyphosate in fencelines and crop margins will lead to glyphosate resistant weeds that can then invade the cropped area of the paddock.
- A range of non-chemical options are available, that may suit some growers.
- A combination of an alternative knock down herbicides with bromacil has proved effective in managing glyphosate resistant annual ryegrass in fencelines.
- Applying residual herbicides to bare ground is an alternative herbicide option to using glyphosate.

The problem with fencelines and crop margins

Fencelines and other uncropped areas of the farm are where weeds can invade and become established. From there the weeds can move into the cropped area, particularly with harvest operations. Increasingly farmers have been keeping these areas bare of vegetation. However, this causes issues with weed invasion due to the lack of competition in the area.

A common approach to managing fencelines and crop margins is to use glyphosate for weed control. Glyphosate is ideal in this situation, because it is a broad-spectrum herbicide that controls both seedlings and larger plants, does not leach through the soil, is easy to use and is cheap. However, glyphosate is also the most important herbicide used for fallow management, prior to crop seeding and for inter-row weed management. It use in all of these places has resulted in the evolution of glyphosate resistant weeds. Once these weeds occur in one location on the farm they can easily move to other locations. Fencelines and crop margins are particularly problematic areas due to the lack of competition present. This means that any glyphosate resistant individual that survives can set a lot of seed.

Weed management options for fencelines and crop margins

There are a number of management options for weeds in fencelines and crop margins. Glyphosate resistance is occurring in this area as a result of the intensive use of glyphosate, limited use of any other controls and the lack of competition. Changing management practices will reduce the problem. The area adjacent to the crop can be cultivated, slashed, rolled for hay, grazed by stock or treated with herbicide. The aim is to reduce the ability for problem weeds to set seed that can be moved to crop areas of the farm.

All of the options for management can result in other problems. Cultivation can leave the area prone to erosion and reduce trafficability. Slashing and cutting for hay takes extra time and may be a

problem for large farms. Grazing can be problematic in sourcing stock, if not already on the farm, and stopping them from straying into the crop.

Increasing competition over the area will help limit the impact of glyphosate resistant weeds. This means limiting the area left bare to the minimum. This could be achieved through growing the crop closer to fences followed by slashing to create a fire break, removing fences and cropping over the area or not putting crop margins in the same place every year. One idea that has been proposed is to grow native grasses in these areas. While they could be very useful in providing competition against weeds, unfortunately many native species are not tolerant of herbicides used in the cropped area and eventually the grasses would weaken and gaps would appear allowing weeds to invade.

Post emergent chemical control options

We recognise that for many situations, herbicides will remain the preferred option for weed control in fencelines. Clearly, relying on glyphosate alone will be a risky option for resistance and for the Group B options available resistance has already occurred. Therefore we explored a range of other options. Among them was bromacil (Uragan®). Uragan is a Group C herbicide with grass and broadleaf activity, is not overly mobile and importantly belongs to a sub-group not being used in the cropping phase and to which we don't have resistance. This means if resistance does occur in the fenceline, it is likely to have less impact in crop.

We conducted a series of trials looking at control of glyphosate resistant annual ryegrass in fencelines in the southern region. Post emergent control in August/September suits growers of winter crops, because it is a time when little else needs to be done. However, it does mean application of herbicides to larger well established plants.

A variety of treatments were applied at two trial sites in South Australia in August 2011. The trial was assessed by counting the number of seed heads in December 2011. The annual ryegrass was more resistant to glyphosate and weed populations were larger at Hilltown compared with Ungarra (Table 1). Mixtures of other herbicides with Roundup PowerMax® were not effective in fully controlling annual ryegrass in the fencelines at either site. However, Spray.Seed® at high rates, Alliance® and Basta® plus Amitrole T were more effective, as was Uragan mixtures with Spray.Seed or Basta. Spray.Seed was more effective where the annual ryegrass population was lower at Ungarra than at Hilltown. The double knock application of two treatments of Spray.Seed 14 days apart was also effective.

Table 1. Control of glyphosate-resistant annual ryegrass with alternative herbicides at Hilltown and Ungarra in 2011.

Treatment	Rate	Hilltown		Ungarra	
	(kg or L ha^{-1})	Seed heads* (m^{-2})	Seed head reduction (%)	Seed heads* (m^{-2})	Seed head reduction (%)
Untreated	-	1111 a	0	271 a	0
Roundup PowerMax	1 L	1002 ab	10	78 ab	71
Roundup PowerMax	2 L	919 ab	17	61 ab	77
Roundup Power Max + Amitrole T	1 L + 6 L#	367 bc	67	86 ab	68
Roundup Power Max + Uragan	1 L + 3 kg#	433 bc	61	58 ab	79
Spray.Seed	3.2 L	172 bc	85	3 b	99
Alliance	4 L	76 cd	93	3 b	99
Spray.Seed + Uragan	3.2 L + 3 kg#	0 e	100	3 b	99
Basta + Amitrole T	6 L# + 6 L#	138 cd	88	1 b	99.5
Basta + Uragan	6 L# + 3 kg#	0 e	100	0 b	100
Spray.Seed fb Spray.Seed	3.2 L fb 3.2 L	27 d	98	3 b	99

* treatments in each column followed by different letters are significantly different (P=0.05).

Uragan label rate for non-crop areas is 3.5-6.5 kg/ha, with the 2.0kg rate on the label for 'retreatment'. Basta label rate is 1.0-5.0L. Amitrole T label rate is 1.1L/100L water

A second trial was conducted in 2013 at Clare and Kapunda in South Australia. Again, treatments were applied in August and assessments made in December. This trial looked at the rates of Uragan required for mixtures to be effective. In this trial, Roundup PowerMax at 2 L ha^{-1} was relatively ineffective at both sites (Table 2). At both sites, Uragan at 2 kg ha^{-1} was effective in mixtures with either Spray.Seed or Basta; however in these high annual ryegrass populations, the higher rate of Uragan was sometimes better.

Table 2. Effect of herbicides on annual ryegrass seed head production in the fence line trials at Clare and Kapunda in 2013

Treatment	Rate	Clare		Kapunda	
	(g or L ha^{-1})	Seed heads* (m^{-2})	Seed head reduction (%)	Seed heads* (m^{-2})	Seed head reduction (%)
Nil		3553 a	0	4287 a	0
Roundup PowerMax	2 L	1627 b	54	3253 ab	24
Spray.Seed	3.2 L	1100 b	69	1580 bcd	63
Basta	5 L	833 bc	77	1767 bcd	59
Spray.Seed + Uragan	3.2 L + 2 kg#	860 bc	76	107 f	98
Spray.Seed + Uragan	3.2 L + 3 kg#	7 f	99.8	73 f	98
Basta + Uragan	5 L + 2 kg#	47 ef	99	347 ef	92
Basta + Uragan	5 L + 3 kg#	113 def	97	67 f	98

* treatments in each column followed by different letters are significantly different (P=0.05).

Uragan label rate for non-crop areas is 3.5-6.5 kg/ha, with the 2.0kg rate on the label for 'retreatment'.

What we learned from these trials is that simply mixing another herbicide with glyphosate was not going to be effective, except where populations were small and without high levels of resistance. Even then, this just places the selection pressure on the mixing partner. Use of a residual herbicide with appropriate activity on the weeds and registration with an alternative knock down herbicide was the best approach. A strategy of two applications of paraquat-based products was effective and could be used in situations where Uragan cannot be used.

Pre-emergent control options

An alternative approach is to apply a residual herbicide to bare ground as a means of stopping weeds from establishing. Uragan can be used for this; however, a few other herbicides are also available for residual, broad spectrum weed control in fencelines. These typically need to be applied to bare soil for best effect. These herbicides include simazine, fluometuron and imazapyr, but all are herbicides where resistance has occurred.

It is anticipated that flumioxazin (Terrain®) will be registered for this purpose soon. Much higher rates of Terrain than used as a spike with glyphosate will be needed. Terrain at these rates will provide long residual control of weeds, without risk of movement through the soil and damage to trees, that can occur with some other herbicides. To get the best out of Terrain it will be important to achieve a surface seal on the soil to stop germinating weeds. This means using the high rates and applying them to bare soil. It is important that the soil is then not disturbed to achieve the best results.

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Wild oats: the challenge of managing this weed in the northern region cropping

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Key words

HWSC, crop competition, weed seed production

GRDC code

US00084

Take home message

Sustaining herbicide the efficacy of herbicides available for wild oat control is going to be extremely difficult. Herbicides will remain critical to the ongoing effective management of wild oats in northern cropping region. The real challenge is that the only alternate strategies currently available for routine use within winter crops are crop competition and harvest weed seed control, which have reduced efficacies and are difficult to implement effectively compared to herbicides.

Background

Wild oats is the most competitive grass weed infesting northern region cropping systems. Wild oat plants are just as competitive as wheat plants, and therefore at low infestations (<10 plants /m2) can cause significant yield losses (>20%) (Quail and Carter, 1968; Radford et al., 1980). It is the most widespread weed of the northern cropping region infesting approximately 600,000 ha, costing growers about $4.5M annually due to control costs and production losses.

As with all annual weed species wild oats has the ability to establish and maintain a viable seed bank. Potential seed production is high, up to 10,000 seed/m^2 in large infestations however, within crop, wild oats typically produces about 225 seed/plant (Medd, 1996). Once established, a large viable seedbank ensures that this weed will be an ongoing problem that will annually impact on crop production. Although the wild oat seed in the soil seed bank have a relatively short life span, regular annual inputs maintain seed bank viability. Without these inputs, a seedbank can be completely depleted in 3-4 years (Martin and Felton, 1993).

Herbicide Resistance is now a relatively common occurrence in wild oat populations occurring in Australian cropping systems. Random surveys of many cropping regions have identified high frequencies of resistance to Group A ‘fop’ (40% diclofop WA and NSW) and ‘Dim’ (30% tralkoxydim NSW) herbicides (Table 1). At present there are much lower levels of resistance to other herbicide modes of action commonly used to control this weed (i.e. Group B (2-10% mesosulfuron)). Although there is herbicide resistance present in northern region wild oat populations the frequency of resistance is not currently well quantified. A random herbicide resistance survey of this region is currently underway, with the results to be available in 2018.

Resistance evolution continues to occur in wild oat populations but fortunately at much slower rates than has occurred in other problematic weeds (e.g. annual ryegrass and wild radish). The biological attributes of self-pollination and hexaploidy are responsible for the slower evolutionary process that nonetheless still occurs and results in the loss of herbicide use.

Table 1. Proportion of randomly collected wild oat populations with resistance to a range of herbicides[-1]

Active ingredient	Trade name	WA[-2]	NSW	SA	Vic
Triallate	Avadex®	0	0		
Diclofop		44	37	≥2	
Clodinafop	Topik®			4	8
Haloxyfop	Verdict®			2	2
Fenoxaprop		27		4	
Pinoxaden	Axial®	3	8	2	1
Tralkoxydim	Achieve®	8	32	2	
Sethoxydim	Sertin®	8	8		
Clethodim	Select®		0	0	0
Mesosulfuron	Atlantis®	2	0	4	10
Imazamox + Imazapyr	Intervix®	1			
Glyphosate		0	0		
Paraquat		0			
Flamprop		8	10	7	6
Trifluralin			0		

[-1] Data from (Broster et al., 2013; Owen and Powles, 2016) and Boutsalis pers. Comm.[-2] NSW and WA values are proportion of populations with at least 1% survival while Vic and SA values are for >20% survival to recommended rate.

Attack the seedbank

The overall aim for any weed management plan focusing on annual weeds must be the seedbank. The easiest approach to targeting the wild oat seedbank is to prevent the input of fresh seed. Wild oats has a relatively short lived seedbank (3-4 years) so preventing seedbank replenishment will potentially eliminate this weed in relatively short period of time.

Herbicide options

Herbicides are, and can remain, the most effective tool for controlling wild oats in northern region cropping systems. Despite significant herbicide resistance levels these are mostly confined to Group A herbicides and particularly to 'fop' herbicides. There remain several in-crop selective herbicide options available for wild oat control. As well as preventing seedbank inputs, in-crop control during the growing season also removes the significant competitive effects of wild oats on crop plants. Additional pre-emergence herbicide options have become available of the last few years (Mark Congreve, https://grdc.com.au/Resources/IWMhub/Weed-Webinars/Ecology-and-management-of-wild-oats). There are also later season herbicide options (pinoxaden and flamprop) available for specifically targeting the seed production of wild oat plants.

Harvest weed seed control

Harvest weed seed control (HWSC) can play a part in wild oat management but is likely to be in addition to current control tactics and not likely to be robust enough to be able to be relied on as a

stand-alone option. Although high proportions of seed retention have been recorded for wild oat populations maturing in wheat crops, seed shedding begins at plant maturity and continues throughout the harvest period (Walsh and Powles, 2014; Widderick et al., 2014). Therefore, although there is an opportunity to target wild oats with HWSC, this opportunity may be brief. There is a further research need to quantify the general efficacy of HWSC systems on this weed.

Crop competition

Increasing the competitive ability of crops has a major role to play in the management of wild oats as well as other weed species. Over many years several studies have identified the benefits of increasing competition on wild oat management specifically in relation to reducing seed production (Martin and Felton, 1993; Radford et al., 1980) as well for improving herbicide efficacy (Walker et al., 2002).

In a recent pot study, we observed a 40% reduction in wild oat seed production by increasing wheat plant density from 60 to 120 plants/m^2 (Figure 1).

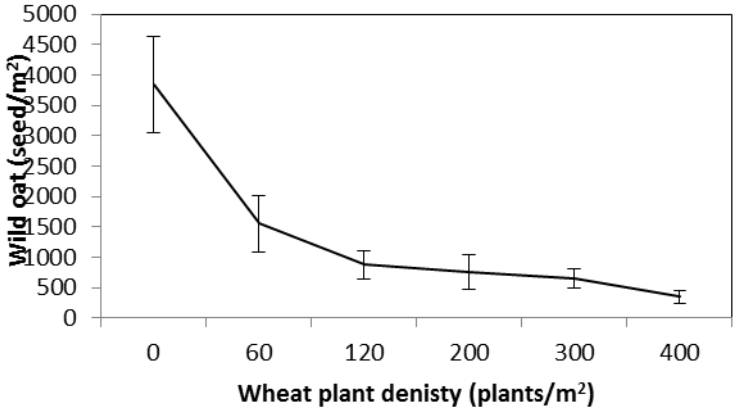

Figure 1. Influence of increasing wheat plant density on wild oat seed production

This same competition study found that wheat crop competition increased the proportion of seed retained higher in the canopy. (Figure 2). Increasing the height of seed retention height potentially improves the efficacy of HWSC by increasing the amount of weed seed collected during harvest. For wild oats though there was only a slight increase in the proportion of seed retained higher in the canopy substantially lower than that for the other weed species.

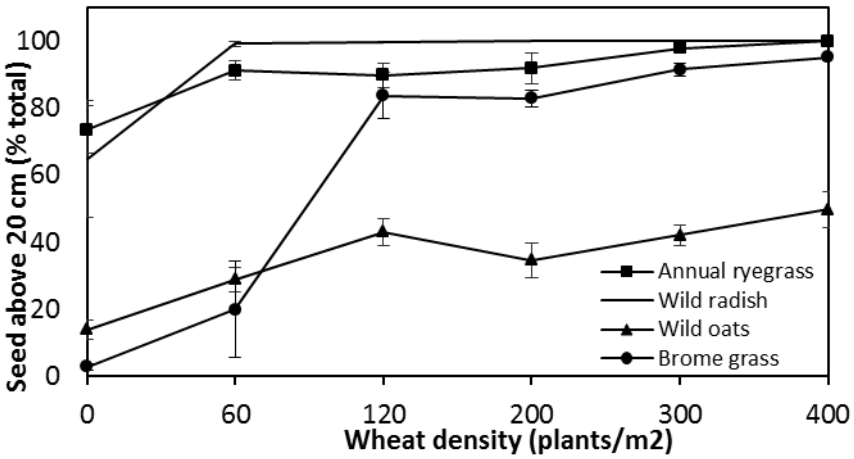

Figure 2. Influence of crop competition on the seed retention height of annual ryegrass, wild radish, wild oats and bromegrass

Conclusions

Eliminating the seedbank needs to be the focus for effective long term wild oat management. Only with a much reduced seedbank will the impact of this species on crop production be reduced, and more importantly, the ongoing management much easier. Additionally, lower seedbank levels will greatly assist in sustaining herbicide efficacy. The challenge though is that aside from herbicides the alternate options for routine in-crop wild oat control are limited. Additionally, the available options of HWSC and crop competition are much less effective than herbicides and are difficult to implement effectively.

Acknowledgements

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New developments and understanding in resistance mechanisms and management

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Key words

Herbicide resistance, resistance testing, temperature, glyphosate, clethodim

GRDC code

UA00158

Take home messages

- There are new weeds with resistance to paraquat, glyphosate and the Group I herbicides.
- False negative results in resistance testing can occur due to inappropriate sampling or conditions at testing being different to those in the field.
- Temperature affects the performance of many herbicides in Group A, Group C, as well as paraquat, glyphosate and glufosinate.
- Understanding cross resistance patterns can help determine which herbicide products might still work.

Recent developments in herbicide resistance

The continual reliance on herbicides for weed control is inevitably resulting in the evolution of more herbicide resistance. This is complicating weed control, because other or additional tactics need to be brought in to manage the resistant weeds. Where there are several different weeds with resistance to different herbicides on the same farm, the complications increase.

The main new developments in herbicide resistance over the past 2 years have been the identification of new species with resistance to glyphosate, paraquat and 2,4-D. In addition, there has been the identification of resistance in annual ryegrass to Group J herbicides.

New species with resistance to glyphosate are sweet summer grass (*Brachiaria eruciformis*), feathertop Rhodes grass (*Chloris virgata*), red brome (*Bromus rubens*), common sowthistle (*Sonchus oleraceus*), prickly lettuce (*Lactuca serriola*) and tridax (*Tridax procumbens*). These have occurred in several situations including summer fallows, crops, road sides and orchards. It is clear that continued reliance solely on glyphosate in fallows, horticulture and road sides will lead to more glyphosate resistant weeds appearing.

Paraquat resistance has been identified in flaxleaf fleabane (*Conyza bonariensis*), crowsfoot grass (*Eleusine indica*), black nightshade (*Solanum nigrum*) and Pennsylvania cudweed (*Gamochaeta pensylvanica*) from horticulture and viticulture. We generally consider paraquat resistance harder to select for than glyphosate resistance, but this shows that over-reliance on paraquat will lead to resistance.

A concerning issue has been the identification of Group I resistance in common sowthistle (*Sonchus olreaceus*) and capeweed (*Arctotheca calendula*). These have come from intensive in-crop and fallow uses of Group I herbicides. Currently, common sowthistle has resistance to Group B, I and M only not all in the same population. These comprise the majority of the herbicides used for fallow weed control.

In 2015 resistance to Group J herbicides triallate (Avadex® Xtra) and prosulfocarb (Arcade® and also the main ingredient in Boxer Gold®) was identified in annual ryegrass. Groups D, J and K are the main pre-emergent herbicides for grass weeds and annual ryegrass now has resistance to two of these.

Temperature effects on herbicide resistance and implications for resistance testing

Prevailing environmental conditions often influence herbicide efficacy in the field. This can result in perceived herbicide failure in the field that is not the result of herbicide resistance. Additionally, the opposite can occur where resistance in the field can be tested with a false negative test result. Temperature is a key environmental factor that can affect herbicide performance as well as herbicide resistance test results. Temperature can influence many aspects of herbicide performance including absorption, translocation, metabolic degradation and the development of symptoms. It is the interrelationship between these effects and the herbicide resistance mechanism that determine whether temperature will affect test results.

Case study: Glyphosate resistance in barnyard grass

Temperature has a significant impact on the response to glyphosate of many herbicide resistant barnyard grass populations (Figure 1). At 20°C, most populations are less resistant to glyphosate than at 30°C. This has implications for both the use of glyphosate and testing for resistance. Glyphosate resistant barnyard grass populations are more likely to be controlled when prevailing conditions are mild than when conditions are hot.

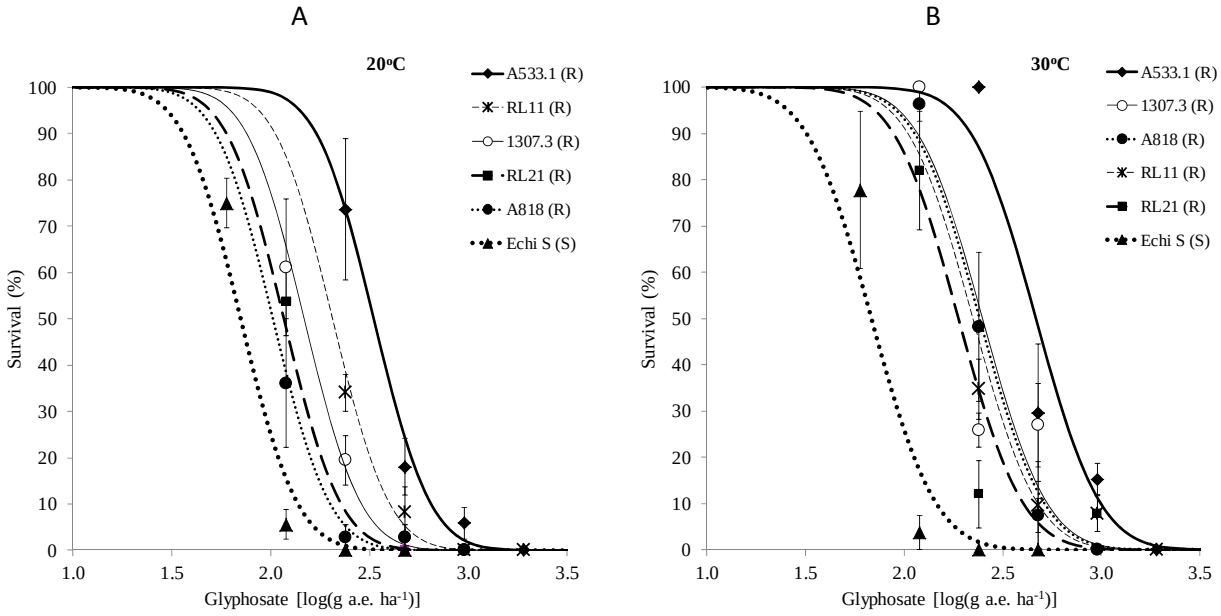

Figure 1. Effect of higher temperature on response to glyphosate of resistance and susceptible barnyard grass populations. A) Dose response at 20°C; B) Dose response at 30°C. Almost all of the glyphosate resistant populations are more resistant to glyphosate at 30°C compared with 20°C. Source: Nguyen et al. 2016.

More importantly, testing for resistance to glyphosate in barnyard grass can give conflicting results. For populations with lower levels of resistance, test results may indicate little or no resistance at the field rate if tested under cooler conditions. However, farmer experience in the field may be a complete failure of the herbicide.

There are several things going on in this case. As a general rule, glyphosate tends to be less effective under high temperature conditions. In part this is because glyphosate is one of those herbicides

whose activity limits its own translocation. The more rapidly glyphosate symptoms appear, the more likely herbicide is to be trapped in the leaves, rather than being translocated around the plant. This means that while symptom appearance is more rapid under summer temperatures, plant kill is less complete. Also as temperatures get very high, absorption of glyphosate through the leaf cuticle reduces, leaving more of the herbicide outside the leaf. So in general, increasing glyphosate rates for summer applications will improve weed kill.

In the case of barnyard grass, this is then compounded by the mode of action of the herbicide and the resistance mechanism. It is the build-up of shikimate pathway intermediates that leads to death of plants, so any resistance mechanism that can keep the shikimate pathway operating is likely to lead to plant survival. This means that relatively weak resistance mechanisms, such as target site mutations, can be effective in these summer-growing weeds, as less glyphosate is getting to the target enzyme.

Case study: Clethodim resistance in annual ryegrass

Clethodim is frequently used to control established grass weeds, particularly annual ryegrass, in June to July. Conditions are often cool during this period and frost can be common. Resistance to clethodim is common in annual ryegrass and growers have increased the rate used to attempt to control resistant populations. Cold weather, and particularly frost, can dramatically change the performance of clethodim. Research looking at the impact of frost on clethodim performance showed that twice as much clethodim was required if frost had occurred in the 3 days prior to clethodim application on susceptible annual ryegrass (Figure 2). An even greater difference was observed for some clethodim resistant populations under frost conditions.

Clethodim is a herbicide that is markedly more effective under warmer conditions than under cooler conditions. This means that resistance testing undertaken during warm conditions could lead to false negative results. It also means that resistance populations in the field become much harder to control during extended cold periods. The current most common practice of using clethodim on tillered resistant grass weeds in the coldest part of winter does not play to its strengths. Avoiding frosty periods will improve control.

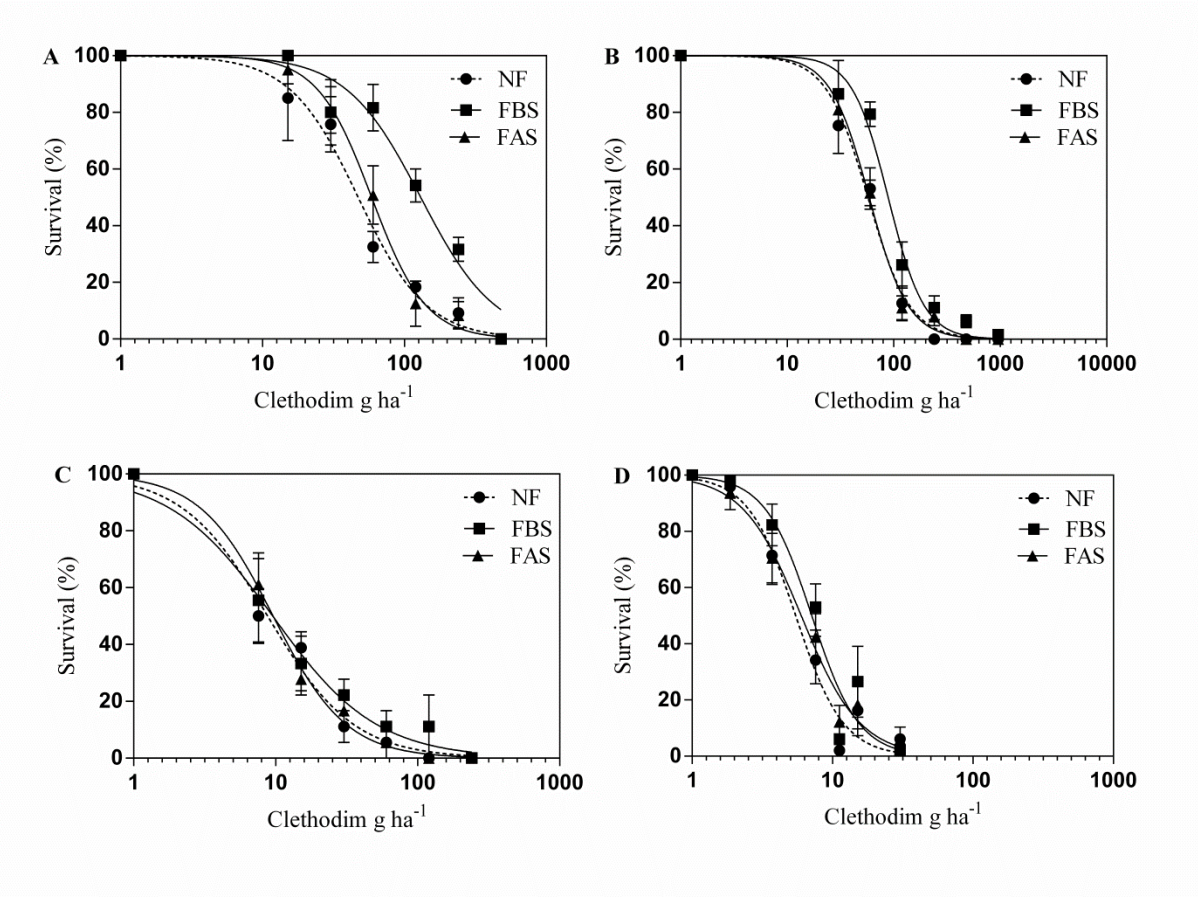

Figure 2. Effect of frost on response to clethodim of three resistant (A, B and C) and one susceptible (D) annual ryegrass populations. Plants were exposed to frost for 3 nights prior to clethodim application (FBS) or 3 nights after clethodim application (FAS) compared with no frost (NF). Some resistant populations became much more resistant with frost. Source: Saini et al. 2016.

Rules of thumb

Quite a number of herbicides have varying performance at different ambient temperatures. Most herbicides do not work well if the temperature is too low, conditions are not that often encountered in Australia, except for night spraying in winter. Table 1, therefore provides rules of thumb that differentiate between average winter spraying and spring or summer spraying of herbicides. For example, Group A fop herbicides typically become less effective in summer compared to winter use. This means that more herbicide will be required for the same level of control. In contrast, the opposite tends to happen with Group A dim herbicides.

Where weed populations have low levels of resistance, these seasonal variations can create a disconnect between observations in the field and formal resistance testing. Most resistance testing only uses one or two herbicide rates, typically starting at the field rate. Testing in a season different to when the herbicide was applied can result in false negatives in these cases. Better results may be obtained through the whole plant Quick-Test™ than with a seed test.

Table 1. Rules of thumb for the effect of summer compared with winter application on herbicide efficacy on weeds

Herbicide Group	Example herbicide	Herbicide efficacy in summer compared with winter
A fops	Diclofop-methyl	Reduced
A dims	Clethodim	Increased
C	Atrazine	Increased
L	Paraquat	Reduced *
M	Glyphosate	Reduced
N	Glufosinate	Increased**

* While higher temperatures make Group L herbicides less effective, resistant populations also become less resistant at higher temperatures.

** However, efficacy of glufosinate is greatly reduced by conditions of low humidy.

Herbicide resistance mechanisms and cross resistance

In general resistance mechanisms can be divided into target site mechanisms and non-target site mechanisms. Target site mechanisms include point mutations in the target site protein that reduce herbicide binding or greatly increased amounts of the target site protein that soak up the herbicide. Non-target site mechanisms include everything else and usually these mechanisms reduce the amount of herbicide reaching the target site. Commonly increased detoxification of the herbicide is involved, but reduced herbicide absorption, reduced herbicide translocation or herbicide sequestration can also be involved.

Target site mutations often give some level of resistance to other herbicides of the same mode of action, but no resistance to herbicides of other modes of action. Non-target site mutations can also give some level of resistance to other herbicides of the same mode of action, although it is often less extensive than for target site mutations, and can provide unexpected resistance to herbicides of other modes of action.

There is frequently confusion that assumes high levels of resistance are due to target site resistance and low-levels due to non-target site resistance. This is true of some modes of action (Group C resistance for example), but not others. Understanding common resistance mechanisms can be useful for determining rules of thumb for using herbicides. In annual ryegrass, target site resistance to Group A fop herbicides was common. The most common mutations gave no or low resistance to dim herbicides. This allowed dims, and particularly clethodim, to be used after resistance to fops had occurred. However, in other grass weeds different patterns emerge. In wild oats/black oats (*Avena* spp.) non-target site resistance to Group A herbicides is common, giving cross-resistance to Mataven®, but meaning Targa®, Verdict™ and Axial® may still work despite resistance to Topik®.

These differences result from a combination of selection history and the biology of the weed species. Where weeds are polyploid (more than one genome) it is more difficult for high level target site resistance to evolve as more than one point mutation is required. This tilts the balance of selection pressure in favour of non-target site mechanisms. Feathertop Rhodes grass (*Chloris virgata*), a diploid species, has evolved resistance to glyphosate through target site point mutations, whereas its close relative windmill grass (*Chloris truncata*), a tetraploid species, has evolved resistance through gene amplification. In addition, different herbicides within the same mode of action may be preferred for use against different weeds, also altering the selection pressure.

While rules of thumb can be developed for resistance to herbicides in some modes of action, these are likely to be somewhat species specific. Herbicide resistance testing is the only way to work out which herbicides might still work on any one population. Even then, it is important to remember that there might be more than one resistance mechanism present in a field and test accordingly.

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Canola, organic matter and fababean concurrent session

Managing canola diseases – blackleg and sclerotinia

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Key words

Canola, blackleg, sclerotinia, disease management

GRDC codes

DAN00177, UM0051

Take home messages

- Impacts on yield due to blackleg of canola are likely to be lower in northern NSW compared to southern NSW.
- Growers should still be vigilant in managing this disease and an integrated approach should be adopted by growers that utilises variety resistance, cultural control and the strategic use of fungicides.
- Sclerotinia stem rot is a production issue where spring rainfall is adequate to provide long periods of leaf wetness in the presence of flowering canola crops.
- If there is a history of sclerotinia stem rot in your district causing yield loss, be prepared to use a foliar fungicide to reduce yield loss.
- Sclerotinia stem rot occurred in those districts with a frequent history of the disease in 2016. Wet conditions in spring were ideal for disease development.
- Extended periods of leaf wetness (at least 48 hours) are ideal for triggering epidemics of stem rot.

Sclerotinia stem rot – 2016 Update

Seasonal overview

Growing season conditions in winter and early spring were highly conducive for the development of sclerotinia stem rot in 2016. Prolonged wet weather in winter was ideal for the germination and development of apothecia, the fruiting structures of the sclerotinia fungus. The first warning signs appeared in early July with apothecia being observed within canola crops in southern NSW, with flowering commencing shortly afterwards in some early sown crops. Continued wet weather throughout August and September provided periods of extended leaf wetness and opportunities for disease epidemics to develop in many districts.

In general, disease levels were low across southern NSW despite the wet conditions. Widespread use of foliar fungicides in high disease risk districts was effective in managing the disease.

How does the disease develop?

The complexity of the disease cycle of sclerotinia stem rot results in disease outbreaks being sporadic compared to other diseases. There are several key stages that must be synchronised and completed in order for plant infection to occur. Weather conditions must be suitable for the pathogen at each stage. These stages of development include:

1. Softening and germination of soil borne sclerotia
2. Apothecia development and release of ascospores
3. Infection of petals by air-borne ascospores
4. Senescence of infected petals in the presence of moisture and subsequent stem infection

Weather conditions during flowering play a major role in determining the development of the disease. The presence of moisture during flowering and petal fall will determine if sclerotinia stem rot develops. Dry conditions during this time can quickly prevent development of the disease, hence even if flower petals are infected, dry conditions during petal fall will prevent stem infection development.

Research findings in 2016

Commercial canola crops and trial sites were monitored for the development of sclerotinia stem rot in high sclerotinia risk districts in 2016. These crops were located in southern NSW and northern Victoria where the disease is an annual problem. Consistent with the previous year's results, observations within these crops found a very strong relationship between prolonged periods of leaf wetness and stem rot development.

In addition, a small scale petal survey was conducted across southern NSW and northern Victoria in 2016. The aim of this survey was to investigate the relationship between petal infestation with the sclerotinia fungus and stem rot development.

Stem infection

Infection levels at disease monitoring sites were generally low, <10%. Despite above average rainfall, foliar fungicides applied by growers were effective at keeping potential disease levels low. However, some reports were received of higher levels of stem infection in some commercial crops, depending on where rainfall events occurred and crop growth stage. For the third year in a row, results showed that extended periods of leaf wetness of at least 48 hours were most effective for the development of stem infection within crops.

Petal testing

For the second year a petal survey was conducted in southern NSW and northern Victoria. The highest levels of petal infestation (>90%) were detected in crops grown in higher rainfall districts with a high frequency of canola. Crops further west had reduced levels of infestation in general (<60%), with levels of infestation fluctuating with environmental conditions. These results are consistent with the previous year's findings.

Once again the results confirm findings that were observed in research from 10 years ago which found no direct correlation between the numbers of canola petals infested with the sclerotinia pathogen and stem rot development within the crop. **This confirms the importance of leaf wetness within the crop canopy as the driving factor behind development of stem rot**.

Where did the disease occur in 2016?

Traditionally sclerotinia outbreaks are sporadic in southern NSW and northern Victoria and usually restricted to those districts with a history of sclerotinia, high intensity of canola and reliable spring

rainfall. Due to above average spring rainfall in 2016 outbreaks of the disease was widespread and in districts that rarely see the disease develop. Damaging levels of sclerotinia were largely restricted to the 'traditional' districts that frequently see the disease, while in lower rainfall districts the disease was observed but didn't significantly affect canola yields.

What are the indicators that sclerotinia stem rot could be a problem in 2017?

- **Spring rainfall**. Epidemics of sclerotinia stem rot generally occur in districts with reliable spring rainfall and long flowering periods for canola. Consider rainfall predictions for spring and canola crop growth stage.
- **Frequency of sclerotinia outbreaks.** Use the past frequency of sclerotinia stem rot outbreaks in the district as a guide to the likelihood of a sclerotinia outbreak. Paddocks with a recent history of sclerotinia are a good indicator of potential risk, as well as those paddocks that are adjacent. Also consider the frequency of canola in the paddock. Canola is a very good host for the disease and can quickly build up levels of soil-borne sclerotia.
- **Commencement of flowering.** The commencement of flowering can determine the severity of a sclerotinia outbreak. Spore release, petal infection and stem infection have a better chance of occurring when conditions are wet for extended periods, especially for more than 48 hours. **Canola crops which flower earlier in winter, when conditions are cooler and wetter, are more prone to disease development.**

If I had sclerotinia in my canola crop last year, what should I do this season?

There are a number of steps that can be taken to reduce the risk of sclerotinia:

1. **Sowing canola seed that is free of sclerotia**. This applies to growers retaining seed on farm for sowing. Consider grading seed to remove sclerotia that would otherwise be sown with the seed and infect this season's crop.
2. **Rotate canola crops.** Continual wheat/canola rotations are excellent for building up levels of viable sclerotia in the soil. A 12 month break from canola is not effective at reducing sclerotia survival. Consider other low risk crops break crops such as cereals, field pea or faba bean.
3. **Follow recommended sowing dates and rates for your district. BE AWARE OF THE MATURITY RATING OF THE VARIETY AND TIME OF SOWING.** Early flowering crops are more prone to developing sclerotinia stem rot by increasing opportunities for infected petals to lodge in a wet crop canopy. In addition, early sown crops will most likely develop bulky crop canopies which retain moisture and increase the likelihood of infection. Wider row spacings can also help by increasing air flow through the crop canopy to some degree and delaying the onset of canopy closure.
4. **Consider the use of a foliar fungicide.** Weigh up yield potential, disease risk and costs of fungicide application when deciding to apply a foliar fungicide.
5. **Monitor crops for disease development and identify the type of stem infection.** Main stem infections cause the most yield loss and indicate infection events early in the growing season. Lateral branch infections cause lower levels of yield loss and indicate infection events later in the growing season.

Use of foliar fungicides

At this time there are no commercial canola cultivars available on the Australian market with resistance to sclerotinia stem rot. Management of the disease relies on the use of cultural and chemical methods of control. Foliar fungicides should be considered in those districts which are at a

high risk of disease development (eg, districts where the disease frequently occurs, long flowering period and reliable spring rainfall). There are several foliar fungicides currently registered for use in Australia to manage sclerotinia stem rot.

Points to consider when using a foliar fungicide to manage sclerotinia stem rot

1. The most yield loss from sclerotinia occurs from early infection events. Early infection is likely to result in premature ripening of plants and produce little or no yield.
2. Plants become susceptible to infection once flowering commences. Research in Australia and Canada has shown that an application of foliar fungicide around the 20% - 30% bloom stage (20% bloom is 14 – 16 flowers on the main stem, 30% bloom is approx. 20 flowers on the main stem) can be effective in significantly reducing the level of sclerotinia stem infection. Most registered products can be applied up to the 50% bloom (full bloom) stage.
3. The objective of the fungicide application is to prevent early infection of petals while ensuring that fungicide also penetrates into the lower crop canopy to protect potential infection sites (such as lower leaves, leaf axils and stems). Timing of fungicide application is critical.
4. A foliar fungicide application is most effective when applied before an infection event (eg, before a rain event during flowering). These fungicides are best applied as protectants and have no curative activity.
5. In general, foliar fungicides offer a period of protection of up to 3 weeks. After this time the protectant activity of the fungicide is compromised. In some crops development of lateral branch infections later in the season is not uncommon if conditions favourable for the disease continue. The greatest yield loss occurs when the main stem becomes infected, especially early. Lateral branch infection does cause yield loss, but at a much reduced level.
6. Use high water rates and fine droplet sizes for good canopy penetration and coverage.

Consult the Sclerotinia stem rot in canola factsheet for further information. This publication is available from the GRDC website.

Blackleg

Blackleg, caused by the pathogen *Leptosphaeria maculans*, is the most damaging disease of canola and juncea-canola in Australia. In southern NSW this disease is a major concern for producers, mainly due to the high intensity of canola production in the region. In northern NSW the level of blackleg observed in commercial crops has been significantly lower where production of the crop is not as concentrated.

Despite the lower levels of blackleg observed in the north growers and advisors should still be vigilant in the management of this disease. Blackleg is present in all canola paddocks and experience from southern NSW shows higher levels of blackleg development in canola crops with increasing intensity of production in the region.

Symptoms of blackleg

Blackleg most commonly causes distinct lesions on the cotyledons and leaves of canola plants early in the growing season. The lesions are generally pale grey with a dark border and develop distinct pycnida within the lesion. These appear as “pepper like” spots within the lesion.

The blackleg fungus then grows without symptoms through the vascular tissues to the crown where it causes a necrosis resulting in a crown canker at the base of the plant. The crown canker appears as a dry rot at ground level and causes plants to lodge. This crown canker causes yield loss as it restricts

water and nutrient uptake by the plant. Blackleg can occur on all plant parts, however, leaf lesions and crown cankers are the most commonly observed symptoms.

How do we best manage blackleg?

The most effective approach to reduce the impact of blackleg is to use an integrated strategy that utilises cultivar resistance, cultural control and the strategic use of fungicides. The most effective management practices that can reduce the impact of blackleg include:

1. **Sowing canola cultivars with appropriate levels of blackleg resistance**. This is particularly important in districts with a high intensity of canola production where cultivars should be sown with high levels of blackleg resistance. Plant resistance is the first line of defence against blackleg.
2. **Avoid canola stubble, especially from the previous season's crop.** The distance from last season's canola stubble will largely determine the severity of blackleg in this season's canola crop. Where possible a distance of at least 500m will significantly reduce the disease pressure from blackleg on this season's crop. Spores of the blackleg pathogen are released from old canola stubble onto emerging canola crops. The greater the distance from this inoculum source the better.
3. **Apply seed dressing or fungicide-amended fertiliser.** Application of a fungicide seed dressing or use of fungicide amended fertiliser will provide extra protection from blackleg in the critical early stages of crop emergence and establishment. In high blackleg pressure situations this is very important.
4. **Foliar fungicides.** In certain situations it may be economical to apply a foliar fungicide to extend the length of protection from blackleg, such as if disease severity is very high, if genetic resistance is inadequate or has been overcome by the fungus. Results of field experiments indicated that use of a fungicide seed dressing in combination with the application of a foliar fungicide gives good levels of protection. Timing is crucial, with an application at the 4-6 leaf growth stage found to be significant in decreasing blackleg infection. However, the benefits are only found in those canola cultivars with a low level of resistance to blackleg and in situations of high disease pressure.
5. **Canola resistance groups.** The blackleg fungus has a high propensity to overcome resistance in *Brassica napus* (canola) cultivars as it is sexually reproducing, resulting in enormously diverse populations. Therefore, the fungal population evolves very rapidly and responds quickly to selection pressures such as wide-scale sowing of cultivars with specific resistance genes. This will lead to resistance being overcome when cultivars of the same resistance gene are sown for 3 or more years. However, we can use the fungal life traits to manipulate the fungal population, by changing cultivars with different sources of resistance, the selection pressure on the fungal population is constantly changing. All canola cultivars and NVT lines have been classified for blackleg resistance genes and placed into resistance groups. This now allows producers to change or rotate canola cultivars after every 2 to 3 years and prevents the build up of isolates that can overcome resistance. By changing canola cultivars at least every 3 years to a cultivar containing different resistance genes, you are likely to reduce yield losses and reduce the probability of resistance breakdown occurring.

Be sure to check the GRDC website for the latest version of the Blackleg management guide, which will give the latest blackleg disease ratings and resistance groups.

Useful resources

NSW DPI Winter Crop Variety Sowing Guide (Disease updates, variety resistance, fungicide products.)

NSW DPI Southern NSW Research Results 2015

http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/southern-nsw-research-results-2015

https://twitter.com/NSWDPI_AGRONOMY

https://grdc.com.au/Resources/Factsheets/2016/09/Blackleg-Management-Guide-Fact-Sheet

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Canola agronomy and fit in northern farming systems

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Key words

canola, flowering, phenology, harvest loss

GRDC code

CSP00187

Take home message

- Identifying the optimal flowering window is an important consideration when growing canola in northern environments
- It is important to consider both biotic and abiotic stresses when identifying the optimal window
- Short to mid-season varieties are most suited to northern environments
- A large proportion of the final yield comes from the branches and should be considered when deciding to desiccate or windrow.

Background

This paper has been prepared as part of the GRDC funded project Optimised Canola Profitability (OCP) this is a collaborative project between NSW DPI, CSIRO, SARDI and GRDC. A strong focus of the research to date has been on investigating the interactions between sowing date and variety choice of canola as it relates to phenology, biomass accumulation, grain yield and oil concentration. This focus has arisen from the practice of planting canola earlier in southern Australia as a way of capturing a dual purpose use, improving the crops water use efficiency, increasing yield and adapting to early seasonal breaks. The earlier sowing of canola in the southern states has identified differences in canola genetics, where the time to flowering in some varieties differs from when they are planted within their traditional window. The process of identifying and understanding the different flowering process has helped identify canola cultivars and agronomic practices that can help improve the production of canola in the northern grains region.

Detailed flowering trials that included the extension of day length and monitoring of low temperature sensitivity were established in Queensland and Canberra; while variety by sowing date experiments were planted across the Northern and Southern GRDC regions in 2014,2015, and 2016. These trials extended from the Darling Downs in SE Queensland to Tamworth and the Breeza plain, Narrabri and then on to Canowindra on the central-west slopes of NSW, Horsham in the Wimmera region of Victoria and west to the Eyre Peninsula in South Australia. This paper will use some of these results to highlight issues to consider if including canola within a northern farming system.

Identifying the optimal flowering date

Like chickpeas, canola is an indeterminate plant (will continue to flower while they have water and mild temperatures), unlike chickpeas, however, canola can withstand colder temperatures during flowering, but the flowers and particularly the pods are sensitive to frost. In selecting an optimal flowering window, the aim is to avoid frost during the sensitive pod filling period.

On the other end of the season, high temperatures even for short periods can cause stress resulting in yield loss. Higher temperatures can also reduce the quantity and quality of the oil produced. Temperatures above 25°C can inhibit the build-up of oleic acid and therefore alter the fatty acid composition of the oil.

The detailed phenology work that has been a key part of the (OCP) project has been captured within the APSIM canola model, this combined with field trials conducted across the region has allowed us to identify the best time for flowering to occur. The optimum time to flowering is a period calculated from the model that has been adjusted to consider high temperature and frost stress.

The figure below (Figure 1) describes the optimum flowering window for Moree the grey bar depicts the window when flowering should commence. The predicted yield (black line) decreases from this point because water stress (dotted) and heat (dashed) lines increase the stress on the crop. This data is a summary from 50 years of crops planted on a range of sowing dates using short and medium length canola cultivars.

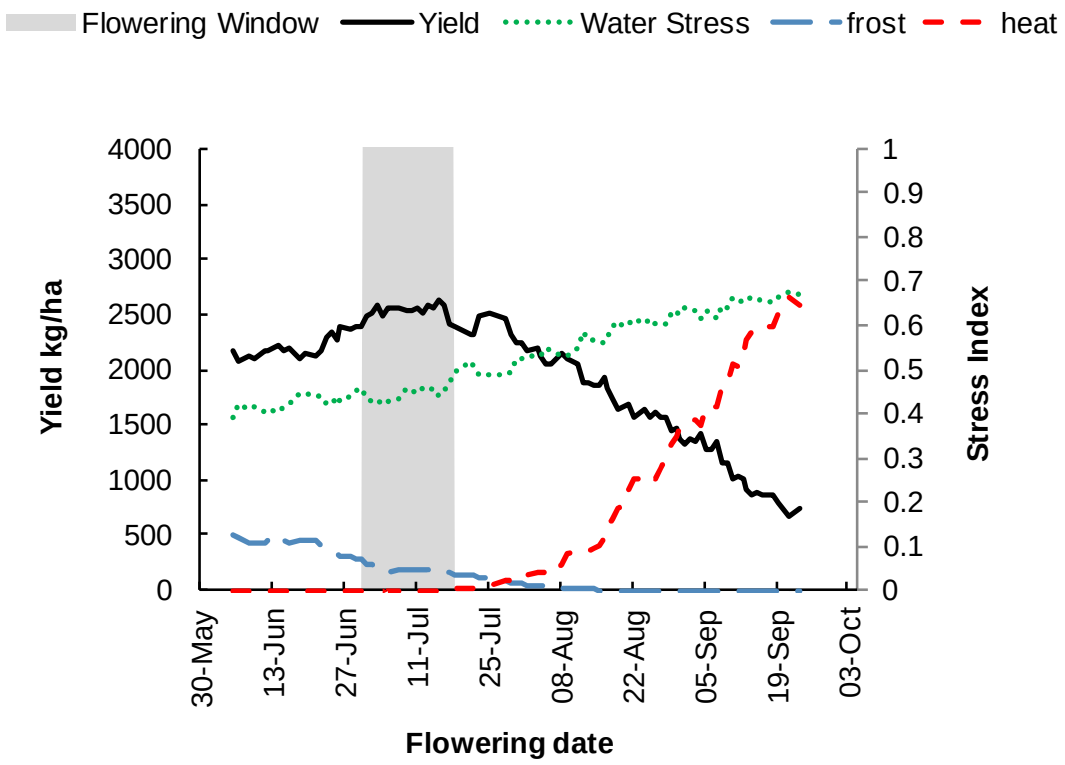

Figure 1. Simulated optimal flowering window for canola production in Moree for short to mid season cultivars. The solid line indicates the frost and heat modified yield. The dotted line indicates increasing water stress and the dashed lines indicate frost and heat stress (frost to August, heat from August).

Once the optimum flowering window has been identified it is important to work backwards and find cultivars that have the correct genetics to flower in this period. For Moree a range of phenology types are presented (Figure 2). The long season types or the winter types are not suited to Moree because they flower too late (not shown). The short season and medium short cultivars are more suitable. Archer is a midum long season and is a possibility for a very early planting, more testing is required.

These results are supported by the trial results collected last year (table1), however, it must be remembered that 2016 was not a typical season with a mild winter and spring allowing good growth well into spring, which resulted in high yields (Table 2).

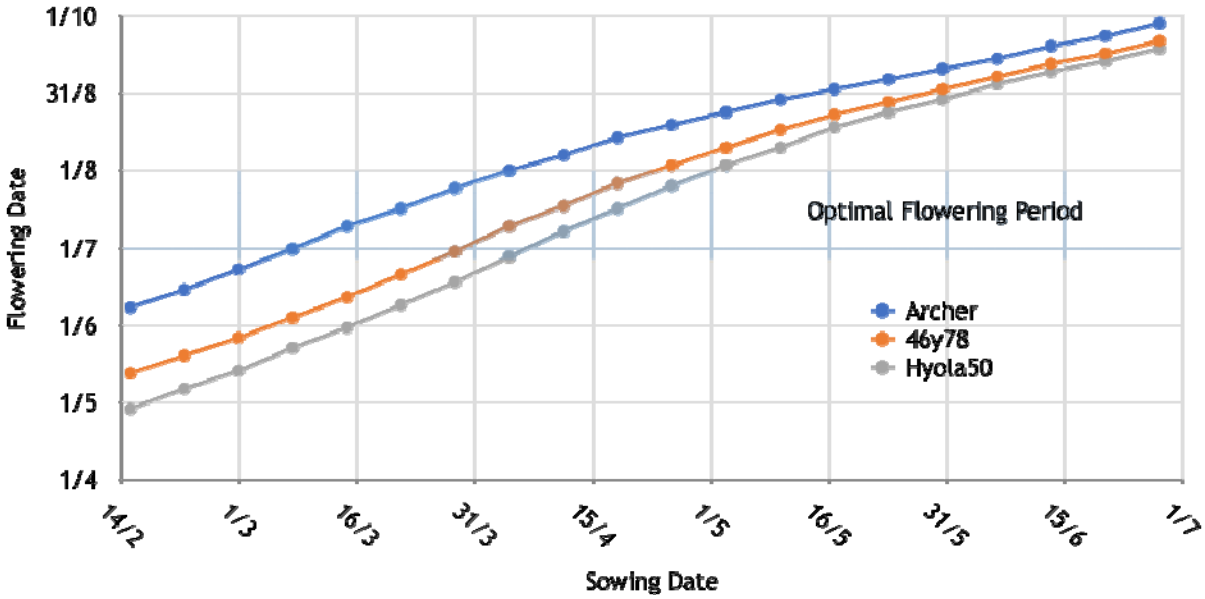

Figure 2. Showing the sowing dates required to flower within the optimal flowering period for different cultivar types.

Table 1. Flowering dates for some current commercial cultivars sown at different times across the northen grains region during 2016

	Norwin			Trangie			Breeza		
Sowing date	**15-Apr**	**29-Apr**	**13-May**	**1-Apr**	**14-Apr**	**17-May**	**13-Apr**	**16-May**	**17-Jun**
Hyola 575CL	14-Jun	29-Jul	29-Jul	7-Jun	10-Jul	19-Aug	16-Jul	26-Aug	12-Sep
44Y89 CL	13-Jun	29-Jul	29-Jul	15-Jun	13-Jul	9-Aug	22-Jul	25-Aug	12-Sep
43C80 CL	13-Jun	29-Jul	29-Jul	25-Jun	19-Jul	*	27-Jul	22-Aug	6-Sep
45Y86 CL	13-Jun	29-Jul	29-Jul	12-Jul	26-Jul	*	25-Jul	22-Aug	16-Sep
45Y88 CL	29-Jul	29-Jul	29-Jul	3-Jul	21-Jul	28-Aug	30-Jul	30-Aug	15-Sep
Archer	29-Jul	29-Jul	15-Aug	29-Jul	5-Aug	31-Aug	11-Aug	5-Sep	22-Sep

Table 2. Yields achieved in time of sowing trials from three sites across the northern grains region.

	Norwin			Trangie			Breeza		
Sowing date	**15-Apr**	**29-Apr**	**13-May**	**1-Apr**	**14-Apr**	**17-May**	**13-Apr**	**16-May**	**17-Jun**
Hyola 575CL	-	3.6	2.6	3.1	3.3	2.6	-	-	-
44Y89 CL	-	4.5	3.2	3.8	3.9	3.0	-	-	-
43C80 CL	-	4.3	3.2	3.5	3.5	*	-	-	-
45Y86 CL	-	3.5	3.5	3.3	3.1	*	3.3	4.0	4.4
45Y88 CL	-	4.5	3.7	3.9	3.1	3.4	-	-	-
Archer	-	2.5	3.8	3.5	3.2	3.2	-	-	-

*43C80 CL and 45Y86 CL had poor establishment from the 17 May sowing date at Trangie so were excluded from the analysis.

Is there a benefit of planting early

Work from the southern grains regions is showing that if rain occurs in ealy April (early sowing) good yields can be achieved by sowing a mid to long season cultivar that flowers in the optimal flowering window. However, this is not the case in warm or northern environments where the warmer conditions prevent longer season cultivars from flowering during the optimum flowering window. Some good, short to medium length cultivars are available for northern environments.

Harvesting

A sucessful canola crop should be planted at a time and with a cultivar that enables flowering to occur within the optimum floweing window. A good profile of stored water and sufficient nitrogen will give the crop the best chance of success. The next important issue is how to harvest that crop. Work conducted by NSW DPI as part of the optimising canola project is idenitifying ways to maintain yield when harvesting canola. The current industry guidelines recomend that canola is ready to windrow when 40-60% of seeds on the primary stem change colour from green to red ,brown or black. However, data from trials conducted in 2015 and 2016 are showing that on average only 25-30 % of the grain is being held on the main stem. This work is showing that later harvesting/windrowing up to 95% colour change on the main stem will increase yield and oil concentration. The tradeoff with delaying is losses through shattering or weather damage, so suggested recommendations are to consider upcoming weather forcasts and windrow when more than 40 % of the mainstem seed has changed colour. If planning to dessicate and direct head, dessicants should be applied after 20% mainstem seed colour change has occured.

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Faba bean disease management update

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Keywords

Stemphylium blight, chocolate spot, rust, fungicides

GRDC codes

UA00127, DAN00176

Take home messages

- The high rainfall during the 2016 growing season favoured development of leaf blights in faba bean in the northern grain region.
- By mid-August severe incidences of chocolate spot (*Botrytis fabae*) were found throughout the northern region, particularly in early sown crops. Timely fungicide applications were able to control disease development in most cases.
- High incidences of uncommon leaf blight symptoms were noted at several sites in NSW and Queensland. The disease was identified as Stemphylium blight, caused by generally saprophytic *Stemphylium* spp. Evaluation of disease screening nurseries sown at the NSW DPI Liverpool Plains Field Station (LPFS) showed a wide range in susceptibility in the faba bean germplasm pool, with the recently released variety PBA Warda(b) among the more susceptible genotypes. Currently little information is available on crop losses or management options. However, initial research indicates that the disease would only cause problems in very wet years.
- Trials at LPFS showed substantial yield gains from foliar disease management after fungicide applications, even on the newest, more disease resistant, varieties.
- Only low incidences of rust (*Uromyces viciae-fabae*) were reported in commercial fields of faba bean. This is likely the result of the frequent fungicide applications used to control leaf blights.
- The dry 2015-2016 summer and the wet 2016 winter season reduced aphid populations resulting in the near absence or viruses in northern faba bean crops.
- Following the wet 2016 season, inoculum loads of residue-borne diseases (chocolate spot, Ascochyta blight, rust and – likely – Stemphylium blight) will be high at the start of the 2017 season. Growers are advised to adhere to the recommended disease management strategy for faba bean diseases. Especially important will be the early (6 – 8 leaves) fungicide application. Mancozeb is still the recommended product for the first application, because of its broad spectrum and absence of restrictions on number of applications.

Development of faba bean diseases in the 2016 season

Among the winter pulses, faba bean is the preferred cropping option in the high rainfall zones and for soils that are prone to water logging. However, high rainfall seasons also provide an environment that is favourable for the development of fungal pathogens. Both rust (*Uromyces viciae-fabae*) and chocolate spot (*Botrytis fabae*) have caused significant yield losses over the past years in faba bean in the northern grain region. While rust can be observed in most seasons (even in those with relatively low rainfall), incidences are generally kept below critical levels by the improved resistance in new varieties and by timely fungicide applications. Chocolate spot is typically only of importance during wet seasons, but has then the potential to cause complete crop failure in a few days. Chocolate spot has a very short latent period (1-3 days compared to at least 10 days for rust) and

unlike the obligate rust pathogen, the necrotrophic chocolate spot pathogen grows and sporulates on senescent and dead leaf tissue, thereby massively increasing inoculum loads in the crop. While new faba bean varieties released for the northern region have increased levels of rust resistance, less progress has been made in combining improved chocolate spot resistance with local adaptation.

Proper control of foliar diseases requires timely application of appropriate fungicides when the disease is detected and rainfall events are predicted. Proper diagnosis of the disease is of crucial importance, eg early symptoms of chocolate spot (brown pin-point lesions) can be confused with symptoms caused by spray oils or abiotic stresses or by symptoms caused by other leaf blights.

Fungicide options in faba bean are currently limited. Mancozeb is often the preferred product because of its broad action and the absence of limits on usage frequency. Carbendazim and procymidone are reported to be better options for chocolate spot control, but our fungicide efficacy trials over the past season (results not reported here) showed that both chemistries have no effect on rust development. The same trials showed efficacy of chlorothalonil on both rust and chocolate spot and a superior control of rust by tebuconazole. Use of tebuconazole on faba bean is currently on permit, but restricted to a maximum of three spray treatments per season, at an interval of 14 – 21 days between consecutive sprays. (Permit no: 13752).

Based on our surveys and on samples submitted by growers and agronomists, the important diseases during the 2016 were chocolate spot and (to a lesser extent) Stemphylium blight (see below). Rust was found in very few commercial faba bean crops and did not develop to levels that limited yield. No other leaf blights, like Ascochyta blight or Cercospora leaf spot, were identified. Climatic conditions did not favour aphid development or movement; consequently viruses did not play a role in the 2016 season.

Stemphylium blight

Symptomatology, losses and control options

Unusually high incidences of leaf blight symptoms were observed on faba bean during the 2016 growing season. The symptoms were identified as Stemphylium blight (StB), a disease known to affect lupins and lentils, but rarely reported in faba bean. Several *Stemphylium* species have been reported as the causal agent in lupins and lentils. Species identity of faba bean isolates from different locations in NSW and Queensland is currently being determined by USQ and QDAF using molecular tools.

Early in the season Stemphylium blight was frequently misdiagnosed by growers and advisors as chocolate spot and symptoms can at times be confusing. However, chocolate spot typically starts as small discrete reddish-brown leaf lesions that after extended periods of leaf wetness increase rapidly in size, move to other plant parts and cause severe leaf necrosis, stem collapse and flower and pod abortion. Stemphylium blight is characterised by large grey-black necrotic lesions, often starting from the leaf edge and restricted to leaves and, to a lesser extent, stems. No symptoms were noted on flowers or pods.

Little is currently known about the effect of StB on faba bean yields. However, high incidences on individual plants could be noted in early August, which would have the potential to reduce yields. A preliminary yield loss estimate was made using the varieties PBA Nasma(D) and PBA Warda(D) grown in non-fungicide treated plots at LPFS. On 12 August in each of three plots of each variety, 10 severely (>25 % affected leaf area) blighted branches were labelled as well as a neighbouring unaffected branch. The 120 labelled branches (30 severely affected and 30 non-affected of each variety) were individually harvested and yield parameters measured. Number of pods, number of seeds and seed weight of affected branches was reduced to half of that of non-affected branches (Table 1). These figures are indicative only and likely to represent a 'worst case' scenario, as faba bean can generally compensate early damage by increased branching of neighbouring non-affected plants.

Table 1. Comparison of severely Stemphylium blight affected (s/a) and non-affected (n/a) branches of two varieties grown in non-fungicide treated plots at the Liverpool Plains Field Station, 2016.

	Pods / branch		Seeds / branch		Seed weight (g) / branch	
	n/a	s/a	n/a	s/a	n/a	s/a
PBA Warda(l)	13	7	33	17	21	11
PBA Nasma(l)	10	4	23	10	18	7

No information is as yet available on the efficacy of fungicides for the control of Stemphylium blight on faba beans, lentils or lupins. Our initial results (not reported here) indicate that out of the currently registered fungicides, the application of tebuconazole resulted in lower incidences, but further trials are necessary before reliable recommendations can be made and tebuconazole is not registered for the control of Stemphylium blight in faba beans.

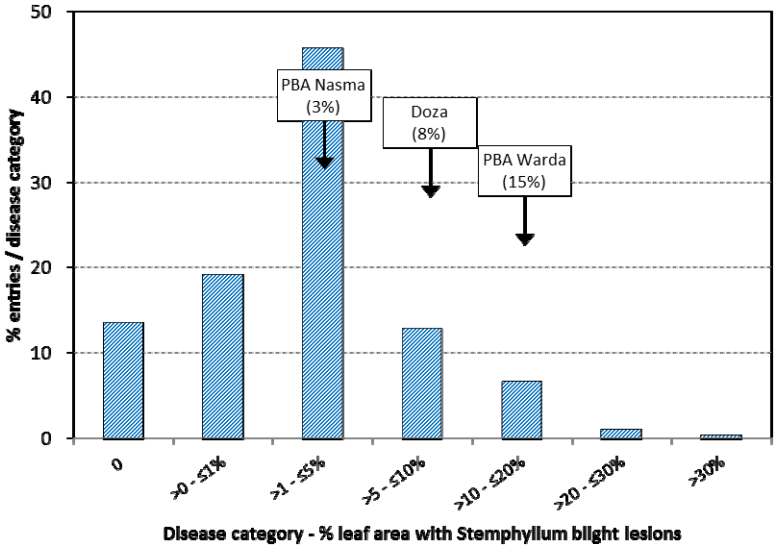

Figure 1. Distribution of 443 faba bean genotypes over Stemphylium blight scoring classes, with %leaf ratings for three current varieries seperately listed, Liverpool Plains Field Station, 10 August 2016

Varietal differences

The evaluation of 443 faba bean genotypes in the disease screening nursery at LPFS showed a non-symmetrical distribution over Stemphylium blight incidence classes, with only 37 entries showing more than 10% blight severity (Fig. 2). The recently (2012) released variety PBA Warda(l) (now the most widely grown variety in the northern region) was among the more affected (15% severity), while PBA Nasma(l) and Doza(l), the other two widely grown varieties in the northern region, had lower levels of infection.

Distribution of the disease within and between plots pointed to a high degree of genetic control. Greenhouse screening tests are ongoing, but initial results confirmed the very large differences in Stemphylium resistance observed in the field among as well as within breeding lines. Clear differences among single plant progenies taken from inbred lines indicate that the resistance is based on a single gene or only a few genes. This is unusual for a saprophytic pathogen, but a similar basis of resistance is operating in the narrow-leaf lupin gene pool against the grey leaf spot disease, which is also caused by a *Stemphylium* spp.

Conclusions

The appearance of Stemphylium blight during the 2016 season is most likely a combination of a very wet season and the growing of a susceptible variety. While the disease will have caused yield losses in severely affected sites, the confusion of Stemphylium blight symptoms with those of other leaf blights (particularly chocolate spot), resulted in unnecessary fungicide applications.

Resistance screening trials are continuing to eliminate from the breeding program highly Stemphylium blight susceptible genotypes. Fungicide efficacy trials are planned for the 2017 season that would allow better recommendations for control as well as providing yield loss data.

Disease tolerance trials

A set of 12 faba bean genotypes, consisting of 6 widely grown varieties (in both the southern and northern region) and 6 advanced breeding lines was tested for tolerance to rust and other diseases at the Liverpool Plains Field Station (LPFS). A split plot design was used with fungicide treatment vs untreated control as the main plots, genotypes as subplots, 3 replicates and a plot size of 15m^2. The trial was located close to the rust inoculated disease screening nursery which provided a heavy rust inoculum load throughout the season.

Fungicide (mancozeb 750 g ai / kg product, applied at 1 kg product / ha) was applied 4 times prior to predicted significant rain events (Figure 1).

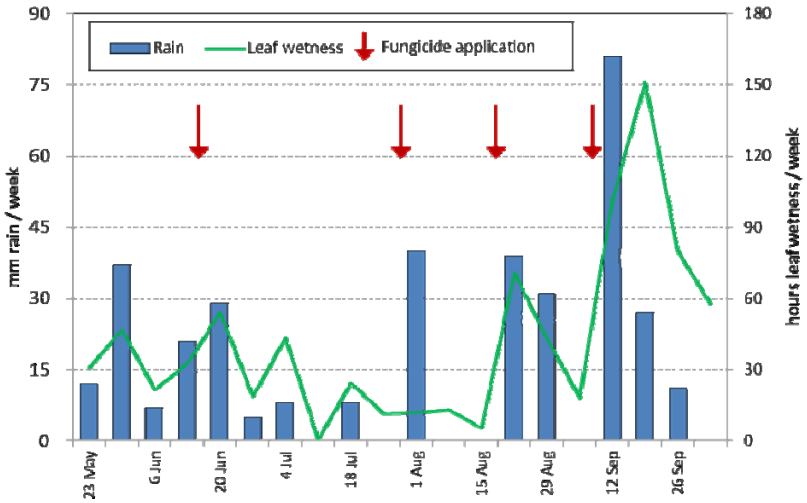

Figure 2. Liverpool Plains Field Station, 2016. Weekly rainfall, weekly hours leaf wetness, timing of fungicide applications

Disease severity (% leaf area affected) was determined on a plot basis by taking the average of two estimates taken on the centre plot row 1 m from the plot edge on both sides of the plot. Figures 2-4 summarise disease readings and yield components of the 6 released varieties and a highly Stemphylium blight susceptible breeding line.

Rust development started early in the season and high rust incidences were noted, particularly on the rust susceptible variety Fiesta. Disease severity readings on 10 August showed a large reduction of rust following the fungicide applications, but no effect of mancozeb on Stemphylium blight (Figure 2). The large differences in Stemphylium blight severity observed among genotypes in the LPFS disease screening trial was also evident in this trial with the breeding line AF11212 showing a very high degree of susceptibility.

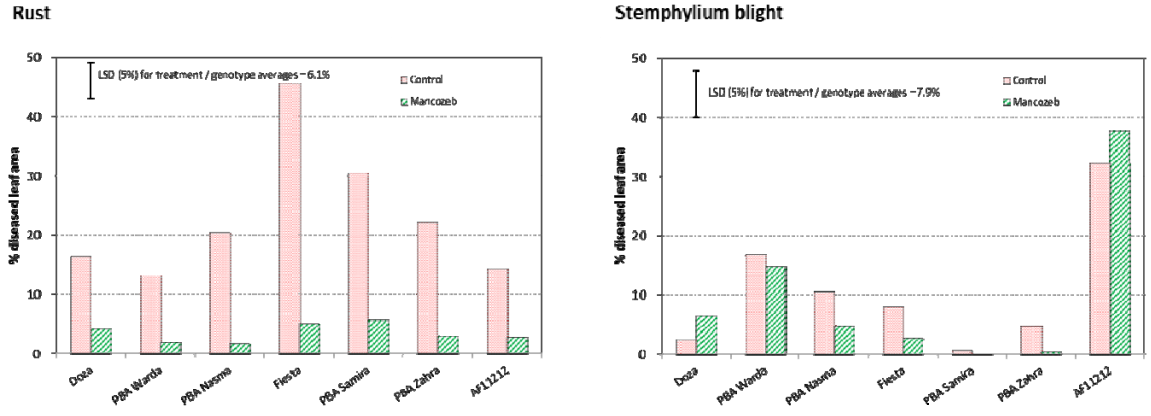

Figure 3. Faba bean disease tolerance trial, Liverpool Plains Field Station, 2016. Rust and Stemphylium blight severity (% leaf area affected) on 10 August.

Later in the season Stemphylium blight symptoms remained largely at the base of the plants and did not progress to younger leaves. High rainfall during the second half of August and early September favoured further spread of rust and, especially, a rapid development of chocolate spot. Mancozeb applications kept rust at low levels, but control of chocolate spot was unsatisfactory (Figure 3).

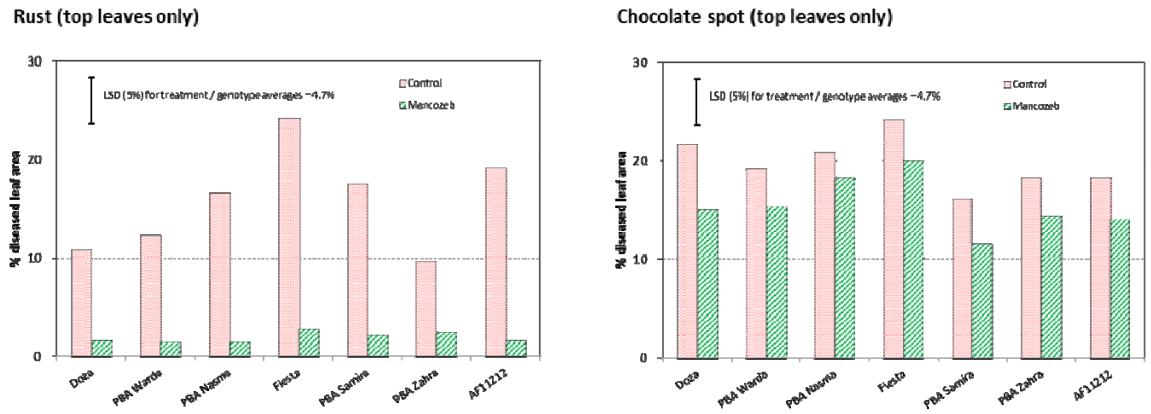

Figure 4. Faba bean disease tolerance trial, Liverpool Plains Field Station, 2016. Rust and chocolate spot severity (% leaf area affected) on 27 September.

Averaged over the 7 entries, the fungicide applications resulted in a 65% increase of yield. The largest increase in yield was on the highly rust susceptible variety Fiesta, but - surprisingly - significant yield gains were as well recorded on varieties with a high level of rust resistance like Doza, PBA Warda and PBA Zahra. No effect of the fungicide application on seed weight was evident. It is interesting to note that the advanced breeding line AF11212, which was severely affected by Stemphylium blight early in the season, ended as one of the better yielders of the trial with and without fungicide application. Proper Stemphylium blight yield loss experiments are needed before definitive statements can be made, but this could indicate that early infection by Stemphylium blight may not have a large impact on final grain yield.

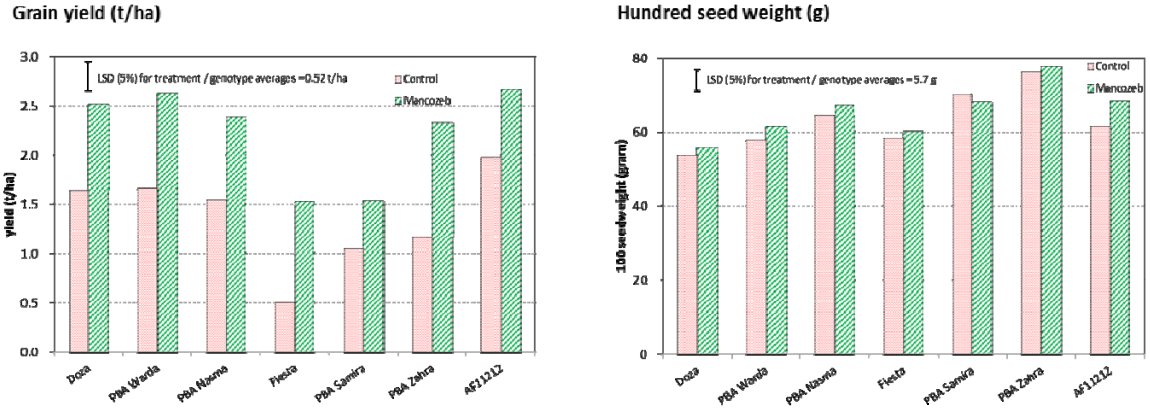

Figure 5. Faba bean disease tolerance trial, Liverpool Plains Field Station, 2016. Grain yield and seed weight.

Acknowledgements

The reported research was made possible by the significant contributions of growers through their involvement in disease surveys and submitting of samples and their support of the GRDC. The authors would like to thank them for their continued support. We also acknowledge the faba bean pathology team at the Tamworth Agricultural Institute (Jule George, Stuart Marshman, Merv Riley, Janine Sipple and Ivan Stace) for their enthusiastic technical support. We like to thank Raechelle Grams from the University of Southern Queensland and Yu Pei Tan of DAFQ for their ongoing work using molecular techniques to identify the causal *Stemphylium* species.

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Soil organic matter – maximising biomass is the key

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Key words

Soil organic matter, nutrition, biomass production

GRDC code

DAQ00182

Take home message

Soil organic matter (SOM) is critical for healthy soils and sustainable agricultural production. Growers understand that crops grown in healthy soils perform better and are easier to manage. Levels of SOM are measured by soil testing for soil organic carbon (SOC), as SOM is composed of approximately 60% carbon. Levels of SOC have decreased under cropping systems. As a result this has reduced soil nutrient reserves meaning a greater reliance on fertilisers. Questions are often asked about how SOC levels can be increased. The simple answer is; maximise biomass production via good agronomy.

SOM is critical in the supply of nutrients to plants

Organic matter is fundamental to the physical, chemical and biological functions of the soil. In the northern grain region, SOM's major role (through its mineralisation) is providing nitrogen and other nutrients in an available form to crops and pastures. To put the value of SOM into perspective, at current fertiliser prices, every 1% of measured SOC is associated with approximately $1500- $2000 worth of nutrients. The other functions (e.g. cation exchange capacity and water holding capacity) will still be influenced with increased SOM but the impact will be largest on sandy soils.

SOM levels have decreased under cropping

Australian soils are generally low in SOM compared to world levels. Initial SOM levels are limited by biomass production (and so climate) for each land type/location. Levels of SOM have declined over the past decades under traditional cropping practices. Changes in SOM and measured SOC levels occur slowly, hence these are difficult to accurately measure in short term experiments. This project sampled and analysed over 1000 paired sites to compare Total Organic Carbon (TOC) during 2012-2015 throughout Queensland and northern New South Wales. Each comparison was taken from two varying land-use patterns with the same soil type on each property. These results confirmed TOC declined dramatically when land is cleared and continuously cropped (Figure 1). This decline affects all soil and land types but is most dramatic for the brigalow/belah soils because their starting SOC levels are amongst the highest in Australia; they have the furthest to drop.

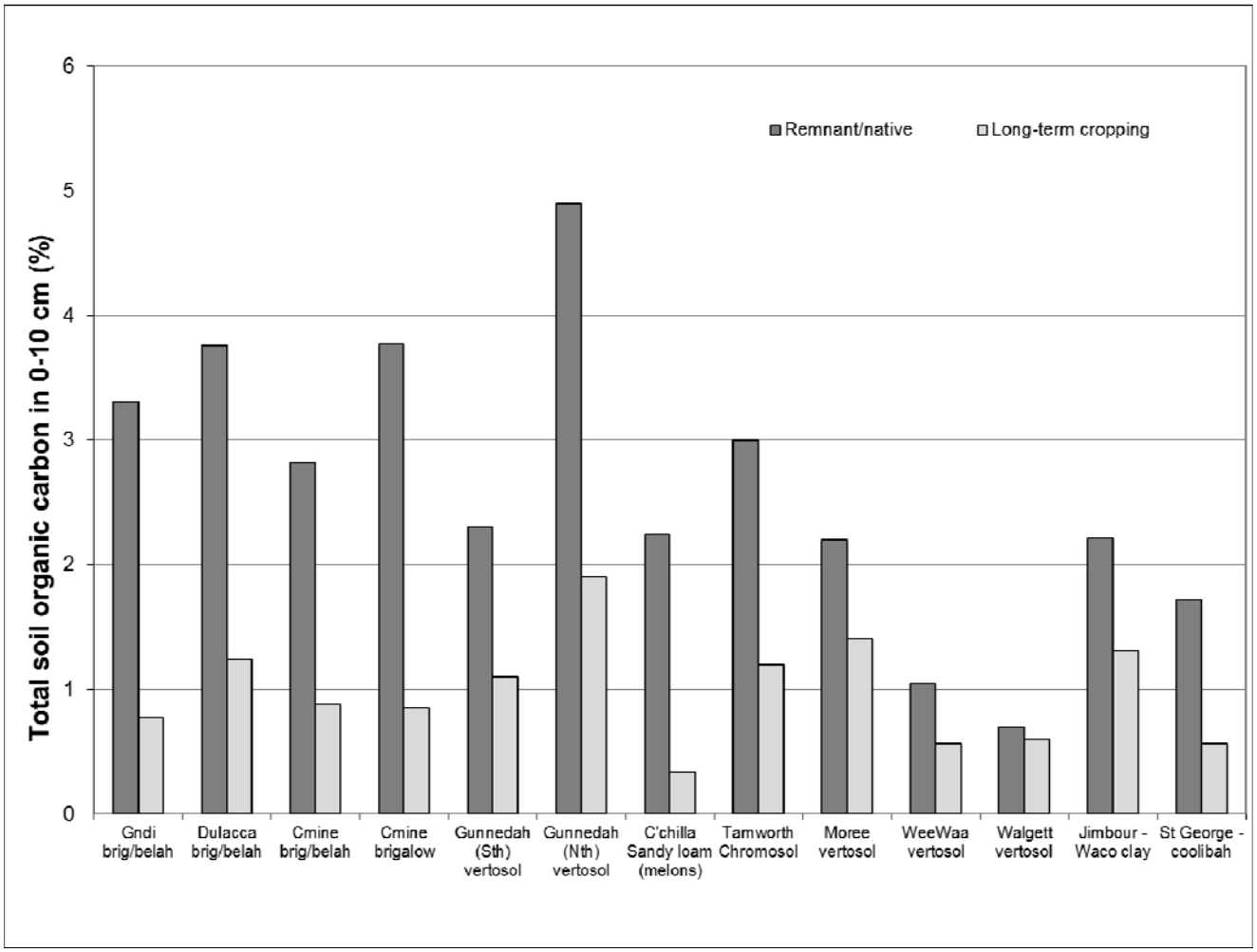

Figure 1. The decline of SOC levels in long-term cropping systems

Current SOM status

Current SOM levels are a result of the historical balance between inputs (e.g. plant residues and other organic inputs) and losses (e.g. erosion, decomposition). The detected decline in cropping systems is largely driven by the length of fallowing and most fallow rain in the northern region (as much as 75-80% in a summer fallow) is lost as runoff or evaporation. This unutilised rain does not grow biomass to replenish the organic matter reserves in the soil. However, increasing stored moisture in the fallow continues to support microbial decomposition of the SOM. This helps accumulate available nitrogen for the next crop, however, SOC levels decrease as a result. The SOM and measured SOC levels will continue to decline until a new equilibrium is reached by which biomass produced in the new farming system can sustain SOM/SOC levels.

Put simply,

'Crops may make more money than trees and pastures,
but do not return as much biomass to the soil'

Levels of SOC vary within a paddock, from paddock to paddock and from region to region. The paired site results for TOC at 0-10 cm level, also varied enormously across sites. The average was 1.46% however TOC levels ranged from 0.5% to over 5% (Figure 2). Even in their native state (under remnant vegetation) TOC levels varied with soil type and location (Figure 3). For example TOC on a brigalow soil type was higher in a wetter climate like Monto as compared to a drier climate like Roma.

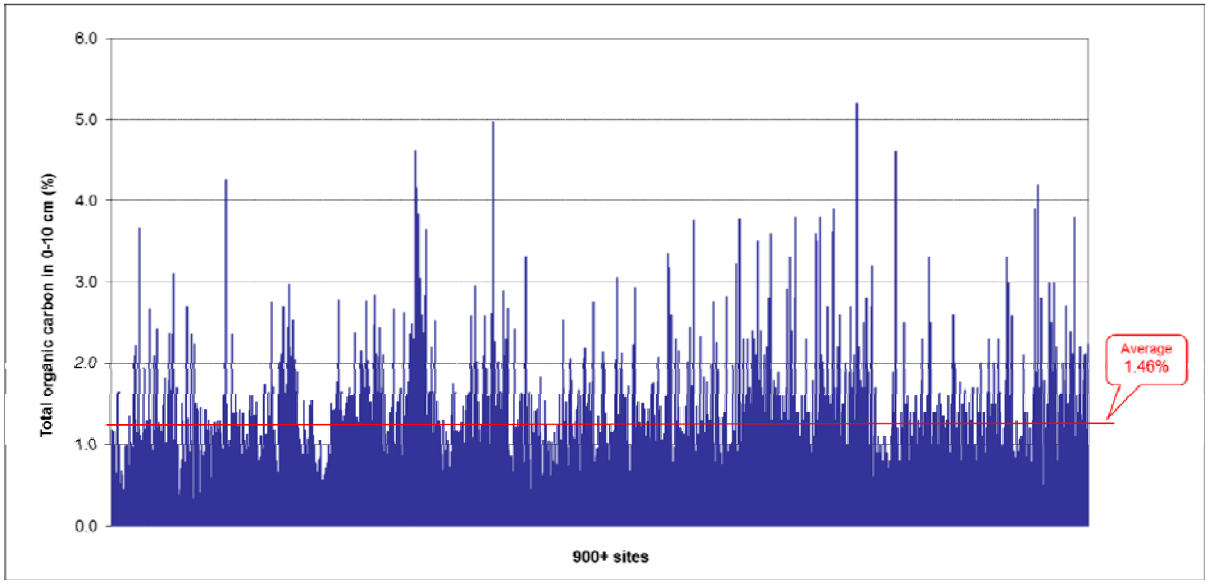

Figure 2. Soil organic carbon levels on mixed farms within the GRDC Northern Region

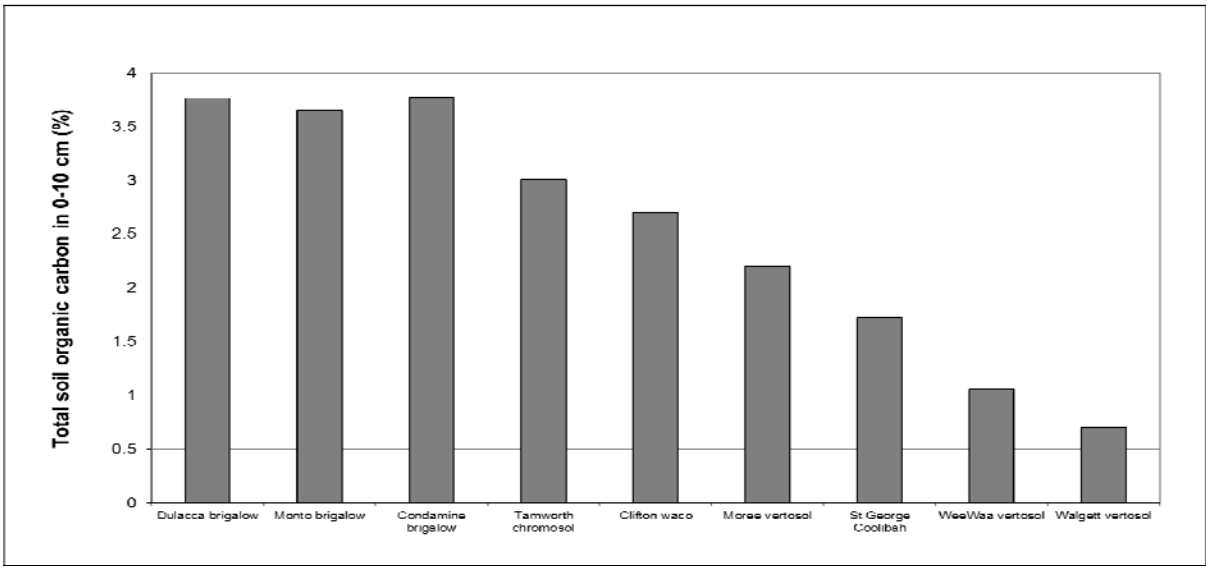

Figure 3. Impact of land-type on total soil carbon levels (0-10cm) under remnant vegetation across northern region

Lower SOM levels = higher reliance on fertilisers

The most important effect of declining SOM levels in the northern grain region is the reduction in the soil's capacity to mineralise nitrogen. This means an increased reliance on other forms of nutrient supply either from synthetic fertilisers or organic sources. To a lesser extent soil structure and soil moisture retention are also reduced.

Options for reversing the decline in SOM

Soil organic matter is an under-valued capital resource that needs to be managed. Levels of SOM (measured as SOC) are a result of a simple equation:

SOC = inputs – losses

Maximising biomass production (i.e. "inputs") and minimising "losses" such as erosion and burning/bailing will encourage higher SOC levels. Modern farming practices that maximise water-use-efficiency for extra biomass production are integral in protecting SOM. For example:

1. Growing healthier, bigger crops
2. Increasing cropping frequency (reducing fallows)
3. Adding organic matter e.g. manure/compost
4. Reducing tillage, burning and bailing
5. Pasture phases

What does current research indicate?

Paired sampling showed that returning cropping country to pasture will increase soil carbon levels (Figure 4). However there were large variations, indicating not all soil types or pastures preform the same. Soil type influences the speed by which carbon levels change, i.e. a sandy soil will lose and store carbon faster than a soil high in clay. As too does the quality and productivity of the pasture; maximising biomass production by ensuring adequate nutrition (especially in terms of nitrogen and phosphorus) will maximise increases in soil carbon over time. The most promising practice to date to rebuild soil carbon stocks in the shortest time frame appears to be the establishment of a highly productive pasture rotation with annual applications of nitrogen fertiliser.

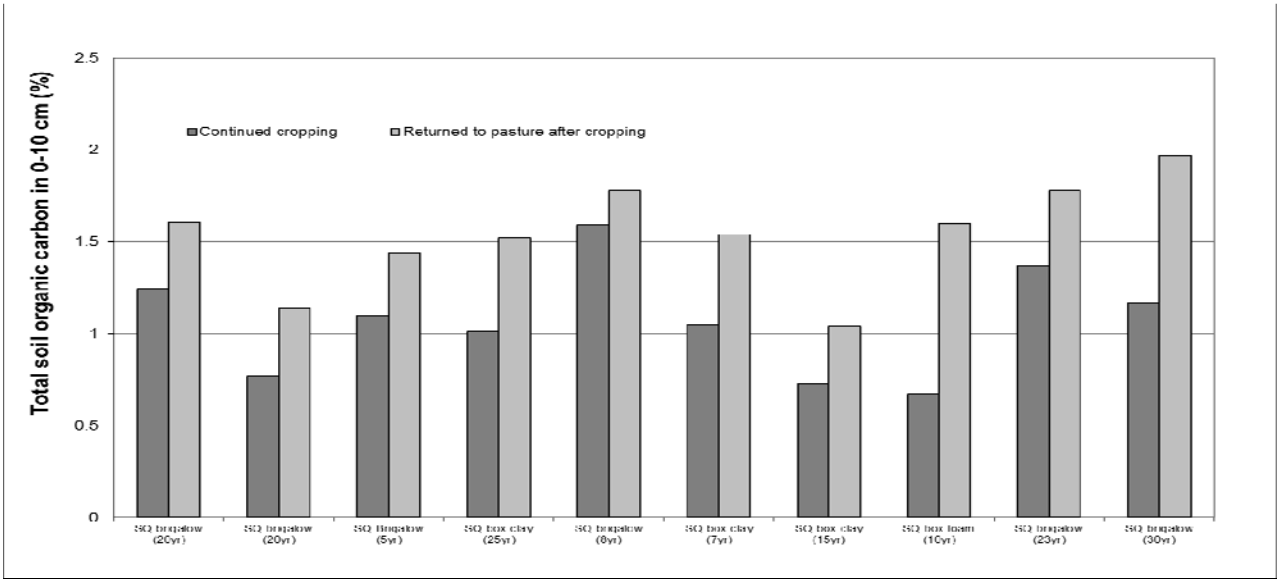

Figure 4. Total organic carbon comparisons for croplands resown to pasture

A trial conducted in Chinchilla, Queensland (2013-2016) on a previously cropped 18 month old Rhodes grass pasture on sandy loam showed the application of 50 and 100 kg N/ha/yr provided 7.8 (~100%) and 14.6 (~200%) tonnes of additional biomass respectively (Figure 5) than the unfertilised pasture. The measured average TOC levels at the beginning of the trial were extremely low (0.22% 0-10cm and 0.12% 10-30cm) reflecting the impact long term cropping has on SOC levels on a light soil. Testing was conducted again at the completion of the trial in August 2016. The mean TOC in the 0-10 layer increased from this very low base by 64% (p=0.000) with four years of pasture growth. However, there was no significant change in 10-30 cm, most likely due to the short term nature of the trial. This change in TOC resulted in significant increases in mean carbon stock (t/ha) to 30 cm across all treatments of 29% (Table 1). The addition of nitrogen fertiliser had a significant increase on both SOC 0-10cm (p=0.000) and carbon stocks to 30cm (p =0.009). There was also an apparent increase in final carbon stocks as the amount of applied nitrogen fertiliser increased (e.g. 100 kg N/ha increased carbon stocks by an average 44% but this was not statistically significant during this short-term trial (Table 2). If real, it is calculated that the 50N treatment had the potential to generate an additional $784/ha of income over the 4 years, or $584/ha ($145/ha/yr) in additional profit, whilst the 100N treatment had the potential for $1460/ha in additional income or $1060/ha

($265/ha/yr) in profit compared to the unfertilised pasture.[2] If this pasture could be utilised by cattle this is a win-win situation economically and in terms of improving SOM.

[2]Calculated using 12:1 Food Conversion Efficiency (FCE), a live weight beef price of $3/kg, and assuming 40% of additional dry matter is consumed it is possible to estimate the economic benefit of these treatments, with urea at $400/t.

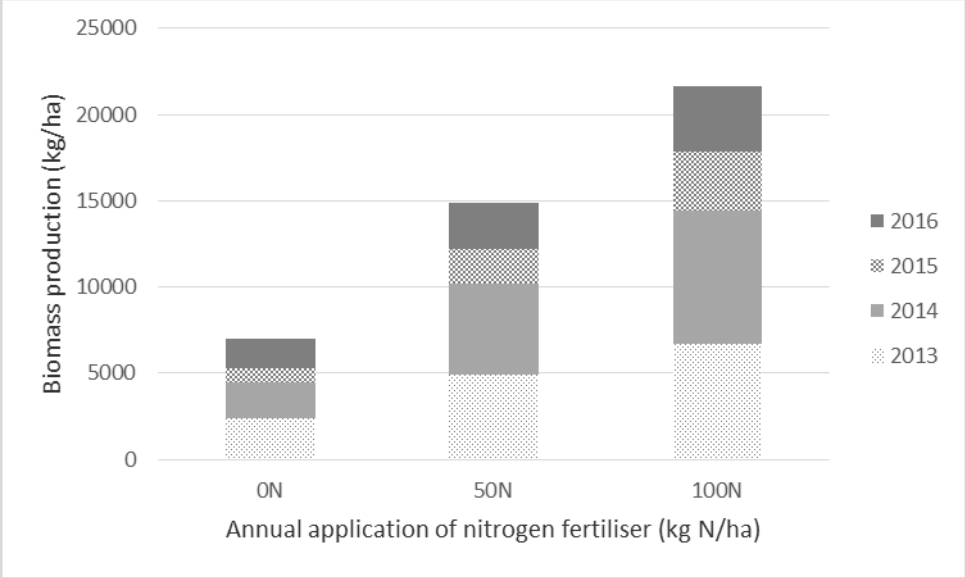

Figure 5. Impact of applying annual applications of nitrogen to grass only pasture – Chinchilla Qld

Note: 2015 season had a dry summer and the 2016 season was cut short due to pig damage

Table 1. TOC and carbon stock in averaged across site (BD (0-10) = 1.31; BD (10-30) = 1.53)

Trial average	Start (2013)	Finish (2016)	% change	P<0.01
TOC 0-10 cm (%)	0.22	0.36	64	yes
TOC 10 – 30 cm (%)	0.12	0.14	17	no
Carbon stock (t/ha)	6.90	8.89	29	yes

Table 2. Change in carbon stock (BD (0-10) = 1.31; BD (10-30) = 1.53)

Treatment	Start (2013)	Finish (2016)	% change
0 N	7.46	8.89	19
50 N	7.49	9.54	27
100 N	5.75	8.26	44

These results are consistent with the paired site data indicating that the quality and productivity of a pasture is directly related to the increase in SOC. Data from a similar trial at Brigalow on a brigalow/belah clay soil, is currently being analysed.

The addition of organic matter in the form of manure or compost is another method to boost SOM levels. A trial at Warra, Queensland, investigating the impact applying manure versus equivalent granular fertiliser rates had on SOC levels was conducted from 2013 – 2016. Results showed at commercial rates of manure application (5t every 3 years) there were no difference between treatments in biomass, yield or SOC. However, paired site testing has shown that farming systems that apply large amounts of organic fertilisers regularly under high production systems can increase SOC levels.

Considerations when testing SOC

It is critical to test for SOC correctly to track changes in SOM and ensure meaningful results that can be accurately interpreted. Soil is normally collected in two increments; 0 – 10 cm and 10 – 30 cm. The number of samples collected will be determined by the size of the paddock to ensure accurate representation. Avoid atypical areas including headlands and areas close to tree lines. Do not include crop residues as these are not a part of the SOM system at this point in time. Note: if monitoring for carbon trading there are specific guidelines please visit www.environment.gov.au/climate-change/emissions-reduction-fund for details.

There are various types of analyses available:

1. Total Organic Carbon (TOC) - will provide a measure of all the carbon from an organic source. This contrasts with Total Carbon which also measures inorganic $CaCO_3$ on high pH soils and can provide very high carbon test results
2. Walkley-Black – used in the past (about 85% of TOC) Caution: be careful when comparing old soil tests to current tests
3. Particulate Organic Carbon (POC) – measures the more labile, active carbon fraction which occurs in small particle sizes
4. Microbial Biomass Carbon (MBC) – measures the total amount of microbes in the soil
5. Fluorescein diacetate hydrolysis (FDA) – measures microbial activity as not all microbes are alive and active

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General plenary session day 2

Understanding and interpreting weather and seasonal climate forecasts - the role of the Indian Ocean Dipole as a driver of climate in Northern NSW and Qld

Jon Welsh, CottonInfo, CRDC Narrabri NSW

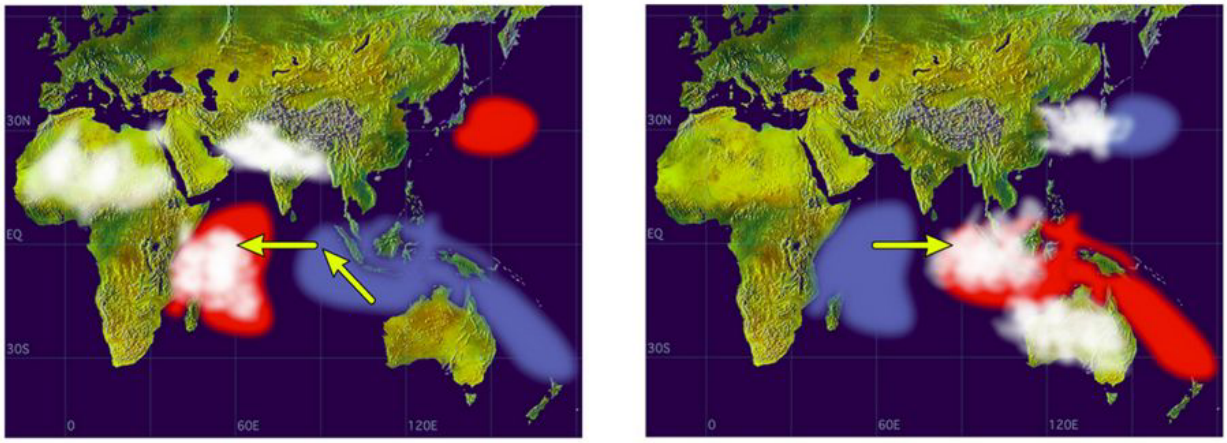
Key words

Climate, IOD, rainfall, risk management, wheat yield, seasonal forecasting

Take home message

- The Indian Ocean - discovered in 1999, is an important driver of soft-season rainfall during the months of June to October.
- The various dipole modes of the Indian Ocean operate independently of El Niño Southern Oscillation and influence the atmospheric moisture circulation patterns in the northern grains region.
- The Indian Ocean Dipole (IOD) has become more dominant as a driver of rainfall and temperature in frequency and intensity since the 1970s.
- The Indian Ocean plays a major role in Australia's entire wheat crop; during IOD positive (dry) events yields are reduced by 28%, and IOD negative (wet) events wheat yields can increase by 13%.

1. Back to Basics: what is the IOD?



Positive IOD Phase Negative IOD Phase

Figure 1. The left image showing the distribution of warm water and easterly moisture circulation during positive Indian Ocean Dipole Mode. The right image shows warm water and moist, westerly winds around Australia during a negative IOD event.

2. Circulation patterns during positive IOD events reduce moisture availability

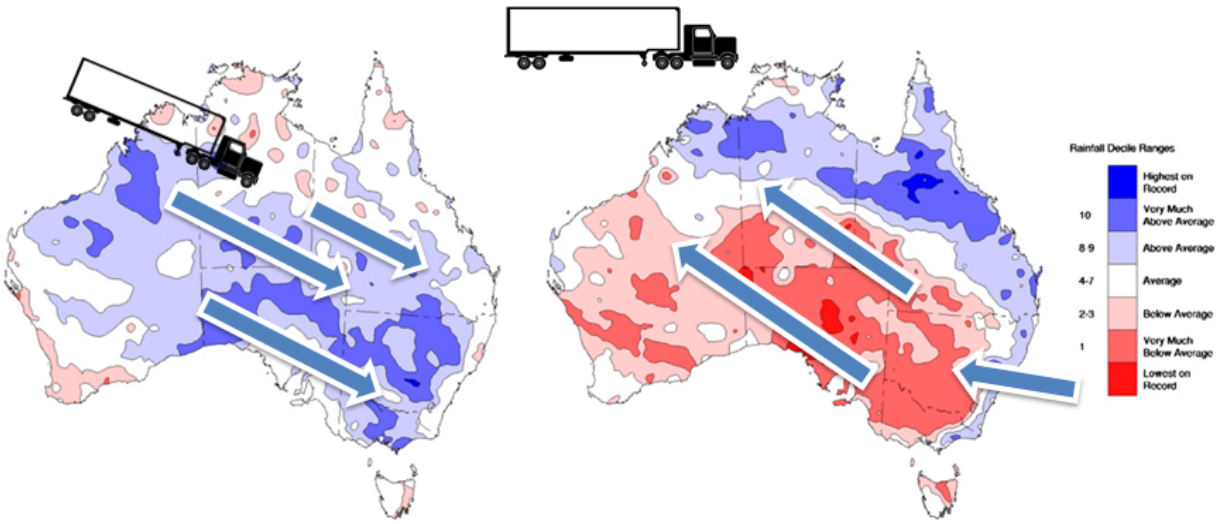


Figure 2. Australian rainfall deciles for Jun-October during the anomalous years (left) 1993 (El Niño and negative IOD) and (right) 2007 (La Niña and pIOD).

3. Climatic indicators and Australian wheat yield

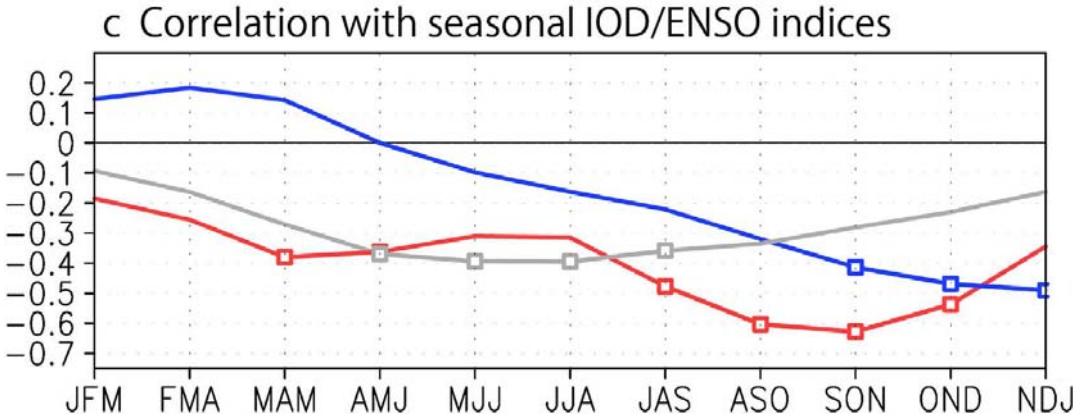


Figure 3. Australian wheat yield correlation co-efficients with the three-month-running mean indices of IOD (red line), Niño 3 (blue line) and ENSO Modoki (grey line). Correlation co-efficients achieve 95% significance where squares are open. National wheat yield has the strongest connection with the Indian Ocean Dipole during winter and spring seasons.

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Can we refine planting dates further?

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Key words

Planting date, frost risk, heat risk, optimum flowering window, elevation

GRDC code

AMPS00010

Take home messages

- Of all the agronomic "levers" available to growers planting date still offers one of the greatest abilities to increase yield potential.
- There are drastic changes in frost risk with only small changes in elevation (20-50 m), which presents significant opportunity to push planting dates forward without necessarily increasing frost risk.
- Lower points in the landscape/paddock have more frost events with greater duration compared to higher elevations. Therefore there is slower accumulation of growing degree days at these lower points in the landscape, consequently slowing the development of the crop.
- There is little variation in maximum temperature across elevations. Therefore in lower parts of the landscape, where the frost risk persists longer into the season, the heat stress will start at the same time as higher elevations. This narrows the window for optimum conditions for flowering crops.

Introduction

Major management "levers" that can be manipulated to achieve yield potentials include planting date, planting configuration (row spacing and seeding rate), variety choice, disease and weed control, nitrogen, phosphorus and other nutrition. Of these "levers" planting date can have the greatest impact achieving yield potential and is one of the few management tools that can be changed with negligible additional costs to the grower. The degree that planting date will determine grain yield potential will be greatest in dry and hot springs and least in wet and mild springs.

Planting date determines when the plant will reach anthesis. Pushing sowing dates earlier increases yield potential through increased biomass accumulation and by extending the length of grain filling period under cooler spring temperatures. However, earlier planting dates also increase the risk of incurring a frost during flowering. Sowing later to minimise frost risk then pushes crops to grain fill under hotter spring conditions leading to lower yield potentials. The key question is are we losing yield with current grower sowing dates and what other tools are available to manage our sowing dates as early as possible without taking on board unacceptable frost risk. Growers generally take a conservative approach to planting date as the fear of frost damage influences their decisions to a greater extent than the often intangible yield loss from heat stress during grain fill.

Currently growers and agronomists rely heavily on previous experience, local weather station data, sowing guides and predictive models such as Climate or APSIM to determine planting dates. The problem for growers and agronomists is that typically the local weather stations are located some distance from paddocks or farms which then requires a degree of interpellation. Models are also based on these weather stations as well, which means growers can only use results as a guide. In relatively flat areas like Walgett the individual farm variation from the weather station may be very

small. For other locations like the Liverpool Plains where there is a large variation in elevations there is likely to be large differences across farms in their temperature regime as compared to the Gunnedah or Quirindi weather stations.

This project aims to reduce some of the interpellation required by growers and agronomists by looking at the impact that elevation has on frost risk and subsequently planting dates across different elevations. However, the project hasn't taken into account other factors that will influence frost risk or cold air drainage such as aspect, drainage, tree lines and the point in the landscape. The data produced from this project could be used in models to enable them to better predict frost risk and planting dates across the landscape rather than localised near a weather station.

What has been done?

In 2014, 2015 and 2016 two paddocks containing significant elevation differences (20 – 45m) were selected, one near Gurley and one on the Liverpool Plains. In each paddock a site was selected at the top of the slope and a site was selected at the bottom of the slope. Tiny Tags were installed along with rain gauges at both sites in each paddock to record temperature (every 15 minutes) and rainfall. Six wheat varieties including LPB Dart(Þ), LPB Spitfire(Þ), Suntop(Þ), LPB Lancer(Þ), EGA Gregory(Þ) and EGA Eaglehawk(Þ) were planted on three planting dates (Approximately Last week of April, Mid May and Early June for all trials) at both sites. Regular phenology measurements were taken to ascertain development difference both between varieties but also between top and bottom slopes. A summary of the site planting dates and elevation differences is given in Table 1.

Table 1. Details of planting dates and elevation differences at each site between 2014 and 2016

	Premer 2014	Gurley 2014	Spring Ridge 2015	Gurley 2015	Premer 2016	Gurley 2016
Planting Dates	30th April 20th May 13th June	26th April 16th May 11th June	30th April 19th May 11th June	26th April 15th May 8th June	29th April 18th May 13th June	30th April 17th May 10th June
Elevation Difference	401-377 (24 m)	271-302 (32 m)	354-309 (45 m)	306-263 (43 m)	384-404 (20 m)	309-274 (35 m)

Trial results

Estimations of starting plant available water (PAW) indicated that although profiles were similar between top and bottom slope at all sites the bottom slope generally had slightly higher starting PAW between 2 and 20 mm more than the top of the slope. In 2015 and 2016 the starting PAW was approximately 70 to 90% full at the Liverpool Plains and Gurley sites, however, in 2014 starting PAW was closer to 50% full at both locations (Table 2). Similar to starting PAW the measured available soil N values were generally slightly higher at the bottom slope sites compared to the top of slope sites containing an additional 2-17 kg N/ha available at the start of the season (Table 2).

The elevation differences at both sites resulted in significant variation in temperature over the season. Average minimum temperatures across all three years were 2.4 and 2.9°C lower at the bottom slope compared to the top slope at the Liverpool Plains and Gurley, respectively, whereas average maximum temperatures were similar for both top and bottom slopes (Table 2). The differences in average minimum temperatures was exemplified by the differences in frost events (<0°C) with bottom slope at the Liverpool Plains and Gurley. At Spring Ridge and Premer in 2014, 2015 and 2016 the bottom slope experienced an additional 27, 35 and 28 frost events, respectively, compared to the top slope (Table 2). At Gurley in 2014, 2015 and 2016 the bottom slope experienced an additional 31, 29 and 36 frost events, respectively, compared to the top slope (Table 2). There were not only more frosts at the bottom slope sites but frosts had a greater duration. On average across years the time that temperatures were at or below 0°C at the top slope was only 36 and 7% of that measured for the bottom slope sites on the Liverpool Plains and Gurley, respectively

(Table 2). Length of the frost event can be a major determining factor of damage. On average across the three years the length of frost events at the top slope sites were 3.3 and 2.5 hours for the Liverpool Plains and Gurley, respectively. This is compared to the bottom slope sites on the Liverpool Plains and Gurley where frost events typically lasted for 4.3 and 4.6 hours, respectively. Lower average minimum temperatures and greater number of frost events both contributed to the slower accumulation of thermal time throughout the season at the bottom slope compared to the top slope. At both locations the difference in accumulated thermal time (Growing Degree Days – GDD) was in excess of 150 GDD higher at the top slope sites (Table 2).

Table 2. Soil and temperature differences between top and bottom slope at all sites from 2014 to 2016

Site	Slope	Starting PAW	Soil N (0-1.2m)	Average Min	Average Max	Frost events (<0°C)	Cum. Hours <0°C	Season GDD
Premer 2014	**Top**	139	110	5.1	24.6	31	97	1963
	Bottom	158	122	2.5	24.8	58	226	1655
Gurley 2014	**Top**	90	154	7.1	30.7	7	21	2230
	Bottom	108	145	4.4	30.3	38	184	2038
Spring Ridge 2015	**Top**	185	175	5.4	22.6	16	32	1998
	Bottom	200	192	2.6	23.1	51	243	1752
Gurley 2015	**Top**	144	104	6.4	25.2	7	17	2186
	Bottom	146	118	2.9	24.8	36	176	2008
Premer 2016	**Top**	225	125	4.9	22.8	31	132	1869
	Bottom	230	128	3.1	22.9	59	253	1655
Gurley 2016	**Top**	115	138	6.8	27.9	1	0.45	2138
	Bottom	126	142	4.3	28.0	37	143	1967

The variation of minimum temperature and ultimately GDD had significant impact on crop maturity. Despite being planted on the same day at the top and bottom slope sites the varieties, did not reach 50% flowering on the same day. An example of how visual this difference was is given in figure 1. The bottom slope sites were on average across the six varieties 13, 9 and 7 days longer than the top slope to reach flowering on the late April, mid May and early June planting dates, respectively for the Liverpool plains (Table 3). Similarly, for Gurley the differences in time taken to reach flowering were 9, 8 and 6 days longer at the bottom slope sites than the top slope for the late April, mid May and early June planting dates, respectively (Table 3). The Liverpool Plains trials were on average 17 days later to reach flowering compared to the Gurley trials across the three years (Table 3).

Table 3. Average days to flower for LPB Dart(þ), LPB Spitfire(þ), Suntop(þ), EGA Gregory(þ), LPB Lancer(þ) and EGA Eaglehawk(þ) plant across three planting dates at the top and bottom slope sites at the Liverpool Plains and Gurley.

Site	Slope	Late April	Mid May	Early June
Premer 2014	Top	131	126	116
	Bottom	147	138	127
Gurley 2014	Top	94	114	102
	Bottom	106	123	108
Spring Rdg 2015	Top	130	124	117
	Bottom	144	133	124
Gurley 2015	Top	118	109	99
	Bottom	126	116	106
Premer 2016	Top	141	132	121
	Bottom	149	135	126
Gurley 2016	Top	123	119	110
	Bottom	130	126	116

Figure 1. A visual representation of how different maturity was between top and bottom slope at Spring Ridge in 2015.

Both the Liverpool Plains and Gurley experienced hot and dry springs in 2014 and 2015 and in these seasons the real benefit of early planting was realised. For example on the Liverpool Plains at the top slope site delaying planting from late April to early June resulted in a 2.24 and 1.04 t/ha loss in grain yield when averaged across six varieties in 2014 and 2015, respectively (Table 4). Assuming a wheat price of $250/t this is equivalent to $560/ha and $260/ha increase in net returns, respectively.

Despite very favourable spring conditions on the Liverpool Plains in 2016 there was still a 1.34 t/ha yield penalty for delaying planting dates from late April to early June at the top of the slope. Again assuming a wheat price of $250/t the late April planting date allowed an additional $425/ha and $1155/ha net return to be realised, compared to the mid May and early June planting dates, respectively at the top of the slope over three years (Table 4). Frost damage did occur at the bottom slope sites on the Liverpool plains in all three years, particularly in LPB Dart(Þ and LPB Spitfire(Þ. For example LPB Dart(Þ in 2015 at Spring Ridge yielded 6.17 and 1.23 t/ha at the top and bottom slope sites, respectively (data not shown). The frost damage at the bottom of the slope reduced average grain yield of the six varieties by 1.91 t/ha across the three years (Table 4). There was minimal frost damage incurred on the two later planting dates as grain yields were similar between the top and bottom slope sites for the Liverpool plains and Gurley in all three years. Unlike the Liverpool Plains in 2016, there was no yield penalty in delaying planting date from late April until early June at Gurley (Table 4). This is compared to 2015, which had a hot dry spring, where the same delay in planting date resulted in a 1.88 t/ha reduction in grain yield (Table 4).

The optimum flowering window was retrospectively established by plotting grain yield against flowering date to see what period achieved the maximum grain yields. At Gurley in 2014 and 2015 the optimum flowering windows were generally 12-14 days from mid to late August for the top of slope site, whereas in 2016 the optimum flowering window was much wider (24 days) and began in early September (Table 4). The length of the optimum flowering window for the bottom slope site at Gurley was similar to the top slope for the respective years, however, it generally started 9-13 days later. The delayed optimum flowering window for the bottom slope sites was also observed on the Liverpool Plains where it started 10-22 days later than the top of the slope (Table 4). Optimum flowering windows on the Liverpool Plains for the top slope sites generally started around the beginning of September while the optimum flowering window for the bottom of the slope generally started around mid-September (Table 4).

Table 4. Average grain yield for LPB Dart(Þ, LPB Spitfire(Þ, Suntop(Þ, EGA Gregory(Þ, LPB Lancer(Þ and EGA Eaglehawk(Þ plant across three planting dates at the top and bottom slope sites at the Liverpool Plains and Gurley and restrospective optimum flowering times for highest yield potential.

Site	Slope	Late April	Mid May	Early June	Optimum Flowering Window
Premer 2014	**Top**	5.24	4.28	3.00	1st Sep - 12th Sep
	Bottom	4.68	4.42	3.16	10th Sep - 20th Sep
Gurley 2014	**Top**	-	1.56	1.19	18th Aug - 3th Sep
	Bottom	1.26	1.60	1.42	28th Aug - 10th Sep
Spring Ridge 2015	**Top**	5.37	4.90	4.33	25th Aug - 5th Sep
	Bottom	4.53	5.18	4.60	16th Sep - 25th Sep
Gurley 2015	**Top**	5.25	4.56	3.37	11th Aug - 24th Aug
	Bottom	4.62	5.01	3.62	24th Aug - 9th Sep
Premer 2016	**Top**	7.52	7.25	6.18	8th Sep - 28th Sep
	Bottom	7.01	7.34	6.05	20th Sep - 10th Oct
Gurley 2016	**Top**	6.32	6.41	6.57	6th Sep - 30th Sep
	Bottom	5.98	6.56	6.51	15th Sep - 30th Sep

The 2015 season data for Spring Ridge and Gurley is presented below to demonstrate how the optimum flowering window was determined and how fine the line is between frost damage, particularly at the bottom of the slope. Further the 2015 season clearly illustrates the hot dry

conditions during grain fill. At the Spring Ridge top slope the highest grain yields were achieved when varieties flowered between the 25th August and the 5th September. There were no frost events that occurred during this same period, with the last frost event occurring on the 18th August (Figure 2A). In the first week of October there were 5 consecutive days where maximum temperature exceeded 35°C (Figure 2B). Maximum temperatures exceeded 28°C everyday between the 28th September and the 22nd October (Figure 2B).

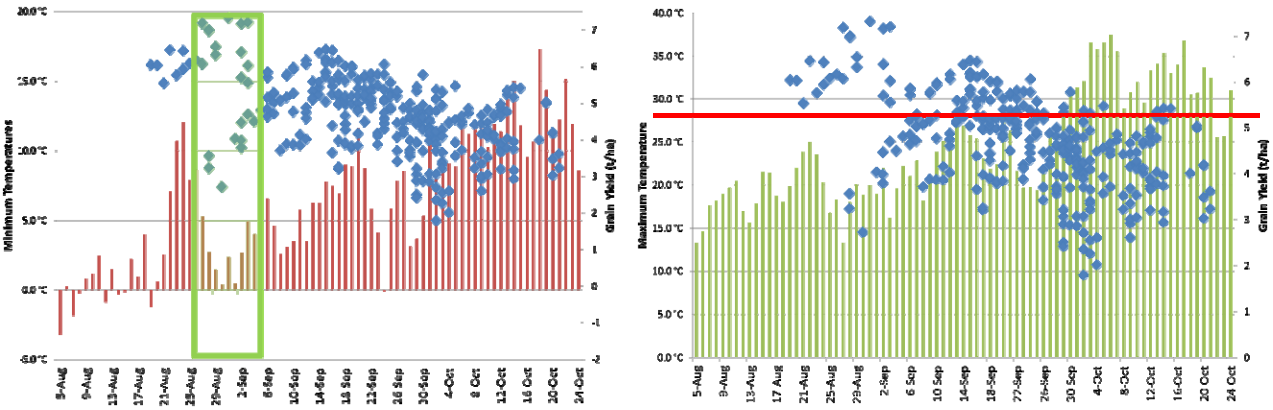

Figure 2. A) Minimum temperatures (red bars) and grain yield x anthesis date (blue diamonds) for individual plots for top slope at Spring Ridge in 2015. Green box indicates the retrospective optimum flowering date at site. **B)** Maximum temperatures (green bars) and grain yield x anthesis date (blue diamonds) for individual plots for top slope at Spring Ridge in 2015. Red line indicates 28 °C.

Retrospectively, the highest yields were achieved when varieties flowered between 15th and 25th September for the bottom slope site at Spring Ridge (Figure 3A). Unlike the top slope, the last frost at the bottom slope site occurred on the 30th September. Frost events in the last week of August appear to have had a significant impact on grain yields of varieties that have flowered prior to the 10th September (Figure 5). The extent of this frost damage was evident in LPB Dart$^{\Phi}$ in the field, where in excess of 90% of primary tillers had frost damage (Figure 3B).

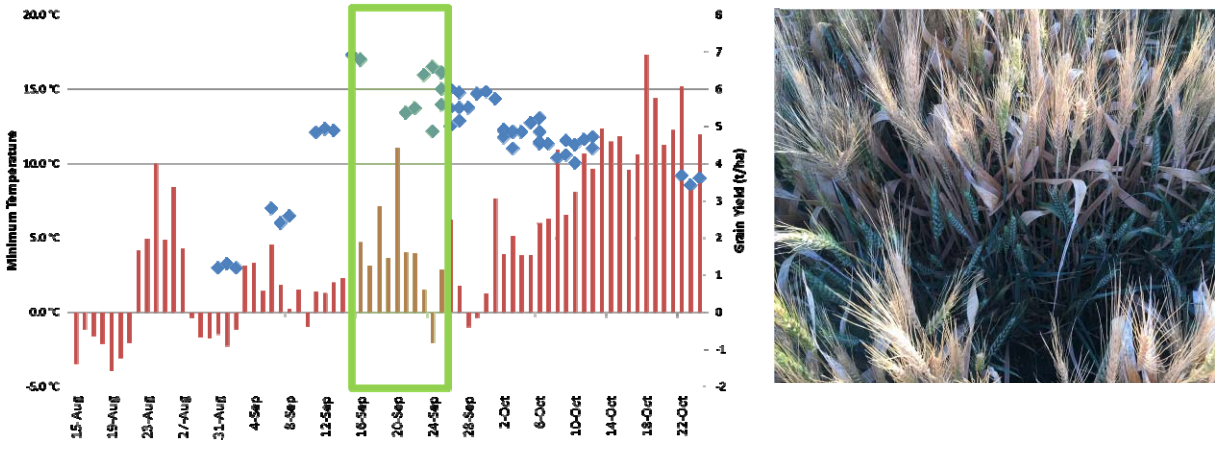

Figure 3. (A) Minimum temperatures (red bars) and grain yield x anthesis date (blue diamonds) for individual plots for bottom slope at Spring Ridge in 2015. Green box indicates the retrospective optimum flowering date at site. **(B)** Picture of frosted heads in LPB Dart$^{\Phi}$ plot at the bottom of the slope.

Maximum yields for top slope at Gurley were achieved when flowering dates occurred between the 11th August and the 23rd August (Figure 4A). There was one small frost event that occurred during this period. However, there were only two frost events that occurred near flowering that were lower than -0.5°C (28th July and 5th August) (Figure 4A). After the 28th October there were 13 consecutive

days where maximum temperatures exceeded 28°C and 4 days where temperatures exceeded 35°C (Figure 4B).

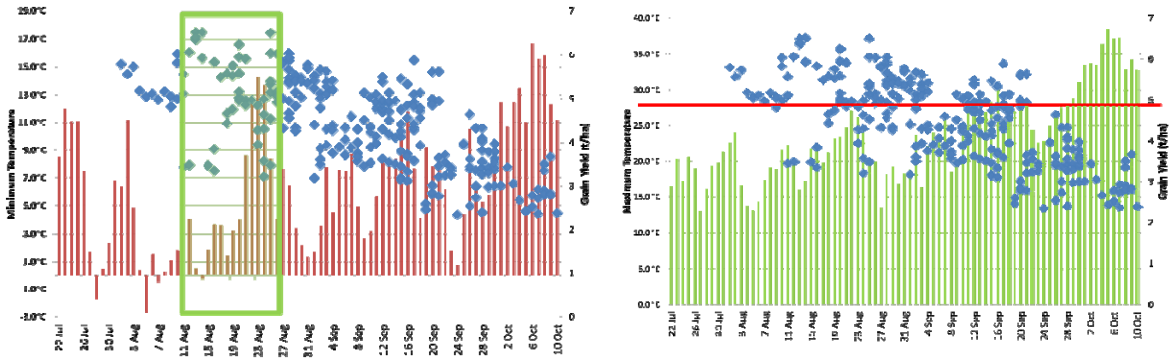

Figure 4. A) Minimum temperatures (red bars) and grain yield x anthesis date (blue diamonds) for individual plots for top slope at Gurley in 2015. Green box indicates the retrospective optimum flowering date at site. **B)** Maximum temperatures (green bars) and grain yield x anthesis date (blue diamonds) for individual plots for top slope at Gurley in 2015. Red line indicates 28 °C.

For the bottom slope the retrospective optimum flowering dates were between the 24th August and the 9th September. Interestingly, 4 frost events occurred in this same period (Figure 5). Unlike the top slope there were 17 frosts that occurred between the 27th July and the 9th August that had minimums below -0.5°C (Figure 5).

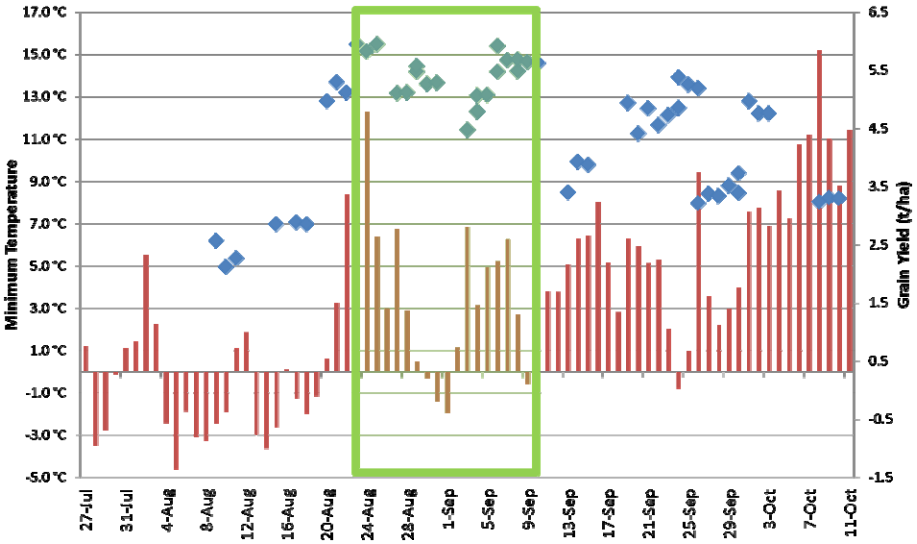

Figure 5. Minimum temperatures (red bars) and grain yield x anthesis date (blue diamonds) for individual plots for bottom slope at Gurley in 2015. Green box indicates the retrospective optimum flowering date at site

Discussion

The data collected in these trials demonstrates why there should be significant motivation to plant paddocks as early as possible to maximise optimal grain filling conditions while avoiding risk of frost damage. On the Liverpool plains assuming a wheat price of $250/t the late April planting date has created an additional $425/ha and $1155/ha net return compared to the mid May and early June planting dates, respectively at the top of the slope over three years. Even in 2016 when optimal spring conditions prevailed there was still a 1.34 t/ha yield penalty for delaying planting dates from

late April to early June at the top of the slope on the Liverpool plains. There are few other management tools available to growers that can manipulate net returns to this extent. Admittedly, the 2014 and 2015 seasons exacerbated the impact of planting date due to well below average September rain that was followed by extremely hot weather in early October. Both these factors would have contributed to restricting the grain filling period for long season varieties or later planting dates. For example at Gurley in 2015 a variety that flowered on the 20th August had an additional 31 days of favourable grain filling conditions compared to a variety that flower on the 20th September before the extremely hot temperatures started in the beginning October.

The two locations demonstrate that frost risk can vary greatly within the landscape, particularly with elevation differences. This represents an opportunity for growers to be able to plant earlier in certain parts of the landscape without necessarily increasing their exposure to frost risk. The top slope sites only had 30 and 20% of the frost events that occurred at the bottom slope on the Liverpool plains and Gurley, respectively. Not only are there less frost events but the frost severity is also greatly reduced. Top slope sites had 45% higher average minimum temperatures and only accumulated 11% of the time spent <0°C compared to the bottom of the slope when averaged across all sites and locations. The impact of this drastic difference in frost risk is evident on the April planting date in 2015 at both Spring Ridge and Gurley with the two quicker varieties, LPB Dart and LPB Spitfire. For the bottom slope LPB Dart® was 60 and 81% lower yielding compared to the top slope sown in late April at Gurley and Spring Ridge, respectively. Also on the late April plant LPB Spitfire® was 61 and 43% lower yielding at the bottom of the slope compared to the top slope site at Spring Ridge and Gurley, respectively. It was interesting to note that at both Spring Ridge and Gurley, Suntop® flowered approximately 5 days later than LPB Spitfire® yet grain yields were 2.4 and 2.7 t/ha higher, respectively. This suggests that 4-5 days difference in flowering date could be a difference of 50% in yield losses to frost damage. Varietal difference in tolerance to frost damage may in part also explain some of the differences between LPB Spitfire and Suntop. Despite the top slope sites at either Gurley or the Liverpool plains experiencing frost events during all three seasons there was not one instance where significant frost damage was recorded, even in the quickest variety, LPB Dart®. Therefore, even earlier planting dates were required at the top slope sites to incur yield penalties from frost.

The significant differences in minimum temperatures between top and bottom slope has also had an interesting impact on crop maturity. The greater number of frost events and severity has in turn slowed down the accumulation of GDD throughout the season, to the extent that the bottom slope at both locations accumulated over 150 GDD less than the top slope. As a direct result of this the crop maturity was delayed. The maturity delay is greatest on the early planting with and average delay of 11 days for varieties to reach flowering. This is interesting as the delay in maturity is actually helping to negate some of the frost risk at the bottom of the slope. In a majority of cases the optimum flowering window at both Gurley and Liverpool plains was 14 days later at the bottom of the slope compared to the top slope. Alarmingly, there were a number of instances where frost events had occurred during the optimum flowering window at the bottom slope sites for both locations. Although these frost events appear to have had little impact on grain yield in these years it does highlight the higher risk of incurring frost damage in these lower parts of the landscape. Furthermore, it highlights that frost events at lower elevations are persisting longer into the season, yet on set of potential heat stress is no different to higher elevations, thus reducing the length of the optimum flowering window.

Conclusions

As in previous experimental work these trials have demonstrated to benefits of early planting from a production and economic point of view. However, this work does demonstrate that elevation has a large impact on frost risk, which in turn represents an opportunity for growers to plant earlier in higher parts of the landscape without necessarily increasing the frost risk. Although the frost risk

changes with elevation the risk of heat stress during grain fill does not change with maximum temperatures being similar for top and bottom slope sites. Therefore lower parts of the landscape have a narrower optimum flowering window. Lower minimum temperatures and a greater number of frost events in lower parts of the landscape reduce the accumulation of GDD and hence delays crop development. Despite the delayed development there is still a need to adjust planting date to achieve an acceptable level of frost and heat risk during grain fill. The paddocks selected to conduct these trials were selected because of their large variation in elevation, however they do demonstrate how frost risk varies significantly within the landscape and how difficult it may be to interpolate frost risk/planting decisions from the nearest weather station, which could be located some distance away. It is important to remember that elevation can be used as a valuable tool to evaluate frost risk but other factors such as drainage lines, aspect, tree lines and position in the landscape also need to be considered.

Acknowledgements

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New fungicides and disease management strategies for wheat and barley

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Key words

Fungicide management strategies, Succinate dehydrogenase inhibitor (SDHI), Integrated Disease Management (IDM), Septoria tritici blotch (STB), Adult Plant Resistance (APR)

GRDC code

CUR 00019, CCDM/GRDC Programme 9, FAR 00002 & GRDC 0004-A

Take home messages

- Results with the new Succinate Dehydrogenase Inhibitors (SDHI's) have been very promising against a range of barley and wheat diseases including net blotches and scald in barley and in wheat yellow leaf spot and Septoria tritici blotch (STB).
- The wet spring encouraged greater issues with wet weather stubble borne diseases such as STB and net form of net blotch which has been more widely reported in 2016.
- 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.
- Combining two Adult Plant Resistance (APR) genes in Avocet Near Isogenic Lines (NILs) reduced the maximum yield response to stripe rust control from (significant responses) 0.98 and 0.4 t/ha where the single APR genes were used alone down to a non-significant response of 0.22 t/ha where the APR genes were combined.
- Controlled environment studies have shown that the curative activity of fungicides such as epoxiconazole against stripe rust is approximately 7-14 days depending on the mean temperature.
- 2016 research work shows that multiple APR genes reduce the need for fungicide applications.

New products for foliar disease control

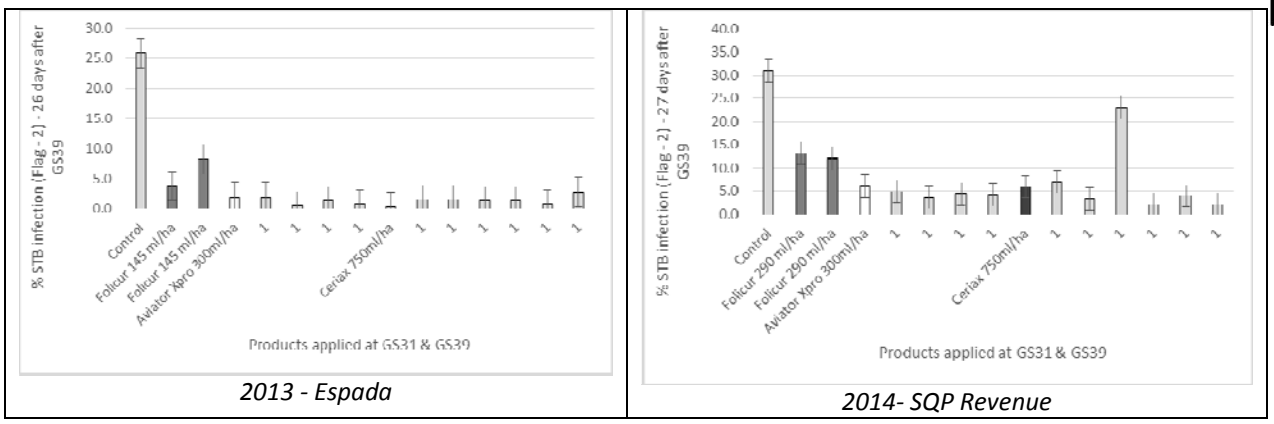
Research into new fungicide active ingredients

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 in Australia. These research projects have and continue 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 new products experimented upon. To recognise commercial sensitivities, where products have not been registered or where permission has not been given to reveal their code, fungicides have been given a treatment number (e.g. '1') in the graphs.

New products for the control of Yellow leaf spot and STB

In research work conducted on the new fungicide active ingredients, some of the new succinate dehydrogenase inhibitors (SDHI) fungicides have performed extremely well against the STB pathogen. In studies conducted on the SDHI fungicides containing bixafen and fluxapyroxad, results have been very promising against STB (Figure 1). The performance of Aviator® Xpro (containing prothioconazole & bixafen which at present is registered only for the control of blackleg in canola) and the foliar fungicide proposed to be called Ceriax (based on three active ingredients from three different modes of action epoxiconazole, pyraclostrobin and fluxapyroxad) which are currently undergoing registration, have been independently tested since 2013 in GRDC New Actives and CCDM Programme 9 field trials. (Figure 2). The same is true for independent testing carried out on YLS, where trials have shown that if infections persist through stem elongation, the new combination of SDHI with triazoles and strobilurins appear to confer a good level of disease control, although it is noticeable that the level of YLS control with fungicides does not match other diseases.



2013 - Espada

2014- SQP Revenue

Figure 1. Influence of new SDHI fungicides on % STB infection on flag -2 assessed during early grain fill (26-27 days after application of flag leaf spray in a two spray programme) – cv Espada 2013 & SQP Revenue 2014 , Southern Victoria.

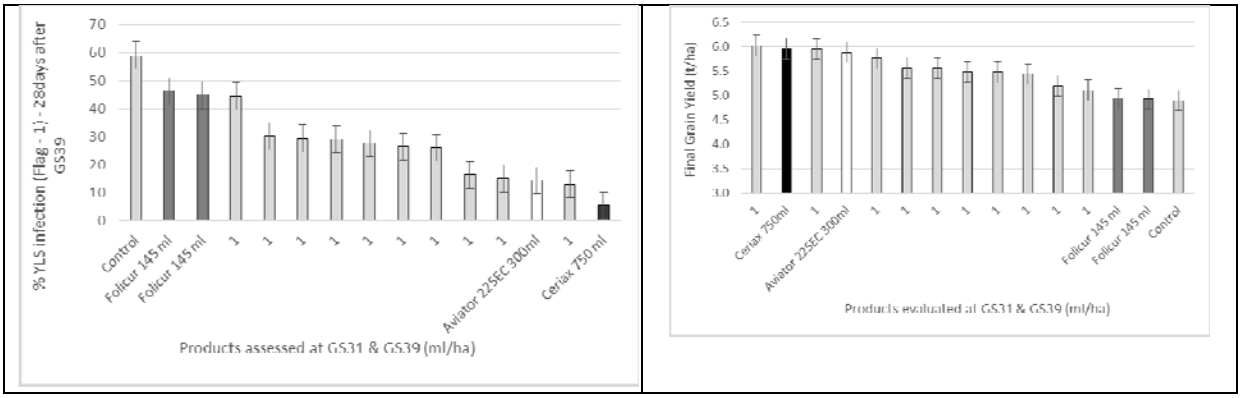


Figure 2. % Yellow leaf Spot infection on flag-1 28 days after two spray programmes of 14 different foliar fungicides and subsequent yield response – Yorke WA, cv Scout 2013

In barley there are a number of new and future fungicide products that offer a higher level of powdery mildew, NFNB, SFNB and scald control than the existing standards such as propiconazole (e.g. Tilt®). These new actives take the form of both currently registered seed treatments and foliar fungicides. The future introduction of the SDHI bixafen (a component active in Aviator Xpro) and fluxapyroxad (as the currently registered seed treatment Systiva® and the component in the proposed foliar product Ceriax) will provide a step forward for the control of wet weather stubble diseases such spot form of net blotch (Figure 1 & 2). The new active quinoxyfen (available as Legend™) is a new mode of action for powdery mildew control in barley, which whilst less problematic in the eastern states, it does provide a new option for controlling this disease in barley without depending on the triazoles, SDHI's and strobilurins, however unfortunately its range of activity is limited outside of powdery mildew so it would need to be mixed with a triazole for broad spectrum activity (Figure 3). Note that SDHI's and actives such as quinoxyfen may improve our ability to control diseases that are more prone to resistance development, however it should be emphasised that these new actives may themselves be more prone to pathogens developing resistance and therefore need to be mixed with other modes of action if not already formulated with a mixer partner. If the SDHI seed treatment is used, make sure follow up fungicides are of a different mode of action. Do not repeat use of Systiva year after year in barley to control disease. It should also be remembered that Systiva's control of powdery mildew and leaf rust is less effective than with net blotches and scald.

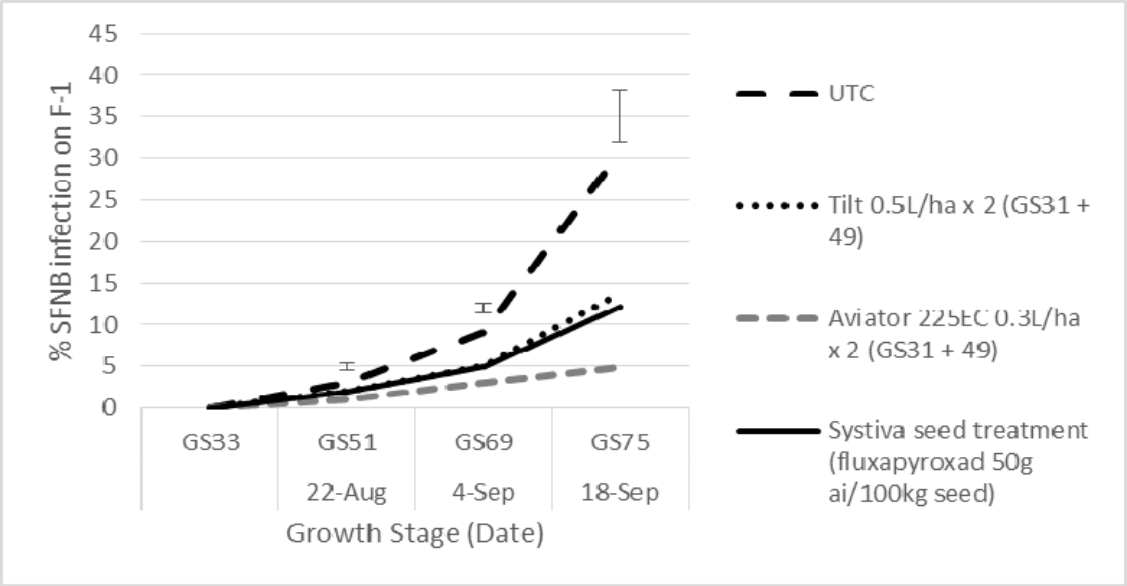


Figure 3. Spot form net blotch (SFNB) control using the new SDHI's Fluxapyroxad (Systiva® seed treatment) and the new SDHI foliar fungicide active bixafen mixed with prothioconazole (Aviator Xpro 225EC®) compared to propiconazole applied as a foliar two spray programme in barley cv Hindmarsh – Meckering, WA 2013.

Yield performance and screenings in these trials correlated with disease control assessments (Figure 3), indicating that products containing new active ingredients offer us new and potentially alternative management tools for barley disease control.

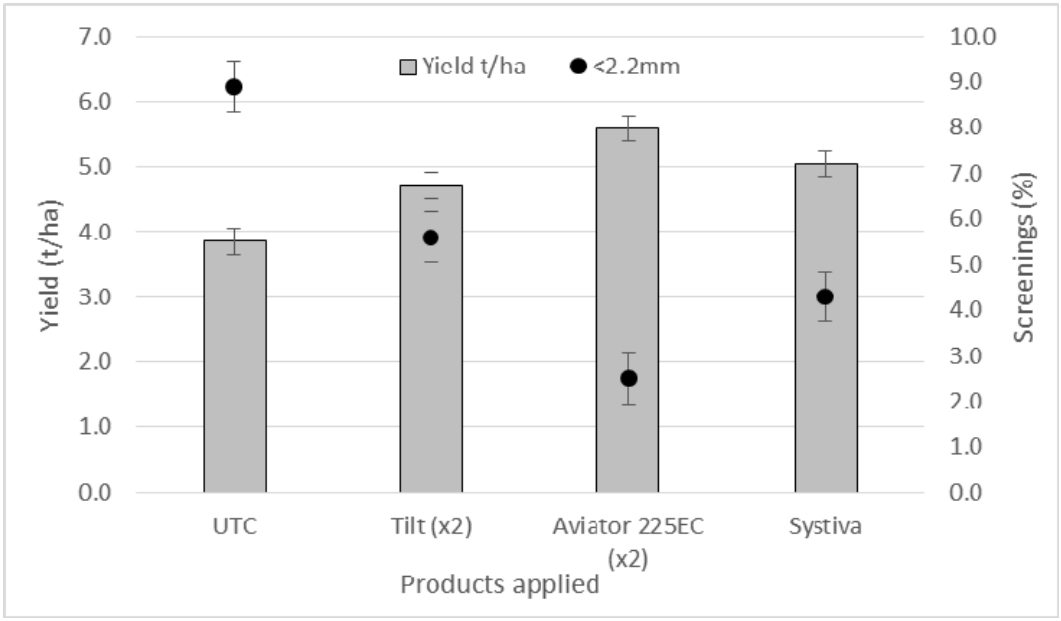


Figure 4. Influence of Spot form of net blotch (SFNB) control on barley yield and quality cv Hindmarsh(b) – Meckering, WA 2013

Notes: Tilt 500mL/ha and Aviator Xpro 300mL/ha 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.

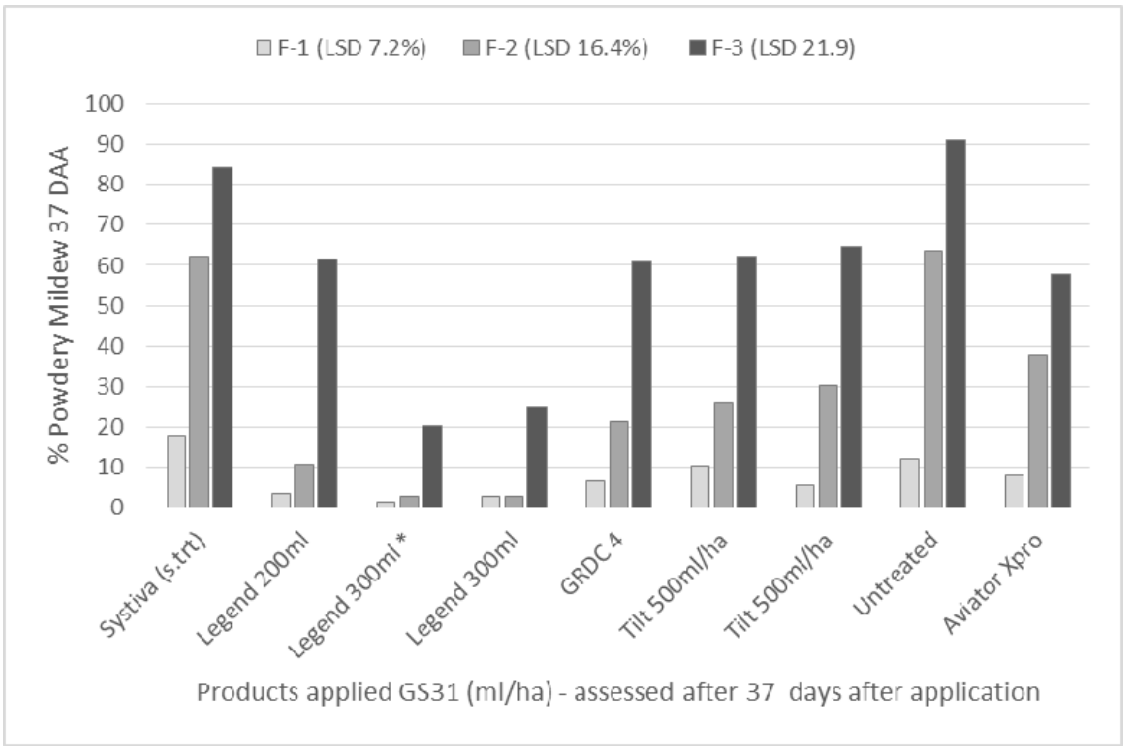


Figure 5. Powdery mildew control in barley using the new active ingredient quinoxyfen (now available as Legend) cv Baudin(b) – Kojonup, WA 2013.

Adjustments to cereal management strategies

The proposed introduction of the SDHI's, bixafen and fluxapyroxad actives, provide better opportunities to control wet weather diseases such as STB and YLS in wheat and net blotch and scald in barley. Quinoxyfen gives growers better protectant activity against powdery mildew but will need to be mixed with a triazole in order to control other diseases and act as an anti-resistance strategy.

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 in successive years with no follow up foliar fungicide. 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.

Curative activity of new fungicide actives against stripe rust

One of the most frequently asked questions with foliar fungicide strategies is how much curative activity do the fungicides exhibit, in other words, how long after a crop becomes infected can control of the disease still be achieved with a systemic fungicide? New research conducted under the ACRCP research programme has shed light on this with experiments performed under controlled environment conditions. Work on stem, stripe and leaf rust is just being completed by FAR working in collaboration with Sydney University. Initial indications for stripe rust suggest disease control can be achieved up to seven days after infection with triazole fungicides such as epoxiconazole under controlled conditions. The results indicated that whilst fungicides applied seven days after infection substantially reduced active pustulation (85-95% control), there was still a level of leaf necrosis associated with the disease that the fungicide could not prevent (Figure 4). Since temperature is a key driver for the development of both the crop and the disease, it is important to describe the seven days curative activity in terms of average daily temperatures in the glasshouse. This was 20^{0}C for the stripe rust experiment, or 140^{0}C. day degrees. Clearly if average daily temperatures were cooler, the curative activity would be longer in calendar days. For example at an average daily temperature of 15^{0}C might be equivalent to nearer 10 days (140^{0}C. days /15^{0}C = 9.33 days). At eleven days under these temperatures (11 days x 20^{0}C = 220^{0}C. days), the level of active rust infection evident increased, reducing the level of control to 37 – 82% control. Again the majority of leaf damage was as necrosis associated with the disease, rather than leaf area affected by active pustulation.

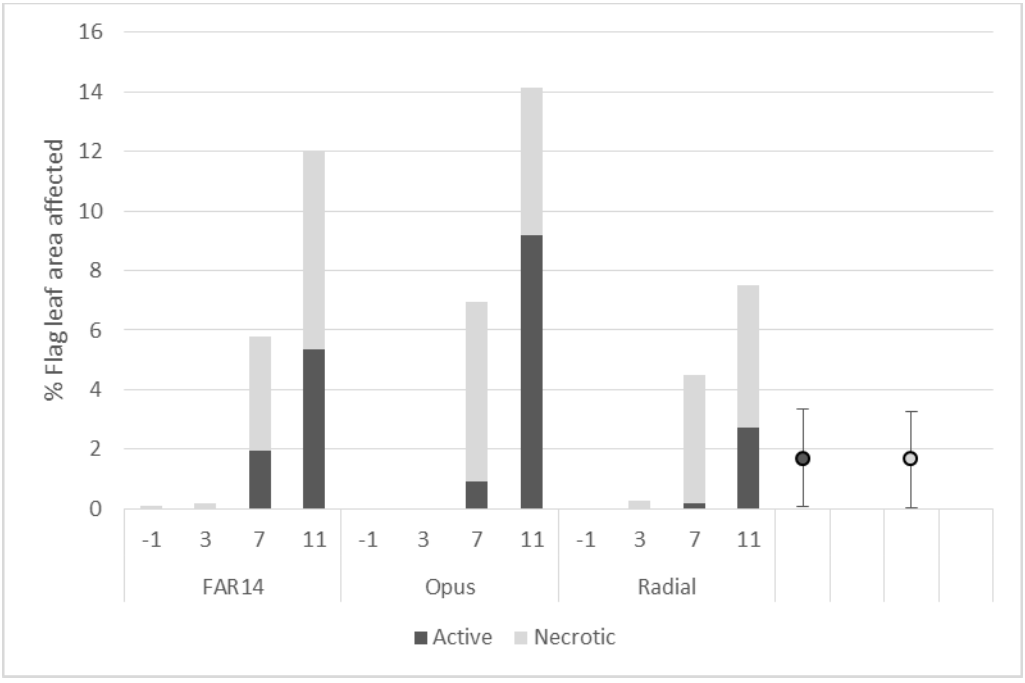


Figure 6. The influence of three fungicides (an experimental SDHI compound FAR F1-14, Opus® 125 and Radial®) applied 1 day before, 3, 7 and 11 days after inoculation with stripe rust - cv Elmore CL Plus

Value of combining more than one APR gene against stripe rust in wheat

One of the most frequently asked questions with newer foliar fungicides that confer greater green leaf retention is "do they have a value with cultivars protected by Adult Plant Resistance (APR)?" FAR Australia in collaboration with The University of Sydney have been attempting to answer this question using both commercial cultivars and Near Isogenic Lines (NILs; genetically uniform lines that differ only in the presence of a rust resistance gene). Using NILs allows the influence of the APR gene to be assessed in a common genetic background.

In work conducted at Wagga Wagga on the AGT trial site, NILs carrying different APR genes were treated with a combination of a triazole & strobilurin fungicide (Radial® - epoxiconazole and azoxystrobin) at different development timings. The work funded under the Australian Cereal Rust Control Programme (ACRCP) revealed that the single APR genes *Yr18*, *Yr29* and *Yr46* significantly reduced a late infection (GS55-59) of stripe rust compared with the fully susceptible Avocet, which is known to have no APR genes. The NILs with *Yr29* and *Yr46* single genes were more effective than *Yr18* alone at preventing stripe rust necrosis (Figure 5). The combination of two APR genes in an Avocet background had significantly less stripe rust necrosis on the flag leaf than any of the single APR genes. The late onset of infection gave the APR genes the best opportunity to express their resistance to the disease given that APR genes are usually considered to be fully active by the flag leaf – ear emergence stage (GS39-59). With the late onset of infection, the most effective spray timing was the single flag leaf emergence application, though this was only statistically superior to the head spray with NIL+Yr18 and susceptible Avocet. The early GS31 spray gave poor results because the infection onset was late and the leaves protected were flag-3 and flag-2 and not the flag leaf and flag-1.

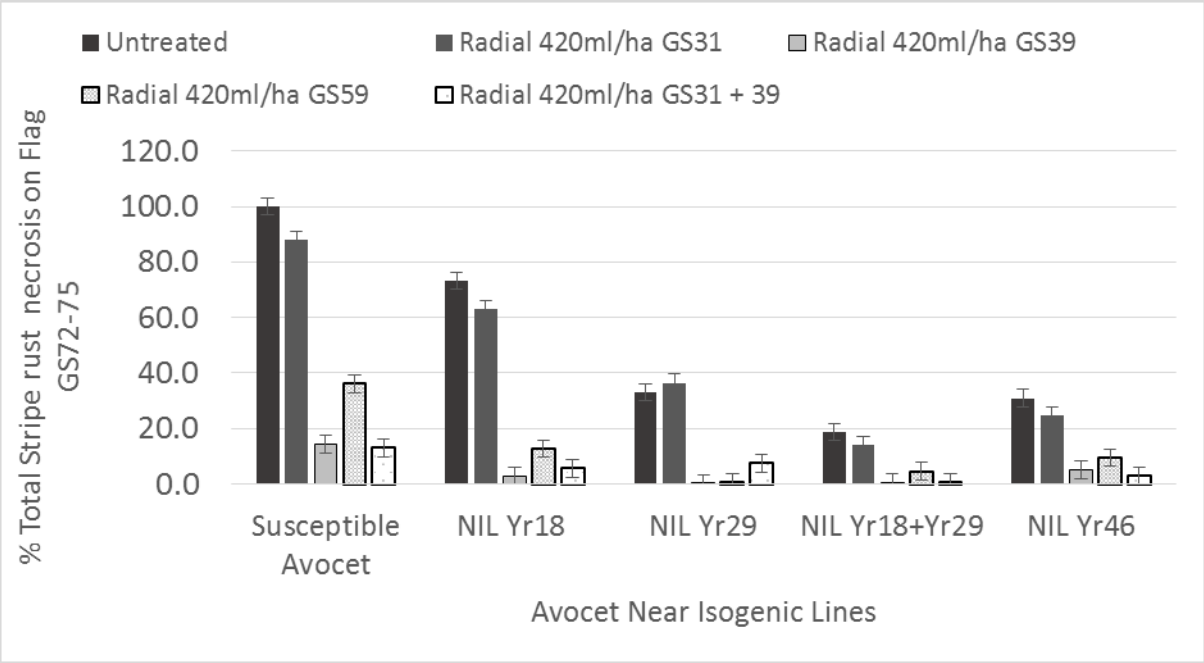


Figure 7. Influence of different APR genes *Yr18, Yr29* & *Yr46* in a common Avocet background on stripe rust necrosis during grain fill GS72-75.

The differences in stripe rust necrosis lead to the fungicide Radial® giving significant yield increases with all Near Isogenic lines except NIL Yr18+29 where two APR genes were incorporated into the genome (Figure 6). With NIL Yr18+Yr29, a single fungicide application (Radial at GS39), significantly increased green leaf retention of the flag leaf at the doughy ripe stage (GS78-83), from 9% to 39% and increased yield by 0.22t/ha, however this increase was not statistically significant. With the exception of the fully susceptible Avocet, there was no significant difference in fungicide response

amongst the GS39, GS59 and two spray fungicide approaches. The early GS31 spray did not give a significant yield response over the untreated with any of the germplasm lines tested.

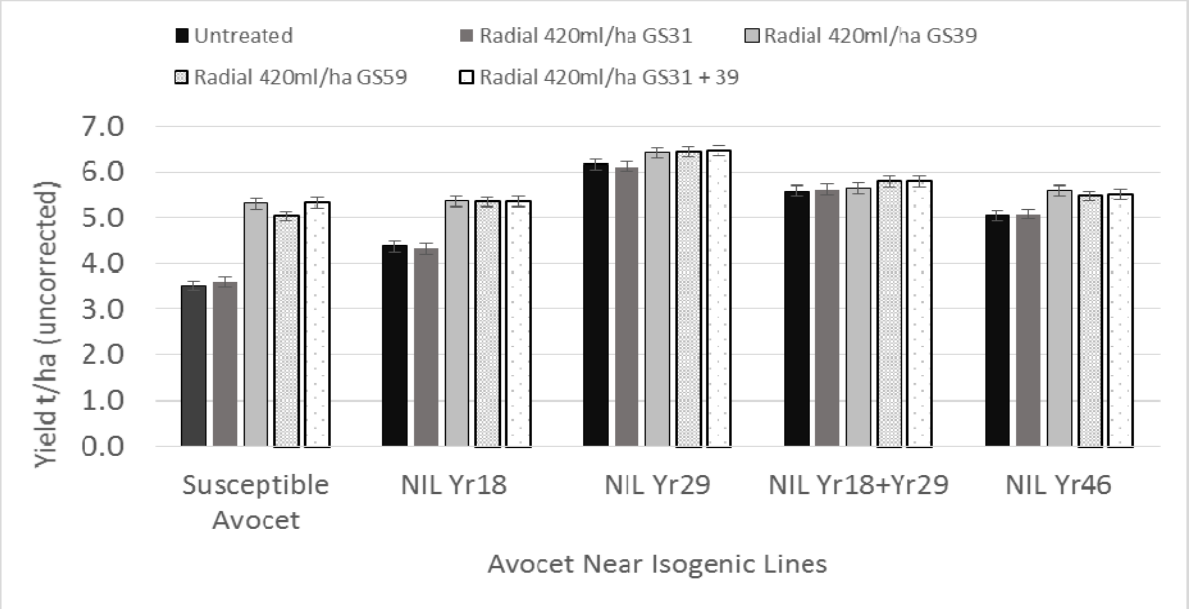


Figure 8. Influence of different APR genes *Yr18, Yr29* & *Yr46* in a common Avocet background on fungicide response from different application timings.

Conclusions

New GRDC research being conducted on integrated disease management (IDM) 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 IDM control options.

Controlled environment studies suggest that the curative activity of fungicides such as epoxiconazole against stripe rust is 7 days when the mean daily temperature is 20^0C, meaning that at lower temperature the curative activity could be extended. Near Isogenic Lines with an Avocet background illustrated that two APR genes Yr18 + Yr 29 when combined, significantly reduced stripe rust necrosis compared to single APR gene effects of Yr18, Yr29 and Yr46. The differences in stripe rust necrosis led to the fungicide Radial® giving significant yield increases with all Near Isogenic lines except NIL Yr18+29 where two APR genes were incorporated into the genome.

N. B. 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.

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Fungicide resistance in grain crops - what's happening and how should we respond?

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Key words

Fungicide resistance, mutations, DMI fungicides, resistance detection, monitoring, fungicide resistance management strategies, yellow leaf spot, net form net blotch, barley powdery mildew, wheat powdery mildew, DMI, SDHI

GRDC code

CUR00016, CUR00022, DAW00229 and CUR00023

Take home message

- Fungicides are key resources for sustainable farming practices.
- Misuse of fungicides and poor disease management practices have an impact on everybody.
- Overuse of fungicides with the same mode of action will speed up the development of resistance.
- Fungicide resistance is already present in nature but resistant populations get selected and build up under continuous use of fungicides from the same mode of action.
- Resistance is a numbers game and the only viable option to slow it down is to limit the size of pathogen populations. We can do this by use of appropriate rotations, use of clean seeds, early spraying and the use of fungicide mixtures and alternation.
- Fast (and cheap) monitoring of pathogen populations is central for the sustainable chemical management of diseases.

Fungicide resistance overview

Along with cultural practices, the main control measures for the management of fungal diseases are the application of effective fungicides and the use of crop varieties with genetic resistance. However, due to the lack of highly resistant varieties in the grains industry, fungicides are frequently solely relied upon for the control of many fungal diseases. In Australia, the fungicides used against grain diseases are predominantly of the azole or demethylase inhibitor (DMI) group 3, although there are other groups like the quinone outside inhibitor (QoI) group 11 and the succinate dehydrogenase inhibitor(SDHI) group 7 that also contribute to the control as existing mixing partners or new solo and mixed formulations. The threat of so few fungicide modes of action, is that when a fungal disease develops resistance to one fungicide all other fungicides which share the same mode of action, or within the same fungicide group, are also at risk.

So far seven cases of fungicide resistance and two cases of fungicide tolerance in grain diseases have been detected in the last five years in Australia (table 1); many horticultural crops have not been studied yet but anecdotal evidence suggests that many more cases remain to be uncovered.

Table 1. Fungicide resistance cases identified in Australia during the period 2012 – 2017

Disease	Fungicide
Barley powdery mildew[a]	DMI
Wheat powdery mildew[a]	DMI[c], strobilurins
Canola blackleg[a, b]	MAP/Kinase, DMI[c]
Legume Botrytis[a]	MBC
Lentil Ascochyta	MBC
Barley net-blotches[a]	DMI
Wheat septoria leaf blotch[b]	DMI
Grape powdery mildew[a]	QoI/DMI
Grape downy mildew[b]	PAA
Grape Botrytis[a]	MBC/E1/E3/D1

[a]Identified by the Fungicide Resistance Group (FRG) 2012-2017
[b]Identified by other researchers
[c]Tolerance

The azoles remain the backbone of crop protection in broad-acre cropping worldwide and no catastrophic cases of resistance have been reported anywhere in the world. For these reasons, the monitoring of fungicide resistance in Australian agriculture generally was considered unimportant until comparatively recently. Today we can see that the situation in Australia is at a cross-road, with significant levels of resistance in all studied crops.

Resistance in barley powdery mildew starts to develop in the East

DMI resistance in barley powdery mildew was first documented in 2009 in WA. The high levels of resistance detected against certain DMIs were associated with a number of mutations in the target site of this group of fungicides, the most important being mutations Y136F and S509T. Since 2009, great efforts have been made to understand the factors responsible for the rapid onset of this resistance and the spread of the problem (for details see previous paper presented at Bendigo updates titled "*From the lab to the field: The scale and impact of fungicide resistance in Australia*"), especially to other states across the country.

In 2012, the first of these two mutations, Y136F, was found in barley powdery mildew samples collected from Victoria. This mutation alone has only marginal effects on the sensitivity levels to the fungicides in laboratory conditions, but it is required for the development of further mutations which have been reported to show field resistance. This mutation is therefore what we call a gateway mutation. In 2015, and thanks to the implementation of a new detection technology used in cancer research, the second mutation, S509T, was subsequently detected in NSW, Victoria and Tasmania (figure 1).

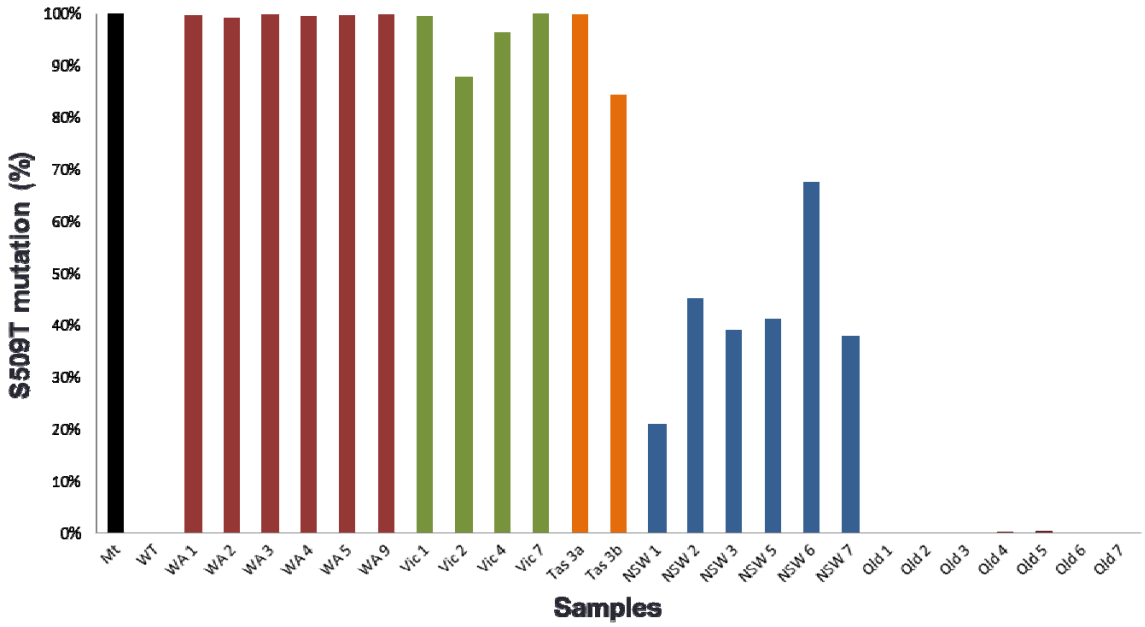

Figure 1. Mutation rates in barley powdery mildew samples quantified by digital PCR in 2016 in Western Australia, Victoria, Tasmania, New South Wales and Queensland. Samples were obtained from barley bait trails specifically developed to catch resistant strains.

In order to limit the potential impact of these mutations spreading across the barley growing areas in the Eastern states, we need to answer the following questions i) is the resistance coming from the West?, and ii) how are the resistant populations going to evolve considering the differences between barley crops in the East and the West in terms of pathogen selection pressure?

The answer to the first question is part of an ongoing research in which the analysis of DNA from both populations tries to determine if there is one centre of origin (West) or if the Western and Eastern fungicide resistant populations evolved and established independently. The second question is probably most important from the disease management point of view. Considering the chemical and cultivar alternatives available, and the existing cultural differences between both areas, it is difficult to envisage a situation similar to the 2009-2012 barley powdery mildew fungicide resistance outbreak recorded in WA. However, in order to reduce the spread of these resistant populations it is necessary to monitor and implement anti-resistance management strategies based on the use of i) chemistries from different modes of actions, ii) varieties with higher levels of resistance, and iii) the introduction of break crops to decrease the disease load from season to season.

Net type net blotch joins the fungicide resistance race

In Australia, emergence of multi-DMI resistance in net type net blotch has been observed in samples collected from the years 2013 onwards. Resistant isolates were geographically widely dispersed across Western Australia, originating in Kojonup, Beverley, Bakers Hill, West Arthur and Dandaragan (Figure 2). We used trials in these studies so as to increase the likelihood of finding resistant isolates even when their frequency is still low. We therefore cannot reliably estimate the frequency of the resistant net type net blotch isolates, but results so far indicate it is at a significant level in Western Australian populations.

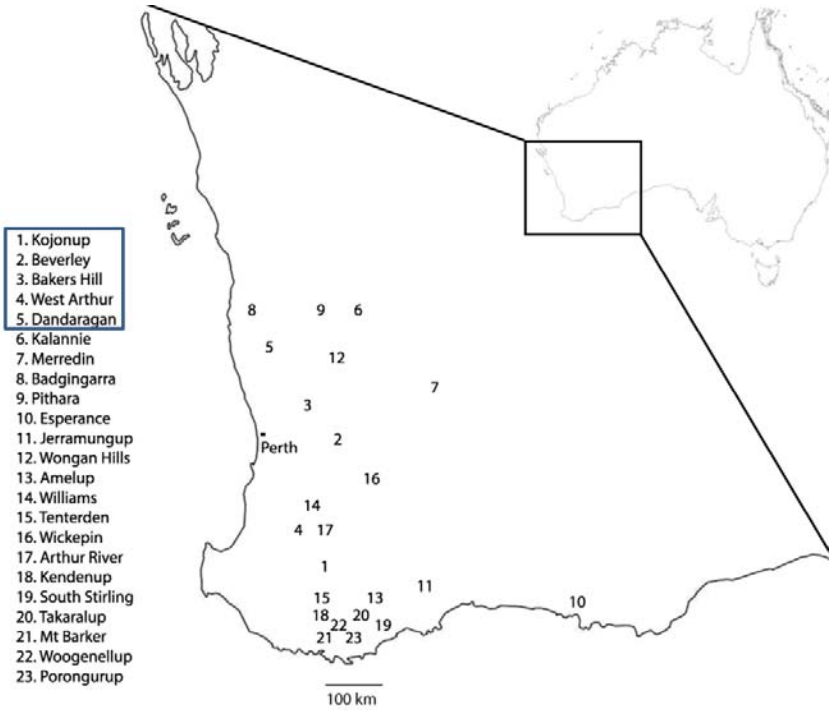

Figure 2. Map of Western Australia showing geographic origin of net type net blotch isolates. Leaf samples were collected from 23 separate locations in Western Australia from a combination of fieldtrips and bait trials. Locations 1, 2 and 14 were specially designed bait trials. Resistant strains were isolated from samples taken in locations 1–5.

When the resistance mechanism was analysed, we found that a combination of mutations and increased expression of the fungicide target were responsible for this resistance in the fungus.

These changes were effectively increasing *in vitro* the resistance factor (how many times a resistant isolate is more resistant to a given fungicide compared to the average sensitive pathogen population) of the resistant strains when exposed to the fungicides epoxiconazole (RF=1.5), prothioconazole (RF=2.6) and propiconazole (RF=7.7). However, these changes were also increasing the resistance factors for non-registered fungicides such as difenoconazole (RF=12.4), tebuconazole (RF=16.5) and prochloraz (RF=27.7), which critically highlights the fact that fungicides belonging to the same mode of action group (DMIs) are often affected by this type of resistance due to the existing similarities in their structures even if they have not been exposed to the disease previously. So far no resistance has been found in any of the analysed samples from the Eastern States. However, it is important to mention that only a small number of net type net blotch samples were tested and that a large scale analysis is required to determine whether resistance has developed outside of Western Australia.

An important question that remains is the reason why resistance has not developed in spot type net blotch. Net and spot type are two diseases caused by two pathogens that, in addition to the host, share many genetic similarities and undergo similar selection pressures for resistance in the field. We believe that understanding the mechanisms responsible for resistance in net type can contribute to the development of better anti-resistance management practices that can help the industry minimise the risk of fungicide resistance in spot type.

The big question: what is wheat powdery mildew up to?

Wheat powdery mildew has been under the spotlight during the last few seasons due to the increase in field reports claiming lower efficacy of some DMI group 3 fungicides. After a thorough search across the country, in 2015 the gateway mutation Y136F was found in the Eastern Estates but not in WA. As in barley powdery mildew, this mutation has only a marginal effect over resistance but it is necessary for the development of further mutations. In vitro experimental work suggests that the S509T mutation found in barley powdery mildew and responsible for the high levels of resistance against some older DMI fungicides, could develop in wheat powdery mildew as well due to the high similarity between both pathogens. It is then vital to manage the wheat powdery mildew populations carefully so that the development of this concerning mutation is delayed if not prevented.

Unfortunately, and while looking for mutations affecting DMI fungicides, researchers found this year a very important mutation affecting strobilurins (group 11 QoI fungicides) in samples received from Tasmania and Victoria in late 2016. This mutation, named G143A, has been previously described overseas and is associated with a type of cross-resistance that affects all fungicides within group 11. This news will have an important impact in those areas affected by wheat powdery mildew. Formulations containing strobilurins in mixture will be compromised in areas where the resistant populations are found, and their use will potentially add more pressure on the group 3 fungicides. It is recommended to monitor and implement anti-resistance management strategies if growers are planning to grow wheat in mildew prone areas. The fungicide resistance group tests samples for resistance as part of their research activities.

And what about legumes?

With the increase in price for chickpeas and interest building in legumes as crop rotation options, the popularity of legume crops is once again starting to rise. Along with this comes the concern for fungicide resistance development in legume crops, which is fast becoming a hot conversation amongst the grains industry. One concern being raised by chemical sellers is the increase in reliance on fungicides to control Ascochyta blight in chickpea crops, particularly in the northern NSW and southern QLD growing areas where disease inoculum levels are expected to be high from growing chickpeas into infected chickpea stubble. With limited varietal resistance, growers are relying on the control of Ascochyta by fungicides and up to six applications of fungicides have been reported in previous seasons.

So far in vitro resistance to only Ascochyta blight of lentis has been detected to carbendazim a methyl benzimidazole carbamate (MBC) group 1 fungicide (figure 3). Legume botrytis resistance to some MBC group 1 fungicides has also been confirmed. Both cases of resistance have only been detected in samples from South Australia. The research on these two cases of fungicide resistance is limited, and therefore spread of resistance, particularly the presence in other states across Australia, is unknown. However, resistance to strobilurins in Ascochyta blight is well documented overseas and a reminder that this fungal pathogen is capable of developing resistance to different fungicides in Australian legume crops.

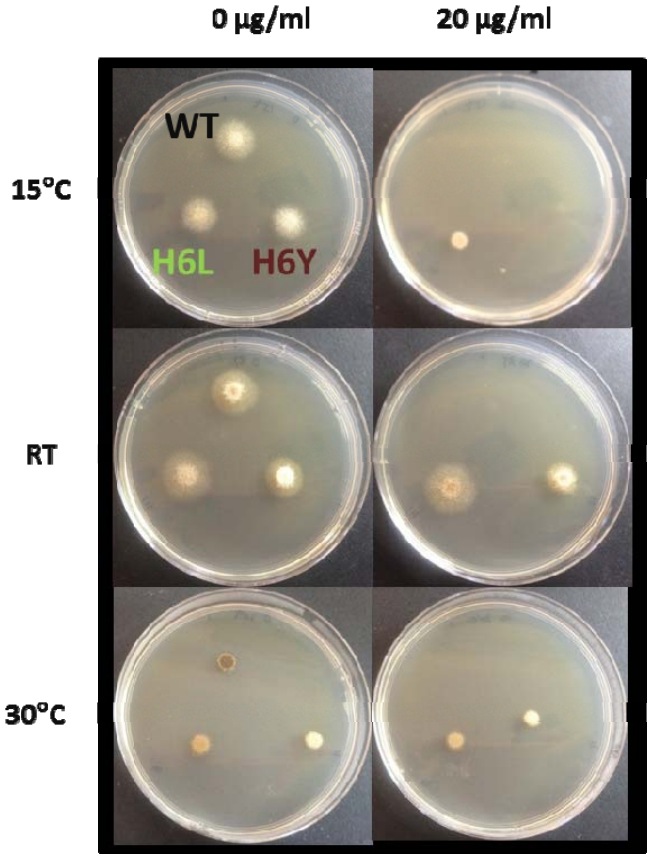

Figure 3. I*n vitro* growth analysis of *Ascochyta lentils* on two concentrations of carbendazim at three different temperatures. Wild type isolate (WT), mutant H6L and mutant H6Y are labelled on the top left plate.

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