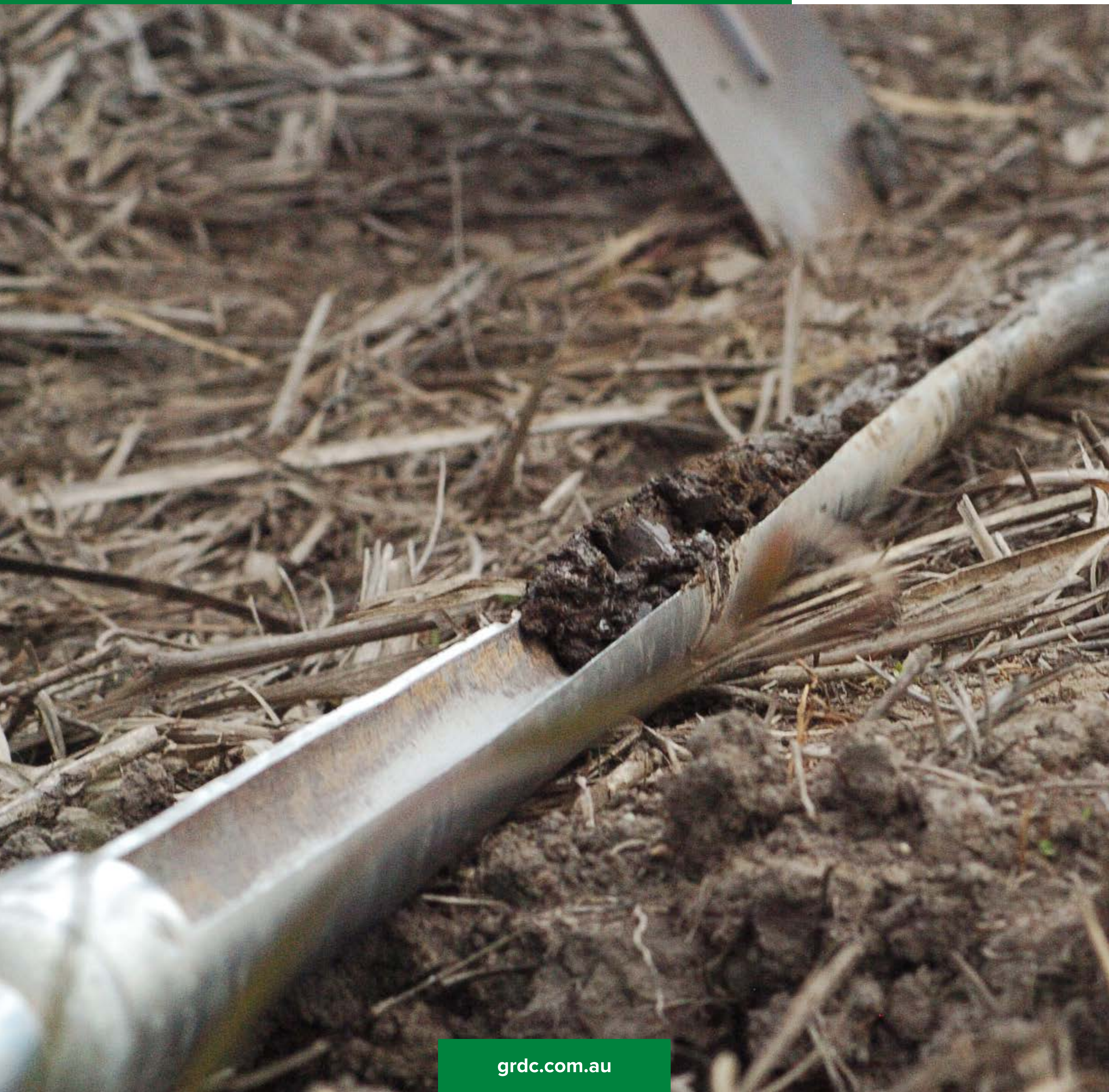
NORTH STAR
NEW SOUTH WALES
JULY 2020

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION



GRDC 2020 Grains Research Update Welcome

If you are reading this, then chances are you have taken time out from an extraordinarily tough season in our very sunburnt country to hear the latest grains research, development and extension (RD&E) information.

Welcome.

We at the GRDC understand how very challenging the current situation is for growers, advisers, agronomists, researchers and those associated with the grains industry across New South Wales and Queensland.

Drought takes an enormous toll financially, emotionally and physically on those working and living through it daily. We trust that these GRDC Grains Research Updates will offer you new research information to help guide your on-farm decisions this season and to be best placed to take advantage of future seasons. We also hope the Updates provide a chance to connect with your peers and temporarily escape work pressures.

We would like to take this opportunity to thank our many research partners, who, like growers and advisers, have gone over and above in recent years to keep trials alive in rain-deprived environments.

Challenging seasons reinforce the importance of rigorous, innovative research that delivers genuine gains on-farm. For more than a quarter of a century the GRDC has been driving grains research capability and capacity with the understanding that high quality, effective RD&E is vital to the continued viability of the industry.

Sharing the results from this research is a key role of the annual Updates, which are the premier event on the northern grains industry calendar and bring together some of Australia's leading grains research scientists and expert consultants.

To ensure this research answers the most pressing profitability and productivity questions from the paddock, it is critical the GRDC is engaged with and listening to growers, agronomists and advisers.

For the past four years we have been doing that from regional offices across the country. Through the northern region offices in Wagga Wagga and Toowoomba and a team of staff committed to connecting with industry, we are now more closely linked to industry than ever.

Today, GRDC staff and GRDC Northern Panel members are at this Update to listen and engage with you. This is a vital forum for learning, sharing ideas and networking, all of which are critical to effect successful change and progress on-farm.

Regards,
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Australia's grains industry in 2030 – key challenges and opportunities

Professor Ross Kingwell, Australian Export Grain Innovation Centre

Keywords

Grains industry, grain markets, competition

Take home message

- The grains industry in eastern Australia will experience further structural change towards 2030 as east coast demand for feed grain grows
- Farmers in eastern Australia are likely to increase their commercial dependence on grain storage, feed grain production and domestic marketing
- Improved harvest technology and transport logistics will enhance farmers' capitalising on market opportunities
- Australia's population and income growth, although slower than might have been anticipated in a pre-COVID world, will help underpin feed grain demand in Australia, as will the gradual re-build of cattle and sheep populations
- Towards 2030 the grains industry faces a carbon challenge.

Background

Although the business of grain-farming will largely stay the same towards 2030, some things are changing to challenge grain-farming and deliver further market opportunities. The sources of change and challenge include:

(i) Technological change
The ability in real-time to affordably track grain quality at harvest will improve, enabling farmers to more cost-effectively segregate grain at harvest and better match end-user preferences. Improved logistics and multi-mode hubs will facilitate greater use of containerisation. Lower cost grain storage combined with low interest rate will allow more grain to be stored, and stored for longer.

(ii) New crops and changing crop mixes
The wheat-sheep belt, the mainstay of Australian agriculture, will more flexibly switch its land use to favour greater crop diversity. Canola, chickpeas, lentils and lupins, once little known crops, will remain as important crop options in different regions. The swing into reliance on crop revenues is evidenced by Australia's sheep population now being as small as it was almost 120 years ago and in the early 1900s Australia only produced 1.5mmt of wheat from 2.5mha whereas this year Australia is on track to produce over 27mmt of wheat from 13mha. Moreover, 17.8mmt of other grains is also likely to be produced this year.

(iii) Altered soil management
Traditionally fields were ploughed repeatedly to combat weeds and form a friable seed bed. However, the advent of conservation agriculture now sees crops established in single pass operations, with minimal soil disturbance, increased reliance on herbicides and weed seed management at harvest. Soil amelioration is increasingly commonplace.

(iv) A changing climate
Grain production in Australia is based on rain-fed farming systems. Hence, temporal and spatial changes in rainfall and temperatures are crucially affecting national crop production. Extreme heat during grain filling is an increasing problem in some regions with farmers observing occasional 'heat frosts' that worsen grain yield and quality.

(v) An altered role of government
Traditionally, government played a major role in Australia's grain industry. Rail systems were owned and operated by State governments. Statutory grain marketing was ubiquitous. Research and advisory services were funded and supplied principally by State governments, with the Commonwealth government playing an important collaborative role in research funding. Provision of new plant varieties was almost solely the province of State government agencies, universities and the CSIRO. Governments were important employers in many rural towns. Yet now, the march of privatisation, the lesser relative economic contribution of agriculture and the emergence of other claims on the public purse (natural disaster relief, COVID relief, health and social welfare) have altered the role of government in the farm sector. Increasingly grain farmers pay fully or in large part for advice, grain marketing, research services and grain transport.

Privatisation has not only affected government services. Even farmers' ownership of the key services of grain handling and storage has passed into private ownership (GrainCorp, Viterra).

(vi) Maturing low-cost overseas competitors
Over the last few decades, a seismic shift in grain export prowess and rankings has occurred. In previous decades North America, Europe and Australia were main grain exporters. However, first South America (i.e. Brazil and Argentina) and then the Black Sea region (Russia, Ukraine and Kazakhstan) have greatly increased their grain production and grain exports. Russia has replaced the USA as the world's main exporter of wheat. Argentina and Brazil are main export suppliers of feed grains (soybean and corn).

(vii) Altered populations, incomes and power
As people become richer their indirect per capita consumption of feed grains increases as they consume more meat, aquaculture and livestock products (dairy, eggs). South Asia, sub-Saharan Africa and the MENA (Middle East & North Africa) are increasingly dominant contributors to the world's population. Although China's population growth is slowing, nonetheless its per capita income growth continues almost unabated helping it to flex its political muscle which has affected Australia's barley industry.

(viii) An increasing emphasis on the sustainability credentials of grain production
The costliness of grain and its quality matter to most consumers, especially overseas customers. Yet within agriculture and the urban consumers and voters that influence Australian agriculture, the sustainability credentials of farm production also increasingly matter. For example, major agricultural organisations like the MLA and NFF have signalled the need for Australian agricultural industries to plan to be carbon-neutral.

All these changes, in combination, are affecting the current and future potential of grain production in Australia.

Australia's grain industry towards 2030

- Towards 2030, feed grain demand and supply will increase in prominence in Australia, especially in eastern Australia
- In a COVID-affected Australia, the national population is likely to increase by around 16 per cent by 2030. This means about 4.1 million additional people in Australia
- Little increase in the area sown to winter and summer crops in Australia has occurred since the mid-2000s and further increases are unlikely towards 2030
- Despite plant breeding, agronomic and technology improvements, the average rate of crop yield improvement has been only 0.6 per cent per annum since the late 1980s. There is spatial variation in yield improvement trends and yield volatility has worsened in eastern Australia

- Climate change and seasonal variation are limiting yield growth in many grain-growing regions
- The mix of crops grown across Australia is fairly stable with a slight increase in the relative importance of canola over the last decade. In eastern Australia, coarse grains and pulses feature more in the mix of crops
- The pattern of meat consumption among Australians is changing, with a growing dominance of chicken and pork consumption at the expense of beef and lamb
- Increasingly, the main meats consumed by Australians are from grain-fed animals
- By 2030 in Australia:

    (i) Feed grain demand will increase by around 2.3 mmt

    (ii) An additional 0.6 mmt of grain will be required for flour and malt production

    (iii) An additional 5.6 mmt of grain will likely be produced

    (iv) The additional surplus of grain available for export could be around 2.7 mmt

    (v) Most of the additional grain produced in eastern Australia will need to flow to the east coast domestic market to satisfy its growth in feed and food demand

    (vi) The main sources of additional exportable surpluses of grain will be WA and SA; and bumper years in eastern Australia

    (vii) The grain quality profile of Australia's main export crop, wheat, is likely to alter, as WA's and SA's share of national wheat exports increases

    (viii) Grain farmers' increased use of liming and urea to boost grain production is increasing emissions from grain production and will increase the cost of ensuring the carbon-neutrality of Australian grain production.

A key implication of above projections is that towards 2030, with grain production being climate-constrained, Australia's domestic requirements for grain will become increasingly important in eastern Australia where most of the population increase and greater demand for feed grains, flour, oil for human consumption and malt will occur. By contrast, most of the exportable surpluses of grain will increasingly come from the less populous states of WA and SA.

The task of finding export markets for the additional ~2.7 mmt of export grain available by 2030 may not be overly challenging, given the projected increase in grain imports envisaged for many of Australia's current overseas grain customers. Nonetheless, it needs to be noted that this task of selling more Australian grain will occur against the backdrop of burgeoning exports from low-cost international competitors who may not have the same commitment to carbon-neutrality.

Assuming crop production in Australia towards 2030 remains seasonally volatile (whilst the stable east coast domestic demand for grain increases in relative importance), then grain farmers and grain users in eastern Australia are likely to react by:

(i) Investing in more grain storage; especially whilst interest rates are low, making the cost of carrying grain affordable

(ii) Focusing more on domestic market opportunities

(iii) Focusing more on feed grain production

(iv) Looking more closely at grain supply security when investing in export-focussed grain processing/animal protein industries – with access to export parity grain rather than exposure to import parity

(v) Committing to further enhancement of the sustainability of grain production (e.g. reduced net emissions of greenhouse gases) whenever price premiums, regulation or market access opportunities reward those commitments

(vi) Supporting varietal development, crop research and grain organisation innovation that delivers benefits throughout the grains industry, but especially to grain producers.

Implications for Vic and NSW Grain Producers

Although the increased demand for feed grains in eastern Australia may encourage its grain producers to alter their crop mix towards more feed grain production, it is unlikely that most farmers will additionally allocate more land to cropping rather than sheep production. Despite the sizeable reduction in the national sheep population since the early 1990s, most NSW and Vic farmers have maintained their investment in sheep since the early 2010s (Figure 1), despite the period of serious drought in 2018 and 2019.

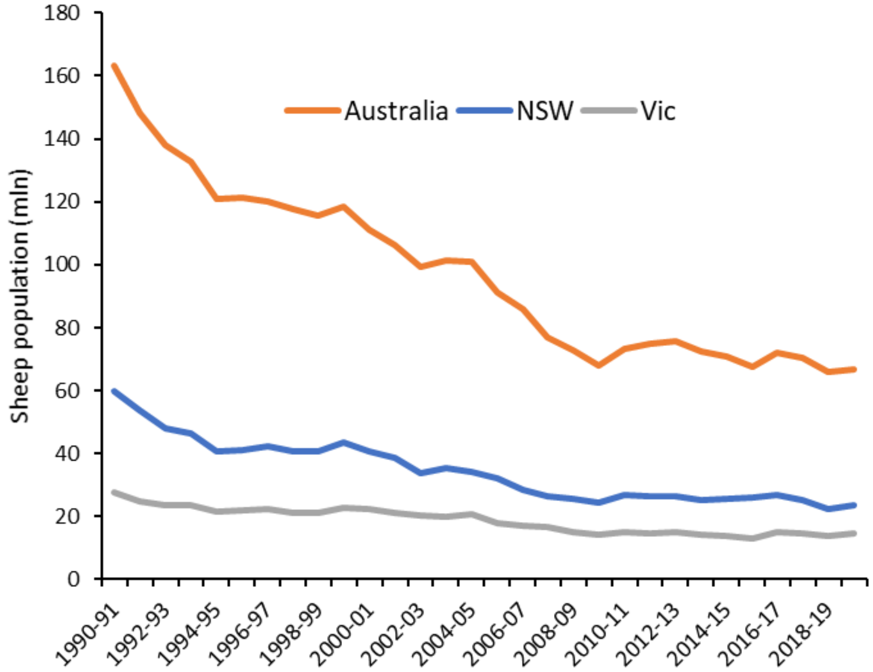

Figure 1. Sheep population in Australia, NSW and Vic since 1990

In order to retain sheep numbers, either pasture areas need to be allocated for sheep production or affordable feed grains always need to be readily available. Given the strong upward movement in sheep meat and wool prices up until the impact of COVID-19, on a gross margins basis, farmers have been less likely to switch land and other resources away from sheep production. Moreover, as the domestic and overseas demand for sheep meat continues to increase, then retention of sheep in farming systems is increasingly likely. In addition, retaining sheep provides a means to add value to feed or downgraded grain produced on a farm. Currently, sheep enterprises form a profitable, risk-diversifying role for many farm businesses. As a result, crop production growth over the next decade is more likely to be based largely on yield increases rather than crop area increases. Accordingly, crop breeding and crop agronomy will play crucial roles in ensuring gains in crop production in NSW and Vic.

In coming decades, the traditional flow of grain from Vic and NSW farms down to ports for overseas export could be a less dominant feature of their crop production, as east coast demand for grain increases in relative importance; and especially in years of low production in eastern Australia.

Interstate grain flows from SA or WA (see (Figure 2) could feature when prolonged drought in NSW and Vic leads to depletion of their grain storages such as occurred in 2018/19

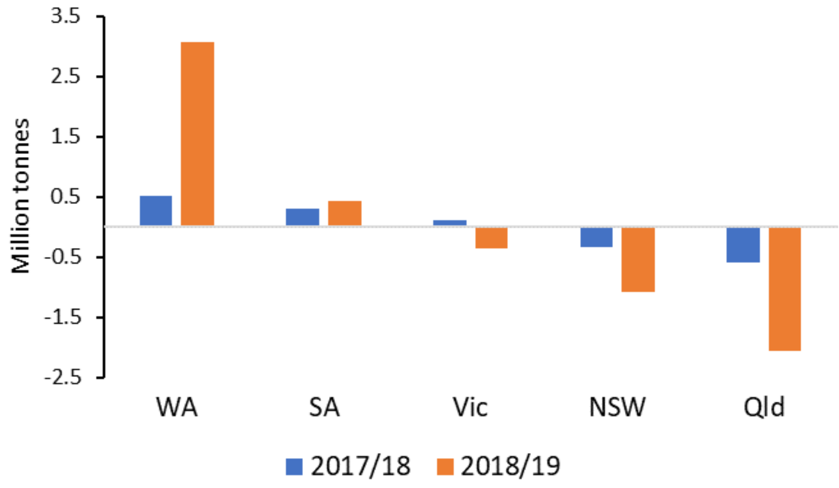

Figure 2. Coastal shipping flows from or into each State in 2017/18 and 2018/19

Source: Based on data in an appendix in ACCC (2019)

In 2018/19 some regions in SA were also affected by drought. The SA grain harvest was only around 5.6 mmt, of which the main grain handler and exporter, Glencore, only exported around 2.6 mmt, indicating that around 3 mmt was either stored, used locally or exported to eastern Australia. Hence, due to SA's small domestic market, even in low production years, SA is able to capitalise on favourable market opportunities in eastern Australia.

In years when SA or WA escape drought, yet eastern states are drought-affected, then sizeable interstate grain flows from these states are likely (see Figure 2). Freight differentials in coming decades could be further affected by construction of the inland rail in eastern Australia, due for completion in 2025. If the inland rail is sufficiently cost-effective, then interstate grain flows from SA could be much enhanced in some years. In addition, construction of additional grain port infrastructure in SA will facilitate coastal trade. In eastern Australia, south to north flows of grain by rail, road and ship are likely to become increasingly important towards 2030 as a product of climate volatility and continuing growth in the demand for grain in eastern Australia.

The constant challenge of a warming, drying climate is likely to limit winter crop yield growth in all winter crop regions of Australia and will increase the dependence of extensive livestock production (sheep, cattle, dairy) on supplementary grain feeding. Simultaneously, further population growth, especially in Qld, NSW and Vic, will increase the national market demand for grains, especially feed grains. The corollary is that growth in grain production in Australia is likely to be modest and the tendency will be for a growing proportion of grain to flow to domestic markets, especially in eastern Australia. Exports of grain from NSW and Vic are likely to be constrained by the growth in the Australian domestic market in eastern Australia and the constraints of climate trends on crop yields. In a low interest rate environment, storage of grain becomes more affordable as a strategy to lessen price volatility and improve the affordability of grains. Hence, grain storage is likely to become part of major grain users' and producers' risk management strategies.

In coming decades, export grain supply chains in Vic and NSW will be affected by the combination of limited growth in crop production and an increased role of grain storage to improve the reliability of supply to domestic markets. Low interest rates make affordable the cost of carrying grain across seasons. In eastern Australia easily stored feed grains like lupins and barley, if high-yielding varieties become available, could feature more in farmers' crop portfolios. Farmers are likely to enlarge their focus on feed grain production and any feed grain value-adding opportunities.

Farmers are likely to have increasing choices over where and when they sell grain, due to the lower cost of storing grain (i.e. a low interest rate environment), and the emergence of a range of domestic market opportunities.

Conclusion

Modest growth in Australian grain production is expected towards 2030. By contrast, Australia's population is projected to increase by around 16 per cent by 2030. This means about 4.1 million additional people, mostly residing in eastern Australia. Despite this projected increase in population and the associated demand for feed and human consumption grains, little increase in the area sown to crops in Australia is envisaged.

The corollary is that, especially during periods of drought in eastern Australia, domestic market opportunities in eastern Australia will drive grain flows, support grain storage and increasingly affect the viability of the ownership and operation of export grain supply chain infrastructure, especially in eastern Australia. Grain storage will increasingly form part of many businesses' risk management strategies. Establishing and maintaining low-cost interstate supply chains will be an increasing complementary strategic need, already being supported by the inland rail project.

How grain is produced (i.e. its sustainability credentials) will be increasingly important, especially to domestic users and consumers.

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How has Yallaroi's climate changed and what impact has it had on sorghum productivity

Jeremy Whish and Elizabeth Meier, CSIRO

Key words

climate, historic climate, changing yield potential, sorghum

GRDC code

CSP1806-01

Take home messages

- Increasing temperatures and reduced rainfall have lowered the yield potential of sorghum in many areas
- Avoiding high temperatures at flowering and using a conservative sowing trigger (>100mm PAW) can reduce the impact of a changing climate
- There is still room to reduce the yield gap with targeted sowing dates, nitrogen rates and soil water triggers despite a changing climate reducing sorghum yield potential.

Introduction

Australia's climate is warming, including an increase in average temperature, increase in number of days exceeding 35°C and a decrease in rainfall (CSIRO and BOM, 2015).

But what is happening at Yallaroi? How will this affect the crops I grow? What can I do to manage this change?

These are some of the questions we have tried to address.

Over the last few years, several suggestions have been made to GRDC that have warranted our examination of sorghum production in response to changing climates. The key concern was that a changing climate had reduced the yield potential of central Queensland crops and would cause the key sorghum production areas to move south to cooler and less variable climates. In this paper we review local annual and growing season climates, sorghum production and compare these results to other sorghum production areas to see how or if things have changed.

Methods

Current climate was compared with historical climate using a climate normal approach to compare overlapping 30-year time periods. This is recognised as the most statistically sound method to determine if a change in climate has occurred (Arguez and Vose, 2011), and is recommended by the World Meteorological Organisation's standard for placing current climate conditions in a historical perspective. A simulation analysis of sorghum production in response to a range of initial soil water and sowing dates was then conducted using APSIM (Holzworth,2014) to identify whether changing these management practices could mitigate the effect of any changes in climate.

How is the Yallaroi environment changing?

Rainfall

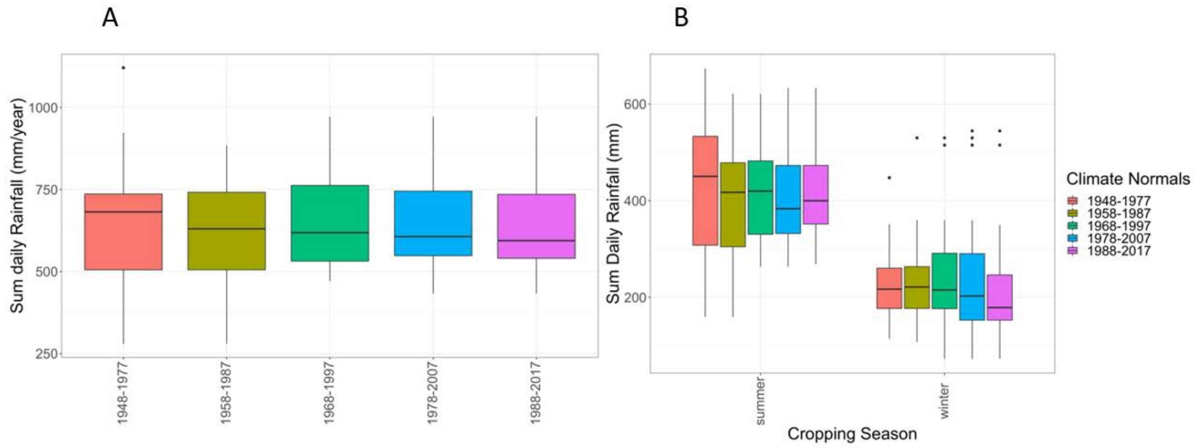

Figure 1. Sum of rainfall for each 30-year climate normal period on an annual (A) and cropping season (B) basis at Yallaroi. The results show a reduction in variability and slight lowering of the average rainfall over time. The decline has occurred in both summer and winter rainfall.

Temperature

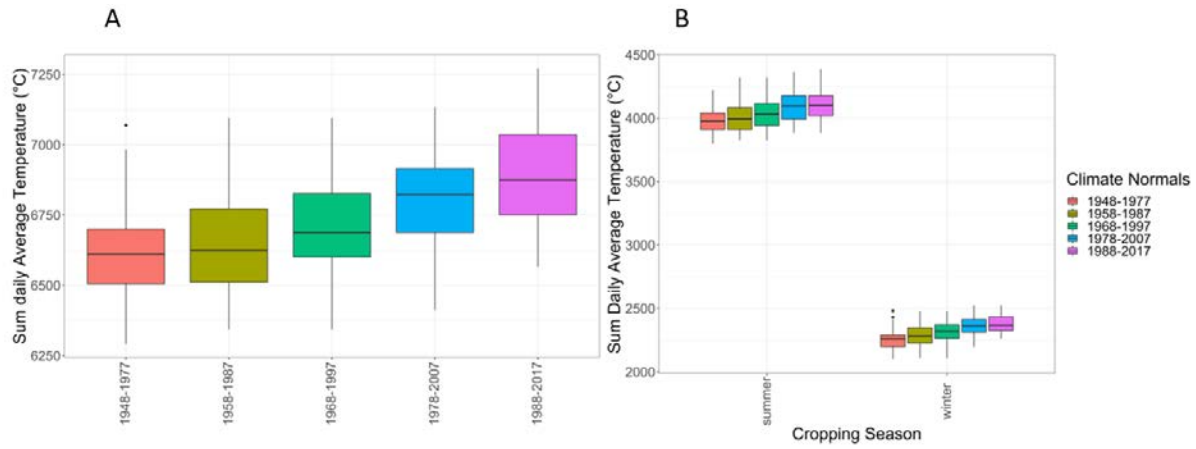

Figure 2. Sum of daily average temperature on an annual (A) and cropping season basis at Yallaroi. Average temperature showed a continual increase in heat to the most recent climate normal (1988-2017). The change in accumulation of heat was similar in both summer and winter growing seasons.

Extreme

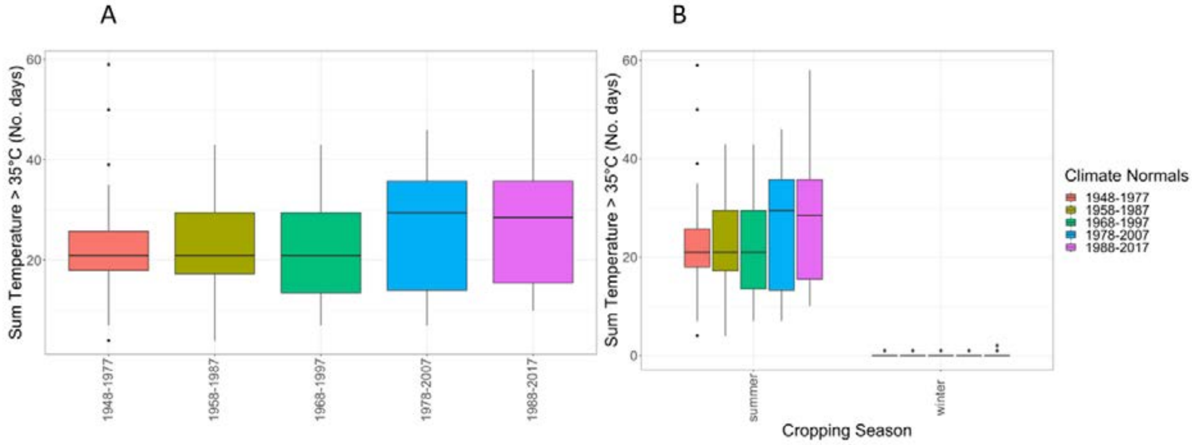

Figure 3. Number of days of extreme temperatures (above 35°C) summed on an annual (A) and growing season (B) basis. The days above 35°C follow a similar pattern to the heat sum on an annual basis increasing to the most recent normal (1988-2017). Extreme temperatures occurred in the summer only.

How will these changes in climate affect sorghum?

Higher temperatures increase the rate of crop development and the amount of water transpired by the crop. If rainfall remains stable or decreases then this will increase the chance of moisture stress occurring in the crop. However, if the growing period of the crop can be matched to the timing of rainfall then it may be possible to maintain or increase crop grain yield despite an annual reduction in rainfall.

To identify whether the yield potential of sorghum crops had changed over the last 60 years a series of simulations were undertaken. The 60-year period from 1958-2017 was used for this analysis and sub-divided into two climate normals – 1958-1987 and 1988-2017 - that could be compared.

Water stored within the soil helps to buffer crops from variability in the climate. In order to understand the effect on yield of changes in the climate, the median yield from a crop sown into a full profile of water was compared across the 60-year period. This approach was expected to demonstrate the least difference between the two climate normal periods, because each site by sowing date combination had optimal soil water at sowing. The study was completed for a selection of locations ('transects') in both the eastern and western parts of the GRDC northern growing region (Figure 4).

Sorghum crop yields sown on a full profile of soil water

For northern sites of the western transect (from Mungindi north) there was little change in yield except for a reduction in yield of around 0.5 t/ha at the extremes of early sowing and late sowing (Figure 4). For the northern sites of the eastern transect there was a clear reduction in yield for sites north of Goondiwindi, especially for sowing dates before November. For the eastern transect there were distinct groupings of change in yield: improved yield between Goondiwindi and Moree for crops sown between November and January and decline in yield on the Liverpool Plains that worsened with later sowings and culminated around a mid-December plant.

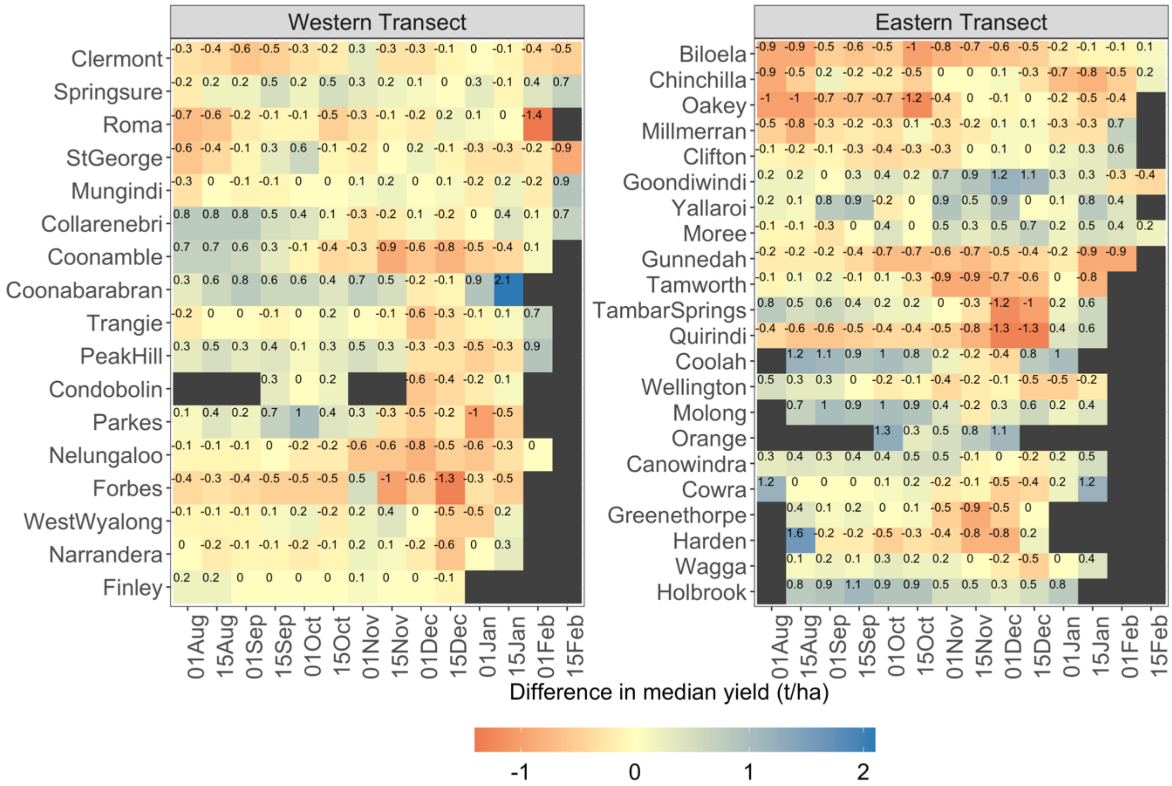

Figure 4. Difference in median yield of sorghum crops between climate normals 1958-1987 and 1988-2017 when sown into a full profile of water, for different sowing dates for locations divided into western and eastern transects. Red shading in cells indicates a decrease in yield, blue indicates an increase, and yellow indicates sowing dates where there was minimal to no difference in crop yield. Only median yields from sowing dates that had fewer than 50% failed crops are included (other location-sowing date combinations were considered unsuitable for crop production and are coloured black). Values within each cell are the difference in yield between the climate normals (t/ha).

What has been the effect of changing climate on yield when there isn't a full profile of soil water at sowing?

The objective of simulating sorghum crop yields in response to a full profile of water in the previous step, was to understand whether the most recent 30-year climate normal period was different to the previous 30-year normal in terms of its effect on crop yield. However, it can be inefficient to wait for a soil profile to fill because producing adequate crops regularly, can more be financially rewarding than waiting for ideal conditions (such as a full soil water profile) to occur. In this section we present results for crops sown into a profile with an initial amount of 100mm of available soil water. This amount is towards the lower end of soil water that would be present when a decision to sow occurs (the general sowing rule for western sites (west of the Newell highway) is commonly, 150mm of plant available water). In the eastern sites with higher rainfall 100 mm is more common. The use of 100mm for both transects is a compromise.

There was an increase in crop failures (cells shaded black) between crops sown on a full profile of soil water (Figure 4) and those sown into a profile containing 100mm (Figure 5). This difference in initial soil water also explains the use of wide row configuration and 150mm soil water trigger that is used by many grain growers along the western transect. However, despite these differences in yield arising from differences in initial soil water. The general patterns of changes in yield and optimal sowing dates between climate normals were the same. There were minimal differences in yield between climate normals for the north-western sites, but a decrease in yield potential for the eastern sites. The November to mid-January sowing dates between Goondiwindi and Moree continued to demonstrate an increase in yield for the more recent normal, while later sowing in the Liverpool Plains continued to demonstrate a yield reduction.

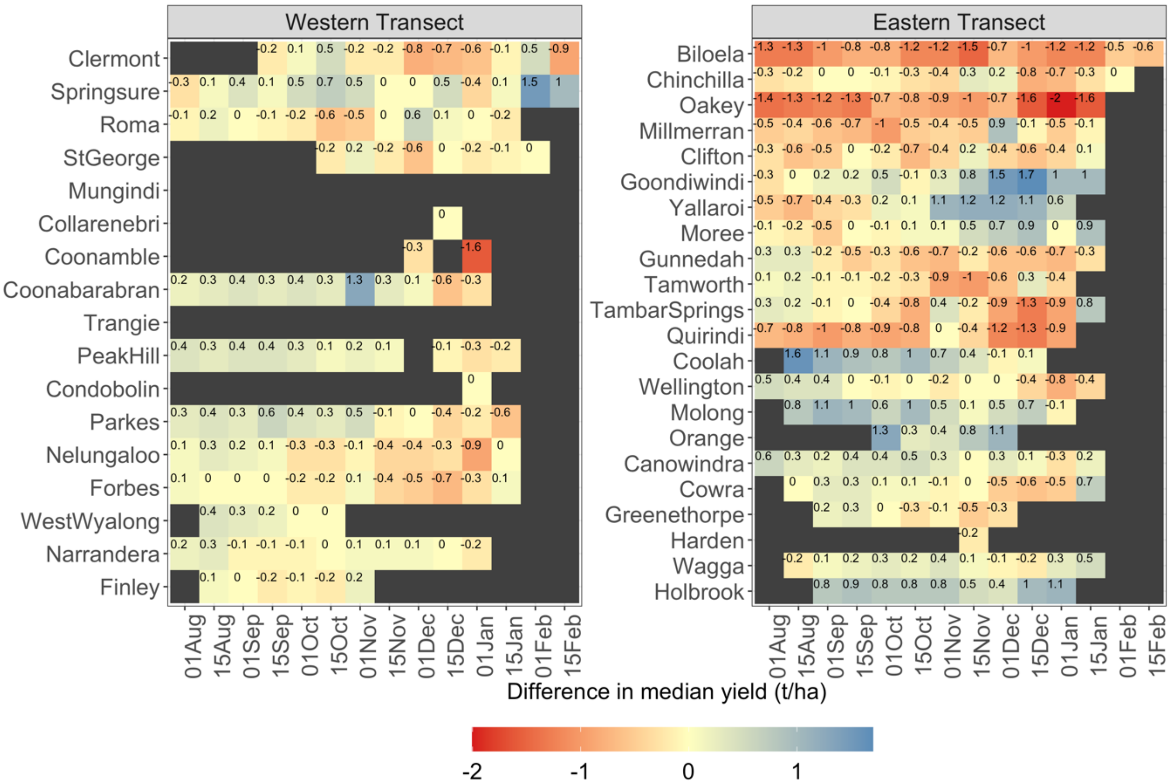

Figure 5. Difference in median yield of sorghum crops between climate normals 1958-1987 and 1988-2017 when sown into a profile of 100mm of water, for different sowing dates for locations divided into western and eastern transects. Red shading indicates a decrease in yield, blue shading indicates an increase in yield, and yellow shading indicates sowing dates for each location with minimal to no difference in yield. Only median yields from sowing dates that had fewer than 50% failed crops are included (other location-sowing date combinations were considered unsuitable for crop production and are coloured black). The values within each cell specifies the magnitude of the difference in yield between the climate normal periods (t/ha).

Why are yields changing?

Rainfall

The availability of water to the crop is the key determinant of yield in Australia. The value of stored soil water is its ability to buffer the demands of the plant in between rainfall events and ensure optimal plant growth. The timing and size of rainfall events are critical to maintaining this buffer as is the specific soil type. In general, the quantity of in-crop rainfall decreased or remained neutral across locations in both eastern and western transects, although there was an increase in in-crop rainfall at a few locations (e.g. Coonabarabran, Goondiwindi and Yallaroi for some times of sowing). These locations are those that showed an increase in water limited yield potential (Figures 4 and 7), and highlight that this increase in rainfall pattern has directly resulted in increased yield.

Yallaroi being one of these sites has seen an increase in rainfall for crops sown in late October to mid- November over the last 30 years despite a slight decline in summer rainfall overall.

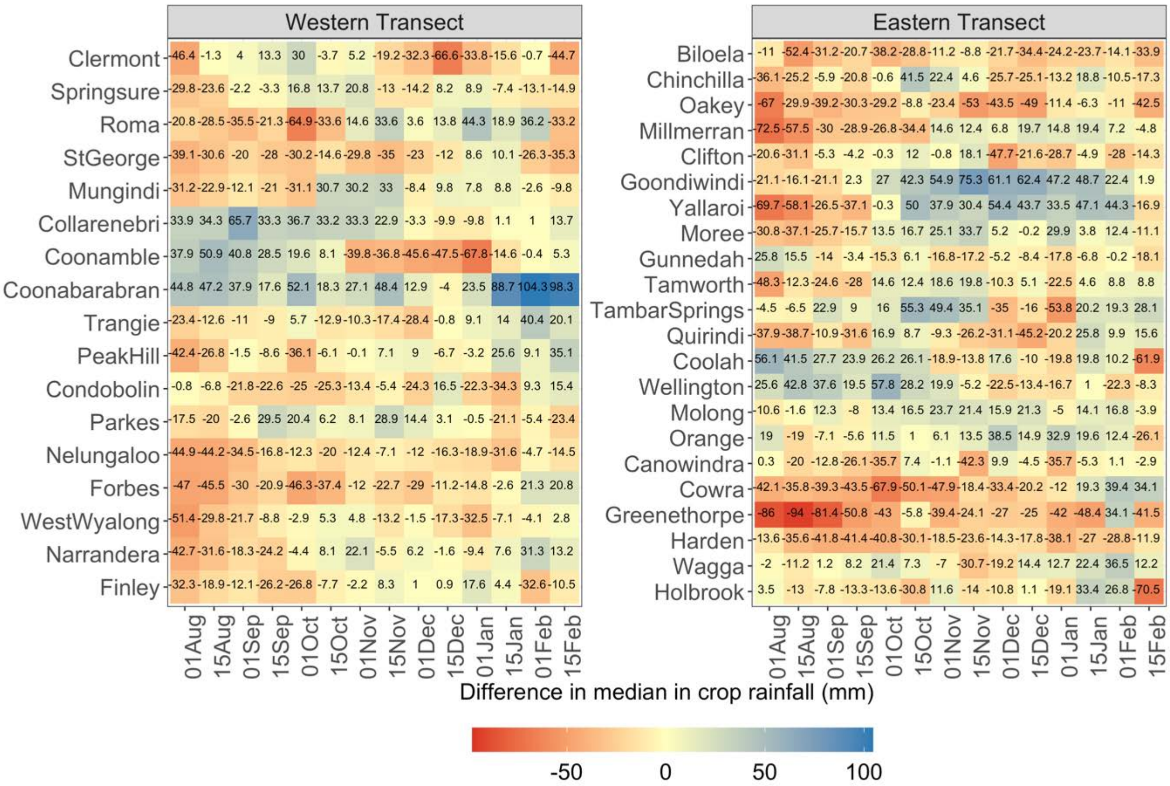

Figure 6. Difference in median in-crop rainfall for the 14 different sowing dates between the two climate periods 1958-1987 and 1988-2017, for locations in western and eastern transects. Red shading indicates a decrease in in-crop rainfall, blue shading indicates an increase in rainfall, and yellow indicates sowing dates with minimal to no difference in rainfall between normals. The values within each cell are the difference in median in in-crop rainfall (mm).

Extreme temperatures

High temperatures around flowering can significantly reduce sorghum grain yield (Lobell et al., 2015; Singh et al., 2017; 2016). The difference in the number of days with temperatures in excess of 35°C increased between the past 30-year climate normal period (1958-1987) and the more recent 30-year normal (1988-2017). The increase in days with extreme temperatures was greater for the western transect, especially for crops sown between October and November. For the eastern transect there was a general increase in the number of days with extreme temperatures for all sowing dates before December. However, a few specific sites experienced a reduction in extreme temperatures; these sites and sowing dates correspond with those that experienced an increase in rainfall and consequently an increase in median yield potential (Figure 7).

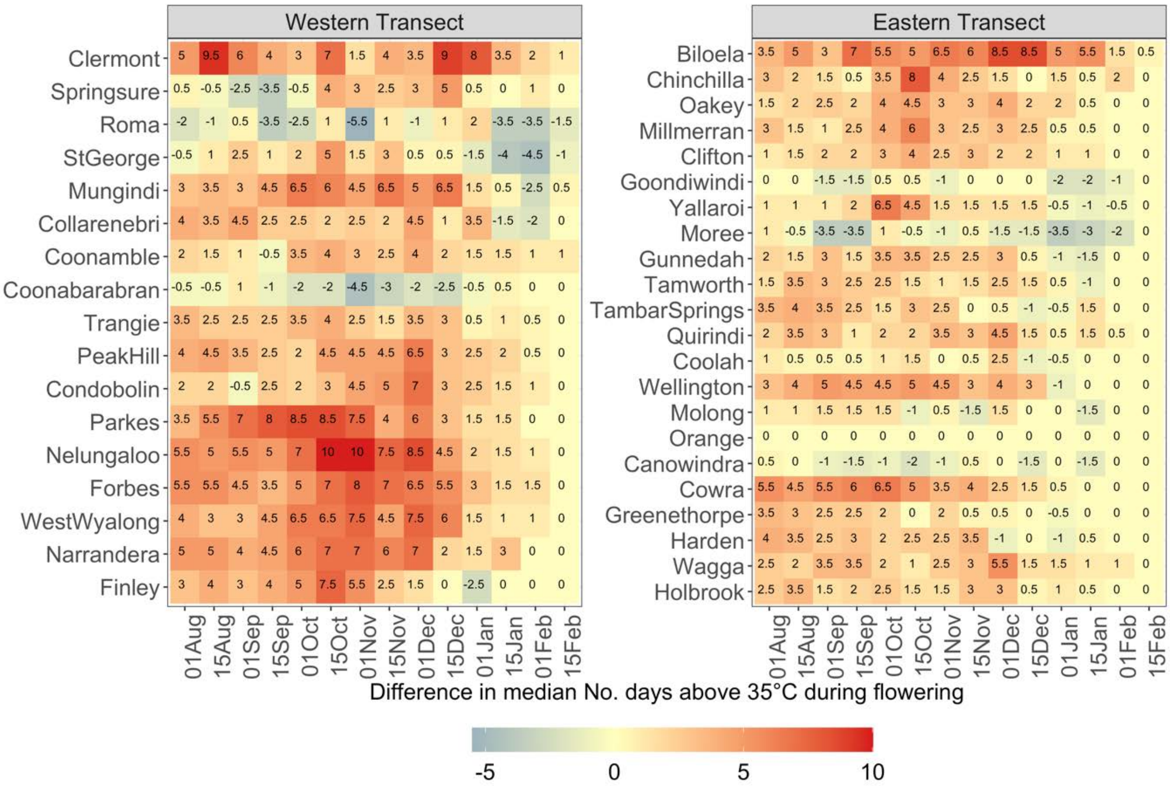

Figure 7. Difference in the median number of days above 35°C during flowering for the 14 different sowing dates between the two time periods of 1958-1987 and 1988-2017, for western and eastern transects within the northern grain zone of eastern Australia. Red indicates an increase in rainfall while blue indicates a decrease, yellow highlights those sowing dates with minimal to no difference. The values within each cell are the difference in median number of days above 35°C during flowering.

So, what does it mean and what can I do?

The climate of Australia's sorghum production area has changed, with increases in the average daily temperature, an increase in the number of days with extreme temperatures during flowering, and a decrease in in-crop rainfall for many locations. These changes have resulted in an overall reduction in crop yield potential. However, despite this decrease the yield potential has not been reduced to a point where it is no longer economical to grow sorghum. Good agronomy and the use of high soil water triggers at sowing will help maintain profitable returns under changing climates. For sites that had an increase in yield for some sowing dates, this could be traced to increased rainfall and a decrease in extreme temperatures during flowering. However, these increases were relative only to the areas historic production and not an increase above traditionally high yield regions. Thus, despite a decrease in the yield potential over the study period for many areas, this decrease has not caused a noticeable shift in sorghum production areas, and so NSW is not the new central Queensland for sorghum production.

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The impact of harvest management in chickpeas – desiccation and front of header losses

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Key words

chickpea desiccation, harvest losses

GRDC code

NGA00004: GRDC Grower Solutions for northern NSW and southern Qld

Take home messages

- Generally minor impact from desiccant treatments or application timing on yield or grain quality
- Decisions on harvest management choice should be determined by cost, attitude to Ally® plant back restrictions, weed spectrum present at harvest and speed of desiccation required
- Delayed harvest at low % grain moisture caused more damaged and split grain than desiccant treatment or timing
- Ideally target desiccation at ~85-90% pod maturity and schedule harvest 7 days later to reduce grain quality issues
- Large levels of pod and grain losses were measured at the front of the header in four commercial evaluations (~100-200 kg/ha)
- Losses reduced by ~50-90 kg/ha when harvested with air assist or when brushes were attached to the reel
- Impact from the harvest modifications would have improved returns by $34-67/ha
- In the trials conducted in 2018 and 2019, this represented an additional 5-18% yield.

Background

Northern Grower Alliance have been researching two important aspects of chickpea harvest management during the period 2017-2019.

The first has been to evaluate the impact of desiccant choice and timing on yield and grain quality. The second has focussed on the magnitude of header losses and the impact on yield and economics from changes in harvest approach.

Desiccation evaluation 2017-2019

The area of focus has evolved over the three seasons:

2017 – 5 trials evaluating current and new desiccation tools to assist in refining management programs. Treatments included glyphosate alone, glyphosate + Ally (metsulfuron-methyl), glyphosate + Sharpen® (saflufenacil), Reglone® (diquat), Gramoxone® (paraquat) (refer to label and follow use pattern for chickpeas) and Gramoxone + Sharpen.

2018 - 4 trials continuing the original activity. An additional 3 trials focussed on impact of desiccation timing (application ~3, 2 and 1 week prior to ‘planned’ commercial harvest). In all three timing trials, treatments were also harvested after a 14-day delay. Treatments repeated from 2017.

2019 - 3 trials primarily focussed on the impact of desiccation timing (application at ~70%, 80% and 90% pods at physiological maturity). Harvest was conducted for all timings ~7 days after application. Similar treatments to 2017 and 2018 but replaced Reglone with glyphosate + Ally + Sharpen.

Pod maturity was assessed at each application on a minimum of 10 main branches. Pods were considered mature when a 'yellow beak' was starting to extend on the enclosed grains. This stage often corresponded with a purplish tinge appearing on the pod coat.

Key points - desiccation evaluation 2017-2019

Leaf discolouration and leaf drop (visual ratings)

- Treatments increased % leaf discolouration and % leaf drop compared to the untreated but without consistent differences between treatments across sites
- Improvements in % leaf discolouration and % leaf drop compared to the untreated were greatest in 2017 (where high levels of October rainfall encouraged crop regrowth) and generally lowest in 2019 at sites that matured very rapidly under high moisture stress.

Stem dry down (physical rating)

- A 'twist test' was conducted to assess the % of plants where all stems snapped at harvest. This was done to provide an indication of stem ropiness or harvest readiness
- The most consistent treatments in 2017 and 2018 were the mixture of glyphosate + Ally or Gramoxone 250 + Sharpen. In 2019 there was no significant difference, in any trial, between any treatment and the untreated
- There was a positive dose response to glyphosate in 2017 and 2018 with increased stem snapping from the 1.8 L/ha rate (540 g ai/L formulation).

Figure 1. Stem twist test results 10-17 days after application, as an indication of stem dry down. *(Mean of 5 trials 2017)*

NIS = non-ionic surfactant

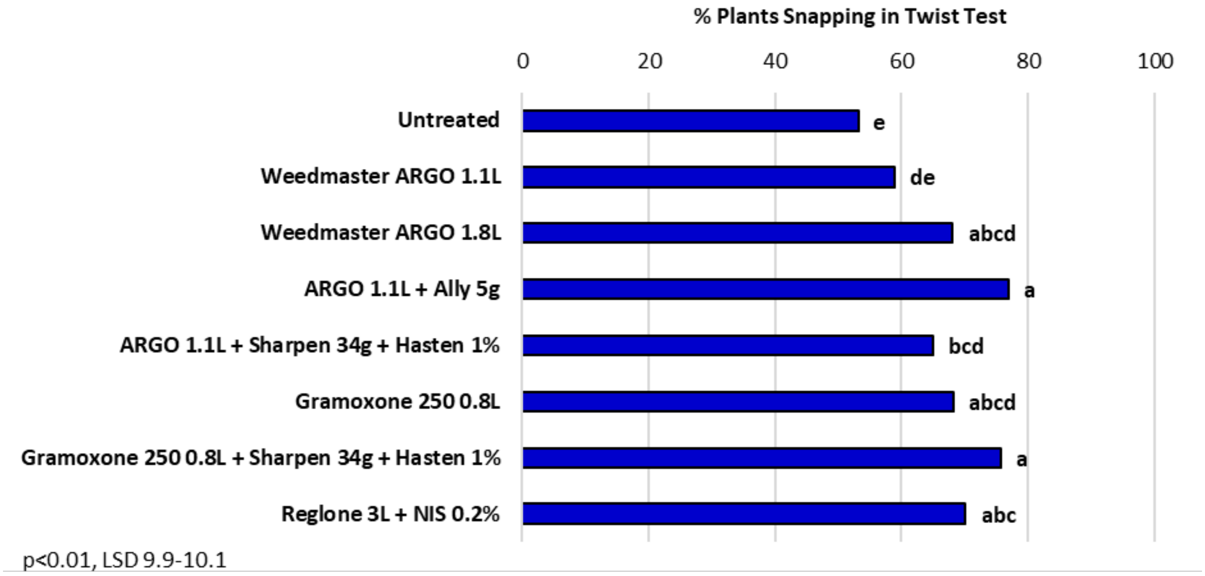

Figure 2. Stem twist test results 7-15 days after application, as indication of stem dry down.
(Mean of 4 trials 2018)

NIS = non-ionic surfactant

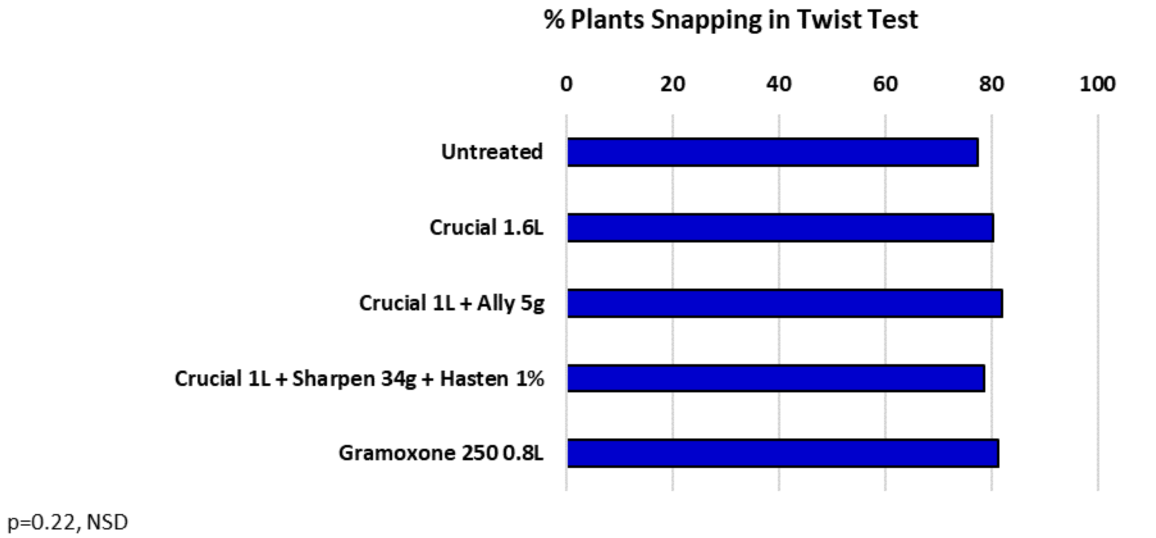

Figure 3. Stem twist test results 6-10 days after application, as indication of stem dry down.
(Mean of 3 trials 2019)

Yield

- In 14 of the 15 trials, there was no significant difference in yield between any treatment and the untreated
- In 2018, there was a significant reduction in yield from Gramoxone 250 at one site where the application was ~4 weeks prior to expected commercial harvest and then harvest was delayed by another 2 weeks. Crop stage at application was only 59% of pods at physiological maturity.

Grain quality (NIR and sievematic)

- Impact on grain quality was generally minor

- Test weight was significantly reduced in 2 trials in 2018 by Gramoxone 250 or Reglone when application occurred ~4 weeks prior to expected harvest. Crop stage at application was ~50-60% of pods at physiological maturity
- There was no significant impact on screenings from any desiccant treatment in 2018 (using a 4mm slotted screen as an indication of defective grain)
- Impact on grain moisture at harvest was minor with no significant difference between desiccant treatments and the Untreated in 12 of 15 trials. All treatments reduced grain moisture by ~1% in a 2017 trial where regrowth was evident and Gramoxone 250 significantly reduced harvest moisture at 2 of the 3 sites in 2019.

Grain grading (visual rating)

- Visual grain assessment on all trials from 2019 showed no significant impact from desiccant treatment or timing on the % green or yellow grain compared to untreated grain harvested at the same time
- In one trial, application of glyphosate alone at 70% of pods at physiological maturity reduced the percentage of mature grain by ~2% and increased the percentage damaged grain by a similar amount. There was no significant impact when glyphosate was applied at 90% pod maturity.

Germination

- Germination tests were conducted on seed samples from application timing trials in 2018 and 2019. Effects were generally minor
- Significant reductions in germination were observed from glyphosate + Ally applied at 58% pod maturity in 1 trial in 2018 and glyphosate + Sharpen + Ally applied at 66% pod maturity in 2019. In both cases, application of the same treatment at later crop stages had no effect
- Reduced germination was observed from all treatments at one site in 2019 when applied at 90% pod maturity where a rain event of ~18mm occurred between application and harvest. There was no consistent impact from treatments on germination from applications at the same site at 70 and 80% pod maturity.

NB The use of desiccants is not recommended when the grain is to be used for seed.

Overall

Differences between desiccant treatments and timing of application were less obvious than originally expected.

- The addition of Ally to glyphosate will generally improve stem dry down compared to other treatments, whilst higher label rates of glyphosate will improve the speed of discolouration and stem dry down.
- Impacts on yield and grain quality were relatively minor, even when application occurred up to 2 or 3 weeks earlier than currently scheduled.

However, in 5 of the 6 trials where harvest timing was also compared, it was clear that the earlier harvest of chickpeas had significantly lower levels of damaged grain. This effect was irrespective of whether the plots had been desiccated or untreated. Although differences in header setup can't be eliminated, it is likely that the lower levels of damaged or split grain is at least partly due to the higher levels of grain moisture at harvest. NB even the early application treatments had grain moisture lower than 10%, when tested within 24 hours of harvest, in 5 of the 6 trials.

Rather than suggesting that the industry desiccate chickpeas at an earlier maturity stage, this data should provide good confidence that desiccation at 85-90% pod maturity is highly unlikely to have any negative impact on yield or grain quality. When combined with harvest scheduled ~7 days after application, this should allow harvest at slightly higher grain moisture and significantly reduce the amount of damaged or split grain in samples.

Commercial harvest losses 2018-2019

Commercial observations have frequently indicated high levels of harvest grain and pod loss in chickpeas, particularly in crops with reduced biomass that 'feed' poorly into the header. This grain loss is different to grain that passes through the header (processing loss) or grain left on plants (harvest height loss). Front of header grain loss is made up of pods and grain that are knocked off by the reel, cut off by the knife but fall outside the header front or thrown out from the header by the drum or belt.

In 2018, data was generated at a site near Gurley where PBA Seamer⊕ was harvested with a header fitted with an air front. Replicated strips were established where the only difference was whether the air front was turned on or off during harvest.

Counts were taken of pods or grain on the ground together with the number of grains/pod and grain weight. In 2018, sampling zones were assessed across the harvested width with no pods or grain apparent on the ground prior to harvest. Results in Table 1 are for the pod and grain losses away from the header trail. These are the harvest losses that occurred at the front of the header but exclude any pods that were unharvested but still attached to plants.

Figure 4. Brushes attached to the header reel Bellata 2019

In 2019 three sites were evaluated with sampling away from the header trail to identify the pods or grain losses at the front of the header. Again there was no indication of pod or grain loss prior to harvest. Two of the sites had air assist fitted to the header that could be simply turned on or off. The third site evaluated lengths of brushes attached to the reel (Figure 1).

Table 1. Impact on chickpea yield losses from air assist or reel brushes

Location and year	Variety and yield	Header set-up	Yield losses on ground			Reduced grain losses kg/ha and ($/ha)
			Pods/m^2	Grain/m^2	Total kg/ha	
Gurley 2018	PBA Seamer⦶ ~0.62 t/ha	Air assist OFF	55 a	10	164 a	89 kg/ha ($67/ha)
		Air assist ON	22 b	8	76 b	
Wee Waa 2019	PBA Monarch⦶ ~1.0 t/ha	Air assist OFF	33 a	5	115 a	45 kg/ha ($34/ha)
		Air assist ON	21 b	3	70 b	
Bongeen 2019	PBA HatTrick⦶ ~0.45 t/ha	Air assist OFF	38 a	1	123 a	80 kg/ha ($60/ha)
		Air assist ON	14 b	0	43 b	
Bellata 2019	PBA HatTrick⦶ ~0.40 t/ha	Reel brushes OFF	62 a	11	217 a	63 kg/ha ($47/ha)
		Reel brushes ON	43 b	9	154 b	

Letters of significance show significant differences **within each site** (2 sample T test, p=0.05)
Economic impact calculated on a $750/t grain price
All results in Table 1 are for sampling away from the header trail. This shows the yield losses occurring at the header front.
Assessment of grains/pod and grain weight was conducted to calculate total grain loss.

Key points – commercial harvest losses 2018-2019

- The majority of grain losses were as whole pods rather than individual grains
- At all four sites between ~100 and 200 kg/ha of grain was lost at the front of the header using a conventional setup
- Use of air assist or brushes attached to the reel significantly reduced the losses of whole pods and the total grain loss, at all sites
- There was no significant difference in losses of individual grains
- The mean reduction in grain loss was 70 kg/ha (range 45 to 89 kg/ha)
- The mean reduction in grain loss was $52/ha (range $34 to $67/ha)
- The reduction in losses would have been equivalent to an extra 5-18% crop yield.

Overall

All four trials highlighted the amount of chickpea grain and income that can be lost at the front of the header at harvest. The impact of air assist or even the simple approach of attaching brushes to the reel provided benefits of ~$50/ha. However some caution is needed as both 2018 and 2019 were low yielding seasons with yields varying between 0.4 and 1.0 t/ha. The benefits of simple header adaptations may be more substantial in lower yielding years or where crop biomass or planting configuration is likely to result in poor levels of ‘feeding in’ of harvested material.

Further evaluation is warranted under more normal conditions to provide growers with realistic indications of the benefits of changes in chickpea harvest management.

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Commercial harvest loss assessments in chickpeas

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Key words

chickpea, harvest, losses

Take home message

- Australian chickpea growers are potentially leaving hundreds of dollars per hectare behind at harvest due to header setup
- Header set up and modifications may have a dramatic impact on harvest losses
- As farm scale has increased over time, harvest efficiency has become more crucial. However, have harvest losses increased to achieve this efficiency? Is there potential to achieve both an efficient harvest and reduce grain losses at harvest?
- Can we produce guidelines to educate growers on what can be achieved by improving harvest setups or using header adaptions in chickpeas?

Introduction

Producing a chickpea crop is a large investment so there is nothing more frustrating than watching a fair percentage of that crop being left on the ground through harvest losses.

Harvest losses are not a new issue to pulse production. Harvest evaluations in mungbeans in CQ in 1985-1987 seasons, found harvest losses to be on average 30% of harvestable yield. This equated to approximately 230kg/ha (Cumming 2010).

Since that time, industry has been extremely fortunate to have had plant breeders working hard to achieve huge advancements in the harvestability of modern pulse varieties including chickpeas. There have also been significant engineering improvements to header fronts: drapers, self-levelling, flex platforms and others.

Air reels were commonly used in the past for harvesting pulses to improve harvestability. Improvements to modern fronts has meant the majority of growers are no longer using air reels as a preferred option. Even with all of these engineering improvements, are we still incurring unacceptable harvest losses?

In recent years growers have been reporting particularly high levels of harvest losses in chickpeas, predominantly at the header front near the knife. Growers were reporting that pod losses were occurring when the knife hit the plant and when pods were rolling off the front over the knife. After observing this happening on many of our clients' farms, MCA undertook some basic pod counts to better understand how much was being left behind. Assessments were undertaken on three farms in the Meandarra district with varying header front set ups. Our data collection and analysis would not stand up to any scrutiny by a biometrician, however the extent of the losses and the potential impact on profitability was extreme in some cases. Refer to Figure 1. (Please note these were multiple fields and in some cases had multiple machines working).

Method 1

Twelve random samples were assessed per field to look at the yield and dollars per hectare lost at harvest. Each sample was 1/10th of a square metre. Whole unsplit pods were counted, and we assumed an average of 1 seed per pod with a seed size of 5000 seeds/kg and an on-farm price \$800/t. Refer to Table 1 and Figure 1.

Table 1. 2018 Pod loss at the header front

	Conventional header set up	Conventional header set up	Conventional header set up	Conventional header set up	Flex front	Flex front	Flex front
Seed counts/0.1m^2	17	10	0	5	12	3	21
	12	81	16	34	2	6	14
	9	47	19	0	6	12	5
	8	12	8	8	15	7	9
	5	4	6	28	17	27	5
	47	2	8	6	52	6	1
	56	14	12	44	2	16	7
	20	8	7	17	1	45	14
	41	27	46	12	1	8	6
	22	2	13	8	3	31	16
	14	17	7	7	24	15	5
	7	31	22	3	2	9	8
Total	258	255	164	172	137	185	111
Average	21.5	21.2	13.7	14.3	11.4	15.4	9.2
Seeds/m^2	217	214	138	145	115	155	93
Seeds/ha	2167339	2142137	1378024	1444557	1150877	1554103	932460
	GROWER 1	**GROWER 1**	**GROWER 1**	**GROWER 2**	**GROWER 3**	**GROWER 3**	**GROWER 3**
Variety	**HatTrick**⦶	**HatTrick**⦶	**HatTrick**⦶	**HatTrick**⦶	**Seamer**⦶	**Seamer**⦶	**Kyabra**⦶
Rigid/Flex front	**Rigid Front**	**Rigid Front**	**Rigid Front**	**Rigid Front**	**Flex Front**	**Flex Front**	**Flex Front**
Kg/ha assuming 5,000 seeds	433	428	276	289	230	311	186
$/ha on the ground assuming $800/t	$347	$343	$220	$231	$184	$249	$149

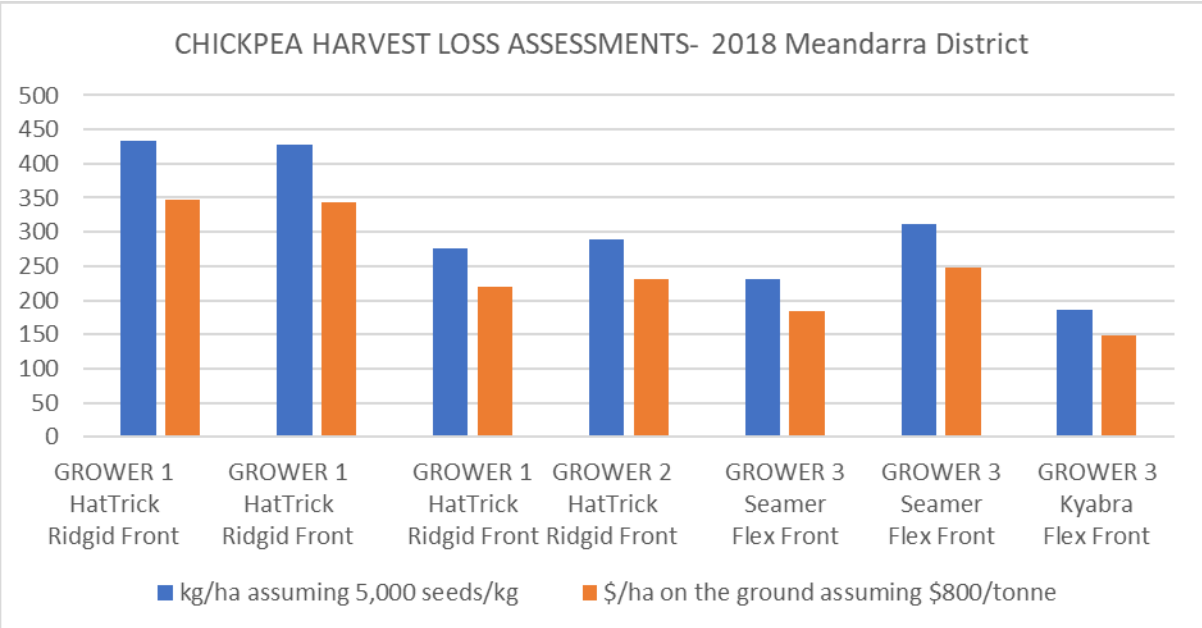

Figure 1. 2018 Pod loss at the header front
(HatTrick⦶, Seamer⦶ and Kyabra⦶ are varieties protected under the Plant Breeders Rights Act 1994)

Of note: Grower 1 for example, had variations from field to field and there were multiple headers working in these fields. The variation may have been operator, ground conditions and/or set up. It appeared that the flex fronts were an improvement, however in one of grower 3's fields, there was still significant losses.

After being quite shocked by what the pod counts were suggesting, we started asking the question, "Can we reduce losses by modifying the header front?".

Multiple clients tried different modifications, including adding paddles to the reel, fixing different light crop fingers, adding bristles behind the knife sections and a combination of these attachments. They achieved varying results. Some clients also purchased flex fronts, again achieving varying results depending on the design of the front, and crop and field conditions.

After observing a well-regarded pulse grower utilise an AWS Airbar® attachment mounted in front of the reel of a John Deere® flex front harvesting mungbeans, and achieving a large reduction in losses, MCA became interested in the concept and started discussing it with clients.

In 2018 and 2019 four of our clients invested in the Airbar systems. We then decided to do some more basic pod counts to try and measure a reduction in losses. The average improvement in losses was 180 kg/ha with one very short low yielding crop showing an extreme improvement of 297 kg/ha.

Method 2

We asked header operators to do strips with the Airbar operating and then set up without the Airbar operating. In these strips we assessed 20 x 625 cm^2 samples and assumed 1.5 seeds/pod and a seed size of 5000 seeds/kg. Please note our data collection and analysis is not to be seen as statistically valid. Refer to Table 2 and Figure 2.

Table 2. 2019 Airbar pod counts (4 comparison sites)

Site 1: HatTrick, yield 0.4t/ha, 50cm rows 2018								
Regular header front								
Counts/25cm^2						Average/625cm^2 (25x25cm)	Average/m^2	Average/ha
1	5	18	5	5	6	7.8	125	
2	13	14	3	1	9	8	128	
3	13	12	10	22	5	12.4	198	
4	33	4	4	7	10	11.6	186	
					Total Av.	**9.95**	**159**	1,592,000
							Av peas/ha (assuming 1.5 peas/pod)	2,388,000
							Kg/ha (assuming 5000 peas/kg)	478
							t/ha	0.48
Air header front								
Counts/25cm^2						Average/625cm^2 (25x25cm)	Average/m^2	Average/ha
1	4	0	9	0	0	2.6	42	
2	2	8	12	5	11	7.6	122	
3	1	6	1	6	0	2.8	45	
4	0	0	2	0	8	2	32	
					Total Av.	**3.7**	**60**	600,000
							Av peas/ha (assuming 1.5 peas/pod)	900,000
							Kg/ha (assuming 5000 peas/kg)	180
							t/ha	0.18
							Difference (kg/ha)	298
							t/ha	0.30
							Cost/ha (assuming $800/t)	$238
							Area (ha)	350
							Paddock benefit of airfront	**$83,328**

Site 2: Kyabra, yield 0.6 t/ha 50cm rows 2019								
Regular header front								
Counts/25cm^2						Average/625cm^2 (25x25cm)	Average /m^2	Average/ha
1	3	0	7	3	3	3.2	51	
2	2	6	2	5	3	3.6	58	
3	5	1	0	6	1	2.6	42	
4	0	5	12	6	6	5.8	93	
					Total Av.	**3.8**	**61**	608,000
							Av peas/ha (assuming 1.5 peas/pod)	912,000
							Kg/ha (assuming 5000 peas/kg)	182
							t/ha	0.18
Air header front								
Counts/25cm^2						Average/625cm^2 (25x25cm)	Average /m^2	Average/ha
1	2	1	5	1	0	1.8	29	
2	1	2	2	4	0	1.8	29	
3	5	2	0	1	1	1.8	29	
4	1	0	2	0	0	0.6	10	
					Total Av.	**1.5**	**24**	240,000

Av peas/ha (assuming 1.5 peas/pod)	360,000
Kg/ha (assuming 5000 peas/kg)	72
t/ha	0.07
Difference (kg/ha)	110
t/ha	0.11
Cost/ha (assuming $800/t)	$88
Area (ha)	292
Paddock benefit of airfront	**$25,789**

Site 3: Seamer⊕, 1.5 t/ha, 75cm rows								
Regular header front								
Counts/25cm²						Average/625cm² (25x25cm)	Average/m²	Average/ha
1	5	2	10	7	10	6.8	109	
2	2	2	6	2	2	2.8	45	
3	0	12	0	1	3	3.2	51	
4	6	6	0	3	4	3.8	61	
					Total Av.	**4.15**	**66**	664,000
							Av peas/ha (assuming 1.5 peas/pod)	996,000
							Kg/ha (assuming 5000 peas/kg)	199
							t/ha	0.20
Air header front								
Counts/25cm²						Average/625cm² (25x25cm)	Average /m²	Average/ha
1	1	1	8	3	1	2.8	45	
2	1	1	2	0	1	1	16	
3	2	1	1	1	1	1.2	19	
4	1	2	0	4	2	1.8	29	
					Total Av.	**1.7**	**27**	272,000
							Av peas/ha (assuming 1.5 peas/pod)	480,000
							Kg/ha (assuming 5000 peas/kg)	82
							t/ha	0.08
							Difference (kg/ha)	118
							t/ha	0.12
							Cost/ha (assuming $800/t)	$94
							Area (ha)	150
							Paddock benefit of airfront	**$14,112**

Site 4: Seamer⊕, 0.5 t/ha, 37cm rows								
Regular header front								
Counts/25cm²						Average/625cm² (25x25cm)	Average/m²	Average/ha
1	11	3	5	0	10	5.8	93	
2	4	1	4	8	9	5.2	83	
3	11	7	4	1	13	7.2	115	
4	10	2	13	8	2	7	112	
					Total Av.	**6.3**	**101**	1,008,000
							Av peas/ha (assuming 1.5 peas/pod)	1,512,000
							Kg/ha (assuming 5000 peas/kg)	304
							t/ha	0.30

Air header front								
Counts/25cm^2						Average/625cm^2 (25x25cm)	Average /m^2	Average/ha
1	0	4	4	6	1	3	48	
2	2	5	0	0	3	2	32	
3	1	3	2	2	5	2.6	42	
4	0	0	1	1	1	0.6	10	
					Total Av.	**2.05**	**33**	328,000
							Av peas/ha (assuming 1.5 peas/pod)	492,000
							Kg/ha (assuming 5000 peas/kg)	98
							t/ha	0.10
							Difference (kg/ha)	204
							t/ha	0.20
							Cost/ha (assuming $800/t)	$163
							Area (ha)	463
							Paddock benefit of airfront	**$75,562**

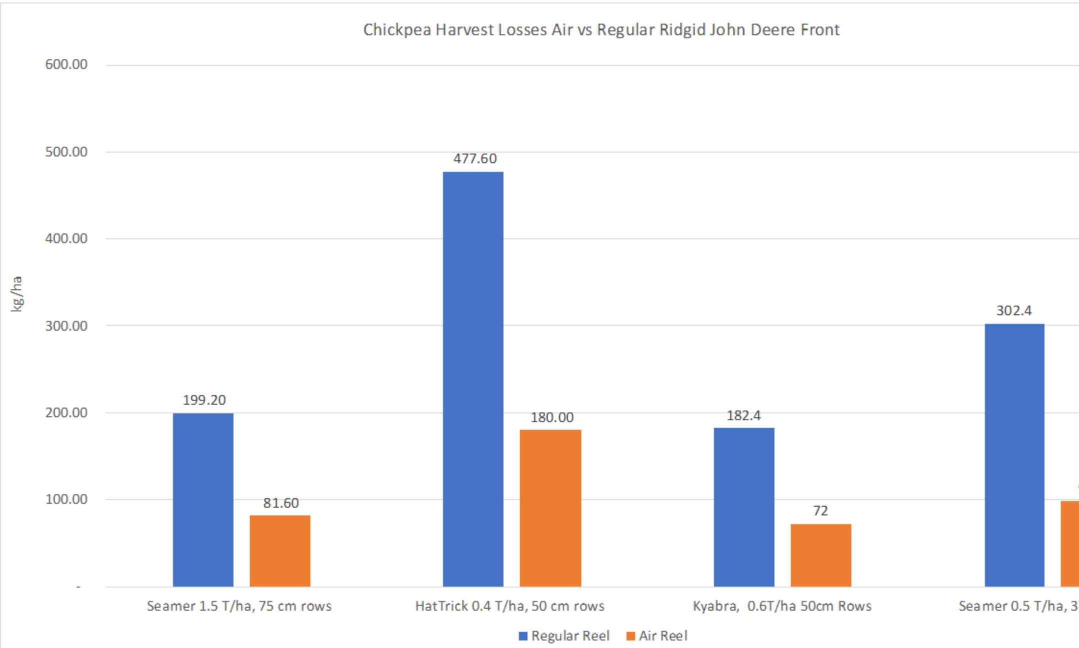

Figure 2. 2019 Harvest losses in chickpeas based on pod counts left on the ground after harvesting with a regular and an air assisted reel
(HatTrick⊕, Seamer⊕ and Kyabra⊕ are varieties protected under the Plant Breeders Rights Act 1994)

Please note: These were all rigid John Deere draper fronts with AWS Airbar attachments. These results may not be replicated with other machines or in different harvesting conditions.

Discussion

From the limited data we collected which was anecdotally supported by machinery operators, header front adjustments and modifications may provide improvements to chickpea harvest losses. Our sampling occurred in varying varieties in a range of crop yields. Of note these years were particularly low yielding. The results may not be replicated in more favourable seasons with taller crop canopies improving feeding over the knife. In fact, in higher yielding years it may be possible that these modifications may have a negative impact on losses. Replicated, statistically significant sampling needs to be collected over multiple years to answer these questions.

Conclusion

Harvest is arguably the most important aspect of chickpea crop management. Very large improvements in profitability may be achieved by adapting harvester set ups in some situations. Growers should invest the time to monitor losses and attempt to reduce these losses as the improvements to profits may be significant.

Acknowledgements

I would like to acknowledge Jess Mickelborough and Edward Britten for conducting the pod counts and tabling the information.

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Stubble Olympics: the cereal pathogen 10cm sprint – growth patterns of fungi causing crown rot, common root rot and yellow leaf spot in post-harvest cereal stubble

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Key words

cereal stubble, cereal disease, crown rot, yellow spot, common root rot, stubble management

GRDC codes

BLG211 and BLG304 – Grains Agronomy and Pathology Partnership (GAPP) PhD
DAQ00208 – Statistics for the Australian Grains Industry – North

Take home messages

- Wetter is better (for cereal pathogens): moist conditions promoted growth of pathogenic fungi (*Fusarium pseudograminearum*, *Bipolaris sorokiniana* and *Pyrenophora tritici-repentis*) within post-harvest cereal stubble, meaning inoculum levels of crown rot, common root rot and yellow spot may increase if wet weather is experienced after harvest
- Not all cereal stubble is created equally: some pathogens progressed further in oat than bread wheat stubble. Additionally, there are indications that the resistance ratings of varieties and crops do not reflect the extent of saprophytic growth post-harvest
- Each cereal pathogen had a unique stubble-colonisation pattern: the crown rot fungus was the quickest to progress within all stubble types and the yellow spot pathogen was the slowest. This is likely to influence which pathogen dominates in following seasons if mixed infections have occurred in the same crop
- Reducing cereal stubble biomass may limit the post-harvest progression of pathogenic fungi in stubble, thereby reducing the amount of inoculum carried forward. Options could include selection of low-biomass varieties, low harvest heights or cutting for hay, however field validation is required.

Introduction to post-harvest (saprophytic) growth of cereal pathogens

Fusarium crown rot, yellow leaf (tan) spot and common root rot are significant diseases of cereal crops in Australia with one important thing in common: they are all caused by stubble-borne pathogens. Expanding adoption of conservation agriculture practises (such as cereal stubble-retention) makes these diseases very difficult to control because inoculum is preserved in the previous years' cereal rows. Surprisingly, we don't know much about what these pathogens are doing between harvest of an infected crop and sowing of the next susceptible crop (except that they generally persist long enough to cause disease in following seasons).

Reports of pathogen growth (we call it saprophytic growth) in standing cereal stubble has been reported, but it is still unclear how frequently this saprophytic growth occurs, and if it contributes to inoculum build-up or disease risks in future cereal crops. Previously, we showed that the crown rot pathogen *Fusarium pseudograminearum* can colonise cereal stubble at an average rate of 1cm/day under moist conditions (Petronaitis et al., 2020). So, saprophytic growth can be rapid if moisture is not limiting. But how much moisture do we need for saprophytic growth to start, and is it the same for other pathogenic fungi, like *Bipolaris sorokiniana* (causative agent of common root rot) and *Pyrenophora tritici-repentis* (causative agent of yellow leaf spot) in different cereal stubbles?

Knowing how these pathogens behave in post-harvest cereal stubble may be the key to controlling them effectively in conservation agriculture systems. As such, we set up an experiment, named the "Stubble Olympics", to explore the following questions: (1) what moisture conditions induce saprophytic growth of these different pathogens, (2) how far and fast inoculum may progress under such conditions, and (3) if crop selection (or other management strategies) can be used to supress saprophytic growth.

The "Stubble Olympics" experiment

Who are our contestants in the "Stubble Olympics"? Three important cereal pathogens: two isolates each of Crown rot (*F. pseudograminearum)*, common root rot (*B. sorokiniana)* and yellow leaf spot) *P. tritici-repentis*. Each isolate was placed inside individual tillers of cereal stubble from four crop types (Table 1) and tested for saprophytic fitness by measuring their growth under moisture conditions ranging from 90% to 100% relative humidity (RH) in 2.5% RH increments. Two varieties of bread wheat and two varieties of barley were selected to have either a relatively susceptible or relatively resistant disease rating for each pathogen.

Table 1. Cereal stubble collection (location), variety information (species, variety and class), and disease ratings for crown rot (CR), common root rot (CRR) and yellow leaf spot (YLS). Rating information sourced from Winter Crop Variety Sowing Guide 2019 (Matthews and McCaffrey, 2019)

Cereal species	Variety (class)	Crop location	CR rating	CRR rating	YLS rating
Bread Wheat	EGA Gregory⅌ (APH)	Narrabri	S	MS-S	S
	LongReach Lancer⅌ (APH)	Narrabri	MS-S	S	MR-MS
Durum wheat	DBA Lillaroi⅌ (ADR)	Tamworth	S-VS	MS-S	MR-MS
Barley	Compass⅌	Narrabri	S	MS	NA
	Rosalind⅌	Narrabri	MS-S	S	NA
Oat	Eurrabie	Narrabri	NA	NA	NA

Abbreviations: Australian prime hard (APH), Australian Premium Durum (ADR), not applicable (NA), moderately resistant (MR), moderately susceptible (MS), susceptible (S), very susceptible (VS)

Individual tillers were inoculated at the base with an agar plug of one of six pathogen isolates, and this end of the tiller was inserted onto a metal nail plate to simulate standing stubble. Custom-built humidity chambers (Figure 1) were used to impose the different RH treatments on the inoculated cereal stubble. Humidity chambers were run for 7 days at constant temperature (25˚C) under alternating ultra-violet light (12 h light/12 h dark). Saprophytic growth was measured as the number of tiller segments (1cm length) and position (1-10) which the pathogen was recovered from on agar.

The experiment was repeated twice over time, with treatments arranged according to a split-plot design, where RH treatments were randomised to main plots and crop, variety, pathogen, isolate combinations were randomised to sub-plots.

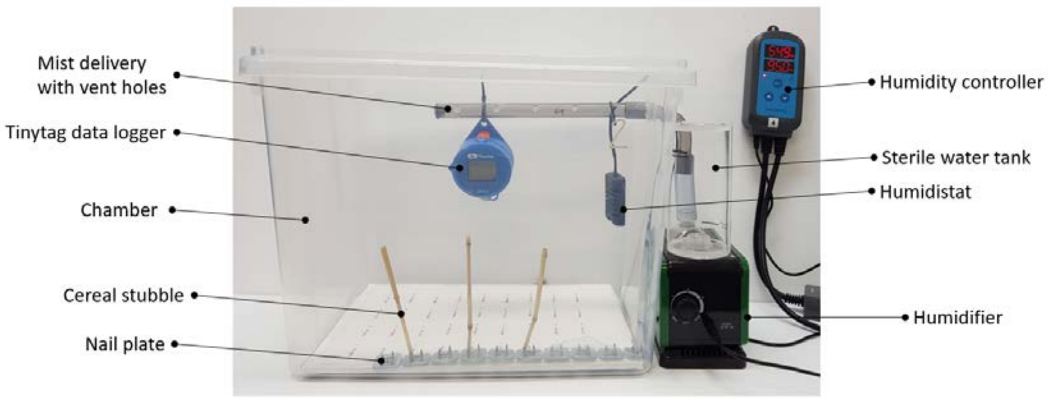

Figure 1. Example of controlled humidity chamber design containing "standing" stubble

Moisture induces saprophytic growth of pathogens in cereal stubble

Moisture (relative humidity (RH)) had a profound effect on the saprophytic growth of all three of our cereal pathogen contestants (Figure 2). In general, pathogens progressed further (i.e. maximum length of stubble colonised) as RH increased. However, each species responded differently to each moisture scenario, except for the driest treatment (90% RH) where all pathogens experienced little-to-no growth. Once moisture was increased to 92.5% RH and 95% RH, the crown rot pathogen was able to colonise stubble twice as fast as the other two pathogens. The yellow spot and common root rot fungi required moisture levels of 97.5% to progress significantly. All pathogens were able to progress the farthest, and produced the most inoculum, under saturated (100% RH) conditions.

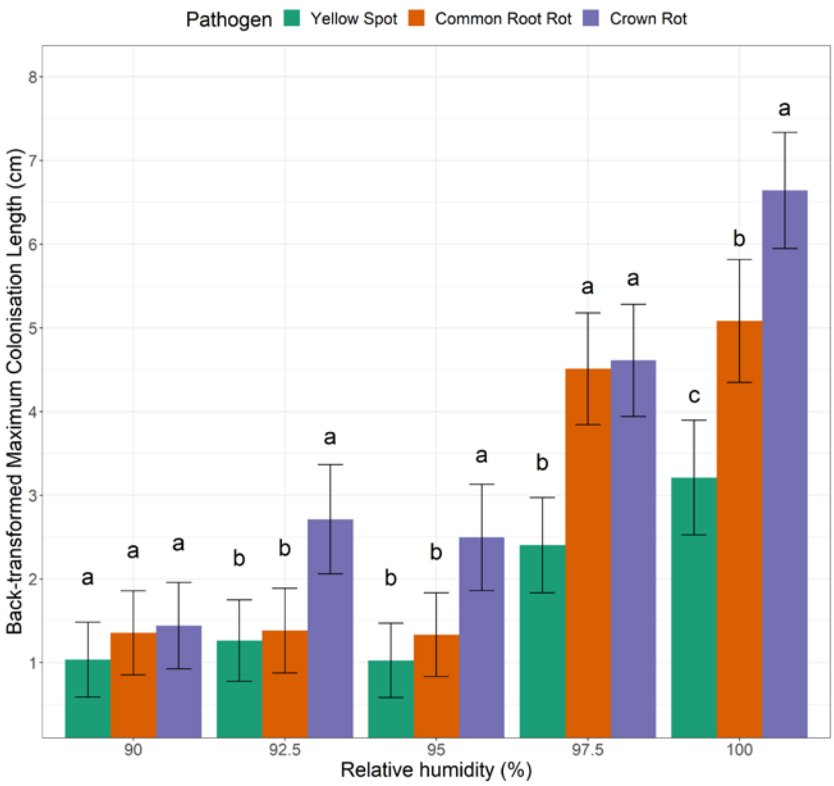

Figure 2. Maximum colonisation (cm) of cereal stubble by three cereal pathogens subject to moisture conditions of 90% RH, 92.5% RH, 95% RH, 97.5% RH or 100% RH for seven days. Note LSD letters only enable comparisons between pathogens within a humidity treatment (not between

humidity treatments). Values with the same letter are not significantly different (*P*=0.05). Error bars represent approximate standard error of the mean.

Inoculum can progress very fast under moist conditions (which pathogen will take home the gold?)

At 100% RH, the crown rot pathogen experienced significantly faster growth than both other pathogens (~1cm/day – takes home the gold!), whilst the common root rot pathogen was significantly faster (~0.7cm/day – silver!) than the yellow spot pathogen (~0.45cm/day – bronze!) (Figure 2). Multiple-pathogen infections (e.g. crown rot + common root rot) are common in the northern region (Simpfendorfer and McKay, 2019). Our work suggests that under saturated conditions (i.e. rainy, dewy or foggy weather) the crown rot pathogen could rapidly vertically colonise stubble of plants already infected during the growing season, making it more likely to dominate in following seasons.

Selecting crops for resistance won't help supress growth in the saprophytic phase

Remember how the two varieties each of bread wheat and barley were selected for their difference in disease resistance ratings (Table 1)? Interestingly, no differences in progression (cm) (Figure 2) or colonisation (%) (Figure 3) were observed between the two varieties of the same crop type regardless of the resistance rating. This indicates that varietal resistance does not reduce saprophytic growth (i.e. further inoculum production) post-harvest. Oats, and barley in the case of yellow spot, have no resistance ratings for the selected diseases because they are not typically considered important hosts. However, the yellow spot pathogen has been detected on non-host crops such as barley in the northern region (Simpfendorfer and McKay, 2019). In most cases, the pathogens are not causing disease and are believed to be saprophytically colonising senescing plants late in the season. Therefore, it is quite troubling that the three pathogens produced the same or more inoculum on oat stubble at 100% RH (Figure 3). For example, the yellow spot pathogen produced significantly less inoculum on bread wheat stubble (a recognised host) under moist conditions compared to oat (non-host). It's possible that the denser tissue and lower biomass of bread wheat stubble may help slow saprophytic colonisation. On the other hand, oat stubble may allow faster progression due to less dense/hollow culms or allow more nutrient exploitation by the fungi (increased lignin content and higher digestibility). So, even if only low levels of infection are experienced during the growing season, or disease is not expressed due to favourable seasonal conditions or plant tolerance, rapid colonisation may still occur after plant senescence.

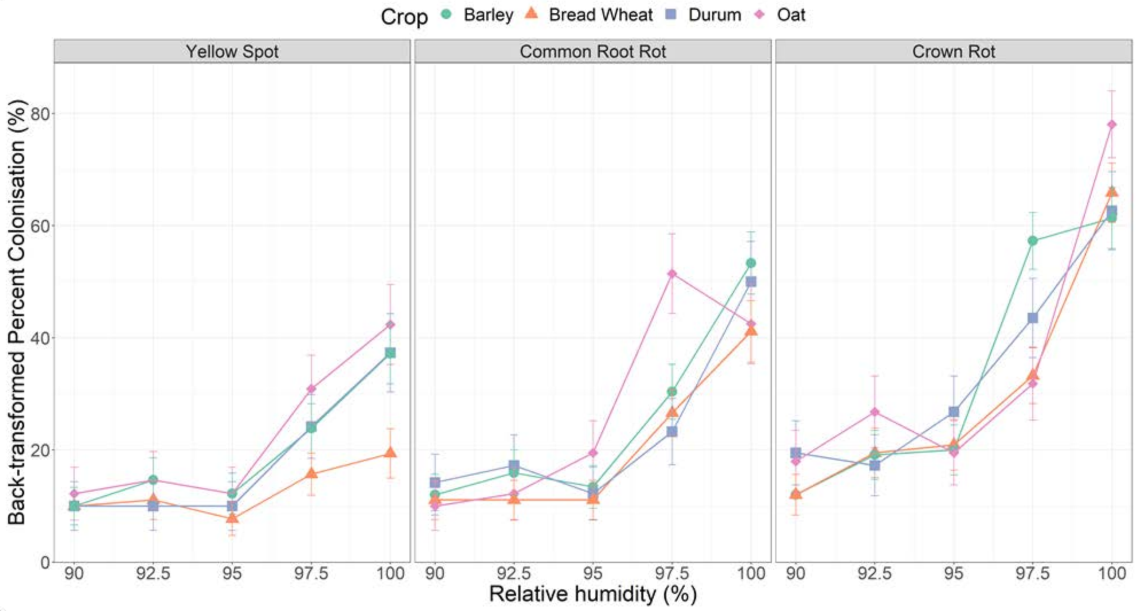

Figure 3. Inoculum production as a percentage (%) of different types of cereal stubble colonised by three pathogens subject to moisture conditions of 90% RH, 92.5% RH, 95% RH, 97.5% RH or 100% RH for seven days. Error bars represent approximate standard error of the mean.

How may this knowledge be important to growers?

Harvest height to manipulate stubble biomass – still a work in progress

Reducing harvest height is a quick way to reduce cereal stubble biomass (Figure 4, field data not shown). This might be useful in severely infected paddocks by removing disease inoculum and/or limiting the amount of vertical stubble available for further saprophytic growth. In severe cases, for example durum wheat affected by crown rot in a dry season, the stubble may already be extensively colonised at harvest (Figure 4). Field testing is underway to reveal if saprophytic growth occurs within taller stubble (i.e. beyond levels at harvest) and whether shorter stubble can limit further growth.

Figure 4. Harvest-height disease management trial at Narrabri, NSW. Durum wheat was harvested at three heights: 10-15cm (A), ~30cm (B) and 40-45cm (C). Far right: recovery of crown rot pathogen *F. pseudograminearum* (red-brown colonies) at harvest shows significant colonisation within the stem at harvest (up to 30 cm). Arrows indicate where the pathogen was recovered from along the stubble length.

Modelling saprophytic growth based on weather patterns/predictions – we're in the early days

Controlling the humidity chambers to be at 25 °C enabled detailed investigation of pathogen response to moisture in stubble. However, modelling saprophytic growth in the field would require knowledge of these growth patterns across a range of temperatures, because air can hold more water at higher temperatures. For instance, during hotter months there is more total water in the air, but we don't know if this water is available to stubble-borne pathogens until high RH (close to dew point) is achieved. Air gives up moisture more freely at lower temperatures (dew point is lower), hence we generally experience more dewy/frosty or foggy mornings during winter. Determining whether the pathogens respond to total water or dew point (or both) will be essential for modelling saprophytic growth.

Should growers be concerned about saprophytic growth of pathogens in cereal stubble?

The short answer: be alert, not alarmed. Right now, we are still trying to understand if and how saprophytic growth of cereal pathogens during fallow and non-host rotation may affect disease risk in subsequent seasons. It is possible that the recent higher rainfall experienced in many areas may have spiked pathogen levels right before sowing, placing new crops at a higher risk than in previous (drier) years. Furthermore, the extended dry conditions (2017-19 seasons) have allowed inoculum to persist at damaging levels for much longer than normal (2-4 seasons). So, be vigilant about checking this years' cereal crops for disease symptoms and consider appropriate in-crop management strategies if necessary.

Always remember that seasonal conditions can affect cereal stubble biota (the good and the bad) during fallows and non-host rotations, and stubble is not "dormant" during these times. In summary:

- **Dry conditions** allow inoculum (and cereal stubble) to persist longer (2-4 years). Stubble will not be as accessible to beneficial microbes (with higher moisture requirements) which can suppress pathogens. Our work reinforces how *Fusarium* species are especially suited to survive and grow in drier conditions.
- **Wet conditions**, like those applied in our study, can potentially increase inoculum, but the cereal stubble will also decompose faster if prolonged wet weather is experienced. Moisture may increase the activity of beneficial microbes, helping with stubble decomposition and pathogen suppression. Moist conditions also promote spore production by these pathogens, and these can persist in soil for many years in the absence of stubble (e.g. conidia of common root rot pathogen).

Testing using PREDICTA® B is a very effective method for determining disease risk (following the up-to-date protocol of adding cereal stubble to the sample). If your paddock/s have returned a below detection limit or low risk PREDICTA B test for cereal disease, then you can continue following best practise agronomy for your next cereal crop.

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Cereal disease management in 2020 – from famine to moving feast!

Steven Simpfendorfer, NSW DPI, Tamworth

Keywords

correct diagnosis, leaf diseases, stripe rust, net blotch, fungicide strategy, stay up to date, COVID-19

GRDC code

DAN00213: Grains Agronomy & Pathology Partnership - A strategic partnership between GRDC and NSW DPI

Take home messages

- 'We're all in this together'
- Ensure you know the latest resistance ratings of cereal varieties you have sown – they change
- Back to basics – destroy the green bridge – oh well, move on from this in 2020
- Ensure correct diagnosis – not everything is disease and if not fungicides won't help
- Timing is everything – protect the top three leaves. However, with stripe rust 'flattening the curve' helps
- Prophylactic or responsive in 2020 with tight fungicide supply? Is a 2-3 week wait for product in Spring a potential consequence?
- Seek information and advice – NSW DPI pathologists are here to help ('we're all in this together').

Introduction

Gotta love 2020! Prolonged drought, bushfires/dust storms, COVID-19 global pandemic, barley tariff, wet/cold and now early development of leaf diseases (stripe rust in wheat and net blotch in barley) in winter cereal crops.

The other significant issue at play is continued concerns around the availability of fungicides throughout the season. The only thing that is certain in 2020 is that whatever I write here will likely be outdated by August when we do the webinar. Hence, I'll try and stick to the principles of disease management.

1. Know resistance levels in varieties you are sowing – they do change!

At the time of writing continuing reports of stripe rust 'hotspots' in the early sown wheat variety DS Bennett⊕ are occurring. This has been a considerable surprise to some growers and their advisers as they thought this variety was rated R to stripe rust. Well it was in 2018, but with the detection of a new pathotype (198 E16 A+ J+ 17+, '198 pathotype') in Tasmania and Victoria in 2018, the rating of DS Bennett⊕ dropped to MS in 2019 sowing guides. The 198 pathotype was detected at 4 sites in NSW, 2 in Victoria and 1 in QLD in the 2019 season with further evaluation of stripe rust reactions to this pathotype seeing DS Bennett⊕ lowered to an S rating for 2020 variety guides. Ensure you are using the latest variety ratings which are updated annually to reflect the expected reactions to new pathotypes of different pathogens if required (Winter crop variety sowing guide 2020).

The resistance within the varieties does not change, rather it is pathogen which has adapted (mutated) to overcome a resistance gene(s) within a variety. This can therefore lower the resistance rating of varieties which rely on this particular resistance gene. How far the rating drops depends on what other resistance genes are sitting in the background within individual varieties. For example, with the 198 pathotype of stripe rust, DS Bennettᶲ has fallen from R to S, Illaboᶲ has dropped from RMR to MR, whilst LRPB Kittyhawkᶲ remains unchanged at RMR. Some other big changes with varieties to the 198 pathotype are in LRPB Trojanᶲ which drops from MRMS to MSS and some durum varieties such as DBA Lillaroiᶲ and DBA Vittaroiᶲ which drop from RMR to MS. Note there have also been changes in leaf rust resistance ratings in wheat to a new Lr24 pathotype. It pays to stay up to date with the latest resistance ratings.

2. Destroy the green bridge is still important – volunteers are not good!

All rusts are what is termed '*biotrophs'* which simply means they need to host in a living plant to enable them to survive between crops. With wheat rusts, volunteer wheat plants are the green bridge, if they are from a susceptible variety. Removing these volunteers and hence the green bridge, delays the onset of rust epidemics if adopted widely. However, many growers have come off the back of a few tough years and with prolonged drought we all expected to have a reduced risk from green bridge build-up of rusts.

Volunteers which emerged on December/January rains were a valuable source of much needed feed and with great growing conditions there was unfortunately not enough stock to keep on top of the growth in many situations. Unfortunately, it has been reported that the growth was so good that some growers have even attempted to hang onto some of these volunteer crops and take to harvest. This, combined with an early seasonal break in 2020 in many regions of NSW and the widespread sowing of longer season wheat varieties, has resulted in a continuous 'green ramp' since January in many areas. The need to reduce input costs has also seen a reduction in the use of seed and in-furrow fungicide treatments for stripe rust which normally provide early protection and delay the onset of stripe rust in regions when used widely. The levels of stripe rust already present in long season wheat varieties across NSW will place pressure on plantings of susceptible main season varieties (potential 'second wave'?).

Some central NSW growers have also hung onto volunteer barley crops, attempting to take them to harvest. With prolonged wet/cold weather there have been issues with getting the heads to dry down, high levels of either spot or net-form of net blotch and weeds. At least with net blotch these situations are largely confined to the paddock where the problem was created. Hence, lesson learnt for the growers. Unfortunately, this is not the case with rust as the spores from infected crops can blow 100s of kilometres. Yes, 'we're all in this together' (COVID-19 parallel 1).

3. Monitor crops and get correct diagnosis

Do not get the impression from this paper that everything that is happening in cereal crops in 2020 is related to disease. Underlying issues with nutrient, herbicides, frost and other stresses are also causing some yellowing or discolouration of leaves in 2020. Physiological spotting not related to disease occurs especially in barley every year with 2020 being no exception. However, disease has clear patterns of distribution within and between paddocks, plants and even on individual leaves. The key message is testing is available which can be as simple as texting or emailing some good quality photos to NSW DPI pathologists (contact details below). This can be a quick way of ruling disease(s) in (or out), before pulling the sprayer out of the shed. If symptoms appear consistent with disease, we can then confirm this through testing of submitted samples. Testing and correct diagnosis is important (COVID-19 parallel 2). Also remember that all diseases have what's termed a 'latent period.' Latent periods which vary in length and are basically the delay/number of days from when the fungal pathogen infects the plant and when symptoms (i.e. lesions or pustules) are visible on leaves. Hence, infections you see in your crop now are actually related to infection events that happened in the past. For example, stripe rust has a 10-14 day latent period, so hot spots that growers are seeing in their crops now started from infection events around or more than a fortnight ago (COVID-19 parallel 3).

4. Fungicide management – timing is everything

Fungicide application does not increase yield, rather it protects yield potential. Not all varieties will need extra protection from in-crop fungicide application if they have an adequate level of resistance to the disease of interest. For example, wheat varieties rated MR or better for stripe rust do not require fungicide management even though they may still show some infections at the seedling stage. The only caveat here is that we have seen some varieties (e.g. Suntop⏀ and Lancer⏀) take a bit more stripe rust when under high levels of background nitrogen nutrition which realistically only drops their rating by one category. That is, they DO NOT become 'suckers' under high N.

When it comes to protecting yield potential from development of leaf diseases in cereals it is the top three leaves (flag, flag-1 and flag-2) that need to be kept green for as long as possible. This is because these leaves intercept the most sunlight to drive grain filling and hence yield. In most barley varieties the flag leaf is smaller compared with wheat so the flag-1 is generally a bit more important with barley, but the surface area of the flag leaf sheath is big in barley and as such, is an important solar panel to protect. However, irrespective of exactly which of these three leaves do the heavy lifting, they all need to be protected in susceptible varieties if under disease pressure and weather conditions conducive to disease development are expected.

The flag-2 leaf is fully emerged at GS32 whilst the flag leaf is fully emerged at GS39. This is why a two spray strategy at GS32 followed by GS39 is effective in susceptible wheat varieties. This could equally be an up-front (seed or in-furrow) treatment followed by an in-crop spray at GS39. In barley, a two spray timing would be at ~GS32 and 49, with the latter spray timed to protect the flag leaf sheath. Leaves that are not emerged at the time of fungicide application are not protected as there is no systemic movement of foliar fungicides into new growth. Hence, early in-crop application prior to GS30-32 are questionable especially with 'necrotrophic' leaf diseases (e.g. yellow spot in wheat or net-blotches in barley) as leaves that emerge after foliar fungicide application are unprotected and exposed to continued infection from ongoing ascospore release from wheat or barley stubble, respectively within the paddock. The situation is more complicated with rusts such as stripe rust because, depending on coverage, a foliar fungicide application within an infected crop can eliminate the disease from a paddock. This can be to an extent that a new infection event from outside the paddock or successive cycles of the pathogen are required for the rust to build back up to damaging levels. That is, you have essentially flattened the curve of the stripe rust epidemic (COVID-19 parallel 4).

5. Prophylactic or responsive in 2020?

All fungicides have stronger preventative than curative activity against leaf diseases. This means that they are generally most effective when applied prior to or early in disease development rather than once the disease has established in a crop. Once lesions or pustules have developed on infected leaves and green leaf area has been lost, it cannot be restored by application of a foliar fungicide.

With tight fungicide supplies, prophylactic applications, if not warranted, could potentially leave growers short in spring when protection of key leaves is required and when spraying is most likely to provide maximum economic return. If the season remains wet and temperatures warm, which decreases the latent period for many leaf diseases, a 2-3 week wait for product in late winter - early spring could cause significant angst. Timing is everything with a foliar application at GS39 in late-winter - spring likely to be the best time to 'flatten the curve' on a leaf disease epidemic. If spraying crops prior to GS30, unless justified (i.e. stripe rust evident in MRMS or lower variety), then first consider the potential implications for your ability to hit a well-timed foliar fungicide application around GS39. 'Cheap insurance' in 2020 may be better addressed by keeping product in the shed for a targeted maximum benefit application at around GS39 (or possibly later in barley), rather than by a more questionable earlier prophylactic application. This situation could vary considerably between growers and change during the course of the season. Ensure you are talking with suppliers now before using up what you have on hand.

Conclusions

It is great to be having a relatively wet start to the winter cropping season across much of NSW and hopefully this continues. Consequently, leaf diseases are more likely to be more prevalent in wheat and barley crops than over the past three seasons. This may be the first experience for some newer agronomists in managing leaf diseases whilst the rest of us are drawing on medium-term memory. Be aware that some things have invariably changed during this time. Do not assume that the resistance levels in your wheat varieties are the same as three years ago, as new pathotypes of rust pathogens have developed and potentially distributed widely across NSW. Make sure you are using the latest resistance ratings and manage crops appropriately based on this.

Stay calm. Panicked decisions are not always the best decisions. Remember any disease you are seeing in your crops are from infection events that occurred 1-2 weeks ago so why do you need to spray in the next 5 minutes? Ensure you have the correct diagnosis as using up tight fungicide stocks on physiological, nutritional, environmental or herbicide related symptoms in leaves wastes product and may leave you short for spring when a timely fungicide application is more likely to have maximum economic benefit.

Remember 'we're all in this together' and NSW DPI pathologists are here to help.

Useful resources

Winter crop variety sowing guide 2020. NSW DPI

Agronomists and NSW DPI pathologists but never be shy to get a second opinion.

Useless resources

'Chicken little' old mate down the pub (if allowed) who is a little excited and full of 'information'. Two weeks in isolation suggested.

Glossy product brochures which claim one product is 'significantly' better than another. Yes, some actives have stronger activity than others but don't let it become a distraction. None of them can restore green leaf area if you have to wait 2-3 weeks to get them in the middle of an epidemic. Research shows that if you apply a registered product for the target leaf disease then timing is generally as or more important than product choice.

Tweets from world leaders.

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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. The author would also like to acknowledge the ongoing support for northern pathology capacity by NSW DPI.

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Three-dimensional measurement of soil water and subsoil constraints using electromagnetic induction

Brendan Griffiths, Andrew Smart, Sally Poole and Nick Barton, PCT Agservices

Key words

soil water measurement, subsoil constraints, EM survey, pedotransfer function

Take home messages

The challenge in our business is to develop methods of measurement of soil physical characteristics that are repeatable, reliable, and accurate to a reasonable degree of confidence. Our current work is revolving around improving the current, and often either fairly subjective, or very labour-intensive methods of assessing soil water, and also understanding and characterising the impact of subsoil constraints.

Most of the work done by PCT Agservices involves the collection and management of spatial GIS data, and applications for the use of that data via management and analytics. Our challenge has been to develop methods of measuring soil physical characteristics that are repeatable and reliable, and accurate to a reasonable degree of confidence. Work largely revolves around the spatial estimation of soil water and subsoil constraints.

A range of different methods can be used when estimating soil water. We are investigating a number of different applications for the use of spatially generated EM datasets. At present, the most repeatable and reliable method we use is derived from a pedotransfer function. These functions model a range of soil physical parameters, including soil water, based on soil textural analysis, from sand, silt, and clay.

Regression analysis is used to create a three-dimensional layer of soil water holding capacity, from geo-referenced soil test points, generated to represent the dataset from the spatially collected EM survey. This provides a modelled, unconstrained soil water holding capacity in three dimensions, and at field level.

From the same EM survey and the same geo-located soil testing points, we again apply regression analysis against other soil test data. This allows us to classify other spatial layers showing the extent of, and depth to, a range of subsoil constraints, largely related to sodicity or salinity, or both.

From this we then can gain a far better visualisation of the ability of the soil to hold water, and the things that may inhibit the ability of the roots to extract it. Once we have classified our layers of soil water holding capacity and of subsoil constraints, we can then relate those layers/datasets back against yield and/or crop biomass to gain an understanding of the extent to which those layers are influencing yield, either positively or negatively.

As mentioned, there are a several other methods/techniques that we are working on that include the use of EM as a tool to spatially estimate plant available water. This is certainly something we are close to perfecting, but at this stage more work is needed to confidently and reliably repeat the method, and we need more full profiles to work with.

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Summer crops: relative water use efficiencies and legacy impacts in farming systems

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Key words

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Take home message

- While summer crops offer rotational options in the farming system, choose the correct crop to match your available soil water and crop history
- Sorghum is a reliable performer often exceeding other options in terms of $ returned per mm used
- Cotton and maize require higher water availability and produce less reliable WUE ($/mm). However, cotton has legacy impacts on water availability for subsequent crops that should be considered
- Mungbean can produce higher $/mm in low water availability situations (<200 mm of rain + soil water). Repeated sowings of mungbeans are likely to induce yield reductions due to disease
- Sorghum crops sown with > 150 mm of plant available water will maximise crop WUE and profitability. Every extra mm at sowing could be worth as much as $35-70 extra return/ha
- Higher density sorghum crops may provide greater crop competition against weeds and potential upside yield benefits in good season. We have seen limited legacy benefits (e.g. improved ground cover) or costs (e.g. greater soil water/nutrient extraction) for soil water or nutrient availability.

Introduction

Summer crops are becoming an increasingly important component of cropping systems in the summer-dominant rainfall zone. They are often useful for providing disease or weed management benefits when in rotation with winter crop dominated systems. While it is widely recognised that summer crops are often critical for improving the system sustainability, a key challenge is transitioning between summer and winter crops or phases in the crop sequence. This requires either double cropping or introducing long-fallows (>10 months) during transitions between the summer and winter crop phases. Hence understanding how effectively different summer crop options convert available water into grain yield and ultimately profit is critical to making better decisions about when summer crops may be used in the crop sequence. Further, differences in water extraction, subsequent fallow water and nitrogen accumulation are likely to influence how subsequent crops will perform or the period of fallow time required to reach critical sowing moisture levels. So, it is important to target the right summer crop option to the system.

This paper will report on several comparisons of relative water use efficiency of different summer crops, and effects of summer crop management practices (e.g. soil water at sowing, sorghum configuration and density) and their legacy impacts in the farming system.

Relative WUE ($/mm) of summer crop options

Over the past 4 years of experiments, different summer crop options have been grown in the same season and under common previous fallow length and starting moisture. Using this data, we have calculated for these various comparisons the crop water use efficiency as $ of income generated per mm of crop water use. This was done using long-term median crop prices and inputs for each of the crops, but these relative values would shift if prices for individual crops were more/less favourable compared to others.

Across a range of seasons and growing conditions, sorghum always exceeded mungbeans in terms of $ generated per mm. This was even though on several occasions mungbean crops use less water and often left significantly more residual soil water than the sorghum crops grown in the same conditions. Sorghum was only bettered in terms of crop WUE by a cotton crop at Pampas in summer 18/19 and sunflowers when they were sown as a double crop in 17/18.

Table 1. Crop water use efficiencies ($ gross margin per mm water used) comparisons between summer crops when grown in the same season with similar starting conditions (long fallow – LF, short fallow – SF, double crop – DC).

	Pampas 16/17 (LF)	Pampas 17/18 (DC)	Pampas 17/18 (SF)	Pampas 18/19 (LF)	Pampas 18/19 (SF)	Pampas 19/20 (DC)	Pampas 19/20 (SF)	Billa Billa 16/17 (LF)	Narrabri 18/19 (LF)
Sorghum	12.0	2.82	9.4	10.1	6.1			3.4	0.7
Mungbean	7.0		3.8		5.5	2.0	12.5	1.3	0.4
Cotton	6.4			15.8					
Maize	7.3								
Sunflower		11.4							
French millet						2.7	3.0		

Figure 1 shows the relationships between crop water use and crop income generated for 100 summer crops (sorghum, mungbean, cotton, sunflower and maize) that have been grown in our farming systems research over the past 5 years. This graph demonstrates that:

- In sorghum, a strong relationship was found between crop revenue and crop water use; on average $4.50 of income generated per mm of crop water use above 200mm. That is, 200mm of available water through in-crop rain or soil water at sowing is required before a positive return is generated
- Mungbeans show a higher return per mm at lower crop water use than sorghum, particularly when available crop water is less than 250mm
- Sunflowers produced a similar return per mm to sorghum in the few seasons when they were grown. This outcome would be greatly influenced by the price obtained for sunflowers which can be highly variable
- In maize and cotton, higher variation in returns per mm were observed. In some seasons, this exceeded sorghum but was lower in others.

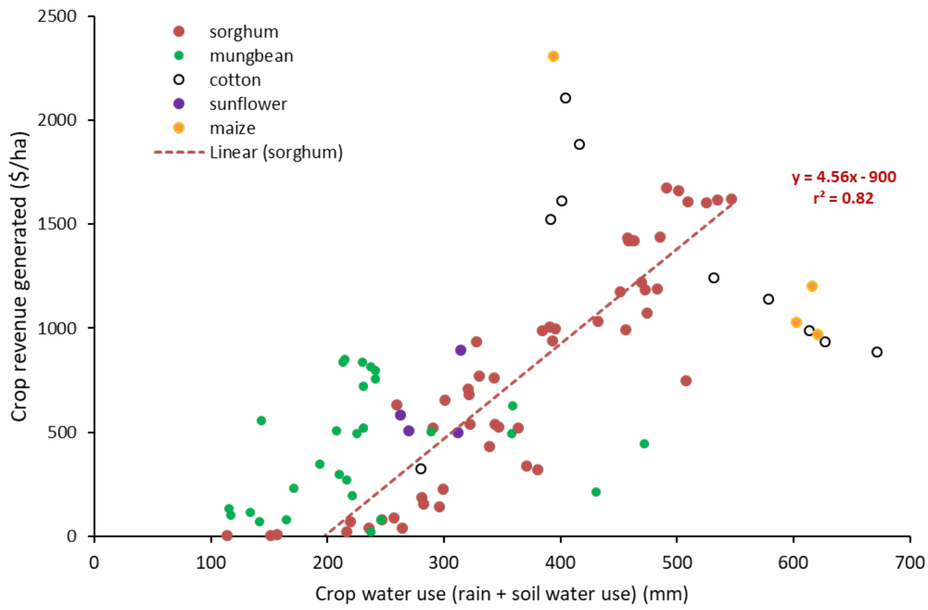

Figure 1. Relationships between crop water use (in-crop rainfall + soil water extraction) and crop revenue generated amongst 100 summer crops grown in farming systems experiments 2015-2019 (sorghum n= 51, mungbean n = 28, cotton n = 10, sunflower n = 4, maize n = 5).

Sowing soil water effects on sorghum crop performance

Soil water at sowing is critical for driving the efficiency of summer crops, especially sorghum. Here we compare the performance of sorghum crops grown in the same season with common nutrient and crop management but with significantly different soil water at sowing (Table 2). As expected, crops with higher soil water at sowing had higher grain yields. But, perhaps something less obvious was that the crops with more staring water regularly converted the available soil water more efficiently into grain and accordingly into profit. This effect was larger in seasons with limited in-crop rain, while the effect was diminished in the wetter growing season (i.e. Pampas 2016/17). This phenomenon occurs because it takes a critical amount of water to grow crop biomass, and hence when there is less available water at sowing there is less water left to efficiently convert any residual water into grain during grain filling. Hence, in wetter seasons this is less pronounced because the crop may still have enough available water to minimise this effect.

Across these studies we calculated the increase in crop return that was obtained for each extra mm of soil water available at sowing. While there was some variation in some seasons, this could be as high as $70 extra return per extra mm at sowing. These effects were largest where crops were sown on marginal soil water (< 100mm) and had limited in-crop rain (e.g. <300mm). These data clearly suggest that for sorghum to maximise its return per mm of water used, higher soil water at sowing is critical. Other analyses by Erbacher et al. (2020 Goondiwindi update paper), suggest plant available soil water at sowing of 150mm was required to optimise sorghum WUE.

Table 2. Starting soil water effects on sorghum crop performance and the marginal water use efficiency i.e. extra $ generated per mm of extra water available at sowing.

Site – year (in crop rain)	**PAW prior to sowing**	**Crop yield (t/ha)**	**Crop WUE (kg grain/mm)**	**Crop WUE ($/mm)**	**Marginal $/mm water at sowing**
Billa Billa 16 (118mm)	98	0.88	3.1	2.2	7.5
	194	1.52	4.1	3.6	
Pampas 16 (345mm)	153	6.12	13.4	12.5	7.2
	245	7.42	13.6	12.0	
Pampas 17 (230mm)	108	0.91	3.1	3.0	70.0
	163	4.52	9.4	9.8	
Pampas 18 (277mm)	62	2.70	7.9	6.1	32.4
	120	4.03	10.2	10.1	

Crop WUE and legacy effects of growing higher density sorghum crops

Integrated weed management practices involving greater in-crop competition with summer grass weeds is seeing interest in increasing sorghum density and narrowing row spacing. In addition to this weed benefit this is likely to have impacts on water and nutrient use efficiency of the crop and legacy impacts on subsequent water and nitrogen accumulation in fallows. It was hypothesised that the higher density sorghum would grow additional biomass which may or may not be converted into grain yield depending on the season. However, this greater biomass would contribute to greater and more even ground cover and improved fallow efficiency. Similarly, this may have impacts on nutrient cycling due to increased immobilisation of soil N from the higher residue with a high C:N ratio.

Across the 3 experimental comparisons we have implemented in our farming systems research, we found that consistently the higher density sorghum increased biomass production, but this was only translated into additional yield at Emerald in 17/18 (Table 3). At the other sites there was no significant yield penalty from growing this additional biomass and grain yields were comparable. Soil water extraction and crop water use was the same amongst the high and low density crops.

The higher biomass production in the higher density sorghum crops has required higher soil N extraction without an increase in grain yield and N. Hence, the nutrient use efficiency of these crops is lower. That is, such higher density crops will require a different nutrient strategy to ensure sufficient N in provided to maximise their yield potential.

Finally, while we anticipated there may be some benefits for improved soil water accumulation over the subsequent fallow following the higher density sorghum crops this was not shown resoundingly. In one season (Pampas 17/18) we did observe an extra 33mm was accumulated in the subsequent fallow after the higher density sorghum crop than the standard management. However, this was largely due to a drier soil profile at crop harvest and there was no significant difference in soil water at the end of the subsequent fallow in any of these cases. However, observations suggested there was greater uniformity of the soil water where more evenly distributed cover occurred following the narrower sorghum rows compared to wider row crops.

Table 3. Crop yield and legacy effects of growing higher density grain sorghum (i.e. 30% higher population & 0.5m compared with 1m row spacing) across 3 seasons in farming systems experiments.

Sorghum crop performance		**Emerald 17/18**	**Pampas 17/18**	**Pampas 18/19**
Sorghum grain yield (t/ha)	Standard	5.0	4.7	4.0
	High density	5.9	4.7	3.7
Sorghum biomass (t/ha)	Standard	11.6	14.1	9.1
	High Density	15.6	16.0	10.1
Sorghum WUE (kg grain/mm)	Standard	15.4	9.4	10.2
	High Density	18.4	10.4	9.6
Sorghum NUE (kg grain N/kg N used)	Standard		0.593	1.7
	High Density		0.484	1.1
Following fallow				
Soil water accumulation (mm)	Standard	+97	+63	+85
	High Density	+71	+96	+79
Mineral N accumulation (kg/ha)	Standard		+89	+107
	High Density		+116	+102

Legacy impacts of summer crop choices

Finally, here we make comparisons of the impacts of summer crops on residual soil water, accumulation during the subsequent fallow and effects on subsequent crop productivity in the sequence.

From these comparisons the legacy impacts of cotton in the farming system are clear, with lower soil water available for subsequent crops due to higher extraction and also lower fallow efficiencies (Table 4). This has translated into reductions in yield of 0.5 t/ha in sorghum and 0.3 t/ha in mungbeans when sown following cotton compared to maize.

Comparisons of sorghum with mungbean show little differences in residual soil water or soil water in the following crops. However, mungbean performance was affected by the preceding crop. ‘Mungbean after mungbean’ yield was 0.5 t/ha lower than ‘mungbean after sorghum’, despite starting with similar moisture after a long fallow (17/18). In contrast, mungbean yields were similar following short fallows out of sorghum and mungbean (18/19), even though the sorghum left less residual water. These effects are likely to be related to disease reductions rather than soil water or nutrient impacts.

Finally, a comparison between sorghum and sunflower legacy effects found little or any effects on subsequent fallow water accumulation or crop yields.

Table 4. Comparisons of legacy impacts of different summer crops on soil water accumulation and subsequent crop productivity in the crop sequence.

Crop year	Crop grown	Residual PAW (mm)	Soil water accumulation (mm)	Subsequent crop performance			
				PAW at sowing (mm)	Crop sown	Crop biomass (t/ha)	Grain yield (t/ha)
16/17	Maize	168	-6	162	Sorghum 17/18	14.1	5.37
	Cotton	149	-23	126		12.8	4.85
	Maize	168	-67	101	Mungbean 17/18	5.0	1.06
	Cotton	149	-67	82		3.4	0.75
18/19	Sorghum	2	+91	93	Not sown yet	-	-
	Cotton	-16	+64	48		-	-
17/18	Sorghum	48	+24	72	Mungbean 19/20	4.75	1.62
	Mungbean	30	+58	88		3.59	1.12
18/19	Sorghum	-10	+45	35	Mungbean 19/20	2.33	0.59
	Mungbean	-26	+112	76		2.15	0.61
17/18	Sorghum	38	+29	67	Sorghum 18/19	7.96	2.80
	Sunflower	2	+39	41		7.38	2.94
	Sorghum	41	+42	83	Mungbean 18/19	2.35	0.74
	Sunflower	3	+22	25		2.23	0.75

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Improving yield reliability of grain sorghum in north-west NSW

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Key words

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DAN00200 Building capacity in the northern grains region

UOQ 1808-001RTX Optimising sorghum agronomy

Take home messages

- Starting with a full profile of soil moisture is the best way to reduce the risk of crop failure in north-west NSW
- Using skip or wide row configurations can potentially reduce the risk of crop failure by saving soil water for post anthesis but can also limit yield potential. Solid plant offers more advantages in seasons where yields are likely to be above 3.0 t/ha
- Plant populations should target establishing at least 5.0 plants/m^2 to achieve average yields
- Moving the planting window earlier than currently recommended is under evaluation and may be a useful tool to manage heat and moisture stress risk associated with flowering in December
- Further interrogation of current data, in combination with simulation using APSIM, is expected to provide a more robust agronomic package for reliable production of sorghum in NW NSW.

Introduction

Grain sorghum is an important rotation crop in the northern grains region of Australia. However, the inability to provide reliable, profitable yields has prevented its inclusion as a set part of rotations in north-west NSW. The prolonged drought during this decade has further exacerbated these issues and reduced the area sown to sorghum across the region.

The north-west region is defined as the area west of the Newell Highway, stretching from the Queensland border south. This area is serviced by the regional centres of Moree, Walgett and Narrabri.

The typical farming system in this area is highly reliant on winter crop production, namely bread wheat and chickpeas with the opportunistic inclusion of summer crops, predominantly cotton but also occasionally sorghum.

The inclusion of sorghum in NW NSW cropping systems provides for rotation of herbicide chemistry to assist in the management of herbicide resistant weeds and is a non-host of the primary winter cereal disease Fusarium crown rot (*Fusarium pseudograminearum*) plus is resistant to the root lesion nematode *Pratylenchus thornei.* The inclusion of a reliable summer crop option in NW NSW would also assist with splitting of human/equipment logistics for planting and harvesting and provide more even cash flow across the year.

In NW NSW the rainfall pattern favours the summer months. In Moree more than half the average annual rainfall is expected in the months of November through to March. The dominance of summer rainfall increases northwards of Dubbo in central NSW.

The average rainfall amount reduces the further west you go from Moree to Walgett by, on average, 150mm per annum. In contrast the difference in average annual rainfall between Moree and Narrabri is only 16mm. Temperatures also increases as you move further west, with fewer frosts and increasing heat. December, January and February display elevated average maximum temperatures in NW NSW.

This combination of higher temperatures and less rainfall means that the risk of failed or uneconomic sorghum crops increases as you move west. However, there are many tools which can be used to build a package for reliable sorghum production in this region. The most difficult aspect is combining each of these decisions and their complex interactions to offer the most robust and reliable sorghum production package to growers, whilst balancing their attitude to risk.

Agronomic levers to reduce risk

Growers and advisers in NW NSW have a limited number of management levers to pull when choosing to grow sorghum as part of their dryland crop rotation. These include varying row spacing or row configuration, altering plant population, or changing their time of sowing, typically between a spring and a summer plant. There are also decisions around nutrition supply to the crop and the acceptable level of starting soil water to trigger planting which can be used to improve reliability of sorghum production.

To achieve the best possible sorghum yields, the interaction of management practices with the selected genetics (hybrid) and environment need to be at the forefront of growers and advisers' minds.

Row spacing and row configuration

Varying row spacing is a management practice which can be used to better match crop growth and development to the availability of soil water resources and/or expected seasonal conditions.

Where crop yields are likely to be > 3.0 t/ha solid plant will provide higher yields. If a grower is achieving 2.5 to 3t/ha on a skip row configuration, the data suggests it is likely that a solid plant would yield 0.5 to >1 t/ha more (Figure 1). Below 2.5 t/ha responses to varying row configuration and plant population are less obvious (Figure 2).

In summer broadacre cropping, the use of skip row technology became common place in the early 2000's firstly with cotton and later with other summer crops such as sorghum in more marginal environments like NW NSW. Initially, single (miss one row) or double skip (miss two rows) were used and later wide row spacing such 120 or 150cm rows on a solid plant came into use.

The adoption of skip or wide rows provides an area of soil water in between summer crop rows which could not physically be accessed by the plant roots until later in the season. With sorghum, it is estimated that roots growing at 2.5cm/ day will not reach the centre of a double skip area until around 60 days post-sowing. This conserves a reservoir of soil water which can possibly be used during flowering and grain fill to mitigate the risk of moisture stress.

There are trade-offs with using skip or wide row configurations. While the risk of crop failure is reduced, so is yield potential, especially in seasons with higher levels of in-crop rainfall.

Consideration must also be given to the management of the bare inter-row area including weed, nutrient, fallow and stubble management when using skip rows. Single skip leaves one third and double skip one half of the field without crop cover. This area is open to moisture loss through evaporation, invasion with weeds and potentially impacts on lateral nutrient distribution.

Plant population

The sorghum plant population established will depend on the initial target density (i.e. sowing rate), seed quality (germination/vigour and impact of any seed treatments), management (e.g. seeding depth) and environmental impacts on the germination and emergence of the seed, such as adequate soil moisture and temperature.

Trials have included plant populations from 1.5 – 7.0 plants/m^2. These populations have been maintained regardless of the row configuration.

Varying plant population is probably the easiest management lever to pull. The ideal plant population for growing sorghum in NW NSW is influenced by the yield potential and sowing date.

Generally, the higher the yield potential of the crop, the higher the plant population which can be supported. However, populations of 5 plants/m^2 can achieve yields close to 5.0 t/ha in NW NSW (i.e. Mungindi 10/11 – Figure 1), which is much higher than average yields in this environment. Populations above 5 plants/m^2 i.e. 7 plants/m^2 rarely produced statistically significant higher yields (analysis not shown) but incur increased expense due to additional hybrid seed costs.

Plant populations below 3 plants/m^2 have been lower yielding in higher yield potential seasons and are also more difficult to achieve even plant distribution across a paddock.

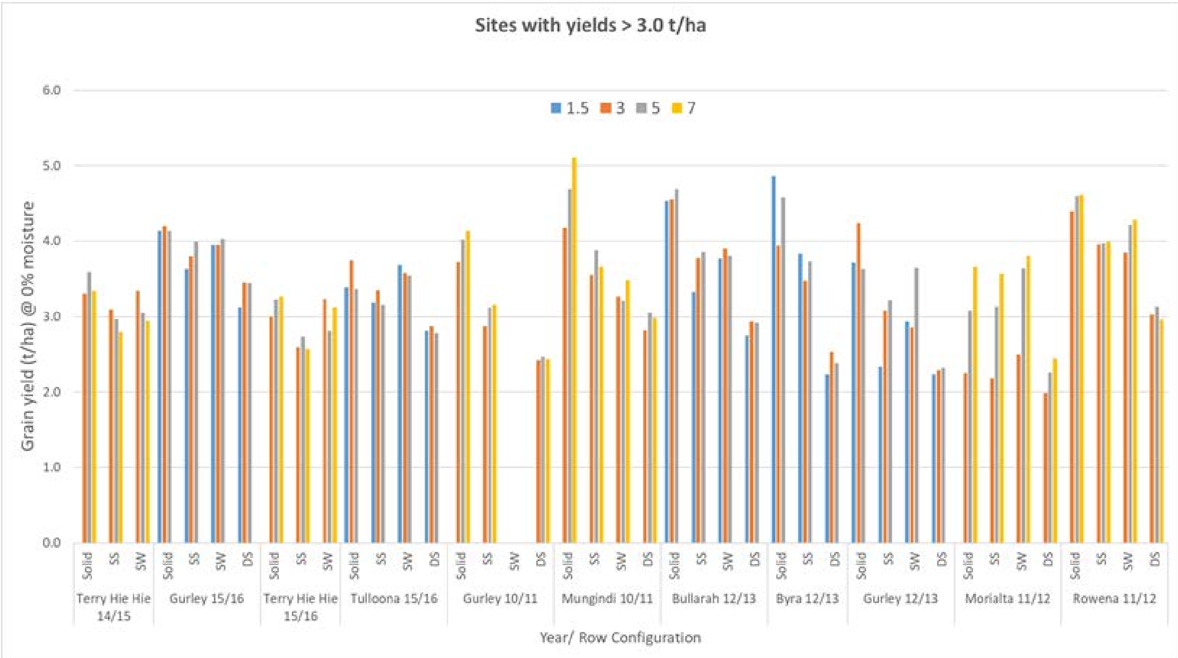

Figure 1. Trial sites with **grain yields > 3.0 t/ha**: Response to varying plant population (plants/m^2) and row configuration in sorghum across north west NSW from 2010-2016 (Solid = solid plant, SS = single skip, SW = super wide (150 cm solid) DS = double skip)

In contrast, at grain yields under 3.0 t/ha, responses to plant population and row configuration tend to be flatter (Figure 2). Some advantages have been seen from very low populations of 1.5 plants/m^2 In these environments responses to row configuration are also less than generally believed, particularly when yields are lower than 1.0 t/ha where this usually indicates terminal moisture stress.

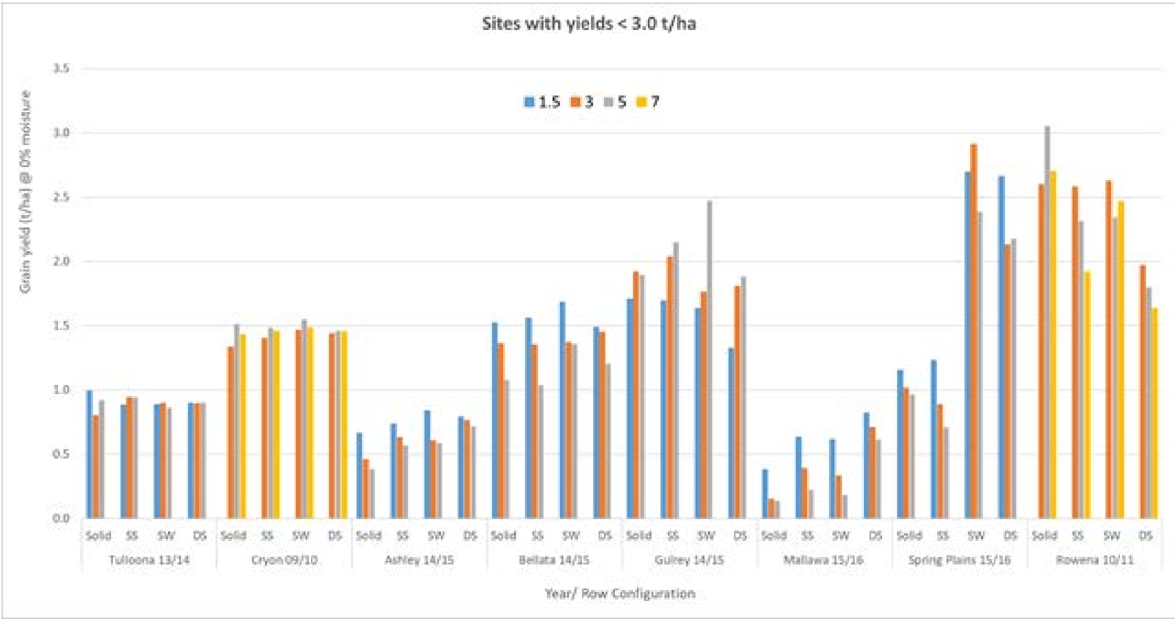

Figure 2. Trial sites with **grain yields < 3.0 t/ha:** Response to varying plant population (plants/m2) and row configuration in sorghum across north west NSW from 2010-2016 (Solid = solid plant, SS = single skip, SW = super wide (150 cm solid) DS = double skip)

Early sown crops often have reduced establishment, hence more seeds may need to be sown to achieve the target plant population. The other important point to consider when deciding on a plant population is that population alone is not responsible for crop yield. The optimum population also depends on the row configuration and the level of tillering within different hybrid sorghum varieties.

Starting soil moisture

Recommendations for sorghum in NW NSW always state that paddocks must have a full profile of soil moisture prior to sowing. Paddocks have been sown with less than a full profile, but the reality is that less moisture at sowing means a higher level of risk as there is a greater reliance on in-crop rainfall, which is known to be highly variable in this environment.

We can compare two sorghum sites (Figure 3), which did not have a full profile at sowing. The first trial had a starting plant available water (PAW) of 50 mm but received 257 mm of timely in crop rainfall resulting in yields up to 4.5 t/ha. The second site started with 100 mm of PAW but only received 15 mm of in-crop rainfall and subsequently failed. Both sites needed significant in crop rainfall to achieve profitable yields.

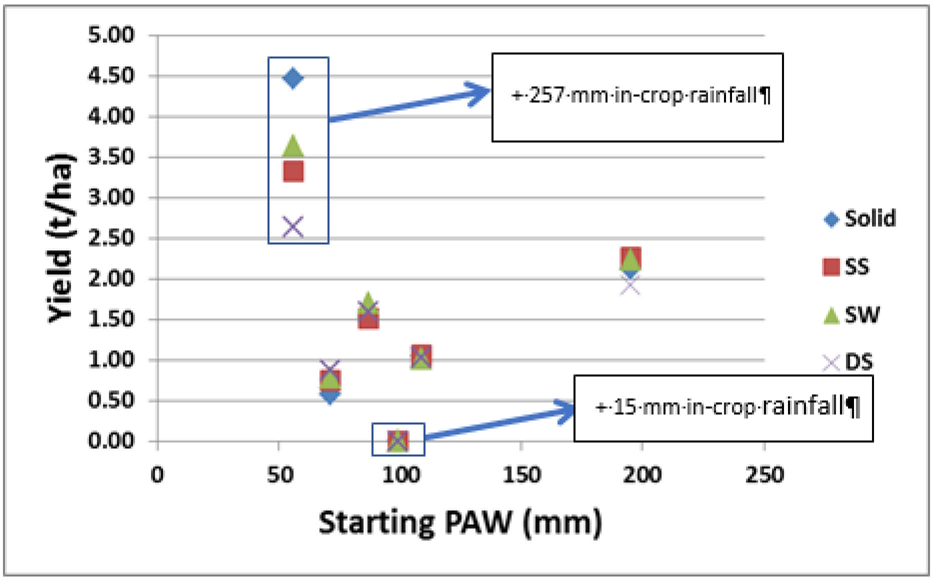

Figure 3. Effect of starting plant available water on sorghum yield at selected sites in north west NSW

If paddocks were only sown when full, they would be starting with a minimum of 150 mm of PAW or more in most soils in northern NSW. If this was combined with average summer in-crop rainfall (September – end January) at Walgett of around 200 mm, then acceptable yield could normally be expected.

There is much less risk from adopting this strategy, than sowing with a half full profile and then hoping to re-fill the deficit during the season via in-crop rainfall when evaporation and transpiration rates are high.

Planting date

Traditionally the sowing window for sorghum in NW NSW was considered to commence in mid-late September. In the last two years, research on the effect of moving sowing times up to 4 weeks earlier has been undertaken.

This results in planting when soils are much colder; a minimum of 12°C; as opposed to the recommended 16-18°C. Planting in late-September, when soil temperature is >16°C, provides rapid emergence (within around 7-10 days), while earlier planting may take 14 days or more to emerge, depending on conditions following sowing. There is often a reduction in establishment in cold soils associated with earlier planting.

However, the goal is to move the period of flowering and grain fill earlier into summer, hopefully closer to early December and away from the peak temperatures seen in late December and January.

Sowing after the end of the first week in August at Moree has enabled flowering to be moved as early as mid-November. In comparison planting in late-September results in flowering from mid-December (Figure 4).

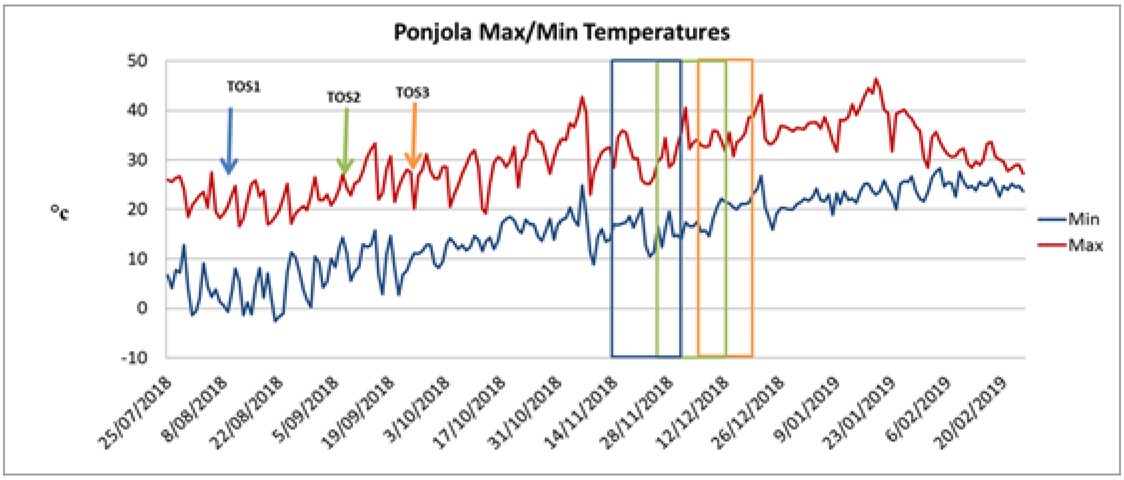

Figure 4. Sorghum flowering windows resulting from sowing 8 August, 11 September and 27 September at "Ponjola" Moree in 2018-19

Moving the sowing window forward has also resulted in improved yields in most of the trial sites such as the Moree site in 2018/19 (Figure 5). The first planting time on the 8th August was the highest yielding at 2.14 t/ha. There was no significant difference in yields achieved between the 11th and 29th September planting dates being 1.51 and 1.68 t/ha respectively.

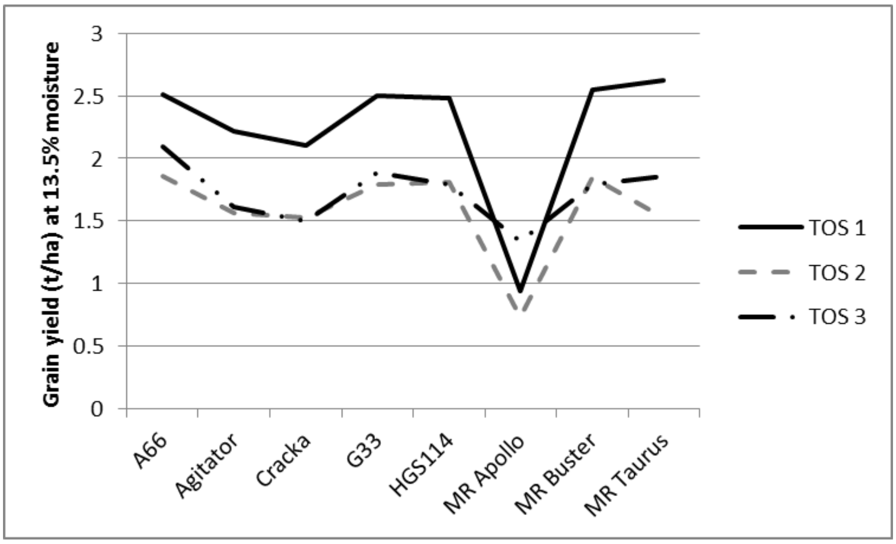

Figure 5. Grain yield at three times of sowing (TOS) at "Ponjola" Moree in 2018-19

Conclusions

Reliable and profitable sorghum production in NW NSW has not been achieved yet. A series of options for improving confidence in growing sorghum in this region have been examined. However further interrogation of this data and extrapolation over an extended period using the crop model APSIM will provide a more robust set of future recommendations.

Currently the sorghum production package for NW NSW to reduce risk is based around only planting with a full profile of soil moisture; using a double skip configuration and aiming to establish around 5 plants/m^2. This package, whilst reducing the likelihood of crop failure, also limits the top end yield potential of a sorghum crop in this region in favourable seasons.

The ideal management package will allow avoidance of the peak heat and lack of soil moisture periods in NW NSW, generate a profitable sorghum grain yield with optimised water use efficiency whilst still maintaining the system benefits such as stubble cover from a cereal crop. This is a significant challenge for the future of our industry but also a massive opportunity waiting to be exploited.

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