GULARGAMBONE
NEW SOUTH WALES
THURSDAY 12
MARCH 2020

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Two Eight Two Eight

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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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GRDC Grains Research Update
GULARGAMBONE

Thursday 12 March 2020
Two eight two eight
28 Bourbah Street, Gulargambone

Registration: 8:30am for a 9am start, finish 2:50pm

AGENDA		
Time	**Topic**	**Speaker(s)**
9:00 AM	**GRDC welcome**	
9:10 AM	**Cover crops for fallow efficiency -** soil water, health, nutrition and crop performance	Andrew Erbacher (DAF Qld)
9:35 AM	**Cover crops** - experiences in Australia and observations from overseas	Discussion led by Andrew Erbacher (DAF Qld) & Bill Burnheim (Pillicawarrina, Warren)
10:00 AM	**Morning tea**	
10:30 AM	**Grazing crops for cash flow and profit** - pro's, con's and strategies	Peter Matthews (NSW DPI)
11:05 AM	**Nitrogen, water and disease in the farming system** - the multi-year impact of crop sequences	Greg Brooke (NSW DPI) and Andrew Erbacher (DAF Qld)
11:40 AM	**New technologies for the Australian grains industry** - observations from a four month Fulbright Fellowship study tour of the USA and Germany	Craig Baille (USQ)
12:10 PM	**Lunch**	
1:10 PM	**Climate change in northern NSW and strategies to adapt**	Steven Crimp (ANU)
1:40 PM	**Cereal pathology after the drought** - evaluating risk after crop and pasture; what's new (seed treatments), Predicta® B for in-crop diagnostics, options for high risk paddocks and Ramularia	Steven Simpfendorfer (NSW DPI)
2:05 PM	**Dealing with the drought and planning for recovery**	Discussion led by Maurie Street (GOA), Steven Simpfendorfer (NSW DPI) and Graeme Callaghan (Delta Agribusiness)
2:50 PM	**Close**	

Contents

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Cover crops improve ground cover in a very dry season

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Key words

cover crops, millet, ground cover, soil water storage, fallow management, stubble, evaporation, infiltration, plant available water

GRDC code

DAQ00211

Take home messages

- Previous trials have shown cover crops can increase stored fallow water and improve crop performance and returns in northern farming systems
- A cover crop in a long fallow (14 months) in a dry season allowed improved ground cover with no net deficit in soil water. The extra ground cover improved the opportunity to deep plant wheat.
- A cover crop in a short fallow had a water cost that translated to a yield penalty.
- When the sorghum stopped growing in dry conditions it continued to use water, for no biomass (or cover) increase when it wasn't sprayed out.

Cover crops in the northern region

After missed or failed crops over recent seasons, ground cover is becoming increasingly important for maintaining fallow efficiency and importantly, for protection from wind and water erosion. Cover crops, sprayed out and left for ground cover, have been used to protect the soil from erosion in low stubble situations, with added benefits of returning biomass that helps maintain soil organic matter and biological activity and provide additional nitrogen when legumes are used. Cover crops also offer an opportunity to increase infiltration and fallow moisture storage for more profitable grain and cotton crops across the northern region of New South Wales (NSW) and Queensland.

Scientific rationale

Stubble and evaporation

Retained stubble provides ground cover, protects the soil from rainfall impacts and so improves infiltration to store more water in the soil. Conventional wisdom is that increased stubble loads can slow down the initial rate of evaporation, but that these gains are short-lived and often lost due to evaporation, unless follow-up rainfall occurs within several weeks. However, further rain within this period and the manipulation of stubble to concentrate stubble loads provides an opportunity to reduce total evaporation and to accumulate more plant available water.

Advances in agronomy and commercial agronomist support have seen growers better use their available soil water and improve individual crop performance. However, more effective capture and storage of rainfall across the whole farming system remain as major challenges for northern grain and cotton growers where only 20-40% of rainfall is typically transpired by dryland crops, up to 60%

of rainfall is lost to evaporation, and a further 5-20% lost in runoff and deep drainage. Every 10 mm of extra stored soil water available to crops could increase dryland grain yields for growers by up to 150 kg/ha, with corresponding benefits to dryland cotton growers as well.

The GRDC funded Farming systems projects (DAQ00192/CSA00050) are assessing ways to improve this system water use, and to achieve 80% of the water and nitrogen limited yield potential in our cropping systems. Previous GRDC Eastern Farming Systems and Northern Growers Alliance trials both suggest that cover crops and increased stubble loads can reduce evaporation, increase infiltration and provide net gains in plant available water over traditional fallow periods. Consequently, cover crops have potential to be part of improved farming systems; providing increased profitability and better soil protection.

Dryland grain systems

Cover crops are used in southern Queensland and northern NSW to overcome a lack of stubble and protect the soil following low residue crops (e.g. chickpea, cotton) or following skip-row sorghum with uneven stubble and exposed soil in the 'skips'.

In long fallows leading to a winter crop, growers typically plant white French millet or sorghum, and spray them out within ~60 days, to allow recharge of the soil water extracted by the cover crop. Allowing these 'cover crops' to grow through to maturity led to significant soil water deficits and yield losses in the subsequent winter crops. However, the Eastern Farming Systems projects showed only small deficits (and even water gains) accrued to the subsequent crops when millets were sprayed out after 6 weeks, with average grain yield increases of 0.36 t/ha in subsequent crops. Furthermore, the Northern Growers Alliance showed that the addition of extra stubble (from 5-40 t/ha) after winter crop harvest appeared to further reduce evaporation, with initial studies showing between 19 mm and 87 mm increases in plant available water. These gains will be valuable if validated in further research and are able to be captured in commercial practice.

Our current project is monitoring sites intensively to quantify the impact of different stubble loads on the accumulation of rainfall, the amount of water required to grow cover crops with sufficient stubble loads, the net water gains/losses for the following crops and the impacts on their growth and yield.

Summary of previous results

Experiment 1 was a winter cover crop followed by overhead irrigated cotton near Yelarbon. Barley cover crops grew 1.2 t/ha biomass for early spray out and up to 5 t/ha for the late sprayed out barley. The early terminated barley had the most plant available water (PAW) when the cotton was planted, however, the extra resilience of the mid and late terminated barley captured more of the applied water in the soil, once irrigation of the young cotton crop commenced. Cotton yield showed a large benefit in all of the cover crop treatments over the bare fallow (control).

Experiment 2 was a spring cover crop followed by dryland wheat near Bungunya. The millet cover crops at this site produced 1.5 t/ha biomass (early terminated), and up to 4.5 t/ha for the late sprayed crop. The treatments with the most cover (and biomass) had the most stored water at the end of April. With the longer fallow after the cover crop, the early terminated cover crop broke-down before the wheat was planted. In deep planted wheat the treatments with higher ground cover established even wheat stands, while the bare fallow (control) and some treatments with fragile cover had an uneven / gappy wheat establishment. The wheat crop in the bare control yielded 1.4 t/ha, while the wheat following late terminated millet had 20 mm more PAW at planting and a more even wheat stand which enabled it to extract more of the stored water, so had an improved yield of 2.8 t/ha (net economic benefit of $280/ha).

A detailed summary of these trials can be found in Queensland grains research 2018-19: https://www.publications.qld.gov.au/dataset/queensland-grains-research/resource/3865017c-7ebf-40bc-89c9-640829b313c7

Or in a 2019 GRDC Update paper at:

https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/03/cover-crops-can-boost-soil-water-storage-and-crop-yields

Learnings from a dry season

This paper reports on two dryland sites in southern Queensland in the record breaking 2018/19 drought years.

The first experiment (Yagaburne) was in a long fallow from sorghum to wheat, so the cover crop was planted earlier in the season allowing earlier spray out and a longer fallow period to recharge the soil water used. This experiment had improved planting opportunities with higher ground cover, but no PAW difference at planting, so the evenly established wheat yielded the same in all treatments.

The second experiment (Billa Billa) was in a short fallow from chickpea to wheat. This cover crop was planted later in spring and had a shorter fallow period after spray out to recharge the PAW used by the cover crop. There was a PAW penalty for growing the cover crop in this season, which translated to reduced grain yield.

Experiment 3 – Yagaburne (Skip-row sorghum, long- fallowed to dryland wheat)

The Yagaburne experiment was in a long-fallow paddock following skip-row sorghum that was harvested in February 2018. This paddock was a zero till fallow, with standing sorghum and wheat stubble present. There were two times of planting for cover crops, with winter cover crops planted in July 2018 with 65 mm of PAW, and spring cover crops planted in October 2018 with 90 mm PAW. The subsequent wheat crop was planted on 30 May 2019, harvest in October 2019. Soil water was measured at key times with gravimetric soil coring, then more regularly with a neutron moisture meter and EM38. Cover crop biomass, and ground cover was measured at termination of the cover crop and periodically through the fallow. Grain yield of the wheat crop following the cover crop was measured to quantify the value of plant available water (PAW) differences between cover crop treatments.

The winter cover crop was wheat at 100 plants/m^2 and winter multispecies cover crop was half recommended rates of wheat, vetch and tillage radish (50, 30 & 20 plants/m^2). The summer cover crop was white French millet at 100 plants/m^2, sorghum cover crop was a sudan x sudan hybrid at 65 plants/m^2, and multispecies was with white French millet, lab lab and tillage radish at half recommended rates (50, 30 & 20 plants/m^2) (Table 1).

Three planned termination times matched key growth stages of the main cereal treatments: Early-termination at first node (Z31) when the crop begins stem development; Mid-termination at flag leaf emergence (Z41) when the reproductive phase begins; and Late-termination at anthesis (Z65) for peak biomass production. The site was planned to be planted to wheat in May 2019, but with no planting opportunity and no rain forecast, it was dry planted on 27 May 2019 using the growers single disc planter (33⅓ cm row spacing), with trickle irrigation applied for crop establishment.

Table 1. Cover treatments applied at the Yagaburne site prior to planting wheat, biomass at termination of each cover crop (does not include the 1700 kg/ha of residual stubble, centred mostly on the sorghum row, in all treatments including the 'bare control') and percentage ground cover at the last termination date and at the end of the fallow period

#	Cover crop	Termination time	Biomass grown (kg/ha)	Ground cover % 5/12/2019	Ground cover % 2/05/2019
1.	Bare (control)		0	8	8
2.	Wheat	Early-sprayout	86	12	11
3.	Wheat	Mid-sprayout	410	26	24
4.	Wheat	Late-sprayout	697	45	42
5.	Wheat	Late-sprayout + roll	718	50	45
6.	Winter multi-species (wheat, vetch, radish)	Mid-sprayout	538	38	31
7.	Millet	Early-sprayout	527	62	37
8.	Millet	Mid-sprayout	1412	89	80
9.	Millet	Late-sprayout	2043	94	87
10.	Millet	Late-sprayout + roll	1945	97	84
11.	Sorghum	Mid-sprayout	2551	96	93
12.	Summer multi-species (millet, lab lab, radish)	Mid-sprayout	1117	65	46

With the late planting date of the winter cover crop the early sprayed wheat grew 86 kg/ha of biomass, which did not provide useful levels of cover (Table 1).

The mid terminated winter cover crop had 36 mm less PAW at termination than planting (Figure 2) for 400 kg/ha biomass. With 50 mm rainfall in October the late terminated wheat was 5 mm drier than at planting with 700 kg/ha of resilient straw. All winter cover crops had recovered to similar PAW as the control when the summer cover crops were planted.

With an extra 90 days and 75 mm rain in fallow, the summer cover crop had 26 mm more PAW than when the winter cover crop was planted. The early, mid and late terminated millet cover crops were 25 mm, 46 mm and 80 mm drier at termination than when they were planted (Figure 2). Biomass produced by the millet was ~ 500, 1400 and 2000 kg/ha for early, mid and late termination respectively (Table 1).

The sorghum cover crop sprayed-out at its mid termination growth stage was sprayed out on the same day as the late terminated millet and used the same volume of water and grew similar biomass as the late terminated millet.

With the dry autumn of 2019, the paddock was assessed on 14 May for the potential to plant wheat across the trial. At ten days after 8 mm rain and 45 days since the last significant rainfall, the conclusion was that only the plots with the highest levels of cover (i.e. greater than 40% cover, but more was better, Table 1), had enough surface moisture to allow an even establishment of wheat. The four treatments with the best cover (mid, late and late + rolled millet and sorghum cover crops), had good moisture for planting; three treatments were too dry (bare control, early and mid wheat cover crops) and the other five treatments would have been a marginal planting opportunity. With no rain received by the end of May and no forecast rain, it was decided to dry plant and apply trickle irrigation to the seed row for crop establishment.

When the wheat 'cash crop' was planted, the bare control had similar PAW as when the trial commenced 11 months earlier after 240 mm rain (580 mm average annual rainfall). Previous trials have shown variability in sampling of +/- 10 mm, so there was no real difference in PAW at this time with the best cover crop treatments having 10 mm more PAW than the control and the worst had 10 mm less than the control. Volumetric soil water post-harvest had a similar spread with the wheat extracting on average 61 mm of PAW from the profile. With only 17 mm of in crop rain the wheat yielded 570 kg/ha.

Two plot header runs were taken for each plot at this site: one over the previous sorghum rows and the other over the skip (Figure 1). There was a consistent yield increase for yield in header runs taken over the old sorghum rows when compared to runs taken over 'the skip row', with an extra 126 kg/ha yield measured on the old sorghum rows versus the skip (632 kg/ha vs 506 kg/ha).

Figure 1. Residual stubble at the Yagaburne site at emergence of the winter cover crop and undisturbed on the right

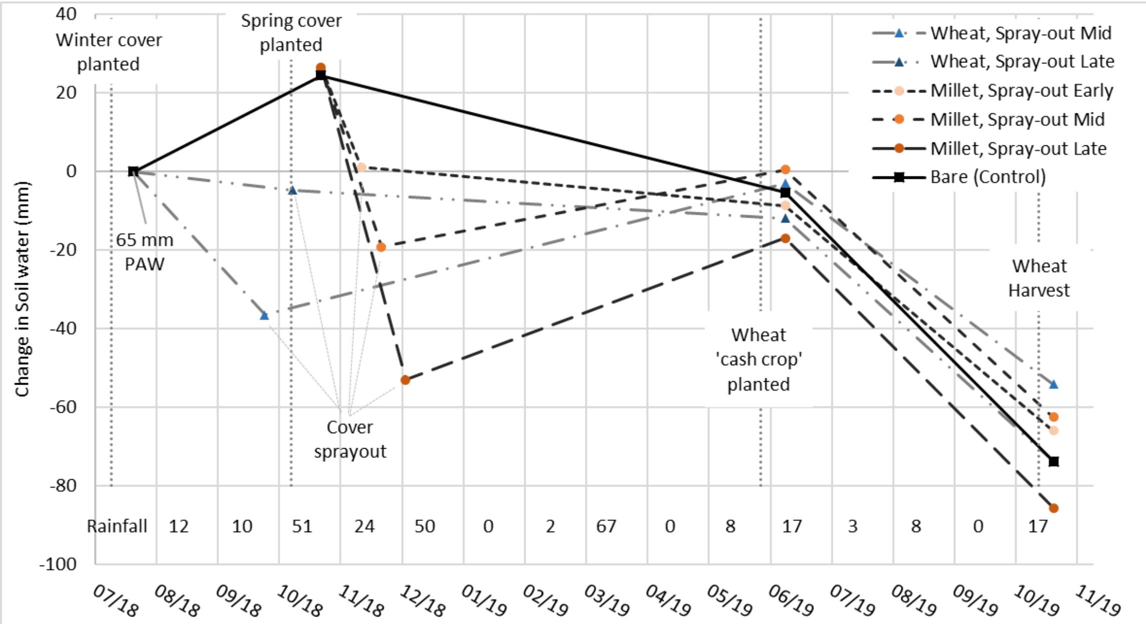

Figure 2. Change in plant available water for a range of cover crops at the Yagaburne site, measured with soil cores to 150 cm depth. Grids represent each month and numbers in the bottom row are mm rainfall for that month

Experiment 4 – Billa Billa (Chickpea or wheat fallowed to dryland wheat)

The Billa Billa experiment had plots pre-planted to wheat or chickpeas to create areas of high and low stubble cover, with the view to grow cover crops in the low cover plots left by the chickpea crops. The wheat plots were also harvested tall (50 cm) and left standing or rolled or harvested short (25 cm) with tops removed or left as mulch (Table 2).

Wheat and chickpea were harvested on 26 October 2018 and a sudan X sudan hybrid sorghum cover crop was planted a month later with 90 mm PAW. The sorghum established over 100 plants/m^2.

Three planned termination times matched to key growth stages were planned similar to previous experiments: early, mid and late. Early termination was sprayed five weeks after planting. With no in crop rainfall and high plant populations, the crop stopped development at second node, so mid termination was sprayed three weeks after the early spray, and late termination was held off until after rain fell, being sprayed 25 March 2019 (four months after planting).

Table 2. Crops planted at the Billa Billa trial to generate different cover levels and stubble or cover crop managements imposed in the fallow period

Preceding crop	Treatment
Wheat	Harvest high (50 cm)
Wheat	Harvest high and rolled
Wheat	Harvest low (25cm), tops spread
Wheat	Harvest low, tops removed
Chickpea	Bare (control)
Chickpea	Sorghum spray-out early
Chickpea	Sorghum spray-out mid
Chickpea	Sorghum spray-out mid + rolled
Chickpea	Sorghum spray-out late
Chickpea	Sorghum spray-out late + rolled

At planting of the cover crop, the wheat stubble plots had 34 mm more PAW than the chickpea stubble plots. From the time of cover crop planting, PAW had decreased by 59 mm to early termination; by 81 mm to mid termination and by 60 mm to late termination (Figure 3). This shows that the sorghum continued to use water after it stopped developing, with minimal increase in biomass (Table 3). Biomass produced by the cover crops averaged 1.3 t/ha for the three termination timings. Whilst this offered a significant improvement in ground cover over the bare control, the cover crops had ~1 t/ha less biomass and ~15% less ground cover than the wheat stubble plots.

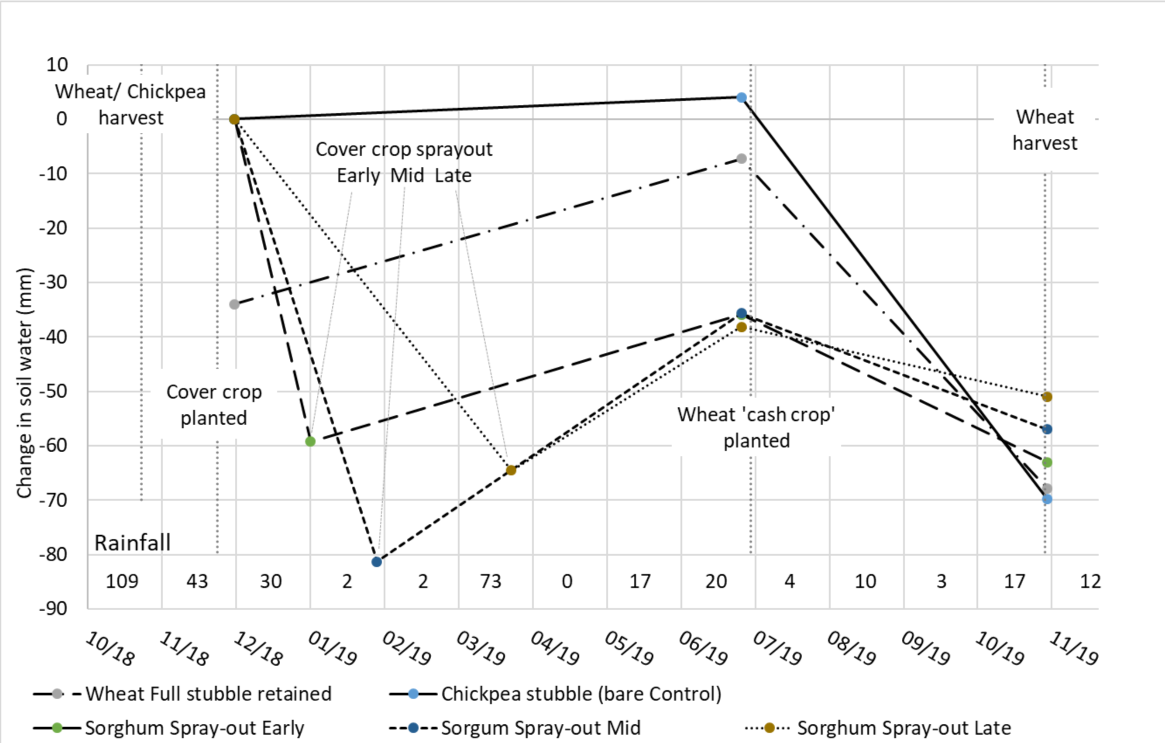

Figure 3. Change in plant available water for a range of cover crops measured with soil cores to a depth of 150 cm, at the Billa Billa site. Grids represent 30 days from the first of each month, and numbers in bottom row are mm rainfall for that month. Nb. Wheat stubble plots were 34 mm drier than ex-chickpea plots when cover crops were planted

Table 3. Starting crop and stubble or cover crop treatment, stubble and cover crop biomass and percent ground cover at the end of the fallow period, and grain yield of the following wheat 'cash crop' at the Billa Billa site

Preceding crop	Treatment	Biomass (kg/ha)	Cover % 2 May 2019	Wheat grain yield (kg/ha)
Wheat	Harvest high (50 cm)	2662	77	526
Wheat	Harvest high and rolled	2357	78	566
Wheat	Harvest low (25cm), tops spread	1800	82	529
Wheat	Harvest low, tops removed	1755	73	551
Chickpea	Bare (control)	267	10	727
Chickpea	Sorghum spray-out early	1270	50	364
Chickpea	Sorghum spray-out mid	1419	67	74
Chickpea	Sorghum spray-out mid + rolled	1245	57	61
Chickpea	Sorghum spray-out late	1732	66	34
Chickpea	Sorghum spray-out late + rolled	1106	66	23

With insufficient rain received in May or June and no forecast rain, it was decided to dry plant and apply trickle irrigation to the seed row for crop establishment in the last week of June.

The fallow efficiency of the wheat stubble was higher than that of the chickpea stubble (control) as wheat stubble plots accumulated 23 mm more PAW over the fallow than the control with chickpea stubble. However, with 34 mm more PAW present after chickpea harvest compared to the wheat plots, the wheat stubble still had 11 mm less PAW, when the wheat was planted in June. This trend has also been measured in the farming systems trials, where pulses leave more water at harvest than cereals, but cereals have higher fallow efficiency, and thus reduce the gap by planting of the next crop (or eliminate the gap in non-sodic soils and be ahead after long fallows).

The cover crops recovered some of the water they used with 73 mm of rain in March, but with little rain after this event, the early, mid and late sprayed sorghum cover crops were 25 mm, 44 mm and 48 mm drier than the control when the wheat crop was planted (Figure 3).

The highest wheat yield was achieved by the fallowed chickpea stubble (bare control; 727 kg/ha), followed by the wheat stubble (average 543 kg/ha) and early sprayed cover crop (364 kg/ha). The mid and late sprayed sorghum cover crops had patches of wheat die during the season for final yields of 68 kg/ha and 29 kg/ha (Table 3). Trickle tape irrigation providing even establishment across all plots and with very low rainfall in crop (34 mm) the yield outcomes were directly related to starting PAW. These yields represent an average yield reduction of 11.6 kg/ha for every mm less water the wheat crop used (i.e. planting PAW – harvest PAW + in crop rain) compared to the bare control.

Conclusions

The project has previously shown that cover crops can indeed help increase net water storage across the fallow and early crop growth in situations that have limited ground cover. We have also seen dramatic yield results for the subsequent cotton and wheat crops, which we attributed in part to more even populations established and greater water extraction.

In this dry season, improving ground cover allowed the opportunity to plant a crop, when the bare plots were too dry. At this longer fallow site (albeit dry) the cover crops recovered most of the water used, so planting with irrigation provided an even establishment and no difference in grain yield was observed.

The short fallow site had a PAW penalty for growing the cover crop and with no extra biomass growth in the later terminations, there was no advantages in persisting with the cover crop once it had stopped development. After an even establishment assisted by irrigation, the grain yield penalty to the wheat 'cash crop' was highly correlated to starting PAW.

Acknowledgements

The research undertaken in this project was made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the CRDC, DAF Queensland, CSIRO and DPINSW. The authors would like to thank them all for their continued support. Special thanks to Peter Jackson at 'Nareen' and Tom Woods at 'Murra Cul Cul', and the DAF Biometry, Technical and Research Infrastructure staff that supported the heavy management and monitoring loads of these experiments.

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Cover crops- experiences in Australia and observations from overseas

Discussion session

Notes

Grazing crops for cash flow and profit- pro's, con's and strategies

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Notes

Nitrogen and water dynamics in farming systems – multi-year impact of crop sequences

Andrew Erbacher[1], Jayne Gentry[1], Lindsay Bell[2], David Lawrence[1], Jon Baird[3], Mat Dunn[3], Darren Aisthorpe[1] and Greg Brooke[3]

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Key words

northern farming systems, nitrogen, fallow, water-use-efficiency, soil water

GRDC code

DAQ00192, CSA00050

Take home messages

- Grain legumes have utilised soil mineral nitrogen (N) to the same extent as cereal crops and have higher N export which often offsets N fixation inputs
- Additional applied N reduced the depletion of background soil mineral N status at most sites; we are recovering a high percentage (>50%) in soil mineral pool.
- Application of ~50 t/ha of compost or manure (10 t/ha OC) coupled with N fertiliser rates for 90th percentile yield potential has dramatically increased the soil mineral N in four years
- Decreasing cropping frequency has reduced N export and so stored more N over the longer fallows, which has reduced N fertiliser requirements for following crops
- Long fallows are mineralising N and moving N down the soil profile even under some very dry conditions
- Most excess N is not lost in the system rather it is moved down the soil profile for future crops
- The marginal WUE of crops (i.e. the grain yield increase per extra mm of available water) is lower when crops have less than 100 mm prior to planting. Hence, waiting until soil moisture reaches these levels is critical to maximise conversion of accumulated soil moisture into grain
- The previous crop influences the efficiency of fallow water accumulation with winter cereals > sorghum > pulses. Long fallows are also less efficient than shorter fallows (<8 months). This has implications for assuming how much soil moisture may have accumulated during fallows.

Introduction

While advances in agronomy and the performance of individual crops have helped grain growers to maintain their profitability, current farming systems are underperforming; with only 30% of the crop sequences in the northern grains region achieving 75% of their water limited yield potential. Hence, identifying ways to improve crop sequences to make more efficient use of soil water is needed. Growers also face challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. Change is needed to meet these challenges and to maintain farming system productivity and profitability. Consequently, Queensland Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and CSIRO are collaborating to conduct an extensive field-based farming systems research program, focused on developing farming systems to better use the available rainfall to increase productivity and profitability. Since 2015 experiments have been comparing farming systems and crop sequences designed to meet the emerging challenges. Experiments were established at seven locations; a large factorial experiment managed by CSIRO at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres by DAF and the DPI NSW (Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (red & grey soils)). A common set of farming system strategies have been employed to examine how changes in the farming system impact on multiple aspects of the farming system.

Systems with best commercial practices (*Baseline*) at each location were compared to alternative systems with higher and/or lower crop intensity, higher crop diversity, higher legume frequency, higher nutrient supply and higher fertility (with the addition of organic matter).

Sites were selected to represent a range of climatic conditions, soil types, nutritional status and paddock history. Each site was comprehensively soil tested at the beginning of the project with ongoing soil sampling conducted prior to planting each crop and again after harvest.

Depths of testing:

- soil water; 0 – 10 – 30 – 60 – 90 – 120 – 150 cm
- nitrate and ammonium N; 0 – 10 – 30 – 60 – 90 cm
- comprehensive nutrient analysis; 0 – 10 – 30 – 60 – 90 - 120 – 150 cm

There is a considerable range in soil fertility across the sites which dramatically influenced the requirements for inputs of N fertilisers in particular at some sites (e.g. Billa Billa and Pampas) where high levels were present at the start of the experimental period.

This paper explores five years of data across all geographical locations to compare the nitrogen and soil water dynamics in different farming systems across the northern region, specifically:

- Changes in system nitrogen dynamics due to increasing legume frequency, increasing fertiliser inputs and decreasing crop frequency
- Where the nitrogen is in the soil profile and how it moves over long fallows and different fertiliser regimes
- Dynamics of soil water over different crop sequences demonstrating how these influence crop water extraction and accumulation during fallows
- How soil water availability influences crop water use efficiency and
- How crop type influences fallow efficiency.

How does increasing legume frequency impact on system N dynamics?

Grain legumes are integral in current farming systems. The area and frequency of legumes has consistently increased due to high grain prices and a belief that they improve soil fertility and reduce overall nitrogen (N) fertiliser input costs. The data produced from the Farming Systems project has allowed us to compare the effects of increasing legume frequency on N dynamics over a large geographic area. However, it is important to note here that as the project only has five years of data, all these systems have only planted 1 or 2 extra legume crops compared to the *Baseline*.

To date, results across our sites show that additional legume crops in the crop sequence has had little positive impact on soil mineral N except at Billa Billa (+ leg Figures 1, 2, 3 & 4). The legumes are actually utilising soil mineral N to the same extent as cereal crops and have higher N export which often offsets N fixation inputs. This result is consistent across various starting soil N conditions, from locations with very high starting mineral N status (e.g. Billa Billa - Figure 2 & Pampas – Figure 3) to locations with low mineral N status (Narrabri - Figure 4) where legumes would need to fix N to meet their needs. These results challenge the common assumption that grain legumes reduce N fertiliser needs in the crop sequence. Improved pulse breeding and agronomy has increased harvest index and hence the ratio of N removed in grain to that left in biomass, so residual N has been diminished after the crop.

What is the impact of increasing fertiliser inputs on system N dynamics?

With declining soil fertility across the northern region there is increasing interest in identifying ways to either halt or reverse the trend of increasing fertiliser inputs. Past research suggests that maximising biomass production is one way to achieve this. More biomass will increase soil organic matter levels which will build the natural supply of nutrients such as N and phosphorus. To maximise biomass production, supplying adequate crop nutrition is critical, along with providing nutrients to promote soil microbial processes.

The capacity to address nutrient depletion by increasing crop biomass and yield potential under favourable conditions was investigated, by implementing a system that increases nutrient supply budgets to target 90th percentile yield (*Higher nutrient*) compared to only 50th percentile yields in the *Baseline*. Another system was also implemented at two of the sites (Emerald and Billa Billa), *Higher fertility,* which also increases nutrient supply budgets to target 90th percentile yield but received an upfront addition of 10 t/ha organic carbon (as ~50 t/ha compost or manure) at the start of the experiment to raise the inherent fertility of the site. This system was designed to determine if a higher fertility level could be sustained with higher nutrient inputs.

The additional N that was applied in the *Higher nutrient* system (+ nut.) reduced the depletion of background soil mineral N status at eight of the ten sites (Emerald, Pampas mixed, Billa Billa & Narrabri shown Figures 1, 2, 3 & 4). The high starting nitrogen levels at Billa Billa has resulted in only one additional application of nitrogen in the *Higher nutrient* system for winter crop 2017, hence all systems have been utilising the original pool of N.

When comparing the *Higher fertility* system (+ fertility) at Emerald and Billa Billa (Figure 1 & 2) the additional organic carbon applied has dramatically increased the mineral N. The last two years has seen this system move ahead of all the systems at both sites. The largest change was seen at the Emerald site with this system holding an additional 150 kg available N/ha than the *Higher nutrition* system. It will be interesting to follow this system over further years to determine if this level of fertility can be maintained through the application of fertiliser rates budgeted for a 90th percentile yield potential.

These results show that applying N fertiliser to aim for a 90th percentile yield potential may reduce the mining of soil available N, and that significant amounts of additional N applied remains in the mineral N pool and hence is available in subsequent crops. To confirm this, longer term trends of underlying soil fertility such as organic carbon or total N pools will need to be assessed.

What is the impact of decreasing crop intensity on system N dynamics?

The Northern region farming system is centred on growing crops mainly on stored soil moisture. With low fallow efficiencies, the belief is often “use it or lose it”. However, others believe it is more profitable to increase fallow length to reduce the risk to individual crops by increasing soil water at planting. The nitrogen dynamics of this *Lower crop intensity* system (-inten.) are shown below at Pampas (Figure 3) and Narrabri (Figure 4). These systems are storing more N over the longer fallows, which is reducing N fertiliser requirements for following crops. Given the recent dry conditions and enforced long fallows it is interesting to consider the amount and location of available N for the next crop.

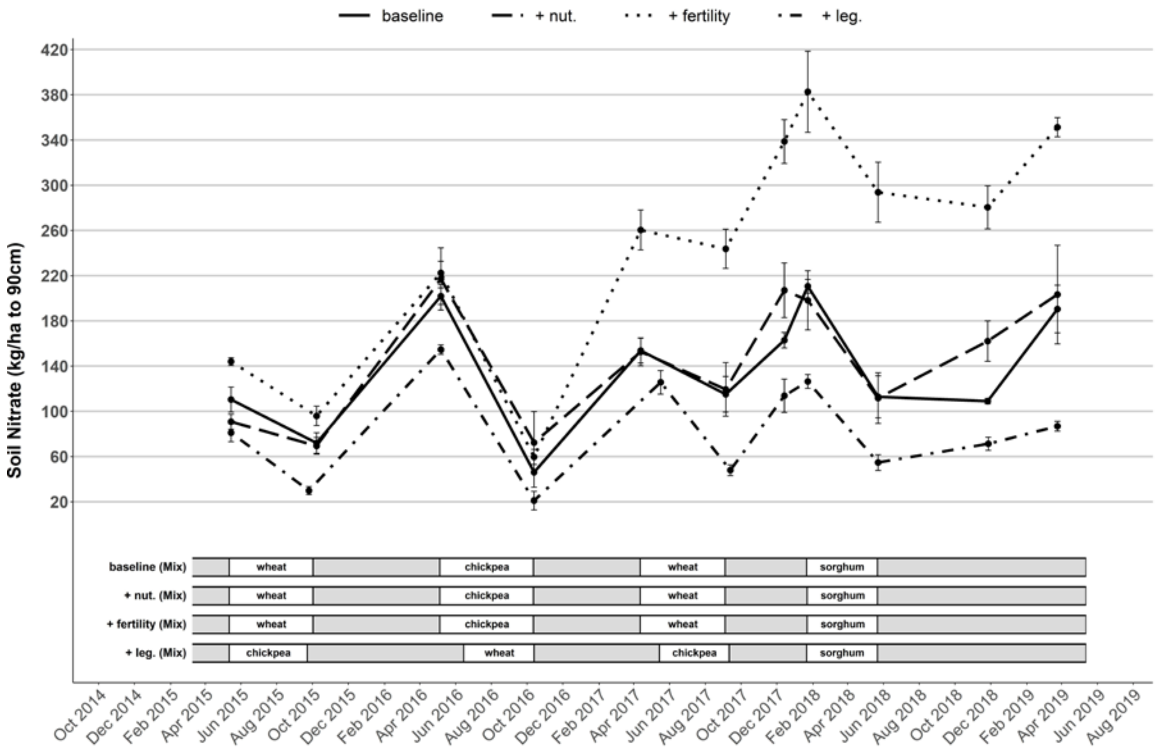

Figure 1. Dynamics of measured plant available soil nitrogen – Emerald

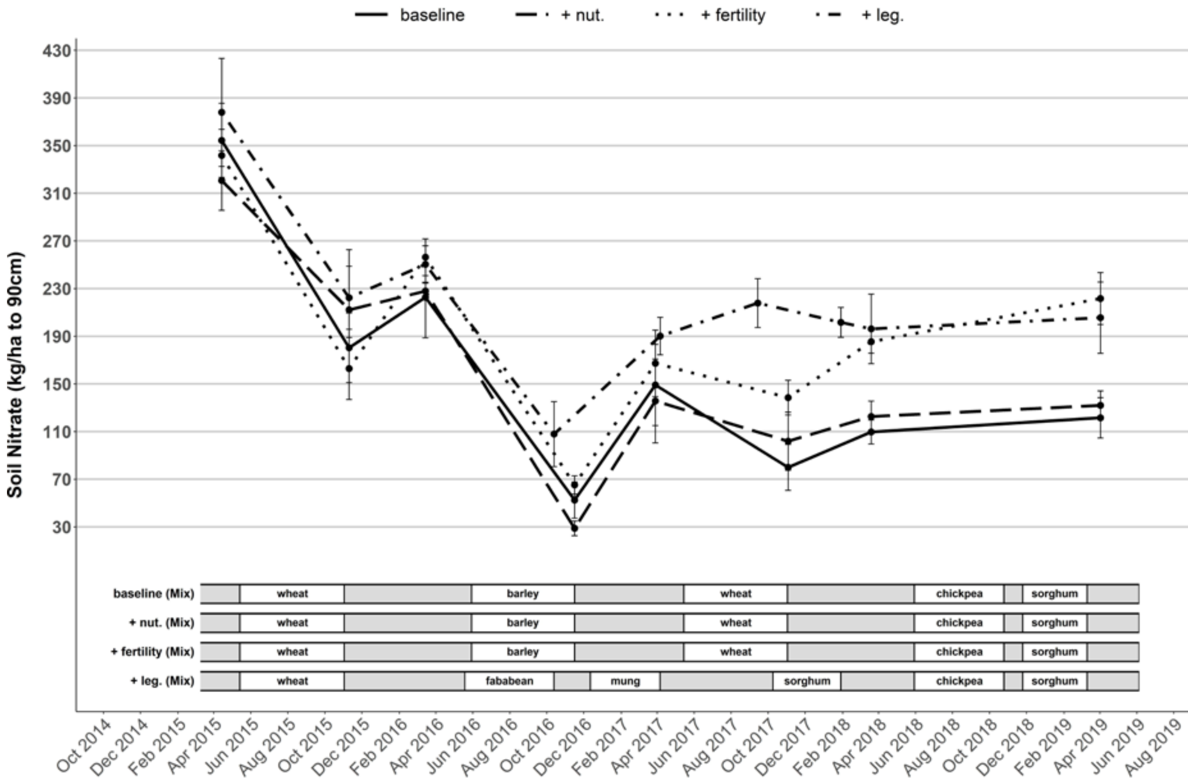

Figure 2. Dynamics of measured plant available soil nitrogen – Billa Billa

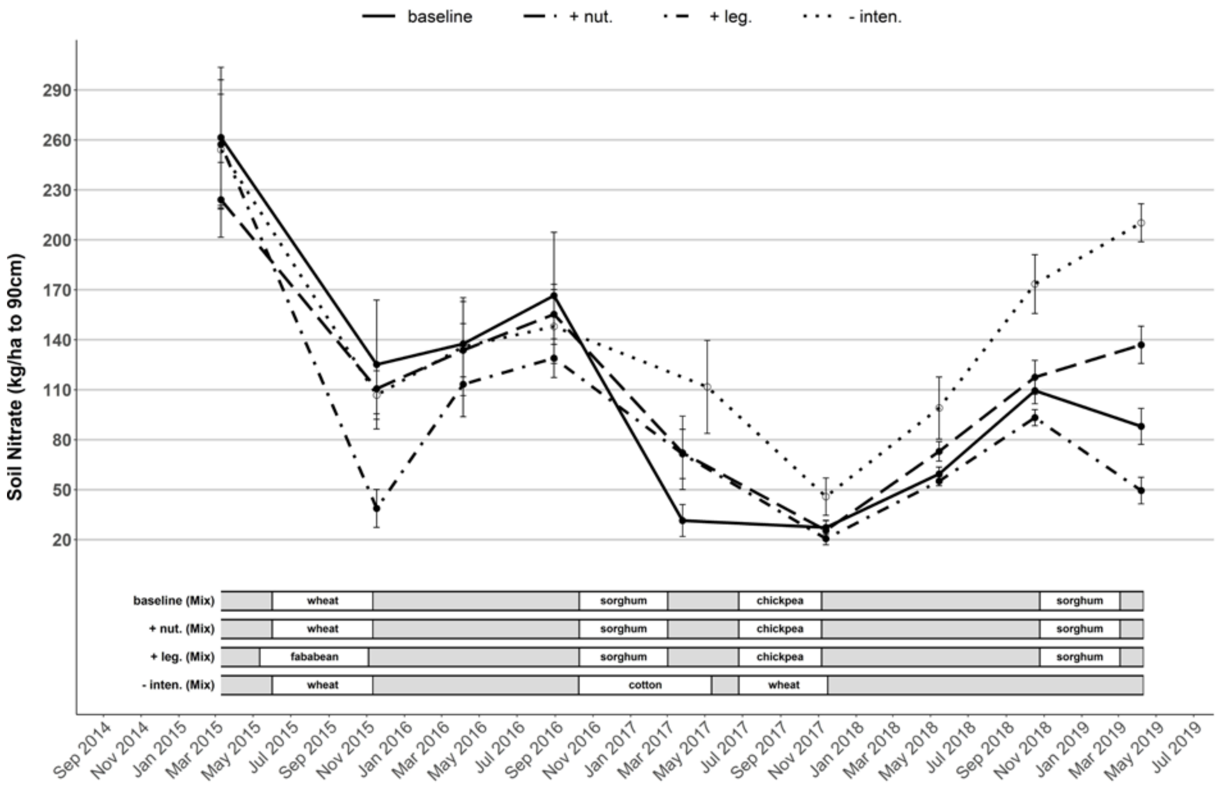

Figure 3. Dynamics of measured plant available soil nitrogen – Pampas mixed

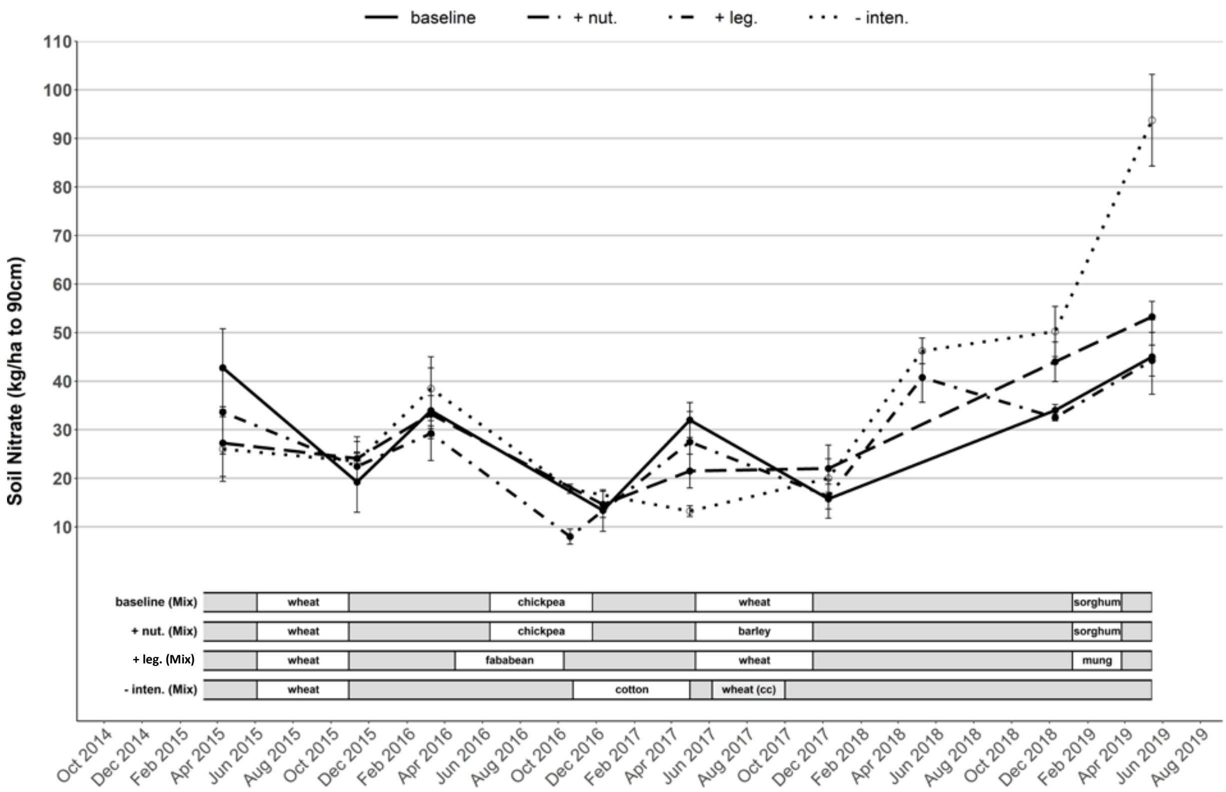

Figure 4. Dynamics of measured plant available soil nitrogen – Narrabri

Where is the nitrogen and how does it move in the soil profile?

When studying N dynamics over time the next question becomes ‘where is the N and how does it move in the profile?’ We have compared the starting available mineral N against that available after four years and where it is positioned in the soil profile at Emerald and Billa Billa (Figure 5). The Billa Billa site with its high starting fertility has seen N throughout the profile decline over time, with the largest change seen in the 0 – 10 cm. However, the Emerald site with its lower starting fertility and use of N fertiliser across all systems, has seen both the *Higher nutrient* and *Higher fertility* systems building N. The majority of this increase was in the 30 – 90 cm layers, indicating that excess N has moved down the profile during this time frame but is still available for future crops.

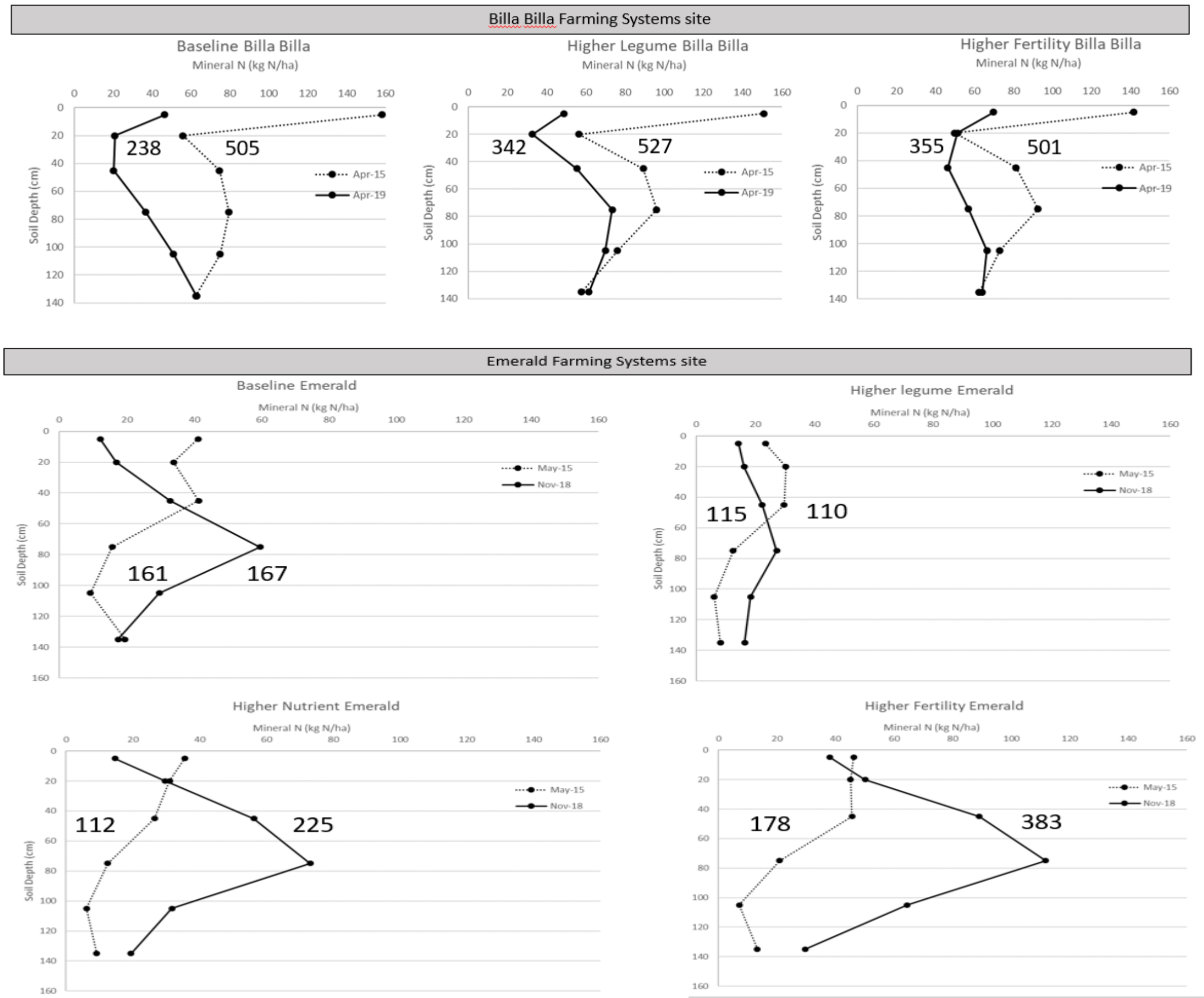

Figure 5. Distribution of mineral N placement within the soil profile from 2015 to 2019 at Billa Billa and Emerald

We know N mineralisation is related to soil type, organic carbon, biomass and rainfall – but what happens during extended dry periods such as the last 18 months across the northern grains region? After the initial increase of mineralised N in the topsoil across several sites, there was a definite movement of mineral N down through the soil profile. For instance, the summer season of 2017/18 saw significant levels of mineralisation within the 0 - 30 cm depth at the northern farming systems sites (Figure 6 - Narrabri and Pampas). This summer recorded below average rainfalls, but there was obviously still sufficient rain to trigger mineralisation. The increase in the 0 – 30 cm corresponds with the location of microbes responsible for the breakdown of organic matter into the plant available form of nitrate and ammonium. Sampling after the winter of 2018 found that the N mineralised during the previous summer, had filtered down the profile into the lower depths (30 - 60 cm). This pattern continued late into the fallow as the accumulated mineral N increased in the 60 - 90 cm depth. These results show that mineralisation can be triggered by even small falls of rain and this N can then move down the soil profile even with lower soil profile moisture levels or when rain does fall. This is important for the next phase of the cropping sequence, as it can be assumed that not only do we have ample mineral N available to maximise grain yields, but the location of the N is within the soil layers where plants require peak N uptake during key growth stages.

The Mungindi site (Figure 7) had preplant N applied for a winter crop that was not planted (2017). The *Baseline* received 20 kg N/ha and the *Higher nutrient* system received 80 kg N/ha in April 2017. The following year soil analysis showed that large amounts of N had mineralised and that this mineralised N and fertiliser N moved into the 10 - 30 and 30 - 60 cm layers during a very dry year. This data shows that if N is applied and not utilised by a crop that it may not be lost from the system but rather move down the profile to support future crop growth and grain production.

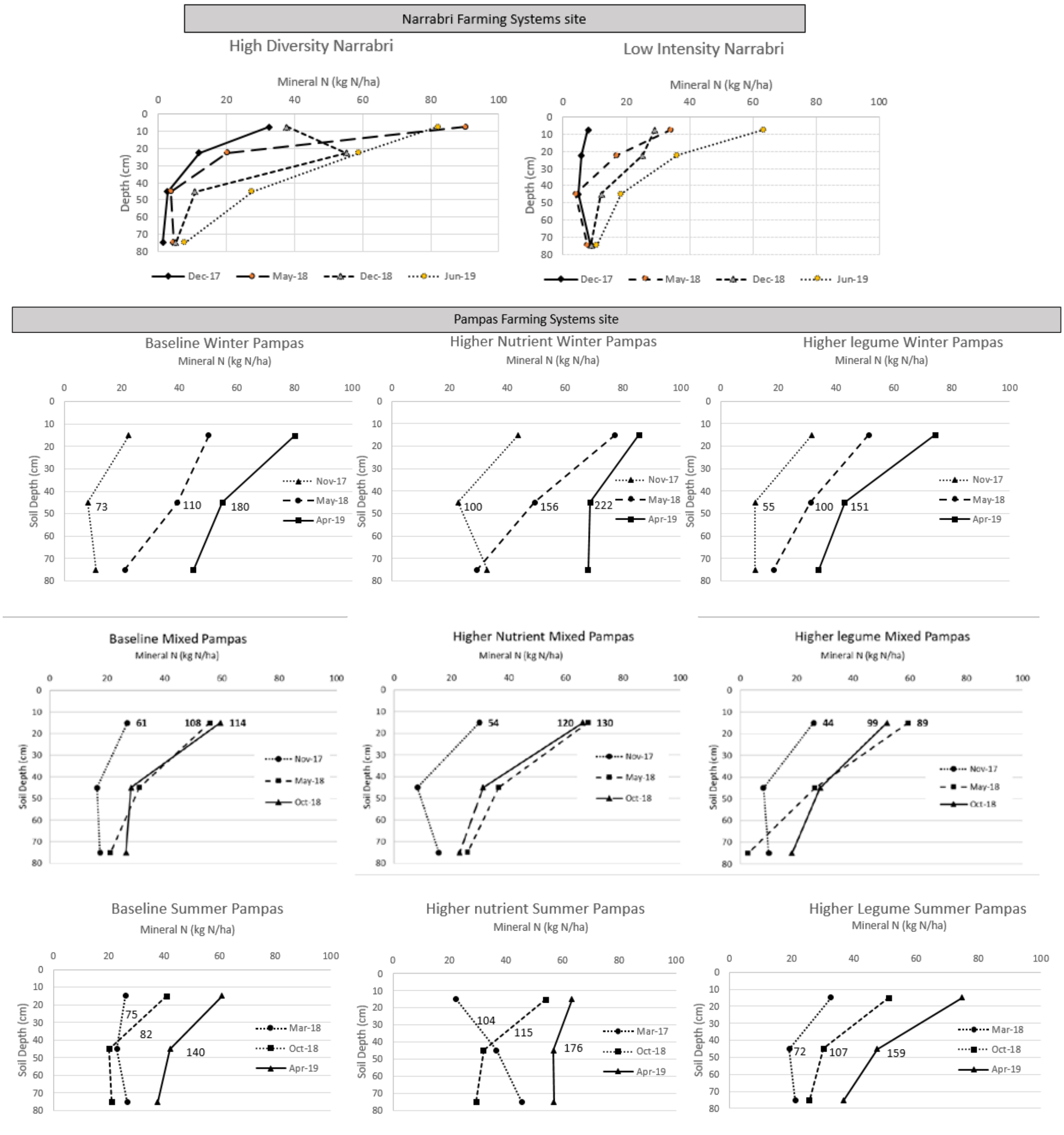

Figure 6. Distribution of mineral N placement within the soil profile over a long fallow period at Narrabri and Pampas

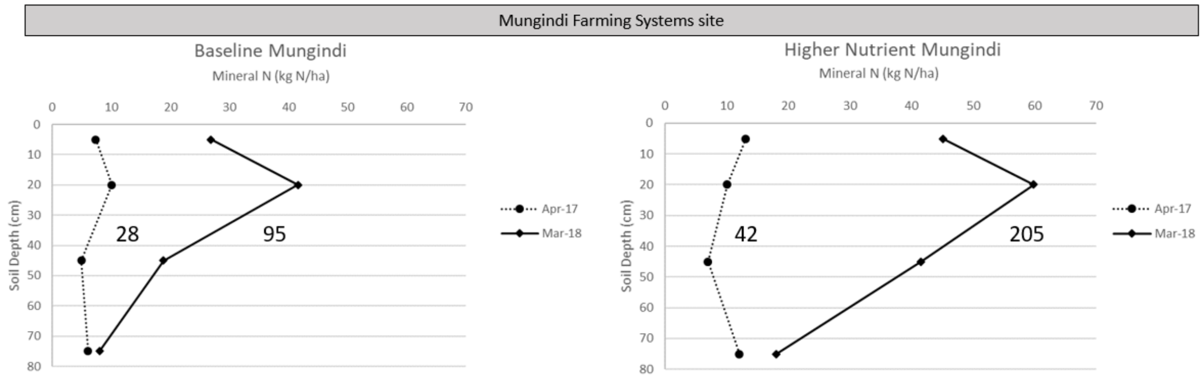

Figure 7. Distribution of mineral N placement within the soil profile over a long fallow period at Mungindi

Untangling the water use efficiency of crop sequences

System water use efficiency of a crop sequence is driven by the efficiency of its fallows (i.e. the proportion of rain falling during the fallow that accumulates in the soil to be available for the next crop) and how efficiently the subsequent crops can convert both the accumulated soil water and in-crop rainfall into grain or product. We have monitored crop water use, water use efficiency and subsequent fallow water accumulation for over 300 different crops to explore how soil water accumulates and is used over different crop sequences.

How does cropping intensity impact on plant available water (PAW) dynamics?

Cropping intensity impacted on the depth of recharge of the soil profile. In the two examples below at Billa Billa (Figure 8) and Pampas (Figure 9) the higher intensity soil profile was never allowed to refill as fully as the *Lower intensity* and *Baseline* systems. While there are implications on yield and WUE (discussed later in this paper) for having less stored water, not allowing the profile to fill may also affect the plants' ability to extract deep nutrients.

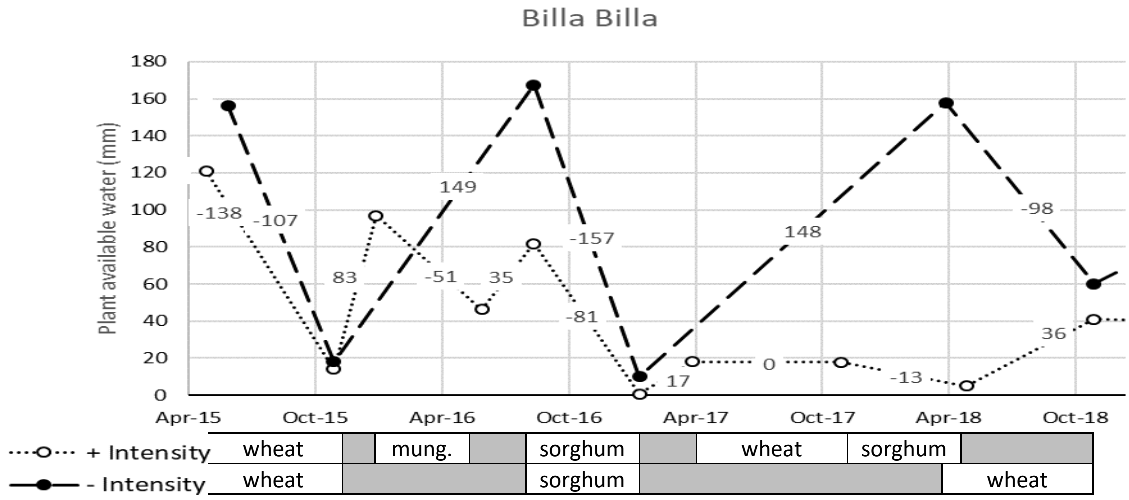

Figure 8. Plant available water (PAW) dynamics of two of the Billa Billa cropping systems. *Nb. Plots were often soil sampled up to 6 weeks prior to planting; crop duration indicated in the chart is from pre-plant soil sample to post-harvest soil sample (not plant to harvest). Numbers show the net change between the two soil water readings

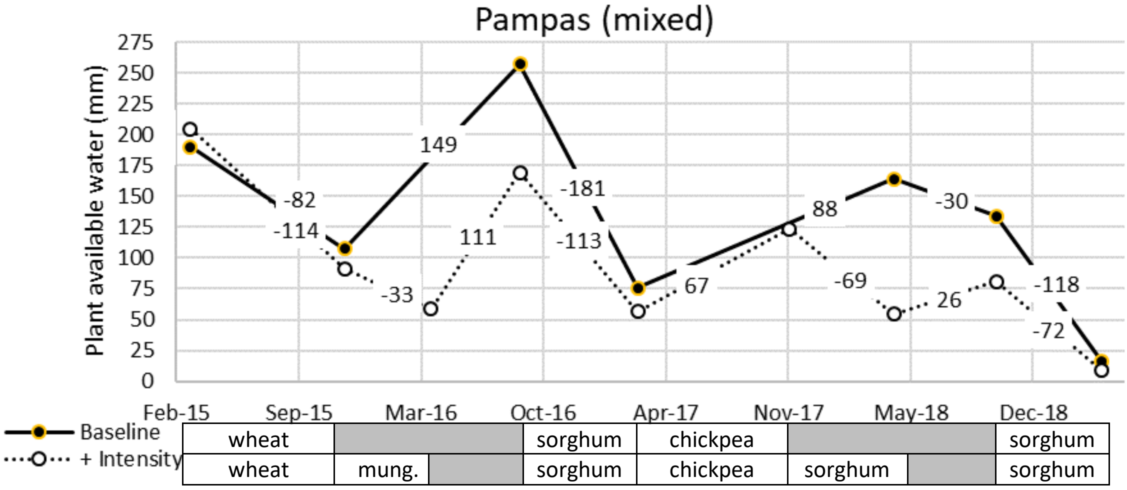

Figure 9. PAW dynamics of two of the Pampas mixed summer/winter cropping systems. *Nb. Plots were often soil sampled up to 6 weeks prior to planting; crop duration indicated in the chart is from pre-plant soil sample to post-harvest soil sample (not plant to harvest). Numbers show the net change between the two soil water readings

How does crop choice impact on PAW dynamics?

The Billa Billa Belah duplex soil is constrained by sodicity at depth, so pulse crops have left water below 50 cm. This deep PAW and rainfall at opportune times has allowed double cropping after pulses – an option that was not available in the systems where cereal crops (or canola) were grown (Figure 10) due to their higher ability than pulse crops to extract water from sodium constrained zones. This has allowed the *Higher legume* system to increase its cropping intensity, with the same PAW planting triggers as the *Baseline*. Similarly at Billa Billa, the *Lower intensity* wheat grown in 2018 reduced the profile by 98 mm (Figure 8) while chickpeas in the *Baseline* and *Higher legume* systems only reduced the profile by 39 and 34 mm respectively (Figure 10), allowing them to double crop to sorghum on the next rainfall event.

On the ‘less constrained’ black Vertosol at Pampas, the difference in PAW extraction is much less stark. There is still a difference in crop lower limits between the pulse and cereal crops, however the difference is much less. For example, faba beans and wheat were planted in the same season, with similar starting PAW (Figure 11). At harvest the wheat had extracted 14 mm more than the faba bean (compared to 53 mm in the constrained site). After harvest the wheat accumulated an extra 14 mm PAW, so that the two systems had the same PAW again when a winter crop was planted in the winter only systems. However, in the mixed systems the fallow was continued to sorghum in October 2016. With the longer fallow, the wheat stubble continued to provide higher fallow efficiency so had 12 mm more PAW at planting than the faba bean stubble. The extra stored PAW was used by the following sorghum crop, so that the two systems had the same PAW post-harvest and have maintained the same rotation and similar PAW since (Figure 11).

At Mungindi the *Baseline* and *Lower intensity* systems had the 2015 wheat crop in common. However, in 2016 the *Baseline* was planted to chickpea, while the *Lower intensity* was fallowed to cotton in the spring (Figure 12). A large portion of the rain that fell in that season was in the spring, when the chickpea and cotton crops were both in the ground, but with very little rainfall from chickpea harvest to cotton harvest. The cotton crop left the soil 32 mm drier than the chickpea at their respective harvests (chickpea was 19 mm drier at cotton picking), but a combination of residual wheat stubble and dry cracked soil post-cotton, resulted in the lower intensity system having an extra 15 mm PAW when the two systems were planted to wheat in 2018.

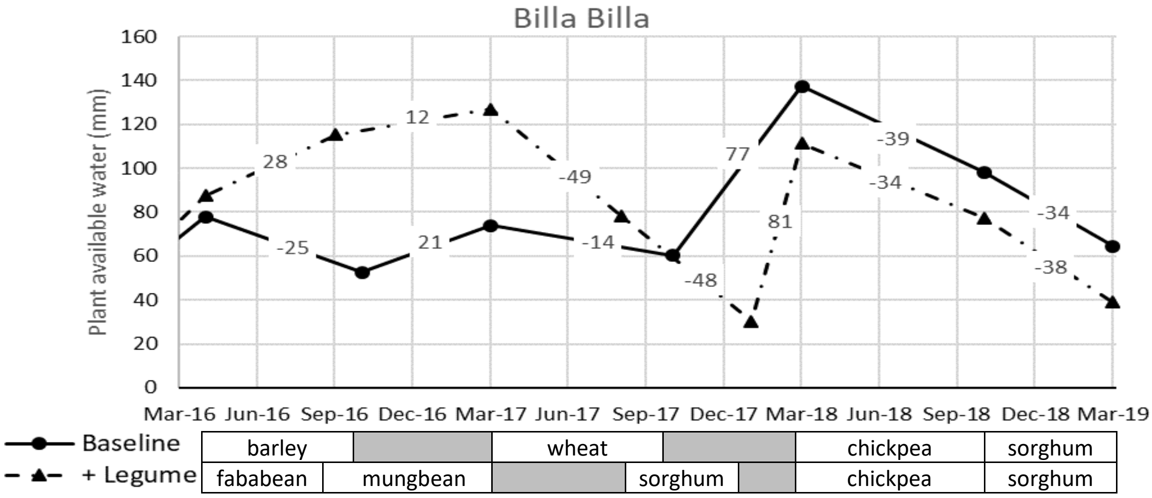

Figure 10. PAW dynamics of two of the Billa Billa cropping systems. *Nb. Plots were often soil sampled up to 6 weeks prior to planting; crop duration indicated in the chart is from pre-plant soil sample to post-harvest soil sample (not plant to harvest). Numbers show the net change between the two soil water readings

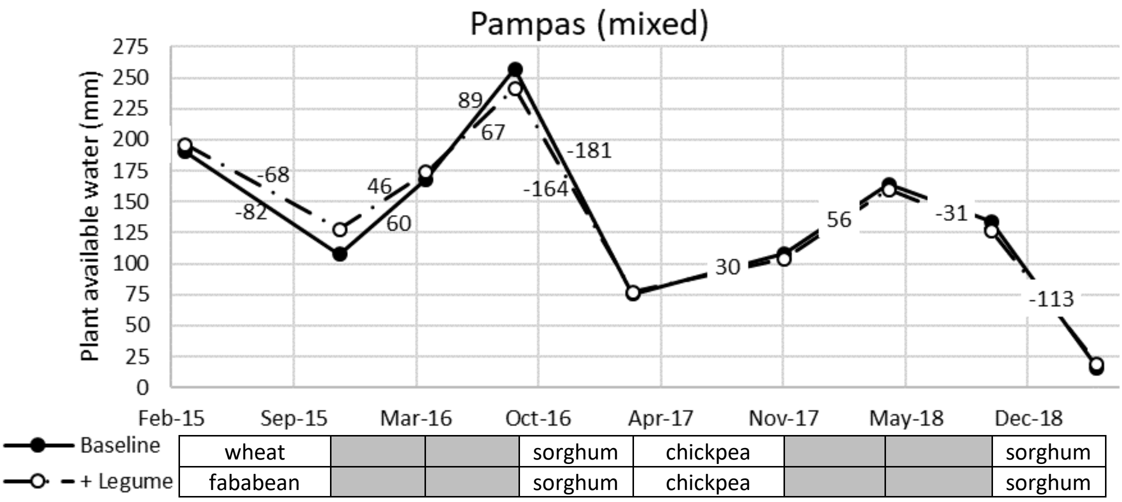

Figure 11. PAW dynamics of two of the Pampas mixed summer/winter cropping systems. *Nb. Plots were often soil sampled up to 6 weeks prior to planting; crop duration indicated in the chart is from pre-plant soil sample to post-harvest soil sample (not plant to harvest). Numbers show the net change between the two soil water readings

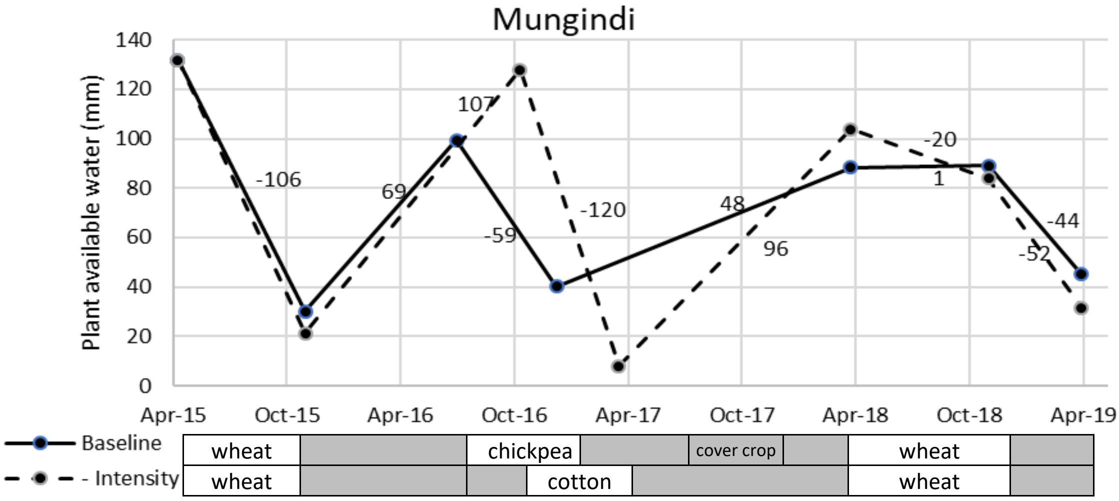

Figure 12. PAW dynamics of two of the Mungindi cropping systems. Numbers show the net change between the two soil water readings

Drivers of crop water use efficiency

The availability of water is a key driver of crop yields in Australian farming systems and hence understanding what drives crop water use efficiency (WUE; the kg of grain produced per mm of crop water use) is critical. A relationship between grain yield and crop water use has been widely used to demonstrate the WUE potential of crops across different environments. In northern farming systems the water available to the crop can come from stored soil water at planting and in-crop rain; In contrast to southern Australia where in-crop rain alone has often been used to calculate crop WUE. Further, the unreliability of in-crop rain can mean that the stored moisture can make up a large proportion of the water available to the crop, and hence has high importance for determining crop yield and crop WUE.

Using the data collected from the farming systems experiments we show that the marginal WUE (kg/mm of additional crop water use) reached its potential at 24 for wheat, 12.5 for chickpea and 18 for grain sorghum. Despite this potential and optimal crop management in these experiments, in most cases the average across all the crops measured was lower; 15.3 for wheat, 8.8 for chickpea and 14.3 for sorghum (Figure 13, TOP). This demonstrates that while WUE is a useful benchmark, there is large season to season variability due to the timing of rainfall events or other stresses that may reduce crop yields.

There is no clear relationship between planting soil water and crop yield across this data, due to large seasonal differences in in-crop rain. Nonetheless, we found some interesting relationships between available soil water at planting for the crop and the marginal WUE that that crop achieved (Figure 13, MIDDLE). This shows that in general, the WUE of crops increases as more soil water is available at planting. Crops of wheat, chickpea and sorghum that had less than 100 mm of plant available water coming into the season, had much less chance of achieving high crop WUE. This is because crops planted on marginal soil moisture are more at risk of depleting the soil profile prior to flowering and the critical grain filling period, unless significant in-crop rainfall occurs. This data suggests that chickpea may be less susceptible than wheat or sorghum to this. We could hypothesize that this is because chickpea has a lower water requirement prior to the start of grain filling and the indeterminate growth habit means that acute water stress at critical phenological times impact less severely on grain yield.

Finally, the gap between the marginal WUE of each crop compared to the potential predicted here (dashed lines) increases significantly in crops with lower soil water prior to planting. Figure 13 (BOTTOM) shows the rate that crop WUE declines per mm of available water across a range of starting soil water conditions. This indicates that the lower the soil water is at planting, the more quickly that WUE will decline. This further demonstrates that crops planted on lower soil water are likely to achieve suboptimal crop WUE and this relationship is not linear. That is, as less soil water is available, the likely reduction in WUE increases further.

In summary, this analysis shows that soil water prior to planting is a critical driver of how efficiently a crop converts the water available to it into grain. It is worth noting however, that this analysis was done using soil water samples prior to planting and hence, in some cases did not include the planting rainfall event itself. Hence, if another 15-20 mm is required to achieve this then this was not included these calculations of soil water at planting.

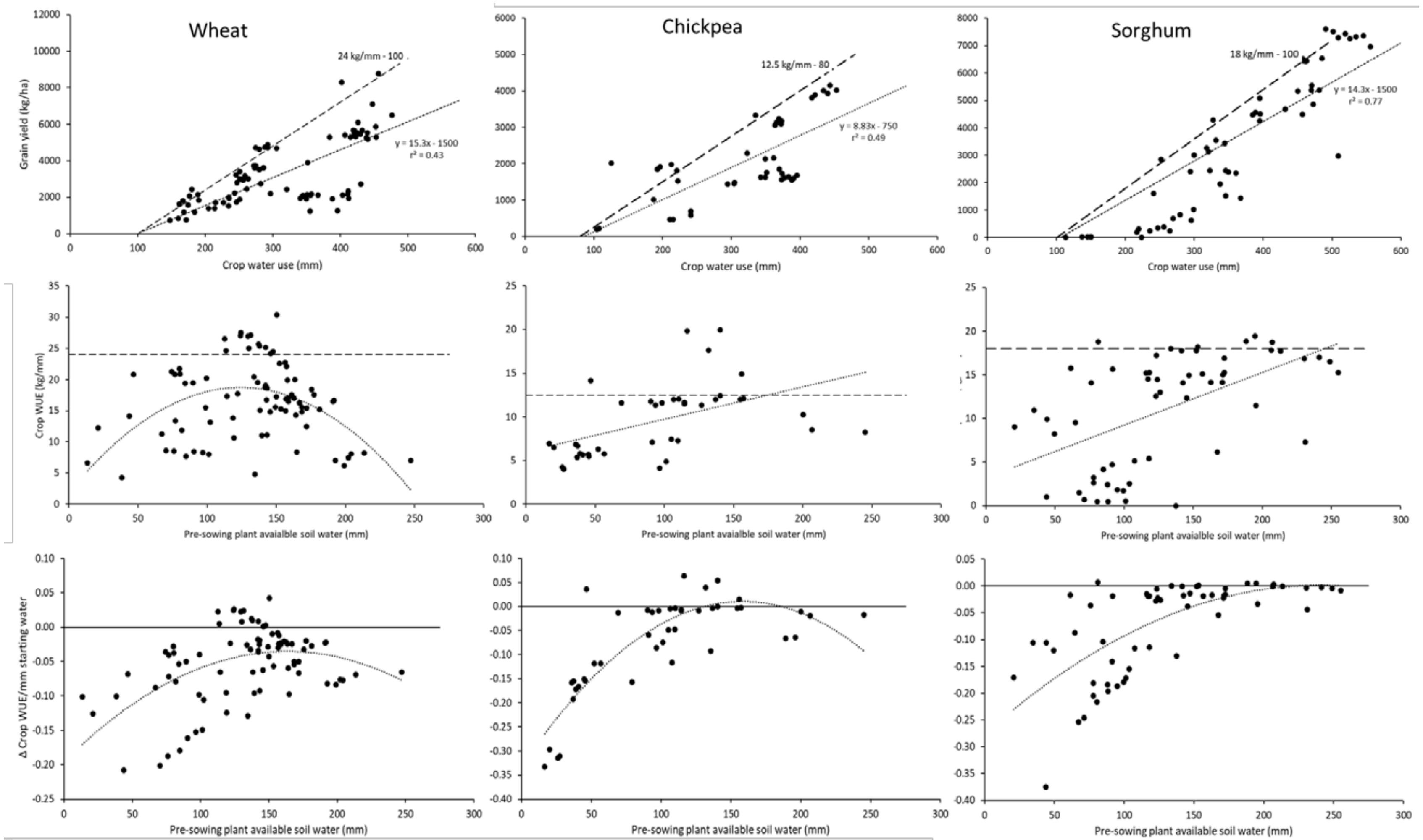

Figure 13. Relationships between water availability and crop yield and water use efficiency (WUE) in wheat, chickpea and grain sorghum collated from data collected across farming systems research sites. TOP –Crop water use (change in soil water plus rainfall) *vs.* grain yield, showing the maximum potential (dashed line) and the average across the dataset (dotted line); MIDDLE – Plant available soil water prior to planting *vs.* crop WUE (as calculated above); and BOTTOM – Plant-available soil water prior to planting vs the difference between the measured crop WUE and the potential WUE per mm of additional water available (dashed lines in above figures)

Crop effects on efficiency of subsequent fallows

Here we have collated this data to compare how different crop types impact on subsequent fallow efficiencies (Table 1). We have removed fallows with little rain (<80 mm) because this distorts the values of FE.

Based on > 20 different fallows we monitored, this quantifies some clear crop effects on subsequent fallow efficiencies – typically related to the ground cover provided and its persistence. Winter cereal crops provide the highest fallow efficiencies while the lower cover after winter pulses results in lower fallow efficiencies. Sorghum is intermediate. With fewer observations, fallow efficiencies after canola were intermediate between the winter pulses and winter cereals. Cotton produced much lower fallow efficiencies. The data also clearly shows that short-fallows are more efficient than longer fallows, because during long-fallows the soil is wetter for longer and hence there is more evaporative losses and residue cover levels are reducing with time.

Table 1. Comparison of efficiencies of fallow water accumulation (i.e. change in soil water/fallow rainfall) following different crops. Data are an average of fallows monitored across the farming systems experiments in northern NSW and southern Qld between 2015 and 2019. Only fallows receiving more than 80 mm of rain are included

Previous crop	**All fallows**	***n.***	**Short fallow (<8 months)**	***n.***	**Long fallows (> 8 months)**	***n.***
Winter cereals (wheat, durum, barley)	30%	*81*	34%	*54*	21%	*27*
Winter pulses (chickpea, fababean, field pea)	20%	*36*	25%	*20*	15%	*16*
Sorghum	22%	*23*	28%	*7*	19%	*16*
Canola	26%	*5*	31%	*4*	6%	*1*
Cotton	16%	*3*			16%	*3*

This means that the impacts of a particular crop on the accumulation of soil water in the following fallow should be considered in the cropping sequence. For example, a fallow receiving 400 mm of rain after a winter cereal would accumulate 120 mm on average, while the same fallow after a grain legume would have only accumulated 80 mm. This difference could have a significant impact on the opportunity to plant a crop and/or the yield and gross margin of the following crop in the cropping sequence.

Conclusions

Nitrogen

Improved pulse varieties and agronomy has seen greater use of pulses. This has not provided increased nitrogen benefits to following crops as the pulse crops often mine mineral nitrogen from the profile. However, increasing nitrogen budgets to 90th percentile yield potential at planting has meant crops have left nitrogen behind in most seasons, so the nitrogen can move down the profile and accumulate in the deeper soil layers. This effect is accentuated where we also added organic carbon to the system, as the soil is suppling more nitrogen to the mineral pool.

Increasing the time spent in fallow is also allowing the soil to mineralise more N, and the small rainfall events in the recent dry seasons have been sufficient to move N down the profile.

Regardless of the source, excess nitrogen was rarely lost to the system, rather it was moved down the soil profile for future crops, and presumably some has moved into the organic pool. But the only way to be sure how much and where nitrogen is positioned is with a well segmented soil test.

Water

In a northern farming system, grain yield is highly dependent on how much water is stored in the profile during the preceding fallow. The efficiency of capturing and storing fallow rainfall is driven by the stubble left by the previous crops and the duration of the fallow period. Crop type also influences how efficiently crop water use is converted to grain. This research suggests storing more than 100 mm PAW prior to planting increases the likelihood of optimising crop WUE.

Increasing cropping intensity by planting with less stored moisture, reduces the potential to recharge deep soils, which can limit the plants ability to access deep stored nutrients.

Crop choice can dictate the next planting opportunity through the different residual water levels at harvest and fallow efficiency of the stubble left behind. This opportunity could be quite different in the presence versus absence of soil constraints.

Acknowledgements

The research undertaken as part of this project (CSA00050, DAQ00192) is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. We would also specifically like to thank all the farm and field staff contributing to the implementation and management of these experiments, the trial co-operators and host farmers.

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New technologies for the Australian grains industry - observations from a 4 month Fulbright Fellowship study tour of the USA and Germany

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Notes

Changes in northern NSW farming system climate conditions - Gulargambone

Steven Crimp and Mark Howden, Australian National University

Key words

climate projections, production impacts, adaptation options

Take home messages

- Greenhouse gas (GHG) emissions continue to accumulate in the earth's atmosphere and drive warmer global temperatures. Warming of globally averaged air temperatures of just over 1°C since records began in 1850 has produced national, regional and local changes in environmental conditions. These changes have shifted debate from "Is climate change real?" to "What should we do about it?"
- Adapting agricultural practises will be required to respond to changing environmental conditions and will require all components of the agricultural value chain to work together in order to maintain resilient and profitable food systems.

Historical changes in climate?

Preliminary results suggest that 2019 is likely to be either the second or third warmest year on record, with globally annual averaged air temperatures now 1°C warmer than the long-term average calculated for the period 1961 to 1990. This warming is driven by increasing concentrations of all the major long-lived greenhouse gases in the atmosphere, with carbon dioxide (CO_2) concentrations rising from 208ppm prior to the industrial revolution, to 413.65 ppm as of 4 January 2020 (NOAA, 2020).

In Australia, warming in average temperature (average temperature) has resulted in 2019 being the warmest year on record (1.52°C above the 1961 to 1990 average of 21.8°C) (BoM, 2020). Average daytime maximum temperatures in 2019 of 30.69°C were 2.09°C above the 1961 to 1990 average. In December 2019 more than 40% of the entire country recorded maximum temperatures greater than the 97th percentile i.e. top 3% of temperatures. Examining the shift in the distributions of monthly day and night-time temperature shows that very high monthly maximum temperatures that occurred around 3% of the time in the past (1951–1980) now occur around 12% of the time (2003–2017) (BoM & CSIRO, 2018). Very warm monthly minimum, or night-time, temperatures have shown a similar change from 2% of the time in the past (1951–1980) to 12% more recently. This shift in the distributions towards hotter temperatures and more extreme high temperature conditions has occurred across all seasons, with the largest change being in spring (BoM & CSIRO, 2018).

In the Gulargambone region over the period 1960 to 2019 (length of the temperature record), warming has occurred in both minimum (1.4°C) and maximum temperatures (2.0°C). For the period 1960 to 1991 an annual average maximum temperature of 27°C occurred, on average, 1% of the time. More recently (1992 to 2019) this temperature now occurs on average 15% of the time. Similarly mean annual minimum temperatures have warmed with the frequency of a minimum temperature of 12°C increasing from 8% to 23% of the time (Figure 1). As a result of the warming, the frequency of extreme minimum temperatures has declined with temperatures of -3°C occurring 33% of the time during 1960 to 1991 and now only occurring 20% of the time in the most recent period. The frequency of maximum temperature extremes have increased with temperatures greater than 42°C now occurring between 8% and 25% more frequently (Figure 2).

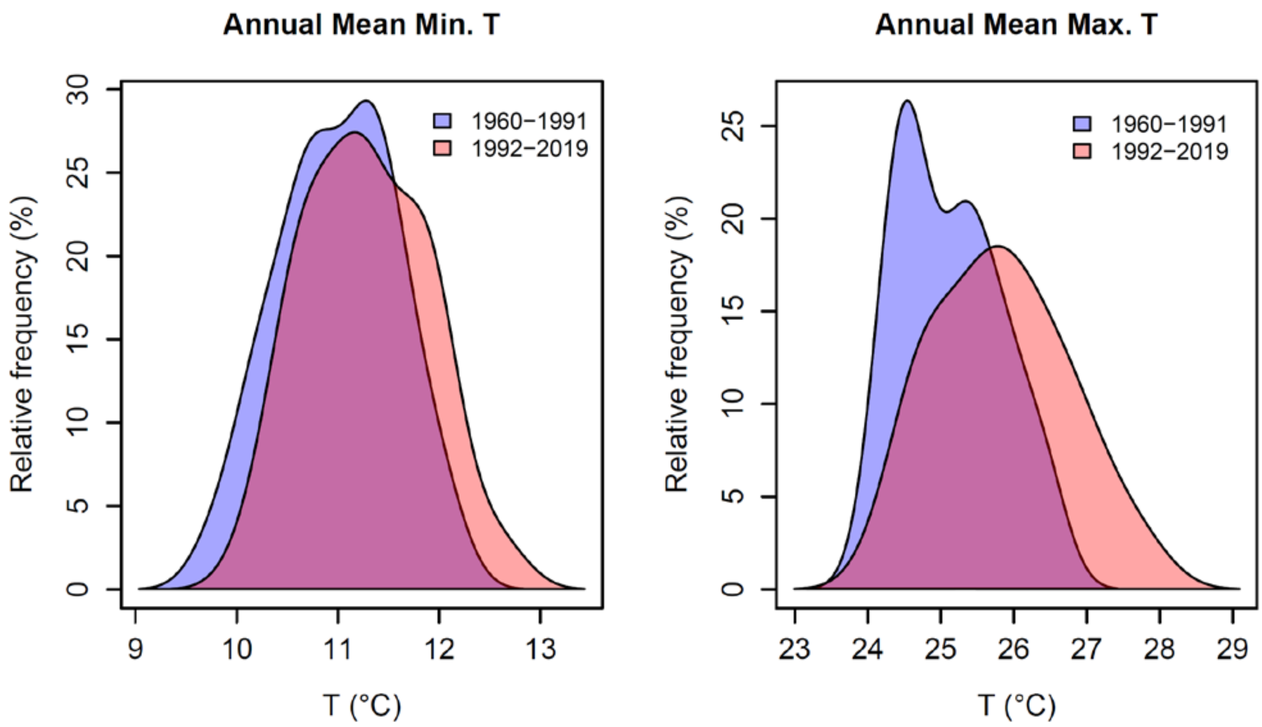

Figure 1. Probability distributions of annual mean maximum temperature (right) and annual mean minimum temperatures (left) for Gulargambone for two periods, namely 1960 to 1991 and 1992 to 2019

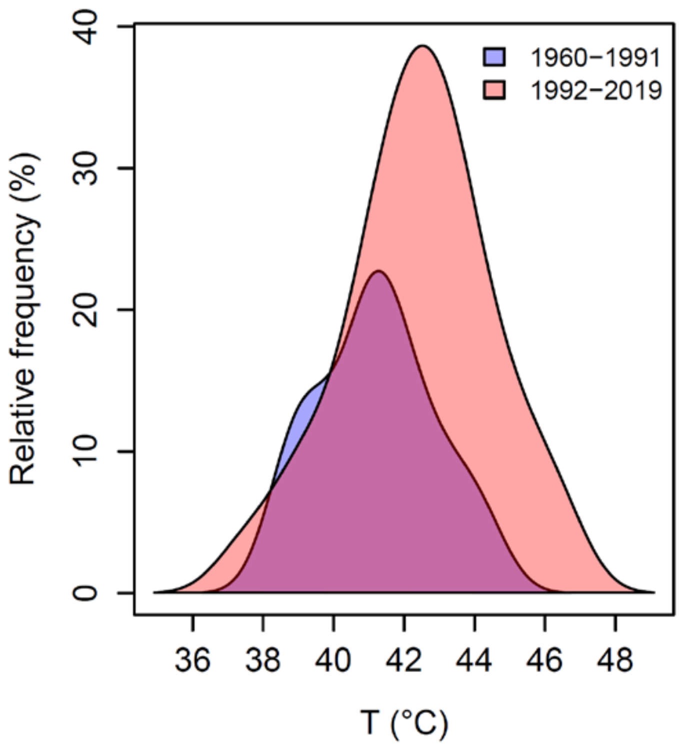

Figure 2. Probability distributions of daily maximum temperature extremes for Gulargambone for two periods, namely 1960 to 1991 and 1992 to 2019

The Gulargambone rainfall record exhibits a declining trend, with an average 60mm less annual rainfall now than in the 1960s. A comparison of the annual rainfall between the period 1960 to 1991 and 1992 to 2019 (Figure 3) does show a considerable change in the annual distribution of rainfall in the Gulargambone region. The analysis highlights an increase in the occurrence of low annual rainfall amounts less than 400mm in the most recent record as well as an increase in the occurrence of annual rainfall amounts greater than 1000mm (Figure 3).

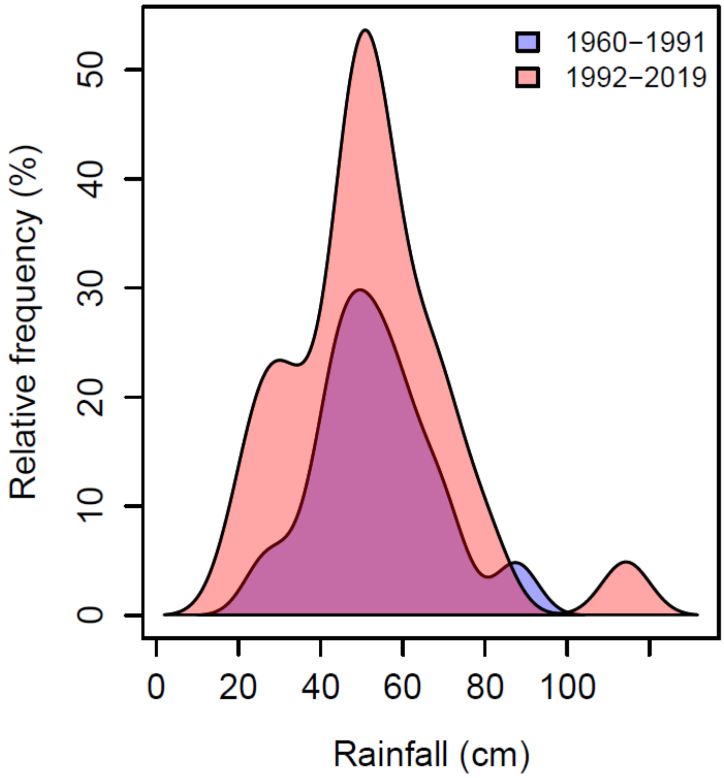

Figure 3. Probability distributions of annual rainfall amounts for Gulargambone for two periods, namely 1960 to 1991 and 1992 to 2019

The current acceleration of global warming is expected to continue based on future greenhouse gas (GHG) emissions trajectories. Previous studies have examined how the rates of record-breaking have changed in the US (Anderson et al., 2011), the UK (Kendon, 2014), and Australia (Lewis & King, 2015). These studies have found increased rates of hot temperature records and decreased record setting for cold temperatures in recent decades (King et al., 2015; King, 2017). Lewis and King (2015) found that from 2000 to 2014 there were 12 times as many hot record-breaking temperatures as cold records in Australia and attributed this to anthropogenic climate change. Recent BoM analyses has shown that from 1960-2018 the ratio of hot records to cold records set across Australia was 6:1 whereas from 1910-2018 the ratio was 9:1 (Blair Trewin pers Comm. 2020). In 2019 the ratio of hot to cold records broken at the state area average level was 34:0 (Blair Trewin pers Comm. 2020). Across the world, there were about five times more record-breaking monthly temperatures than would be expected without a long-term warming trend (Coumou et al., 2013) over the early 21st century.

During the 2018/19 Australian summer more than 206 individual location extreme temperature records were broken in just 90 days (Climate Council, 2019). Climate change has been found to not only increase the likelihood of breaking high temperature records (e.g. Lewis and Karoly, 2013), but record-breaking hot summers and years over previous decades are also attributable to anthropogenic climate change (King et al., 2016). More recent research by Mann et al. (2018) has shown that the synoptic features (large scale weather systems) responsible for prolonged heatwaves are on average 50% more prevalent under a business-as-usual GHG emissions trajectory.

In addition to record breaking temperatures, changes in rainfall patterns, sea levels, rates of glacial retreat and biological responses have also been detected consistent with expected climate change projections. This mounting evidence has led to scientific consensus that:

- Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that affect the climate system and these changes and resultant trends will continue for the foreseeable future; and
- There is at least 95% confidence that humans are the main cause of global warming since 1950, and most likely responsible for 100% of that temperature rise (IPCC, 2018) with a less than 1 in 100 000 chance that human activities are not responsible for the observed increase in global temperatures (Kokic et al., 2014).

These changes are already likely to have negatively impacted on Australian agriculture, acting as a major drag on yield growth with similar impacts on yield growth globally for the major crops (Porter et al., 2014).

A major issue in understanding historical and future climate change is how much are the various human-induced climate forcing's (greenhouse gas emissions, stratospheric ozone depletion, Asian aerosols, and landcover change) interact with components of natural variability (Watkins, 2005, McKeon, 2006). Thus, it is important for successful climate adaptation that agricultural decision-makers keep informed of the evolving climate science and updated climate change scenarios. As scientific understanding improves and there is more confidence in emission scenarios, current and future uncertainties can be rapidly assessed in terms of decision making.

What is expected to happen in the future?

In response to the continued growth in atmospheric GHG concentrations, scientists estimate that global average temperatures could increase by up to 4.8°C by the end of the present century, dependent on global population growth, technological advancement and economic growth (IPCC, 2013). To put this in context, the difference between our historical temperatures and those of the last ice age was only about 5°C. So even though 4.8°C does not sound like much, it signals a huge change in how the climate-ocean-land systems of the earth function and hence how agriculture will operate.

In Australia, national projections suggest additional warming of up to 1.3°C of additional warming could be experienced by 2030 and up to 5.1°C of warming could be experienced by 2090, with the greatest warming being in inland Australia and the lesser warming along the southern coast and Tasmania (CSIRO, 2015). Global studies indicate that a rule of thumb is that global potential crop production drops by 6% per degree warming (Porter et al., 2014).

Whilst changes in rainfall are more uncertain, projections suggest drier conditions in the southern half of Australia, particularly in the south-west and during the cool season months of May to October, with as much as 20% less by 2030 and up to 50% less rainfall by 2090 in the south-western parts of Australia by 2090, respectively (CSIRO, 2015).

At a regional scale, projected change in climate for the Central West and Orana region (Gulargambone represents a town in the centre of this study region) are summarised in Table 1. In addition to warmer temperatures, evaporation rates are likely to increase. By 2030 the median value of annual potential evaporation is projected to increase by 6 % under a high emissions scenario.

Table 1. Projected changes in temperature and rainfall for Central West and Orana region (Gulargambone represents a town in the centre of this study region). Present average temperatures and rainfall are calculated for the period 1986 to 2005. The data contained in this table represents information compiled from the NSW Department of Planning and Environment

Variable	Season	Historical mean (1986 to 2005)	2030	2070
Mean temperature change (°C change)	Annual	18.3°C	0.7 (0.4 to 0.8)	2.1 (1.8 to 2.6)
	Summer	25.6°C	1.0 (0.5 to 1.6)	2.4 (1.9 to 3.1)
	Autumn	18.7°C	0.7 (0.4 to 0.9)	2.0 (1.4 to 2.6)
	Winter	10.7°C	0.4 (0.3 to 0.7)	1.7 (1.1 to 2.0)
	Spring	18.2°C	0.8 (0.6 to 1.2)	2.3 (1.8 to 2.9)
Mean rainfall change (% change)	Annual	524mm	+0.2 (-11 to +8)	+7.6 (-10 to +22)
	Summer	148mm	-1.1 (-14 to +18)	+13.2 (-10 to +26)
	Autumn	131mm	+14.7 (-10 to +43)	+13.5 (-9 to +47)
	Winter	111mm	-4.2 (--11 to +3)	+5.4 (-25 to +35)
	Spring	134mm	-7.6 (-25 to +10)	-5.8 (-25 to +19)

Adapting to projected climate changes

Climate change is likely to pose a significant challenge for Australian agriculture. Of greatest concern are likely to be changes in water availability, and the change in frequency of climatic extremes (e.g. heatwaves, drought and floods).

Many of the actions required for adapting to climate change are extensions of those currently used for managing climate variability. For this reason, efforts to improve current levels of adaptation to climate variability will have positive benefits in addressing likely climate change impacts.

Examples of likely farm level adaptation options include:

- Enhancing the current implementation of zero tillage and other minimum disturbance techniques, retaining crop residues, extending fallows, changing row spacing, changing planting density, staggering planting times, traffic and erosion controls
- Alter planting decisions to be more opportunistic – more effectively taking into account environmental condition (e.g. soil moisture), climate (e.g. seasonal climate forecasting) and market conditions
- Expand routine record keeping of weather, production, degradation, pest and diseases, weed invasion
- Incorporating seasonal climate forecasts and climate change into farm enterprise plans
- Improve efficiency of water distribution systems (to reduce leakage and evaporation), irrigation practices and moisture monitoring

- Learning from farmers in currently more marginal areas
- Selection of varieties with appropriate thermal time and vernalisation requirements, heat shock resistance, drought tolerance, high protein levels, resistance to new pests and diseases and perhaps that set flowers in hot/windy conditions
- Enhance current consideration of decision support tools/training to access/interpret climate data and analyse alternative management options (e.g. APSIM, EverCrop).

There are also longer-term decisions at a family farm level - to sell up, to buy more land, where to invest. These are especially pertinent for farmers in low rainfall regions and it will increasingly be more difficult to find no-regret decisions if climate change progresses as anticipated (Hayman, 2005). These decisions, along with industry infrastructure (silos etc.) and industry support (drought policy) are hard decisions requiring full understanding of the likely future risks (Hayman, 2005).

The value of adaptation

In Australia a number of studies have examined the economic benefits of adaptation in the wheat industry at both national and regional scales under a range of likely future climate conditions. Hochman et al. (2017) highlighted that the adoption of new technology and management systems held actual yields fairly steady: without these advances, water-limited yield would have dropped by 27%. It was estimated that rainfall declines should have accounted for about three-quarters of the fall in simulated yield potential, whilst observed warming should have accounted for about a quarter of fall in yield potential.

Continued adaptation to climate change has been estimated to add an additional AU$500M per annum (Howden and Crimp, 2011) via the introduction of improved water-use efficiency options and may mitigate potential yield losses by up to 18% through broader scale adaptation (Ghahramani et al., 2015).

The results suggest a number of adaptation options exist to manage increased future downside risk however the effectiveness of adaptation is driven by the extent of future change. Under conditions of large climate change, tactical adaptation will only have limited effectiveness and more extensive adaptation options, often defined as transformation adaptation, may be required.

Advisers have a key role to play in changing the nature of the climate change dialogue. In the space of about five years many grain growers and their advisers have moved from asking "What is climate change?" or "Is it real?" to "How do we manage for climate change?" and "What will the impact be on the grains industry?"

Advisers have a vital role to play in this dialogue, not only in assisting grain growers in reducing greenhouse gas emissions from on-farm activities, but also in developing information systems that growers can tap into in order to build farming systems that can cope with current climate variability and can adjust to ongoing climate changes.

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Implications of continuing dry conditions on cereal disease management

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Keywords

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GRDC code

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

Take home messages

- Due to a combination of factors there is likely to be increased cereal plantings in 2020, once the opportunity arises
- Failed pastures with decent levels of grass development are potentially high risk scenarios for cereal diseases in 2020 as grasses host many of the causal pathogens
- Unfortunately, prolonged dry conditions increase the risk of cereal diseases including Fusarium crown rot and rhizoctonia root rot
- However, steps can be taken to minimise impacts which include:
  1. Know before you sow (e.g. PREDICTA®B)
  2. Implementing pre-sowing management options
  3. Sowing quality seed known to have both good germination and vigour
  4. Assessing root health and infection levels around heading – you need to 'dig deeper' than just leaf diseases!

Introduction

Unfortunately, much of central NSW experienced a relatively dry winter cropping season again in 2019. These conditions, especially with hotter and drier conditions during grain filling, are ideal for the expression of Fusarium crown rot as whiteheads and resulting yield loss. Fusarium crown rot, caused predominantly by the stubble-borne fungus *Fusarium pseudograminearum*, infects all winter cereal crops (wheat, barley, durum, triticale and oats) and numerous grass weed species also host this pathogen. However, a key point is that dry conditions do not just have implications for Fusarium crown rot management. There are other potential cereal disease implications that need to be considered by growers and management strategies implemented to maximise profitability when recovering from drought.

Extended dry conditions in 2018 and 2019, possibly longer in some areas, has a range of potential implications on farming systems which can include:

- Reduce stubble cover – increasing wind erosion, reducing fallow efficiency and limiting stored soil moisture levels
- Reduced decomposition of crop residues which can extend inoculum survival to 2 to 4+ years
- Reduced animal stock numbers – extended dry has seen sheep and cattle numbers decline which will take a number of seasons to recover
- Reduced survival of pastures in mixed cropping systems
- Later seasonal breaks reducing opportunities for canola establishment in some districts
- Widespread baling of cereal crops for hay in 2018 and 2019

- Increased pressure on available planting seed for establishing crops in 2020.

Although many of these issues are common across continuous and mixed cropping enterprising, as a general rule those operations that have opted for more intensive broadacre crop production are hopefully more aware of potential pitfalls around limiting cereal diseases and ensuring quality of planting seed. The lack of animal stock, failure of pastures and need for ground cover is likely to see a substantial increase in the area of cereals planted, especially in mixed farming systems once the drought breaks. Grass species and grass weeds tend to dominate as legume species decline in pasture mixes over time and with moisture stress. These are therefore potentially higher risk paddocks for cereal diseases as the grasses serve as alternate hosts for pathogens such as *Fusarium pseudograminearum* (Fusarium crown rot), *Bipolaris sorokiniana* (common root rot), *Rhizoctonia solani* (rhizoctonia root rot), *Gaeumannomyces graminis* var. *tritici* (take-all), root lesion nematodes and some leaf diseases (e.g. barley grass hosts net-blotch pathogen *Pyrenophora teres*).

When the drought does break in impacted regions, hopefully in 2020, growers will be driven by two key factors. The first will be to generate cash flow and the second will be to restore groundcover to bare paddocks through the planting of winter cereals. This will potentially occur with little regard to the risk posed by plant pathogens and the quality of available planting seed. Maximising the profitability of crop production is going to be critical to many farming operations once the drought breaks. The following paper highlights some of the potential issues for consideration by growers and agronomists from a cereal pathology view point. Some practical steps that can be taken to hopefully minimise losses are also outlined.

Step 1: Know before you sow

Although paddock history can be a good guide to potential disease issues, extended dry conditions can allow damaging inoculum levels to still persist from 2-4+ seasons ago. Hence, growers need to consider the longer-term sequences within paddocks. How cereal stubble was handled over prolonged dry conditions can also influence the survival and distribution of cereal pathogens. Paddock history is only a guide and provides no quantitative information on the actual level of risk posed by different cereal diseases.

Consider testing paddocks using PREDICTA®B. This would be especially useful for paddocks coming out of failed pastures which may have become dominated by grasses. PREDICTA®B is a quantitative DNA based soil test which provides relative risk or population levels for a wide range of pathogens that can be used to guide management decisions. However, ensure you are using the latest recommended PREDICTA®B sampling strategy which includes the addition of cereal stubble to soil samples (see useful resources). Addition of cereal stubble (or grass weed residues if present in pasture paddocks) improves detection of stubble-borne pathogens which cause diseases such as Fusarium crown rot, yellow spot in wheat and net-blotches in barley. Considerable GRDC co-funded research has been conducted nationally over the last 5 years to improve the recommended sampling strategy, refine risk categories and include additional pathogens or beneficial fungi (AMF) on testing panels. Recent paddock surveys have highlighted that a single pathogen rarely exists in isolation within individual paddocks but rather multiple pathogens occur in various combinations and at different levels. PREDICTA®B is world leading technology that can quantitatively measure these pathogen combinations within a single soil + stubble sample. Given extended dry conditions the two key cereal diseases of concern for 2020 in central NSW are likely to be Fusarium crown rot and rhizoctonia root rot. The risk of both of these diseases can be determined by PREDICTA®B.

Alternately, cereal stubble or grass weed residues can be collected from paddocks and submitted to NSW DPI laboratories in Tamworth as a 'no charge' diagnostic sample (see contact details). Samples are plated for recovery of only two pathogens which cause Fusarium crown rot or common root rot and provide no indication of other potential disease risks.

Step 2: Consider pre-sowing management options

Generic management options are provided with PREDICTA®B test results which are tailored to the actual levels of different key pathogens detected within a sample. Your PREDICTA®B accredited agronomist should also be able to assist with interpretation which can be daunting given the number of pathogens covered by the testing. NSWDPI are also happy to discuss results (PREDICTA®B or stubble testing) and work through potential management options (see contact details).

Assuming main concern is **Fusarium crown rot**. Based on the following PREDICTA®B or stubble test results pre-sowing management options include:

Below detection limit (BDL) or low:
No restrictions, ensure good crop agronomy

Medium:
Consider sowing a non-host pulse or oilseed crop with good grass weed control.

If sowing cereal then:

- Avoid susceptible wheat or barley varieties, durum is higher risk but oats are fine
- Sow at the start of a varieties recommended window for your region
- Consider inter-row sowing (if previous cereal rows are still intact) to limit contact with inoculum
- Do not cultivate - it will spread inoculum more evenly across paddock and into infection zones below ground
- Be conservative on nitrogen application at sowing (Figure 1) as this can exacerbate infection (e.g. consider split application) but ensure a maintenance level of zinc is applied
- Be aware that current seed treatments registered for Fusarium crown rot suppression provide limited control
- Determine infection levels around heading (see step 4).

High:
Consider sowing a non-host pulse or oilseed crop with good grass weed control.

If sowing cereal then:

- Choose a more tolerant wheat or barley variety for your region to maximise yield and profit (Table 1), durum is very high risk with yield loss >50% probable in a tough finish but oats are still a decent option
- Sow at the start of a varieties recommended window for your region as this can half the extent of yield loss
- If a late break occurs consider switching to a quicker maturing wheat variety or go with barley to limit exposure to heat stress during grain filling which exacerbates yield loss
- Consider inter-row sowing (if previous cereal rows are still intact) to limit contact with inoculum
- Do not cultivate - it will spread inoculum more evenly across paddock and into infection zones below ground
- Be conservative on nitrogen application at sowing (Figure 1) as this can exacerbate infection (e.g. consider split application) but ensure a maintenance level of zinc is applied
- Be aware that current seed treatments registered for Fusarium crown rot suppression provide limited control and get to a Syngenta learning centre in 2020

- Determine infection levels around heading (see step 4) and be prepared from sowing to cut for hay or silage if required.

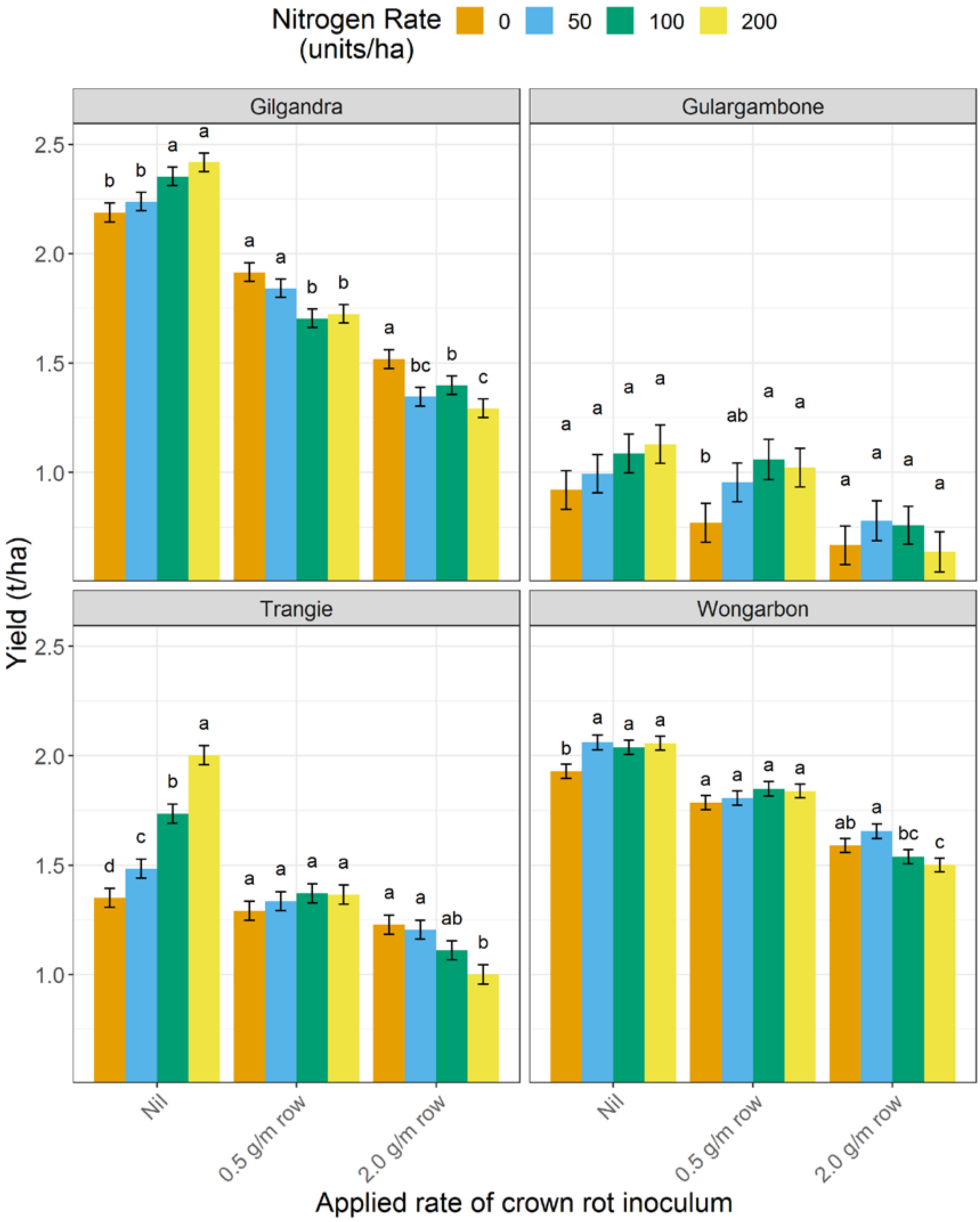

Figure 1. Interaction of nitrogen nutrition and crown rot infection on bread wheat (Suntop⚖ and EGA Gregory⚖) yield across four sites in central NSW in 2018.
Note: Nil applied inoculum represents a BDL/low risk, 0.5 g/m row a medium risk and 2.0 g/m row a high risk of crown rot infection.

Table 1. Average yield (t/ha), yield loss from crown rot (%), screenings (%) and lost income from crown rot ($/ha) of four barley, 5 durum and 20 bread wheat entries in the absence (no added CR) and presence (added CR) of crown rot inoculum averaged across 50 sites in central/northern NSW and southern Qld – 2013 to 2017.
Varieties within crop species ordered from highest to lowest yield in added CR treatment. Lost income and income in added CR treatment based solely on reduced yield (t/ha) in added CR treatment or absolute yield (t/ha) in this treatment multiplied by average grain price of $220/t for barley, $240 for AH and $300/t for APH bread wheat and $350/t for durum. Grain quality impacts and variable costs including PBR not considered.

Crop	Variety	Quality Class.	Yield (t/ha) No added CR	Yield (t/ha) Added CR	Yield loss (%)	Screenings (%) No added CR	Screenings (%) Added CR	Lost income from crown rot ($/ha)	Income added CR ($/ha)
Barley	**La Trobe**ⓟ		4.17	3.59	14.0	6.5	8.4	128	790
	Spartacusⓟ		4.18	3.58	14.3	2.9	4.6	131	788
	Commanderⓟ		4.09	3.40	16.8	6.1	8.2	151	748
	Compassⓟ		4.20	3.39	19.4	2.1	2.9	179	745
Durum	**Lillaroi**ⓟ		3.79	3.00	20.8	3.2	5.9	275	1050
	Bindaroiⓟ		3.88	2.92	24.7	2.7	5.8	336	1023
	Jandaroiⓟ		3.48	2.64	24.3	4.1	9.2	296	923
	Caparoiⓟ		3.34	2.20	34.1	9.0	16.5	399	770
	AGD043		2.72	1.65	39.1	3.8	13.8	372	579
Bread wheat	**Beckom**ⓟ	**AH**	4.57	3.94	13.9	8.8	12.7	153	944
	Mustangⓟ	**APH**	4.17	3.67	11.9	5.2	7.0	148	1102
	Mitchⓟ	**AH**	4.08	3.51	13.9	7.7	10.2	136	842
	Reliantⓟ	**APH**	4.18	3.50	16.3	5.3	8.1	204	1051
	Suntopⓟ	**APH**	3.99	3.46	13.3	7.3	9.6	160	1037
	Sunguardⓟ	**AH**	3.81	3.35	12.0	6.2	8.7	110	804
	Spitfireⓟ	**APH**	3.86	3.34	13.3	5.8	8.0	154	1003
	Gauntletⓟ	**APH**	3.92	3.29	16.1	4.4	7.0	189	987
	Lancerⓟ	**APH**	3.88	3.27	15.8	4.8	7.1	184	981
	Sunmateⓟ	**APH**	4.02	3.23	19.6	6.4	9.7	237	969
	Coolahⓟ	**APH**	4.03	3.21	20.4	5.8	9.4	247	962
	Flankerⓟ	**APH**	4.04	3.12	22.8	6.0	10.4	277	936
	Dartⓟ	**APH**	3.73	2.99	19.9	9.3	12.8	223	897
	EGA Gregoryⓟ	**APH**	3.90	2.89	25.9	6.7	11.4	303	868
	Vikingⓟ	**APH**	3.48	2.89	17.1	10.9	16.8	179	866
	Lincolnⓟ	**AH**	3.88	2.78	28.3	8.6	12.8	264	668
	Crusaderⓟ	**APH**	3.43	2.76	19.4	8.3	13.4	199	829
	QT15064R	**APH**	3.68	2.73	25.7	8.3	15.1	284	819
	Suntimeⓟ	**APH**	3.43	2.62	23.6	10.6	17.2	243	787
	Strzeleckiⓟ	**AH**	3.03	2.17	28.3	12.0	18.0	206	521
		Lsd (P=0.05)	***max. 0.137***			***max. 1.37***			

Note: The extent of yield loss associated with crown rot infection varied between seasons and sites being 21% in 2013 (range 13% to 55% across nine sites), 22% in 2014 (range 6% to 47% across 12 sites), 18% in 2015 (range 7% to 42% across 12 sites), 13% in 2016 (range 6% to 29% across 11 sites) and 29% in 2017 (range 20% to 45% across six sites) averaged across varieties.

Assuming the main concern is **rhizoctonia root rot (AG8)**, which is particularly favoured in lighter red soils**.** Based on the following PREDICTA®B test results pre-sowing management options include:

Below detection or low:
No restrictions, ensure good crop agronomy.

Medium or high:
Consider sowing a non-host pulse or oilseed crop with good grass weed control.

If sowing a cereal then:

- Avoid pre-sowing sulfonylurea herbicides which can restrict early root growth which exacerbates infection
- Consider slightly increasing sowing rate to compensate for potential tiller losses
- Plant at the start of a varieties recommended window for your region as more rapid root growth in warmer soil allows the primary root system to escape significant infection
- Sow wheat instead of barley as it is less susceptible to rhizoctonia, oats are also a good option
- Soil disturbance below the seed (ideally 5-10 cm) at sowing promotes rapid root growth away from rhizoctonia and disrupts the hyphal network, risk is greater with single disc seeders than knife points
- Ensure good nitrogen and phosphorus nutrition as deficient crops are more susceptible
- Current seed treatments registered for rhizoctonia suppression provide useful but limited control, fungicides applied through in-furrow liquid banding can provide improved levels of rhizoctonia suppression
- Assess root health coming into Spring (see step 4).

Step 3: Ensure quality of planting seed

Seed retained for sowing is a highly valuable asset and the way it was treated at harvest and in on-farm storage during summer, or between seasons, is critical to ensure optimum germination potential and crop establishment in 2020. Retained seed can be tested for vigour, germination, purity/weed seeds and disease pathogens. It is advisable to undertake testing at least two months before sowing so that an alternate seed source can be organised if required. Grading to remove smaller grains which inherently have reduced vigour can also improve the quality of planting seed.

Vigour and germination tests provide an indication of the proportion of seeds that will produce normal seedlings and this helps to determine seeding rates. Particular attention should be given to determining vigour of retained seed for sowing in 2020 due to seasonal conditions in 2018-19. Vigour will be even more important if growers plan to increase sowing depth to capture an earlier sowing opportunity through moisture seeking.

NSW DPI, Tamworth normally provides pathology testing of winter cereal seed for common seed-borne fungal pathogens which will continue in 2020. Germination is also noted but this only tells growers how much of their seed is alive with the main purpose of testing to determine levels of fungal infection present. Testing will be extended for the 2020 pre-season to also provide an indication of vigour and emergence which should be used as a guide only (see contact details).

A comprehensive GRDC fact sheet outlining issues with retaining seed after challenging seasons is available from the GRDC website (see useful resources). The fact sheet outlines how growers can test their own seed. Alternatively, a range of commercially accredited providers of both germination and vigour tests are available.

Seed treatments containing fluquinconazole, flutriafol or triadimenol, can reduce coleoptile length in cereals and cause emergence issues under certain conditions. These active ingredients should be avoided if sowing seed with potentially lower vigour, sowing deeper, sowing into cooler soils, in soils prone to surface crusting or where herbicides such as trifluralin have been applied.

Step 4: Assess infection levels and root health prior to head emergence

Improved agronomy has considerably reduced the impact of rhizoctonia root rot (e.g. early sowing, grass free canola, pulse and pastures, knife point seeding systems and fungicides). These changes in agronomy have resulted in a significant shift in the symptomology of rhizoctonia root rot from 'bare patches' due to seedling infection to development of uneven growth in mid-winter due to infection of crown roots when soil temperatures drop to <10°C. Infection can then continue to develop on the crown roots until the crop matures, and can spread to the seminal root system, limiting water uptake in periods of high evapotranspiration and nutrient limitation. Hence, there is the potential for crown root infection by rhizoctonia to go unnoticed in paddocks as wavy and uneven growth is often associated with a range of other factors. This situation can be easily identified with the help of a shovel or spade! Simply dig up some plants around heading, wash soil away from roots and inspect the general root health - paying particular attention to whether the crown roots are restricted with a 'spear tip' appearance. Alarmingly, if seasonal conditions have been good prior to heading, crops with significant rhizoctonia infection of crown roots can appear quite normal but have severely compromised root systems. If the season stays wet with milder temperatures, then infected crops can sneak through with minimal yield loss. However, these same crops are likely to suffer dramatically if drier and warmer conditions are predicted during heading and grain filling.

This is a very similar situation to Fusarium crown rot which can also go unnoticed in paddocks until dry and hot conditions during grain filling trigger the expression of conspicuous whiteheads. However, honey-brown discolouration at the base of infected tillers can be used to determine the extent of Fusarium crown rot infection prior to heading. Simply dig up plants (inspect root health at the same time as above), ensure leaf sheathes at the base of tillers are removed and visually inspect for brown discolouration.

Assessing root health and Fusarium crown rot infection levels around heading allows a grower to make an informed decision at this point in time given seasonal predictions (e.g. cutting for hay or silage, reduce further input costs) rather than simply letting the weather dictate the outcome. Although this would be a less than an ideal situation, such tough decisions can still maximise profitability or minimise losses under these scenarios.

Other potential implications of dry conditions – learnings from north NSW in 2019

Dry conditions can also impact on the lifecycle of necrotrophic fungi which cause yellow spot in wheat or net-blotches in barley. We observed this around Croppa Creek in northern NSW in 2019 with spot form of net-blotch (SFNB) in barley crops. Numerous barley crops in a restricted area had decent levels of SFNB lesions on leaves during tillering. This was surprising as the season was relatively dry up to this point with only low rainfall events (<5 mm) since sowing. Rainfall while limited, was accompanied by early morning fogs. These conditions, while not really contributing to yield potential, were enough to meet the 6 hours of high humidity (>80% RH) to initiate SFNB infections on leaves. Interestingly, due to dry conditions the primary infection propagules (pseudothecia) which have a moisture requirement had not matured on 2018 barley stubble. The primary source of infection was mature pseudothecia present on 2017 or even 2016 barley stubble.

SFNB was also present in two barley crops sown into wheat stubble which was surprising. However, conidia of the net-blotch fungus *Pyrenophora teres* formed on collected wheat stubble after 4 days in humid chambers. This supports 2018 disease survey findings where the SFNB fungus was found to be saprophytically infecting wheat crops due to late rainfall in October, coinciding with senescence of lower wheat leaves.

High levels of SFNB were also present in two barley crops in this same region in 2019 where seed was treated with the fungicide Systiva®. Reduced sensitivity to this SDHI active (fluxapyroxad) was confirmed by the Curtin University fungicide resistance group in net form of net-blotch (NFNB) populations on the Yorke Peninsula of SA in 2019. Pure SFNB isolates collected from these northern NSW barley crops were sent to Curtin University and were shown to have **no** reduced sensitivity to fluxapyroxad. In our situation we suspect that dry conditions around the seed prevented Systiva from dissolving into the surrounding soil, limiting uptake through the roots and movement through the plant into leaves. Seedlings had established well and their root systems had penetrated into deeper soil moisture which was allowing them to progress, but the top 10 cm of soil was very dry with little visual loss of red pigmentation from the seed treatment on seed coats at the time of inspection.

Conclusions

The perpetual risk as a plant pathologist is the perception that we are always the bearer of bad news or the 'grim reaper mentality'. Elevated risk of stubble- and soil-borne diseases in 2020 is inevitable given continuing dry conditions which have prolonged survival of pathogen inoculum. However, practical steps can be taken to identify the level of risk and strategies implemented to minimise but not necessarily fully eliminate disease impacts on wheat and barley crops in 2020. Hopefully wet conditions restrict impact of the two most likely cereal disease risks (Fusarium crown rot and rhizoctonia root rot). However, growers and their agronomists need to be prepared to inspect the root health and stem bases of cereal crops around heading to guide some potentially tough but informed decisions. NSW DPI plant pathologists are also available throughout the season to provide support.

Useful resources

https://grdc.com.au/resources-and-publications/groundcover/ground-cover-supplements/groundcover-issue-130-soil-borne-diseases/correct-sampling-a-must-to-accurately-expose-disease-risk

https://grdc.com.au/__data/assets/pdf_file/0028/186139/grdc-tips-and-tactics-rhizoctonia-southern-print-version.pdf.pdf

https://grdc.com.au/resources-and-publications/all-publications/factsheets/2011/01/grdc-fs-retainingseed

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Managing chickpea diseases after the drought

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Key words

chickpea, disease risk, Ascochyta, Phytophthora, Sclerotinia, root lesion nematode (RLN), management, fungicide rain fastness

GRDC code

Grains Agronomy & Pathology Partnership - A strategic agreement between GRDC and NSW DPI (DAN00213): BLG209 Pulse Integrated Disease Management – Northern NSW/QLD

Take home messages

- Do not underestimate disease risks after a drought – pathogens survive longer and can still threaten your 2020 chickpea crops
- Unless you are in a high risk Ascochyta situation, it is unlikely there will be a cost benefit applying a foliar fungicide to 2020 crops until after the disease is detected
- However, if you are at a high risk of Ascochyta, apply a foliar fungicide before the first post emergent rain event
- High risk situations include planting into paddocks with active Ascochyta inoculum and planting seed that has not been properly treated
- Recent research has shown the Ascochyta fungicides Aviator Xpro and Veritas are rain fast (up to 100 mm rain in 150 minutes)
- Phytophthora and Sclerotinia levels will not have declined much during the drought and pose a medium to high risk in 2020
- Root Lesion Nematodes may have declined during the drought but if numbers at the start of the drought exceeded 10/g soil, it may still be sufficient to cause damage in 2020 chickpea crops.

How drought affects plant diseases

- Drought reduces the breakdown of plant residues. This means that inoculum of some diseases does not decrease as some might expect and will carry over for more than one growing season. The expected benefits of crop rotation may not occur
- Bacterial numbers decline in dry soil. Some bacteria are antagonists of soil borne fungal diseases. These diseases can be more severe after drought
- Abandoned, or drought stressed crops still set seed. Summer/autumn rains can lead to large numbers of volunteers. Low stock numbers make it difficult to control these volunteers, which can host Ascochyta, viruses and virus vectors, and other pathogens
- Weeds that are stressed by drought may be harder to kill and can harbour pathogens
- Soil water and nitrogen may be unbalanced and these are likely to impact diseases in 2020 and beyond.

Chickpea disease risks after the drought and advice for 2020 chickpea farmers

- Ascochyta is unlikely to cause widespread problems in 2020 unless it is wetter than average as inoculum levels have not increased in past two seasons and even if infected with Ascochyta, all varieties recover well during dry conditions. For these reasons, unless you are in a high risk situation, there will be no cost benefit applying Ascochyta fungicides until the disease is detected. High risk situations include planting into paddocks where active inoculum is known to be present (see following examples at Tulloona and Moree) and planting seed of unknown pathogen status that has not been properly treated. In these situations, apply an Ascochyta fungicide before the first post-emergent rain event, then monitor the crop 10-14 days after rain.

- If Ascochyta is detected, apply a registered fungicide before the next rain event. This is especially important during the reproductive stage as Ascochyta on pods causes abortion, seed infection and seed defects. If you miss a spray; fungicides with limited curative activity are now available however they have a limited time of use and tight intervals for application after an infection event occurs. (https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/02/chickpea-ascochyta-research-what-if-i-miss-a-spray-are-there-salvage-options-with-new-chemistry-how-long-do-fungicides-persist)
- Under drought conditions, some plant pathogens survive longer than normal; Ascochyta inoculum for 2020 chickpea crops may have originated in 2017 or even 2016. In August 2019, volunteer chickpeas in a crop of wheat at Tulloona had Ascochyta lesions. That paddock had grown chickpeas in 2016 (under high Ascochyta pressure); wheat in 2017 and chickpeas in 2018 (crop abandoned due to drought). Rain in Oct/Nov 2018 allowed Ascochyta to develop on abandoned plants, and seed left in the paddock germinated on rain in March 2019 to produce the volunteers that got infected during rain events in May, June and July 2019. Another example of how drought can prolong survival of inoculum was provided in August 2019, when we received chickpea stubble from a paddock at Moree that had grown chickpeas in 2017. The stubble contained fungal fruiting bodies. We soaked the stubble in water for several hours then applied the water suspension to chickpea seedlings; 7 days later symptoms and pycnidia of Ascochyta developed on the seedlings, proving that the inoculum had persisted on the nearly two-year old chickpea residue. Both the Tulloona and Moree paddocks are considered high risk if planted to chickpeas in 2020.
- Remember, the Ascochyta fungus is evolving: In our 2010 Tamworth disease management trial, unprotected PBA HatTrick⦶ (then rated moderately resistant (MR)), lost 37% yield to Ascochyta; while in the 2016 trial, unprotected PBA HatTrick⦶ lost 97% yield to Ascochyta. PBA HatTrick⦶ is now rated moderately susceptible (MS) and will require fungicide under conditions that favour Ascochyta. The good news is that whilst Ascochyta can now cause more damage on unprotected PBA HatTrick⦶, it is just as easy to manage as when PBA HatTrick⦶ was rated MR.
- Phytophthora root rot (soil borne) and Sclerotinia diseases (soil borne and air borne) are considered moderate to high risk in 2020 because although inoculum loads are unlikely to have increased, their survival will have been prolonged by the drought.
- Botrytis seedling disease (BSD, seed borne) is only likely in crops planted with seed produced in the 2016 (and possibly 2017) crop year. In any case proper seed treatment provides 100% control of BSD.
- Botrytis grey mould (BGM, air borne); the BGM fungus is ubiquitous, has a very wide host range and is a good saprophyte - if conditions favour BGM i.e. dense canopies, warm humid weather, it will occur.
- Root lesion nematodes (RLN, *P. thornei* soil borne) can survive dry periods. Recent research has shown it takes a double break of 40 months free of host plants to reduce numbers to a minimum threshold (2/g soil) so it is unlikely the current drought will have reduced RLN numbers if they started high (40/g) which was likely in the 2016 season. Even starting numbers of 10/g still need a break of 30 months https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/how-long-does-it-take-to-reduce-pratylenchus-thornei-populations-in-the-soil.

- Viruses are an unknown threat after a drought. Most need green plants as reservoirs (some are seed borne) and hosts for their vectors. However, as vectors can fly or be blown in from regions that have not experienced drought, viruses are still a risk to 2020 chickpea crops.

Seed quality

Obtaining good quality seed after a drought may be an issue in 2020. In Nov/Dec 2019, we tested seed from as far back as 2016 and whilst germination of all lots exceeded the Pulse Australia (PA) minimum standard of 70%, some lots were slow getting there, indicating possible loss of vigour. All planting seed should be germination tested and if it meets the PA standard, we recommend it be treated and 'test planted' into paddocks intended for chickpeas in 2020, and the number that emerge counted – this is your best indicator of seed and seedling vigour and may assist identify herbicide residues, but should not be relied on as the sole indicator for this, as symptoms of residual herbicides can in some situations be slow to develop. Paddock emergence tests are best done in March/April.

If you are sourcing seed from outside your region e.g. interstate, be sure the variety is suitable for your farming system and have the seed germination and pathogen tested.

Irrespective of age and origin, all planting seed should be treated with a registered seed dressing – these control seed borne Ascochyta (internal and external), seed borne Botrytis (BSD) and protect seedlings from a range of opportunistic soil organisms that can reduce seedling vigour and establishment under less than favourable conditions e.g. cold or wet soils, deep planting. Planting quality, treated seed is your best bet of healthy seedlings – these will have a rapidly growing root system to obtain nutrient and moisture, be more competitive with weeds and less susceptible to disease.

Predicta®B for assessing Ascochyta risk

The value of Predicta®B as an Ascochyta management tool has not been determined because we do not know what the numbers mean in terms of risk or management. Predicta®B results that are positive for Ascochyta on samples collected after the drought should not be surprising give the persistence of inoculum under drought conditions. On the other hand, a negative result does not mean your Ascochyta risk is nil or low as the test is only as good as the sampling method and inoculum can arrive in your paddock after sampling via wind, machinery, vehicle, animals, surface water flows or untreated seed.

Chickpea Ascochyta Research Update: Is efficacy of Aviator Xpro and Veritas reduced by rain after application?

Previous research (2007) at Tamworth using a rainfall simulator showed that efficacy of the fungicides Barrack720® (720g/L chlorothalonil) and Dithane® Rainshield® (750g/kg mancozeb) on chickpea Ascochyta on cultivar Jimbour was not significantly reduced by 50mm rain in 10 minutes. 150mm in 30 minutes also did not reduce efficacy of Barrack720 but did reduce slightly the efficacy of Dithane. Such rainfall intensities are not common in chickpea crops grown in eastern Australia. From these experiments we concluded that plant tissue sprayed with these fungicides would still be largely protected if rain fell after application (new growth after application would not be protected as both products are protectants only). The 2010 chickpea season (that had frequent rain events) supported this conclusion.

The recent registrations of Aviator Xpro® and Veritas® (both in 2018) for chickpea Ascochyta (with restrictions on number of applications and timing – see labels for details) raised the question of how rain fast are these products.

Two experiments were conducted at Tamworth Ag Institute in December 2019 - January 2020 to determine the effect of simulated rain on the efficacy of Aviator Xpro and Veritas on Ascochyta; Unite®720 (720g/L chlorothalonil) and water were the control treatments. The first experiment (4 reps) was with cv Kyabra⦶ and the second (4 reps) with cvs Kyabra⦶ and PBA Seamer⦶.

As the results were the same, we report here the second experiment. Plants were sprayed with water, Unite, Aviator Xpro or Veritas using a backpack sprayer with a 1m boom fitted with 110/015 flat fan nozzles at 50cm spacing and a walking pace of approximately 6kph. The fungicide treatments were allowed to air dry for 2hr when the 'rain' plants were placed in the rainfall simulator and exposed to 50mm over 75 minutes or 100mm over 150min (recorded by two rain gauges at each side of the simulator pad). After removal from the simulator, plants were allowed to air dry for 2h, arranged on racks in replicate boxes (55L plastic with clear lids), inoculated to run off with a cocktail (2,000,000 conidia/mL) of 20 Ascochyta isolates obtained from commercial chickpea crops and the boxes placed in a controlled environment facility operating at 12h/12h day/night 15C/20C. Leaf wetness was maintained with ca 50mm depth water in the base of the boxes and firm fitting lids. After 48h the lids were removed and plants were examined for Ascochyta. Five days after inoculation (DAI) first symptoms (petiole wilting) were evident and at 9 DAI, Ascochyta was assessed by counting the numbers of petioles, leaves and stems with symptoms.

The only plants that developed Ascochyta were those sprayed with water; PBA Seamer⦶ had less disease than Kyabra⦶.

We conclude from this experiment that efficacies of chickpea Ascochyta fungicides Veritas and Aviator Xpro with a 2 hour dry period after spraying and prior to rain occurring, are not affected by simulated rainfall of 50mm in approximately 75min or 100mm in approximately 150min. As such intensities are uncommon during chickpea seasons in areas of Australia where Ascochyta occurs, it is reasonable for growers to be confident that once these fungicides have dried on plant tissues, those tissues will remain protected.

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Dealing with the drought and planning for recovery

Discussion session

Notes

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