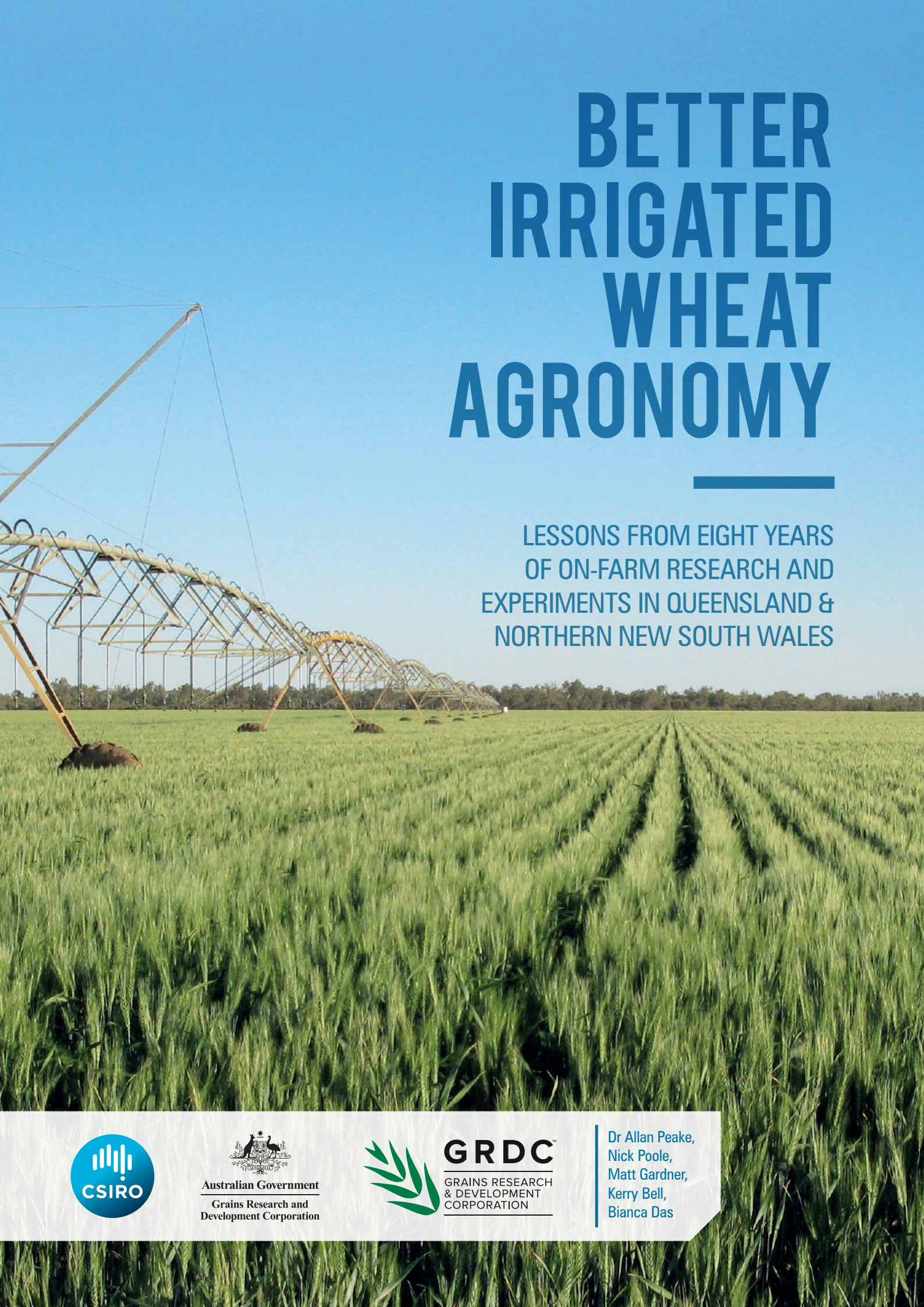
BETTER IRRIGATED WHEAT AGRONOMY

LESSONS FROM EIGHT YEARS OF ON-FARM RESEARCH AND EXPERIMENTS IN QUEENSLAND & NORTHERN NEW SOUTH WALES



CSIRO

Australian Government
Grains Research and Development Corporation

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Dr Allan Peake,
Nick Poole,
Matt Gardner,
Kerry Bell,
Bianca Das

PRODUCED BY

IN PARTNERSHIP WITH

COPYRIGHT NOTICE

IMPORTANT DISCLAIMER

CSIRO and GRDC advise that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, CSIRO, GRDC and the partner organisations listed above (including their employees and consultants) exclude all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

SYMBOLS

Ⓟ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights act, 1994.

® Cycocel® is a registered trademark of BASF, Moddus® and Errex® are registered trademarks of a Syngenta Group Company, Stabilan® is a registered trademark of Nufarm.

ISBN 978-1-921779-49-7 (PRINT)
ISBN 978-1-921779-50-3 (ON-LINE)

TABLE OF CONTENTS

1. INTRODUCTION

In 2008, many growers from irrigated farms in the northern region decided to take advantage of high wheat prices of over $400 per tonne, sowing large areas of irrigated wheat with the aim of fully irrigating the crop and producing yields of 7 or 8 t/ha. Unfortunately, widespread lodging at the end of that season caused large yield losses, which were conservatively estimated to have cost the industry more than $20 million in lost production.

At that time, little was known about growing irrigated wheat in the northern region. The GRDC (Grains Research and Development Corporation) subsequently invested in research with the CSIRO and several other collaborators, most recently through the 'Better Irrigated Wheat Agronomy' project led by CSIRO.

This booklet summarises the key findings from the Better Irrigated Wheat Agronomy project conducted from July 2012 to June 2017, in order to update best practice guidelines for growers wanting to grow irrigated wheat in the northern region. Recommendations are provided for whole-farm irrigation scheduling, agronomy to avoid lodging, the best varieties for irrigation, effective nitrogen application strategies and general agronomic techniques. The guide is intended to be read as a companion to a pre-existing publication 'Irrigated Wheat – Best Practice Guidelines In Cotton Farming Systems' (see reference #6 under 'Further Reading' on page 48). That publication covered topics such as disease management, irrigation scheduling for individual paddocks and establishing crops in cotton rotations. Readers may also benefit from consulting the 'Waterpak' manual for a broader understanding of irrigation practices (see reference #7 under 'Further Reading' on page 48).

When reading this guide, it is important to understand that growers wanting to try new techniques or varieties should do so on a small scale first, to ensure new techniques work for their specific situation. The results from our trials may not apply to all individual farms due to seasonal and locational variation (i.e. farm management requirements, available moisture, crop rotational history etc.). Additionally, readers should be aware that these recommendations have been developed specifically for vertosol soil types and farms within the 'old' GRDC northern region (Queensland and northern NSW), and may not be applicable to other soil types or regions.

Readers who would like clarification on the information in this booklet are welcome to contact the project leader, Dr Allan Peake (CSIRO) whose contact details are listed at the back of the booklet. We hope that this guide is helpful to you, and we wish you good luck with your next irrigated wheat crop.

2. WATER BUDGETING: FULL IRRIGATION OR DEFICIT IRRIGATION?

KEY POINTS

1. When irrigation water (not land area) is the limiting factor to production, growers can choose to fully irrigate a smaller area or deficit irrigate a larger area for the same amount of stored irrigation water.
2. Deficit irrigation is associated with greater production risk, but can be the most profitable option in high rainfall environments and seasons when there are significant amounts of stored water in the soil profile.
3. Applying more irrigation water to a smaller area has lower production risk, but also has lower potential profits in many cases. This strategy is more likely to be the most profitable option when rainfall and stored soil water is limited, and the cost of water is high.

Once the decision has been taken to grow an irrigated wheat crop, the next question that irrigated wheat growers need to consider is, will fully irrigating a wheat crop be the most profitable option? The alternative is known as deficit irrigation – the practice of irrigating with less than the crops maximum water requirement. This strategy can be used to grow a larger area of wheat with the same amount of irrigation water in storage.

The strategy that is more profitable depends on whether water or land area is the limiting factor to production, and how much rainfall and stored soil moisture are available to the crop. Some growers may have small areas of overhead irrigation and sufficient water to fully irrigate that area. However furrow irrigated farms often have more land available than they can fully irrigate, which means water is the limiting factor to production. When water is limiting, it can be more profitable to spread the water over a wider area and combine it with in-crop rainfall and any stored soil water that is available at sowing.

Furrow irrigated wheat near Rolleston, Central Queensland.

2.1

Using irrigation water to maximise profit and minimise risk

A study published by CSIRO in 2016 investigated whether full irrigation or deficit irrigation was more profitable for growers in Queensland and northern NSW (see reference #9 on page 48 for more information). The study was conducted for three locations: Emerald, Goondiwindi and Gunnedah, using the APSIM simulation model (which is widely used to investigate complex whole-farm questions such as this one). A long-term climate data set was used to see if a particular strategy worked for different seasons (i.e. wet, dry or average). The study assumed a wheat price of $250 per tonne at the farm gate and was carried out with two different water cost scenarios, where low cost water was $40 /ML and expensive water was $120 /ML.

The study used the concept of 'risk efficiency' to determine the best strategy, rather than using a long-term average gross margin. Risk efficiency is the balance between risk and potential profit. For example, if you irrigate a large area with just a single furrow irrigation during the season, your risk is high because if in-crop rainfall is low, a high proportion of the water will be lost to evaporation and low yields will be the result. But if rainfall is high and the single furrow irrigation results in a yield of 5 t/ha, then it can be a very profitable decision. **Risk efficiency balances risk and profit by assuming that growers require a 50% increase in profit (on average over many seasons) in exchange for twice as much production risk** – i.e. it assumes growers will accept twice as many unprofitable seasons in exchange for achieving 50% more profit in the long term due to outstanding profits in the good seasons.

Harvesting furrow irrigated wheat, St George, QLD

2.2

How much irrigation water maximises risk-efficiency?

The results of the study are summarised in Table 1 and Table 2. The average growing season rainfall was 212 mm at Gunnedah, 174 mm at Goondiwindi and 100 mm at Emerald. Generally, they showed that in a dry, warm environment (Emerald), the most risk efficient strategy is one which applies more irrigation water to a smaller area of land. At Gunnedah, a cooler environment with higher and more reliable winter rainfall, the more profitable long-term strategy was to deficit irrigate, spreading water over a wider area.

TABLE 1. Number of furrow irrigations*# to achieve maximum risk-efficiency when stored soil water at sowing is 0 mm.

WATER COST	GUNNEDAH	GOONDIWINDI	EMERALD
($40/ML)	Sowing* + 1-2 in-crop#	Sowing* + 1-2 in-crop#	Sowing* + 2-3 in-crop#
($120/ML)	Sowing* + 1-2 in-crop#	Sowing* + 2-3 in-crop#	Sowing* + 2-3 in-crop#

**Sowing irrigation assumed to be 1.7 ML/ha. #In-crop irrigations are assumed to be 1 ML/ha. Irrigation amounts are assumed added to root zone not including distribution and application losses, which vary between soil types and paddocks. Note: applying the greater number of irrigations to a smaller area reduces risk of crop failure in a dry season, but reduces potential profit in a high rainfall season.*

TABLE 2. Number of furrow irrigations# to achieve maximum risk-efficiency when stored soil water is 100 mm and no irrigation is required at sowing.

WATER COST	GUNNEDAH	GOONDIWINDI	EMERALD
($40/ML)	1 in-crop#	1-2 in-crop#	3-4 in-crop#
($120/ML)	1-2 in-crop#	1-2 in-crop#	3-4 in-crop#

#Irrigation applications assumed to be 1 ML/ha. This irrigation amount is assumed added to the crop root zone and does not include distribution and application losses, which vary between soil types and paddocks. Note: applying the greater number of irrigations to a smaller area reduces risk of crop failure in a dry season, but reduces potential profit in a high rainfall season.

3. IRRIGATION STRATEGIES FOR MAXIMUM YIELD

KEY POINTS

1. Stored soil water is critical to achieving high yields in irrigated wheat production, so growers need to understand their soil PAWC and how this impacts on their irrigation strategy, and monitor soil water during the season.
2. Irrigating early in the season can 'bank' stored water, which helps avoid stress late in the season when crop water use can be as high as 7 mm per day.
3. Season water budget should allow for 50-100 mm of water to remain in the soil profile at the end of the season in order to minimise late season water stress.
4. Sow different varieties in a way that allows them to be irrigated separately if necessary.
5. Avoid irrigating when storms or strong winds are forecast.
6. Remember that maximising yield may not maximise profit (see chapter 2)

The main reason some growers struggle to achieve high irrigated wheat yields is that they do not give the crop enough water and nitrogen. This section shares the experience of irrigated wheat growers, consultants, and the project team, on how to irrigate to achieve high yields. This section also assumes that growers have read the previous chapter and have decided that fully irrigating a crop is the best strategy for their situation, or perhaps because they enjoy the challenge of trying to break yield records!

Budget to maintain a soil water buffer: An 8 t/ha crop will use between 4.5 and 5.5 ML (450-550 mm) of water per hectare, but will become stressed if it has to extract every last drop of water in the profile. So when you are preparing your water budget, it is important to allow for an additional 50 - 100 mm of 'buffer' water remaining in the soil at the end of the season, to ensure that the crop does not get moisture stressed.

Understand your soil PAWC: Plant available water capacity (PAWC) is the maximum amount of water the soil can store up for the crop to use. *Different soil types have different storage capacity, and this influences irrigation strategies.* For example, sandier soils require more frequent and smaller irrigations because they do not hold as much water close to the root system as a clay soil.

Monitor soil water: The same principles that apply when irrigating cotton and other crops also apply to wheat. Monitoring of soil water deficits and the optimum 'refill point' to avoid stress is necessary to maximise yield, and will combine knowledge of soil PAWC with monitoring devices to maintain the soil water buffer.

Be careful when planting different varieties in the same irrigated field: Different varieties may require different irrigation strategies at the end of the season if they have different maturity. If one variety is lodging you may want to reduce the irrigations to prevent it from becoming worse, without reducing irrigation on the other variety. If sowing under a lateral move or centre pivot irrigator, consider sowing varieties in a way that means they can be irrigated separately if necessary.

Crop water use increases rapidly in spring: As the crop grows taller and the weather warms up, water use of 5 - 7 mm per day is common in hot weather between flowering and grain-filling (Figure 1). This means that the irrigation requirement of a high yielding crop can be as high as 35 - 45 mm per week in hot weather, so growers need to monitor the weather and be prepared to increase irrigation at short notice.

Put water 'in the bank' early in the season: If using overhead irrigation systems, it can be difficult to supply enough water to match crop requirements during hot weather in spring. So growers are *recommended to maintain a full soil water profile early in the season,* which maintains the soil water 'buffer' for the end of the season.

Avoid irrigating when storms and strong winds are forecast: Wet soil (particularly in vertosol soils) weakens anchorage for plant roots and increases the risk of lodging. Maintaining the subsurface soil water 'buffer' as discussed above will also allow some flexibility to delay irrigation if storms are forecast.

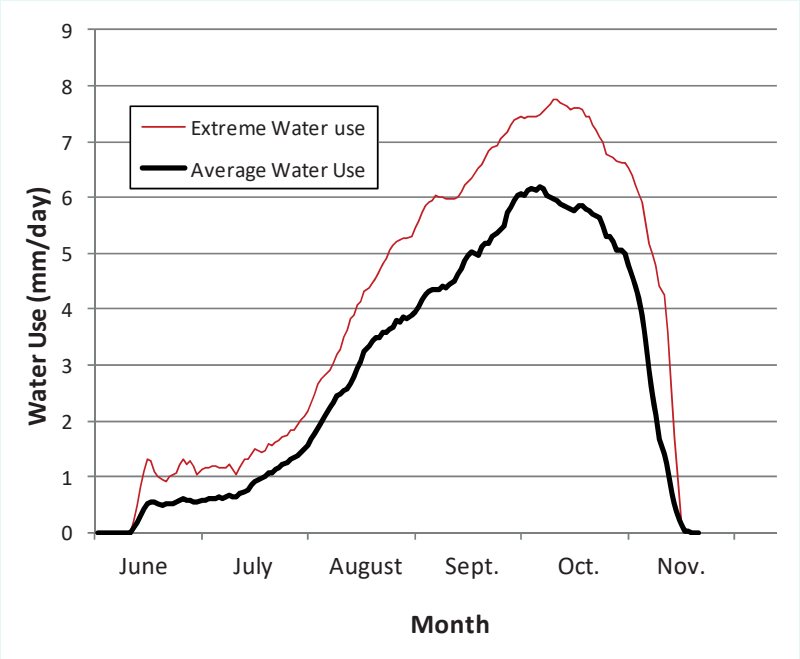
A dry finish improves harvester access: While the crop needs to avoid water stress in order to achieve maximum yields, it is important from a practical perspective to shut off irrigation approximately 4 - 5 weeks after flowering. This allows the soil surface to dry out as the crop finishes grain filling. The decision of exactly when to stop irrigating will depend on individual soil type, whether there is any moisture remaining at depth and the crop stage. In order to achieve maximum yield, irrigation should be kept up for longer on soils with a low PAWC, or when deep subsoil moisture reserves are depleted.

FIGURE 1. Simulated water use of a fully irrigated wheat crop at Wee Waa based on 20 years of climate data.

CROP WATER USE INCREASES RAPIDLY IN SPRING

The APSIM model was used to simulate water use of a hypothetical 8 t/ha wheat crop grown at Wee Waa based on 20 years of climate data. Average use of water peaked at 6 mm/day in October equating to roughly 40 mm/week (Figure 2). For the first two months a total of 80 mm was required for plant growth, but from August an additional 420 mm was required.

Therefore, it is critical to maintain sufficient irrigation for this growth period in order to achieve maximum yields (7-9 t/ha depending on location and season).



4. UNDERSTANDING AND AVOIDING LODGING

KEY POINTS

1. Lodging occurs when wheat crops 'fall over', and is caused by many factors including tall varieties, high yield potential, a thick canopy, wind, rain and wet soil.
2. Lodging risk varies between seasons due to variations in yield potential and the intensity and frequency of storms, wind and rain.
3. Lodging can affect yield and gross margins in many ways, including; physiological disruptions of crops close to flowering, increased risk of canopy diseases, increased risk of grain sprouting and shattering, decreased grain recovery and slower harvesting.
4. Average yield loss caused by lodging in 2008 was 1.7 t/ha, with the worst lodged paddock losing over 4 t/ha.
5. Reducing lodging risk should involve a range of measures used together such as; lodging resistant varieties, low plant populations, in-crop N application, plant growth regulators, irrigation strategies.

4.1

What is lodging and why does it happen?

Lodging is a disorder that occurs when the crop literally falls over because the top of the plant is too heavy for the stem or roots to support. Lodging can cause reduced yield and poor grain quality. There are two types of lodging: stem lodging (when the stem kinks, usually near the base) or root lodging: when the roots dislodge in wet soil (see photo). They are both caused by the same factors:

Tall varieties (extra height which creates a longer 'lever' out of the stem).

High yields and a dense canopy biomass (which put more weight at end of the lever).

Wind, rain (put more force on the end of the lever).

Wet soil – destabilises the root system.

Photo of root lodging showing roots that have been pulled from the soil.

4.2

How does lodging reduce grain yield and gross margins?

1. **Lodging of the green crop is the main cause of grain yield reduction.** Physiological restrictions in the plant prevent nutrient and water movement within the plant e.g. reduced light interception and nutrient uptake during grain filling. The biggest yield losses have been measured when lodging has occurred close to flowering. Lodging that occurs when the crop is drying down before harvest will not cause 'physiological' yield losses, although it can worsen some of the other lodging related issues discussed below.

2. **There is an increased disease risk in lodged crops,** as fungicides are less likely to effectively penetrate into the crop canopy, and the conditions within the lodged canopy (less airflow, higher humidity) are also more favourable for disease development.

3. **Increased sprouting in wet weather and increased grain shattering** (particularly in high yielding crops).

4. **Logistics - decreased harvester recovery and slower harvesting.** Delayed harvest also increases the likelihood of shattering and sprouting, and obviously has a financial cost due to increased machinery operation.

4.3

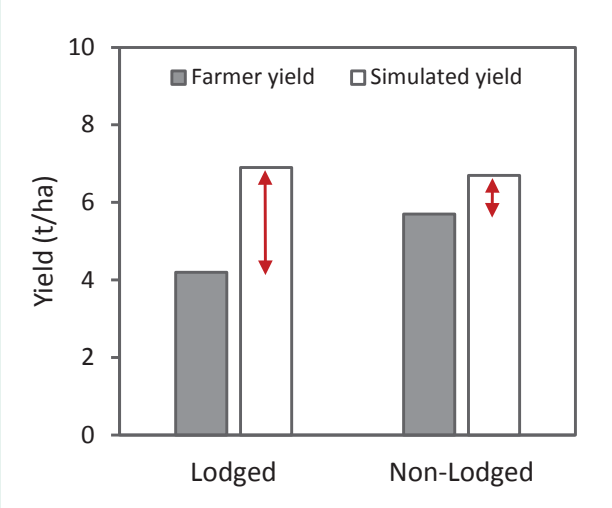
The cost of lodging.

A 'yield gap' is the difference between actual crop yield and computer simulated yield (also known as 'potential yield') under the same climatic conditions, and assuming the same water and nitrogen inputs.

Simulated yields will generally be higher than farm-achieved yields because there is no interference from pests, diseases, storms and other factors. We used yield gap analysis to show the cost of lodging in 2008 by comparing the yield gap of the crops that lodged with the yield gap of crops that did not lodge, for 17 commercial fields across northern NSW and southeast Queensland (Figure 2). Yield gap due to lodging was 1.7 t/ha on average and increased to 4.6 t/ha in the worst lodged field.

A more direct method of lodging assessment is the comparison of yield between lodged and non-lodged crops that have been grown the same way. An experiment was set up at Gatton in 2013 where lodging was prevented using anti-lodging nets (concrete reinforcing mesh, suspended from star pickets). Their yields were compared to the yield of identically managed areas where lodging was allowed to occur naturally. *Lodging losses of 0.8 t/ha were observed in the variety Hartog and 1.4 t/ha in the variety Kennedy in this experiment, in which the lodging began 4 weeks after flowering and was rated 'severe' once it occurred (Figure 3).*

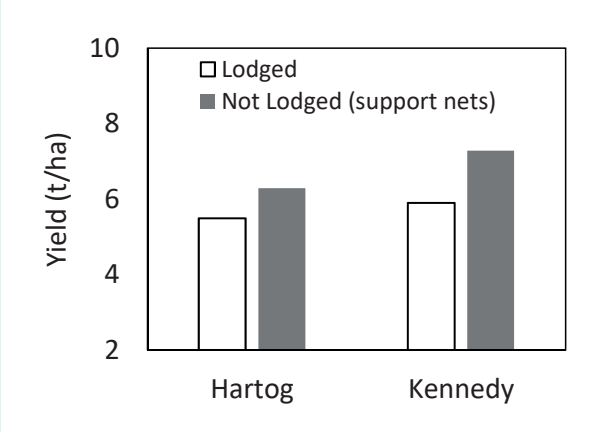
FIGURE 2. Farmer (observed) yield and simulated yield (APSIM) for 17 commercial wheat fields grown in Queensland and Northern NSW in 2008. Yield gaps for lodged and non-lodged crops are the difference between simulated and farmer yields (red arrows).



YIELD GAPS

Were larger in lodged crops compared to non-lodged crops by an average of 1.7 t/ha

FIGURE 3. Results from the lodging-net experiment in 2013 and a photo of lodging nets in use at Gatton.



A heavily lodged plot in an experiment at Gatton. Lodging risk can be minimised but never completely eliminated.

4.4

Agronomy to reduce lodging risk.

When aiming to achieve high wheat yields it is important to understand that lodging risk can never be completely eliminated. Extreme storms can occur that can cause lodging even in the most lodging resistant crops. On the other hand, it is possible for high lodging risk strategies to 'get lucky' and avoid lodging in years when favourable weather is experienced during grain filling.

There are several management strategies that can be used to reduce lodging risk, primarily by controlling how the plant grows and acts as a lever. Dense early-season biomass (i.e. thick, lush, large leaves at the end of tillering) increases lodging risk by increasing shading of the stem base and soil surface. This increased shading has been shown to reduce both the strength of the stem and the spread of surface roots. Therefore, reducing biomass during tillering reduces lodging risk.

Techniques include:

Choose varieties carefully. Some varieties are less prone to lodging, with varying mechanisms such as stronger or shorter stems, and stronger surface root systems. Varieties recommended for irrigated wheat production are discussed in Chapter 8.

Do not increase plant populations for irrigated wheat production. Plant populations similar to those used in rain-fed wheat production (i.e. 100 plants/m^2) are adequate to produce maximum wheat yield in most irrigated situations. Higher populations are more at risk of lodging but could sometimes be appropriate if the sowing date has been substantially delayed, or when sowing N is low enough to use in-crop N application to reduce lodging risk (see Chapter 5 for more detail).

Apply less nitrogen at sowing and more during the growing season according to plant demand (see Chapter 5 for more detail).

If you can't avoid sowing irrigated wheat on a high-nitrogen soil, consider reducing irrigation during tillering to prevent overly-dense canopy growth. Increased water availability will increase nitrogen availability to the crop, so the desire to maintain a full profile of moisture early in the season may need to be compromised in high nitrogen fields.

Apply plant growth regulators (PGRs) at the correct growth stage. Results from the project show that PGR's can reduce lodging risk and often have a positive impact on yield in irrigated fields even when no lodging occurs. See Chapter 6 for a detailed summary on the use of PGRs.

Late sowing can reduce lodging by reducing yield potential but is not foolproof, because late sown crops face greater exposure to spring storms than an early sown crop.

Partial irrigation is less susceptible to lodging than full irrigation, because crops with yield potential of less than 6 t/ha are unlikely to lodge. However, partially irrigated crops are still at risk of lodging if season rainfall is greater than average and yield potential increases above what was originally expected, especially if the crop is planted on very high soil N reserves at sowing. Therefore lodging reduction measures should still be considered for partially irrigated crops.

There is no 'silver bullet' to prevent lodging. Lodging risk varies between seasons because yield potential varies between seasons, and also due to variation in the occurrence, intensity and frequency of storms, wind and rain. A range of measures will work together to build a lodging resistant crop.

5. IN-CROP NITROGEN APPLICATION

KEY POINTS

1. In-crop N application is one of several canopy management techniques that minimises excess canopy growth and can reduce lodging risk.
2. Soil + fertiliser N at sowing should total approximately 30-70 kg/ha N in order to induce N stress and reduce canopy growth during tillering, although different soil types and locations may need slightly different targets in order to account for high soil fertility or cold temperatures.
3. In our experiments, crops needed approximately 200 kg/ha of soil + fertiliser N supplied at (or before) GS31 in order to reliably achieve high yields in different locations and seasons.
4. Varieties responded differently to in-crop N application. Suntop$^{\Phi}$, Wallup$^{\Phi}$, Kennedy$^{\Phi}$ and LRPB Cobra$^{\Phi}$ often had higher yields when N was applied in-crop, but Mitch$^{\Phi}$ and LRPB Lancer$^{\Phi}$ did not.
5. In-crop N application increased grain protein by 0.4% for most varieties and locations.
6. In-crop N application tended to reduce screenings and increase hectolitre weight, but this was not consistent for all varieties.
7. Lodging was not always reduced by in-crop N application, possibly because in-crop N application often increases yield potential which in turn increases lodging risk.

The term canopy management refers to agronomic techniques that change the way the crop canopy develops. Developed in the UK, canopy management aims to ensure that under high yielding conditions the crop canopy does not grow any thicker than necessary, which improves light penetration, water use efficiency and nitrogen use efficiency, and reduces lodging risk without reducing yield.

Variety choice, sowing date and plant population are canopy management techniques that can be implemented before sowing. After these decisions have been made, one of the remaining canopy management techniques is 'in-crop' nitrogen application. Rather than supplying the crop with its entire nitrogen requirement at sowing, this technique delays a large proportion of nitrogen input until the crop needs it during stem elongation. This prevents the production of excess leaves and stems during tillering, which is one of the causes of increased lodging risk.

Wheat crops do not need much nitrogen to produce an acceptable number of tillers. In order to reduce lodging risk, ***soil + fertiliser nitrogen should total approximately 30 - 70 kg N/ha at sowing,*** measured to a depth of 90 cm. Note however that during our study we were unable to test such low N levels at Spring Ridge because sowing N at the trial site was always more than 100 kg/ha. It is possible that slightly higher levels of sowing N may be necessary at cooler environments

(such as the Liverpool Plains) where recovery from N stress may take longer.

If soil tests are taken well before sowing, potential mineralisation of additional N should also be accounted for in this calculation. Once soil mineral nitrogen plus fertiliser nitrogen is above 100 kg N/ha at sowing, the lodging reduction benefits of in-crop N application are less likely to be observed. In this situation growers should consider using Plant Growth Regulators (PGRs) and lower plant populations to achieve an additional lodging risk reduction.

Starting the crop with as little as 50 kg N/ha at sowing (or even less) will induce deliberate nitrogen stress which causes the crop to turn yellow by the end of tillering. The photographs below show how quickly a nitrogen stressed crop can recover once nitrogen is applied at GS30, and watered into the soil (Figure 4). The 'severe nitrogen stress' treatment in this experiment looked healthy and green just two weeks after nitrogen application, and eventually lodged less and yielded more than the sowing nitrogen treatment.

During the course of the project, we conducted several experiments at Gatton and Spring Ridge to investigate just how late N fertiliser could be applied without reducing yield, and whether different varieties need different N application strategies.

FIGURE 4. Nitrogen stress canopy management experiment at Gatton in 2011.
See reference #8 on page 48 for further information.

	SEVERE N STRESS	MODERATE N STRESS	MILD N STRESS
SOIL+ FERTILISER N AT SOWING	15 kg N/ha	65 kg N/ha	165 kg N/ha
CROP APPEARENCE AT GS32 (29TH JULY)			
NITROGEN FERTILISTER APPLIED 29TH JULY	+ 200 kg N/ha	+ 150 kg N/ha	+ 50 kg N/ha
CROP APPEARENCE TWO WEEKS LATER AT GS33 (13TH AUGUST)			
NITROGEN FERTILISTER APPLIED 9TH SEPTEMBER	+ 50 kg N/ha	+ 50 kg N/ha	+ 50 kg N/ha
CROP APPEARENCE AT MID GRAIN FILLING (1ST OCTOBER)			
HARVEST RESULTS	6.9 t/ha 4% lodged	7.0 t/ha 8% lodged	6.6 t/ha 17% lodged

5.1

Results of in-crop N application experiments

The experiments were conducted using a selection of both long season and quick maturing varieties. The total N supplied (soil and fertiliser N combined for the entire season) was approximately 300 kg N/ha at Gatton and slightly higher at Spring Ridge (340 kg N/ha). Soil nitrogen at sowing varied between locations and years, so it was difficult to test exactly the same strategy in each experiment or season. Nevertheless, some interesting results were obtained from the experiments. Note: Long season varieties (Mitch$^{\Phi}$, LRPB Cobra$^{\Phi}$, LRPB Trojan$^{\Phi}$, and LRPB Lancer$^{\Phi}$) were sown on their most appropriate sowing date (i.e. early sown) while quick maturing varieties (Kennedy$^{\Phi}$, Suntop$^{\Phi}$ and Wallup$^{\Phi}$) were sown 2-3 weeks later.

Irrigated wheat can take up 'luxury' nitrogen during tillering.

Wheat varieties bred for Australia will often take up excessive amounts of nitrogen during tillering, if nitrogen levels are high and readily available in moist soil. Figure 5 shows how crops that have been deliberately stressed through lack of nitrogen can recover rapidly and achieve similar grain yield to crops where N has been applied at sowing. The severe N stress treatment for Kennedy$^{\Phi}$ in this experiment had taken up just as much N by anthesis as the sowing N treatment, and its final grain yield was 0.3 t/ha greater than the sowing N treatment. It also shows how a longer season variety sown early (EGA Gregory$^{\Phi}$) can have even greater amounts of luxury biomass N uptake during tillering, due to its greater number of tillers and longer tillering phase.

Crops should be supplied with approximately 200 kg/ha of soil + fertiliser N at, or prior to GS31.

In 2015 and 2016 we conducted experiments to see how late nitrogen fertiliser could be applied without reducing yield. These experiments were conducted at Gatton and Spring Ridge and used several varieties. Paddocks had between 50 and 140 kg/ha nitrogen in the soil at sowing. The remainder of the crops N supply for the season was added using several strategies that progressively applied N later in the growing season, as detailed in Table 3. The average results across all of these experiments can be seen in Figure 6, which shows that the highest yields were achieved in the 'Sowing N' and '200 by GS31' treatments, on average across environments and seasons.

FIGURE 5. N uptake in above ground biomass from an experiment at Gatton in 2014.

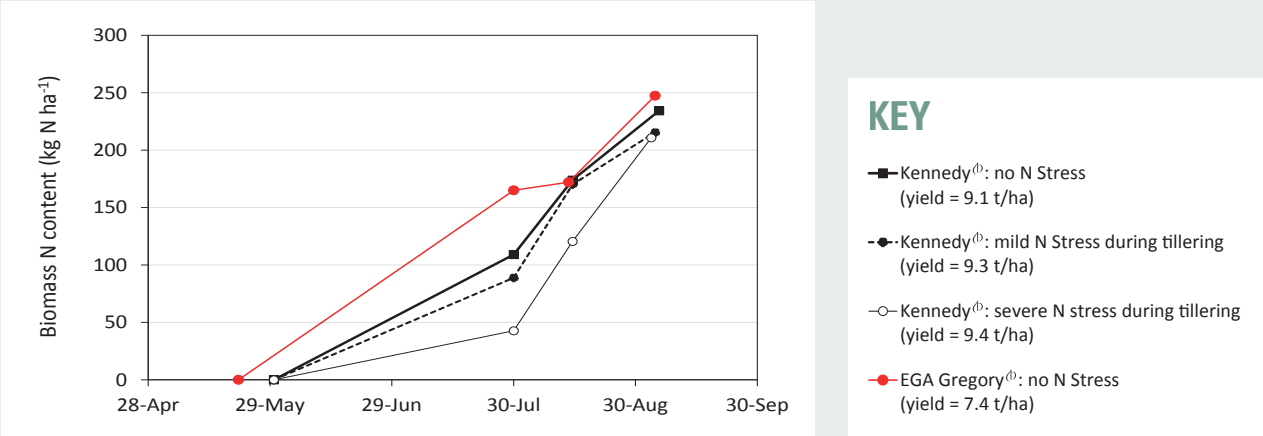
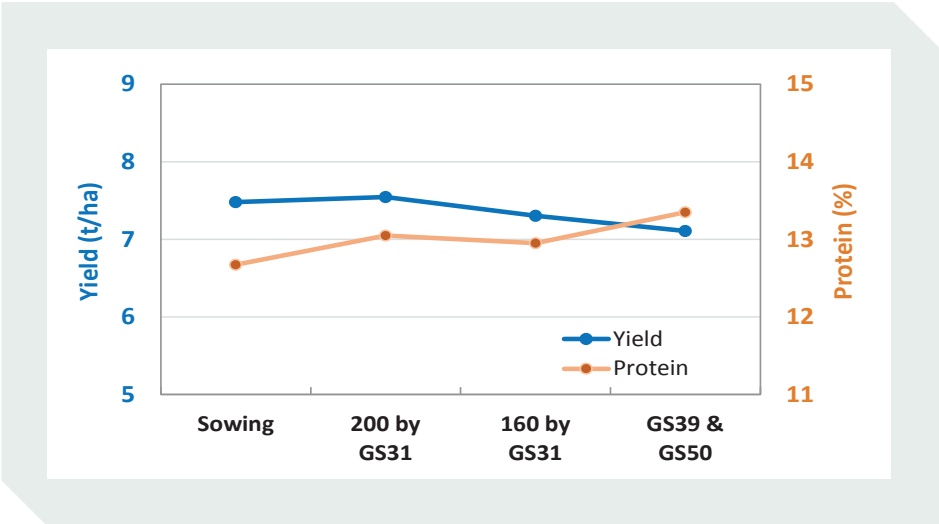


TABLE 3. Nitrogen treatments used at Spring Ridge and Gatton to determine the effect of N fertiliser timing on yield.

NITROGEN TREATMENT	DESCRIPTION
Sowing N	Entire N fertiliser budget for the season was applied as spread urea either on the day of sowing, or in the next ten days. Urea was incorporated into the soil by the sowing operation or a small irrigation after crop emergence.
200 by GS31	No fertiliser N (other than starter fertiliser) was applied until GS31, at which time urea was spread to ensure that the crop had been supplied with 200 kg/ha N (taking both soil N at sowing and fertiliser N into account). The remainder of the N fertiliser was applied at GS39 (flag leaf stage).
160 by GS31	Similar to '200 by GS31' above, except the target N by GS31 was only 160 kg/ha. Another 150 kg/ha was applied at GS39 at both sites, while an additional 40 kg/ha applied at GS50 at Spring Ridge only.
GS39 and GS50	No fertiliser N (other than starter fertiliser) was applied until GS39 when two thirds of the budgeted fertiliser N was applied. The remaining one third was applied at GS50 (awn peep).

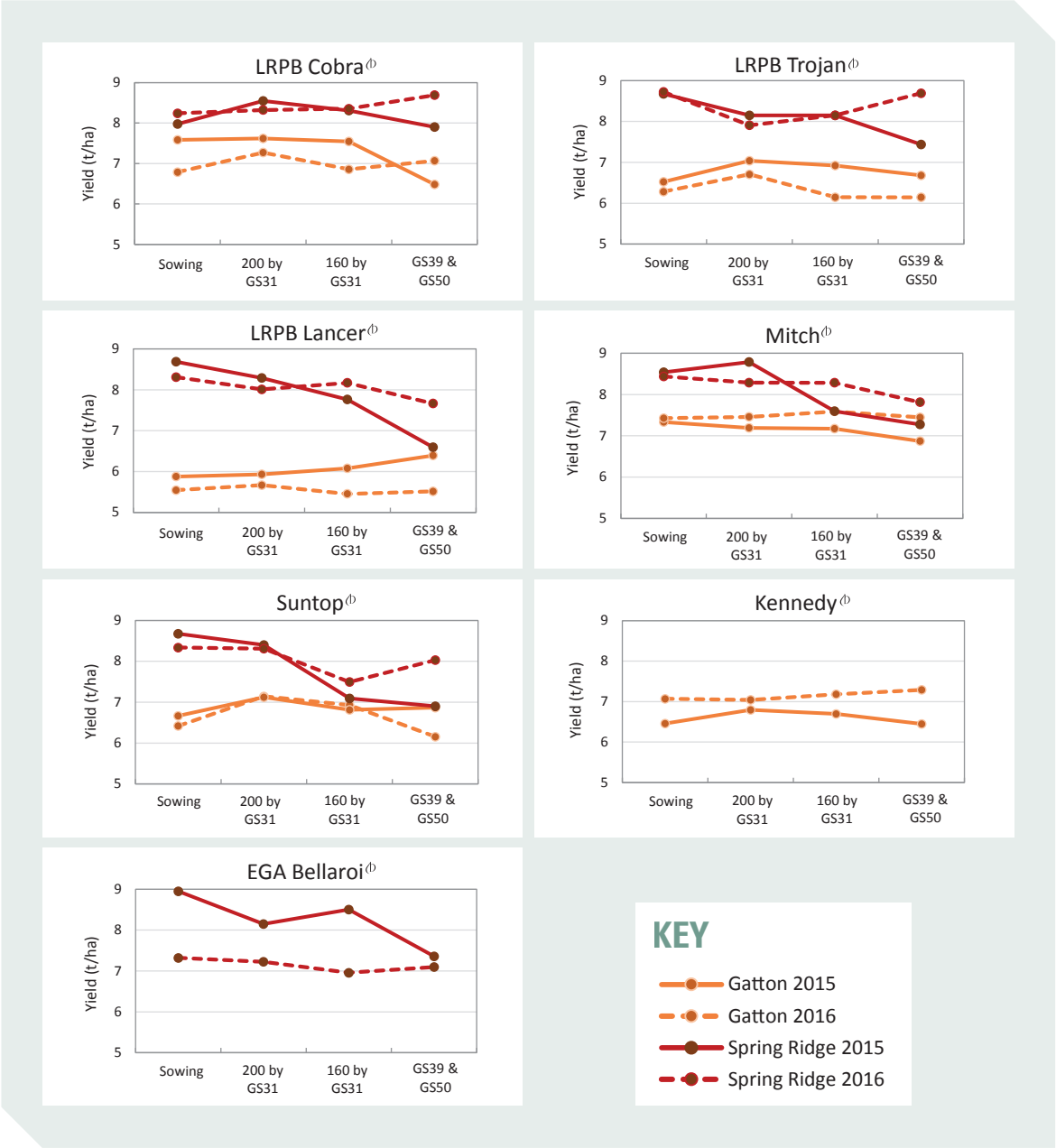
FIGURE 6. Average yield and protein response to alternative N management regimes, on average across 2015 and 2016 at Gatton and Spring Ridge.



Varieties respond differently to 'in-crop' N application

Interestingly, individual varieties responded differently to the alternative N management strategies. As can be seen in Figure 7, in-crop N application in the '200 by GS31' treatment either had a neutral or positive effect on yield in comparison to the sowing N treatment for the variety LRPB Cobra$^{\Phi}$, at both locations. For the variety Mitch$^{\Phi}$, no consistent response was observed, with different responses observed for each site x year combination. For LRPB Trojan$^{\Phi}$ and Suntop$^{\Phi}$, sowing N was more likely to be higher yielding at Spring Ridge, but the '200 by GS31' treatment was higher yielding at Gatton. LRPB Lancer$^{\Phi}$ had a neutral response at Gatton, but decreased in yield in response to in-crop N application at Spring Ridge.

FIGURE 7. Yield response to alternative N application regimes for a range of varieties at Gatton (Gat) and Spring Ridge (SR) in 2015 and 2016.

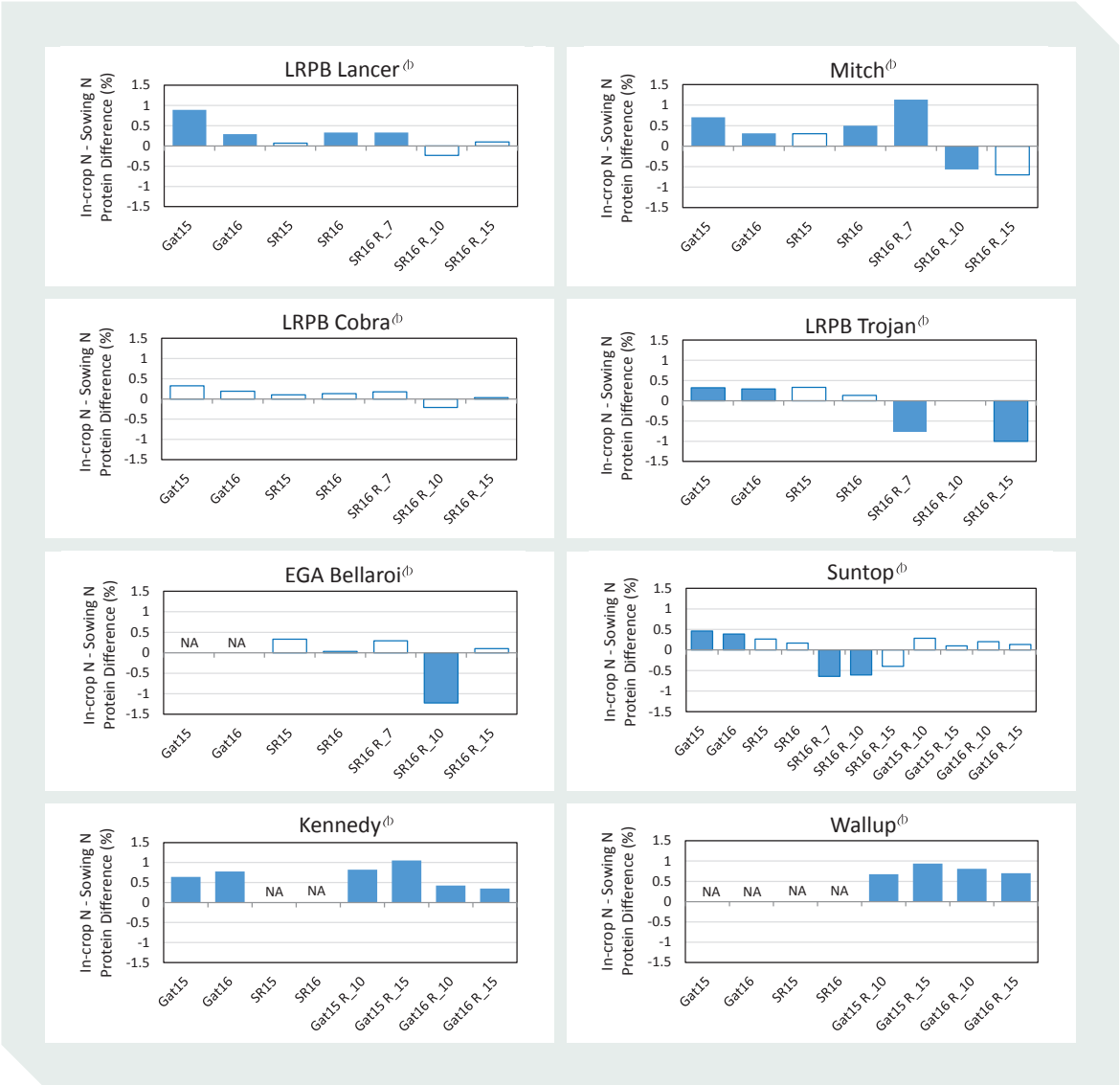


Additional experiments were conducted at the same locations, in which the 'Sowing N' and the '200 by GS31' strategies were tested in combination with different row spacing and PGR strategies. While these experiments are discussed in full in Chapter 10, some of these extra results have been combined into a different format to show the comparison between the 'Sowing N' and '200 by GS31' treatments for a bigger data set (Figure 8). The results need to be viewed carefully because varieties were not always included in the same experiments, due to space restrictions and the relevance of varieties to the environment. Nevertheless, Figure 8 shows that some varieties were more likely to show a positive yield response to the '200 by GS31' treatment, especially Suntop$^{\phi}$, Kennedy$^{\phi}$, Wallup$^{\phi}$ and LRPB Cobra$^{\phi}$, although Kennedy$^{\phi}$ and Wallup$^{\phi}$ were only tested at Gatton. It was also noteworthy that LRPB Lancer$^{\phi}$ and Mitch$^{\phi}$ did not show a significant yield improvement due to in-crop N application in any of these experiments, and it is possible that the in-crop N application strategy may have little benefit for these varieties in terms of yield improvement.

FIGURE 8. The difference in yield between the '200 by GS31' and 'Sowing N' treatments for a range of variety and agronomy combinations at Gatton and Spring Ridge in 2015 and 2016. Gat = Gatton, SR = Spring Ridge. R_7, 10 or 15 = 7.5 inch (19 cm), 10 inch (25 cm) or 15 inch (38 cm) row spacing. 'NA' = not included in this experiment.

In-crop N application increased grain protein content by 0.4% for most varieties and locations. Figure 7 showed that in the N timing experiments, the '200 by GS31' strategy had higher protein than the sowing N treatment, with an increase of 0.4% on average across all varieties compared to the 'Sowing N' treatment. However there were differences observed between varieties. Figure 9 shows protein data for the both the N timing and additional row-spacing experiments and it can be seen that LRPB Lancer$^{\phi}$, Mitch$^{\phi}$, Kennedy$^{\phi}$ and Wallup$^{\phi}$ had the most consistent increases in protein in response to in-crop N application. As Mitch$^{\phi}$ and LRPB Lancer$^{\phi}$ showed no significant yield improvement in response to in-crop N application, it is unsurprising that later N application would increase grain protein. But the trend is particularly interesting in Kennedy$^{\phi}$ and Wallup$^{\phi}$ as it means these varieties tended to simultaneously increase yield and protein as a response to in-crop N application. The remaining varieties were less likely to have higher protein in response to in-crop N application as the differences were smaller and not usually statistically significant, or sometimes negative.

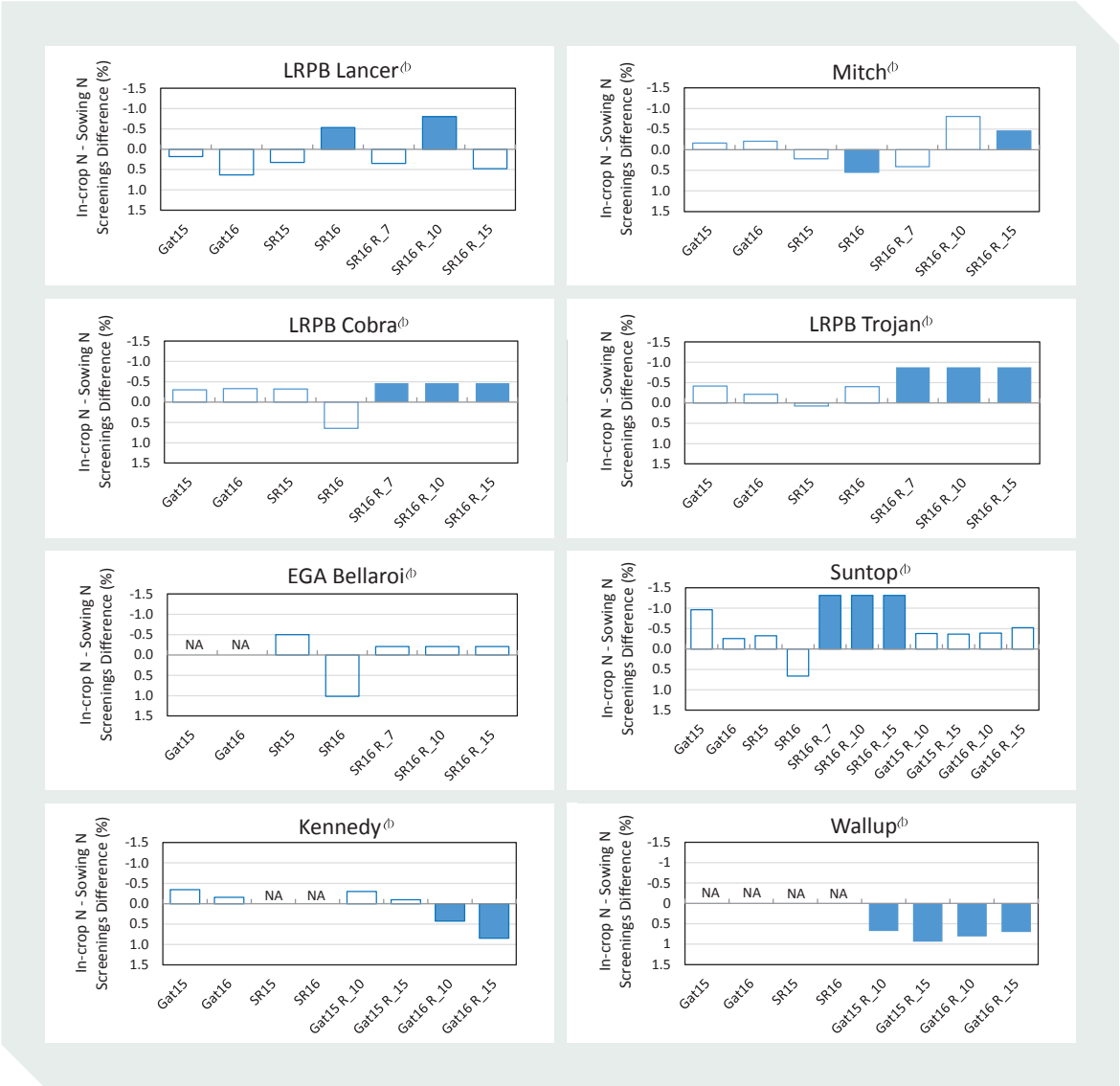
FIGURE 9. The difference in protein between the '200 by GS31' and 'Sowing N' treatments for a range of variety and agronomy combinations at Gatton and Spring Ridge in 2015 and 2016. Bars above the line represent comparisons where the in-crop N application strategy '200 by GS31' had higher protein than the 'Sowing N' strategy. See Figure 8 for graph interpretation "Key".#



#Gat = Gatton, SR = Spring Ridge. R_7, 10 or 15 = 7.5 inch (19 cm), 10 inch (25 cm) or 15 inch (38 cm) row spacing. 'NA' = not included in this experiment.

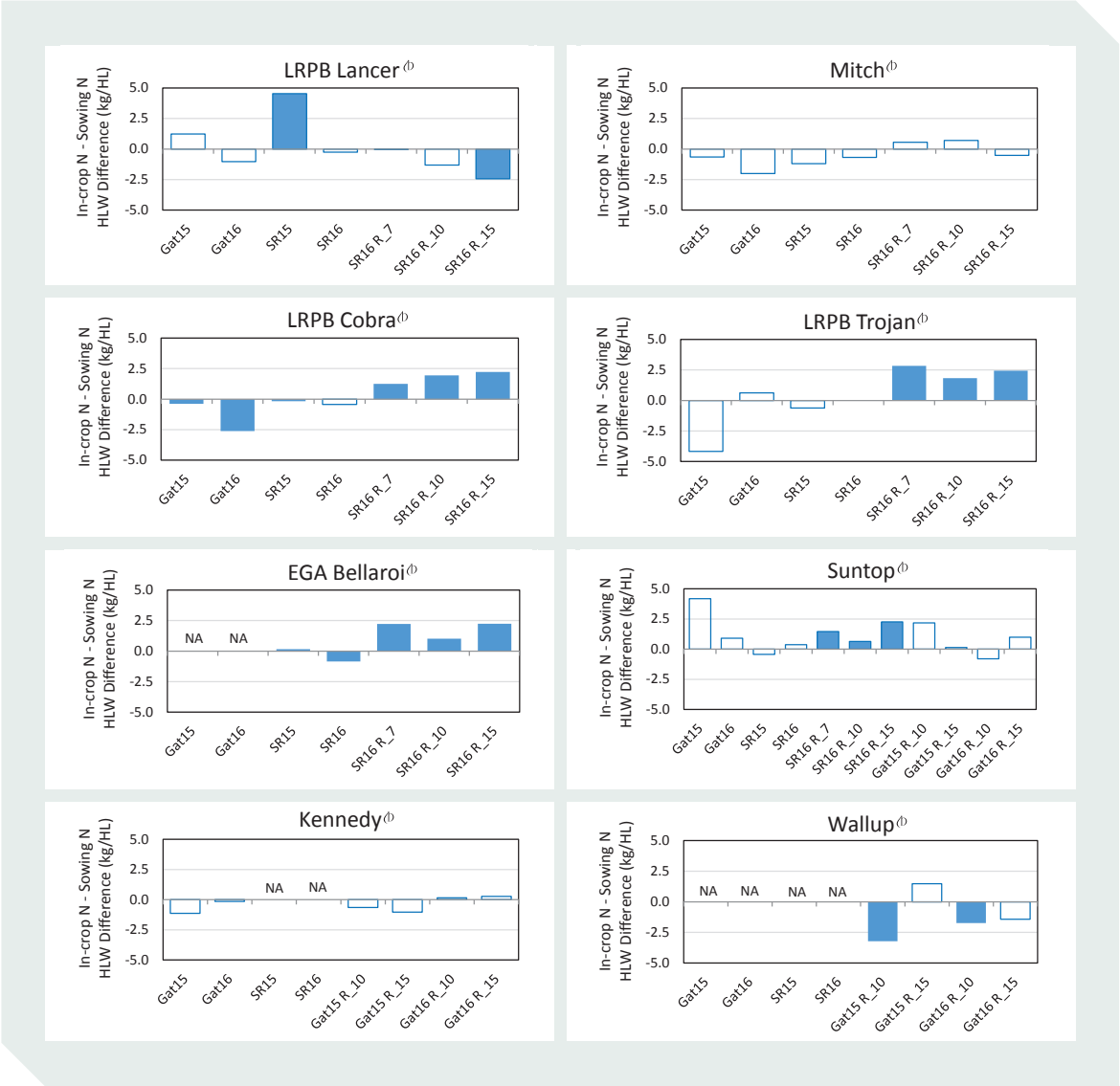
In-crop N application tended to reduce screenings and increase hectolitre weight, but this was not consistent for all varieties. These two quality parameters are obviously very important for achieving the highest quality grade. Figure 10 and Figure 11 show that screenings tended to be slightly lower, and HLW tended to be higher for the '200 by GS31' treatment, in comparison to the sowing N treatment. However this was not consistent across varieties. Wallup$^{\phi}$ tended to have slightly worse screenings and lower HLW in the '200 by GS31' treatment, and Kennedy$^{\phi}$, Mitch$^{\phi}$ and LRPB Lancer$^{\phi}$ didn't have a consistently better or worse HLW for either N application strategy.

FIGURE 10. The difference in screenings between the '200 by GS31' and 'Sowing N' treatments for a range of variety and agronomy combinations at Gatton and Spring Ridge in 2015 and 2016. Note: as screenings is an undesirable trait, the negative and positive sides of the axis have been reversed so that bars above the zero line represent comparisons where the in-crop N application strategy '200 by GS31' had less screenings than the 'Sowing N' strategy. See Figure 8 for graph interpretation "Key".#



#Gat = Gatton, SR = Spring Ridge. R_7, 10 or 15 = 7.5 inch (19 cm), 10 inch (25 cm) or 15 inch (38 cm) row spacing. 'NA' = not included in this experiment.

FIGURE 11. The difference in hectolitre weight (HLW) between the '200 by GS31' and 'Sowing N' treatments for a range of variety and agronomy combinations at Gatton and Spring Ridge in 2015 and 2016. Bars above the line represent comparisons where the in-crop N application strategy '200 by GS31' had higher HLW than the 'Sowing N' strategy. See Figure 8 for graph interpretation "Key".[#]



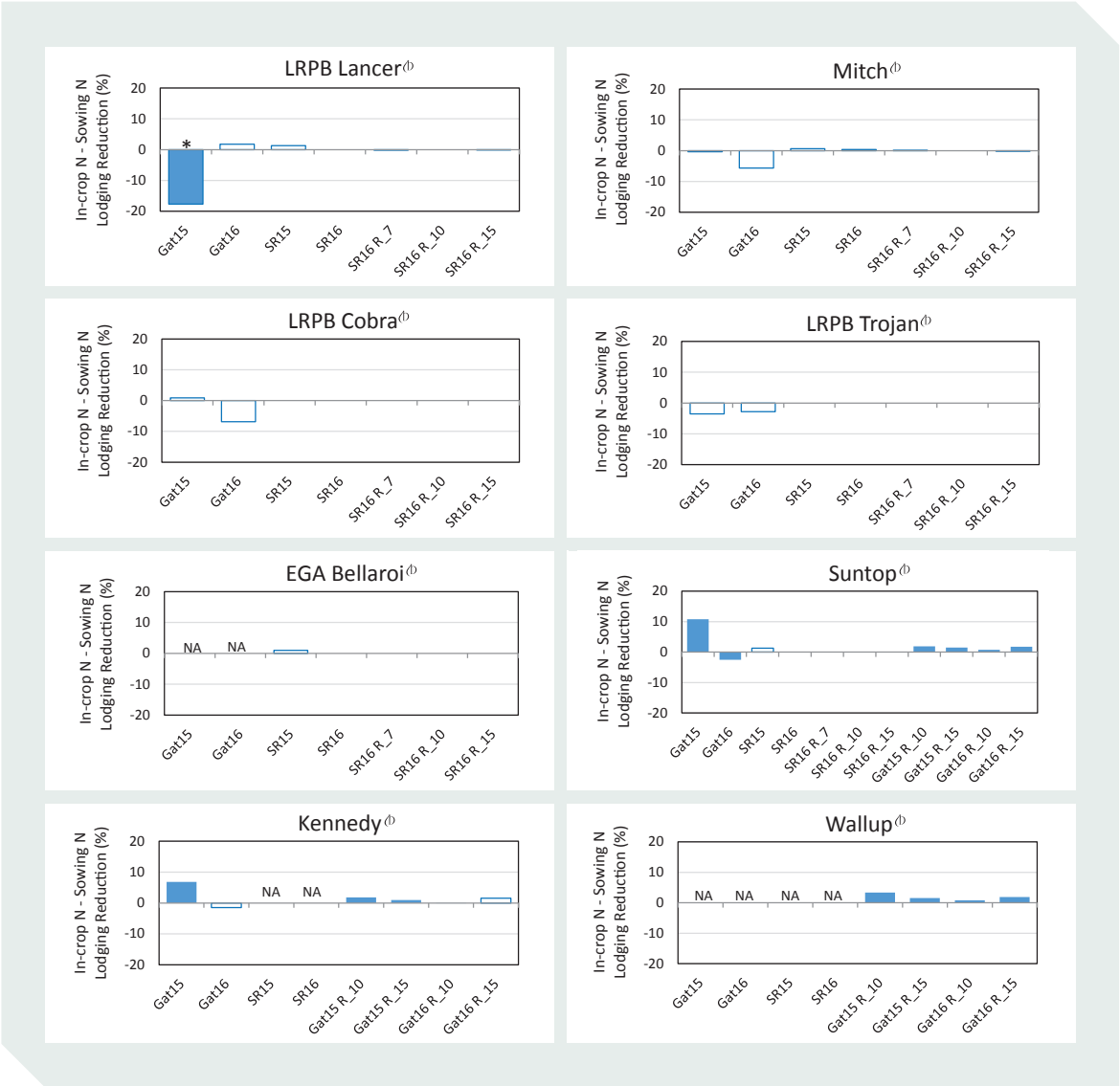
[#]*Gat = Gatton, SR = Spring Ridge. R_7, 10 or 15 = 7.5 inch (19 cm), 10 inch (25 cm) or 15 inch (38 cm) row spacing. 'NA' = not included in this experiment.*

In-crop N application didn't always reduce lodging. In these experiments the lodging pressure was generally low, and only very minor levels of lodging was experienced at Spring Ridge in both seasons. This mild lodging occurred just prior to harvest after the crop had begun to dry down and was not statistically analysable due to the number of zero's in the data set. Lodging was more severe at Gatton where it began before flowering in some cases. Figure 12 shows that delayed application of N was only related to statistically significant lodging reductions at Gatton for the quick maturing varieties Suntop[Φ], Wallup[Φ] and Kennedy[Φ] which were sown on the late sowing date. The biggest reductions were observed in 2015 when just 50 kg/ha N was present at sowing, supporting research conducted in the previous GRDC funded 'Achievable Yields for Irrigated Grains project', which found that low levels of N at sowing were necessary to achieve lodging reductions. However, this lodging reduction was not observed in the long-season varieties sown on the early sowing date (LRPB Cobra[Φ], LRPB Lancer[Φ], LRPB Trojan[Φ], Mitch[Φ]) in the same experiment, and it should be noted that in-crop N

application will probably not give a lodging reduction for all varieties in all circumstances. In-crop N application can sometimes increase yield in the absence of lodging, and this additional yield may increase the susceptibility of the crop to lodging due to the extra weight at the top of the plant. Lodging reductions may be less noticeable as a result of this phenomena.

It should also be noted that there was an unusual occurrence at Gatton in 2015 when the LRPB Lancer$^{\phi}$ sowing N treatment lodged unusually early (at GS39) and recovered by straightening its stems without further lodging, and ultimately had less lodging overall than the '200 by GS31' treatment which lodged later, but more heavily. Readers should be aware that LRPB Lancer$^{\phi}$ is rated MR-MS for lodging resistance and has been observed to lodge heavily under high sowing N in other experiments.

FIGURE 12. The difference in lodging between the '200 by GS31' and 'Sowing N' treatments for a range of variety and agronomy combinations at Gatton and Spring Ridge in 2015 and 2016. Bars above the line represent comparisons where the in-crop N application strategy '200 by GS31' had less lodging than the 'Sowing N' strategy. See Figure 8 for graph interpretation "Key". *Asterisk indicates an unusual data point observed when LRPB Lancer lodged unusually early in the sowing N treatment but recovered by straightening its stems, eventually having less lodging during grain-filling than the '200 by GS31' treatment.#



#Gat = Gatton, SR = Spring Ridge. R_7, 10 or 15 = 7.5 inch (19 cm), 10 inch (25 cm) or 15 inch (38 cm) row spacing. 'NA' = not included in this experiment.

5.2

Nitrogen management strategies for Vertosols

In the light of the experimental results observed in section 5.1 and observations made in on-farm testing, the following suggestions are made for growers wishing to use in-crop N application in irrigated wheat. These recommendations should be used as a starting point and then tailored to specific varieties and growing environments, because differences between varieties, regions, climates, soil types and soil fertility will cause variation for the best nitrogen strategy.

Deep soil test (to 120 cm if possible) for soil nitrogen levels to determine fertiliser application rates.

Create an N-rich test strip to assess soil fertility. An N-rich strip will provide an additional check of soil N status as well as soil fertility, and is particularly useful if growers have been unable to obtain a soil N test before sowing (see Chapter 7.1 for more detail).

Quick maturing varieties such as Wallup$^{\Phi}$, Kennedy$^{\Phi}$ and Suntop$^{\Phi}$ have shown more reliable responses to in-crop N application. If using longer-season varieties (particularly Mitch$^{\Phi}$ and LRPB Lancer$^{\Phi}$), grow a small area to test the strategy before using it on a broad-scale.

Soil + fertiliser N should be approximately 30-70 kg/ha at sowing to create the conditions for successful canopy management. Higher nitrogen levels during tillering are less likely to have a lodging reduction, in which case other lodging control methods should be considered (see Chapter 4 for more information). Note that slightly higher levels may be necessary in cooler environments such as the Liverpool Plains where cooler conditions could slow recovery from N stress.

A crop requires approximately 320 kg N/ha in total during the growing season to achieve 8 t/ha at 13% protein. This nitrogen can be provided from the soil or fertiliser, or nitrogen that mineralises from soil organic matter during the season (which can be significant on high fertility soils or when legumes are part of the crop rotation).

Nitrogen efficiency (fertiliser N uptake into grain) can be higher in irrigated fields (55-60%) compared to dryland (50%), particularly if either PGRs or in-crop N application are used to prevent excessive canopy growth.

TABLE 4. Suggested nitrogen application rates and timing for an 8 t/ha crop grown on vertosol soils.

GROWTH STAGE	ZADOKS GROWTH STAGE	TARGET NITROGEN FOR CROP STAGE (KG N/HA)	CUMULATIVE NITROGEN SUPPLY THROUGH THE SEASON (KG N/HA)	NOTES
Sowing	GS00	30 – 70	30 – 70	Includes soil + fertiliser nitrogen
Stem elongation	GS31	110 – 150*	180 – 200	
Flag leaf	GS39	100 *(or remaining budgeted N)*	320 *(or other total as required for yield and protein target)*	Total supply will vary with soil fertility.

6. PLANT GROWTH REGULATORS

KEY POINTS

1. A PGR mix of 1000 ml/ha chlormequat chloride and 200 ml/ha trinexapac-ethyl was tested on a range of combinations of variety, sowing dates, N application strategies and row spacing.
2. The PGR mix gave the biggest yield response on well-irrigated paddocks with more than 120 kg N/ha available at sowing, with an average yield increase of 0.35 t/ha.
3. The largest yield responses were observed on heavily lodged fields with high sowing N (by 0.6 t/ha on average). However yield was still improved (by 0.32 t/ha) on high sowing N paddocks with little or no lodging.
4. The PGR mix rarely improved yield on paddocks with low sowing N when in-crop N application was successfully implemented, but lodging was reduced by combining in-crop N application with PGR application, and this may be beneficial in high lodging risk seasons.
5. Grain protein tended to be higher and screenings tended to be lower when the PGR mix was applied.
6. PGRs can decrease yield in partially irrigated or rain-fed crops.
7. PGRs didn't always reduce lodging, and should be used in conjunction with other lodging control measures.

6.1

When do they work and how much difference do they make?

Plant Growth Regulators (PGRs for short) are widely used in high yielding wheat production regions such as New Zealand and Europe to reduce the risk of lodging. However previous research in Queensland and Northern NSW has shown inconsistent response to PGRs. Therefore, the Better Irrigated Wheat Agronomy project has conducted widespread testing to try and determine the conditions under which PGRs are most likely to show a benefit.

How do PGRs work and what products are available?

Plant growth regulators available for use in Australian cereal crops are gibberellin inhibitors. Gibberellins are naturally occurring plant hormones that regulate plant activity. These hormones along with other groups such as auxins control many different aspects of the plants growth. Gibberellin activity is particularly enhanced when the plant starts to stem elongate in the spring, being responsible for expanding the stem internodes

as the cereal crop canopy develops. When applied at the start of the stem elongation (or just before) PGRs such as chlormequat chloride and trinexapac-ethyl block the synthesis of these important hormones. The uptake of PGR's into the plant after spray application is influenced by formulation and temperature. It is generally accepted that applications made to crops where temperature at time of application is below 8-10˚C will be less effective and slow to act. They should not be applied in frost conditions or when the crop is under stress, as per the label recommendations.

Chlormequat chloride and trinexapac-ethyl, the two principal active ingredients in PGR formulations block the production of gibberellin at two different points in the biosynthetic pathway and therefore when mixed (as approved for use in wheat) provide a double block on the gibberellin pathway.

This block on the biosynthetic pathway shortens the lower internodes (the length of stem between the nodes or joints) of the cereal stem and depending on environmental conditions has varying effects on the upper internodes. The varying effect on the upper internodes is a result of the activity of the PGR degrading in the plant. As the effect of the PGR diminishes so the production of gibberellin resumes with varying results dependent on the conditions for growth.

TABLE 5. PGR's approved for use on wheat in Australia

PRODUCT (ACTIVE INGREDIENT [AI])	RATES APPROVED FOR WHEAT (ml/HA)	CONCN (G/L)	GIBBERELLIN INHIBITOR	ACTIVE APPLIED (G AI/HA)	ZADOKS GROWTH STAGE
SINGLE ACTIVE PRODUCTS					
Stabilan® 750SL (chlormequat chloride)*	500 - 1300	582	Yes	291 - 757	GS25-35
Cycocel® 750A (chlormequat chloride)*	500 - 1300	582	Yes	291 - 757	GS25-31
Errex® 750 (chlormequat chloride)*	500 - 1300	582	Yes	291 - 757	GS25-31
Moddus® Evo (trinexapac-ethyl)	300 - 400	250	Yes	75 - 100	GS30-32
MIXTURES					
Errex® 750 + Moddus® Evo	1000 - 1300 + 200	As Above	Yes	582-757 + 50	GS30-32

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

6.2

How well do PGRs work on irrigated wheat in QLD and northern NSW?

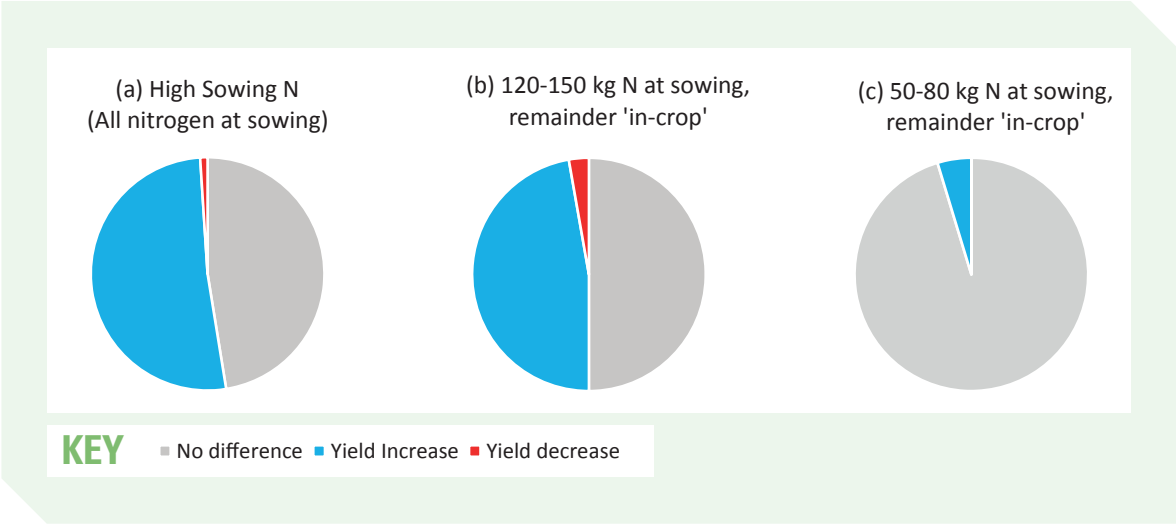
We conducted numerous experiments with PGRs from 2012-2016 at Emerald, Brookstead, Gatton, Narrabri, Breeza and Spring Ridge. In each experiment we used the same PGR mix, consisting of 1000 ml/ha of chlormequat chloride and 200 ml/ha of trinexapac-ethyl. We tested the PGR mix on a range of combinations of variety, sowing date and row spacing, from 15 different experiments between 2012 and 2016. All of the experiments had an average yield of over 5.5 t/ha except the experiment at Brookstead in 2013 which had an average yield of 4.95 t/ha. Overwhelmingly, the results showed that PGRs can regularly produce a yield benefit for growers in certain situations.

The PGR mix gave the biggest yield response on well irrigated paddocks, when more than 120 kg N/ha was available at sowing.

In well irrigated experiments where N was moderate to high at sowing the PGR mix regularly improved yield (Figure 13). When all N was applied at sowing or at least 120-150 kg/ha of soil N was available at sowing and the remainder applied 'in-crop', approximately 50% of comparisons had a statistically significant yield increase, while only 1-3% had a statistically significant decrease (Figure 13 a,b). ***The average yield increase across all 211 comparisons in these paddocks was 0.35 t/ha.*** It is important to remember that these were high yielding, well irrigated crops and the same yield increases may not apply in dryland crop scenarios.

In experiments where in-crop N application was implemented successfully (i.e. there was 50-80 kg/ha of soil + fertiliser nitrogen at sowing), the PGR mix only occasionally made a significant difference to yield (Figure 13c). Out of 64 comparisons on the low sowing N fields, only 3 showed a significant yield increase, with the rest showing no significant difference in yield from the application of the PGR mix.

FIGURE 13. Proportion of PGR mix comparisons resulting in a statistically significant yield increase or decrease for well irrigated paddocks with (a) all N applied at sowing, (b) 120-150 kg/ha N at sowing with the remainder applied 'in-crop', and (c) low sowing N (50-80 kg/ha N applied at sowing) followed by in-crop N application.



On well-irrigated paddocks with high sowing N, yield was often improved even in the absence of lodging.

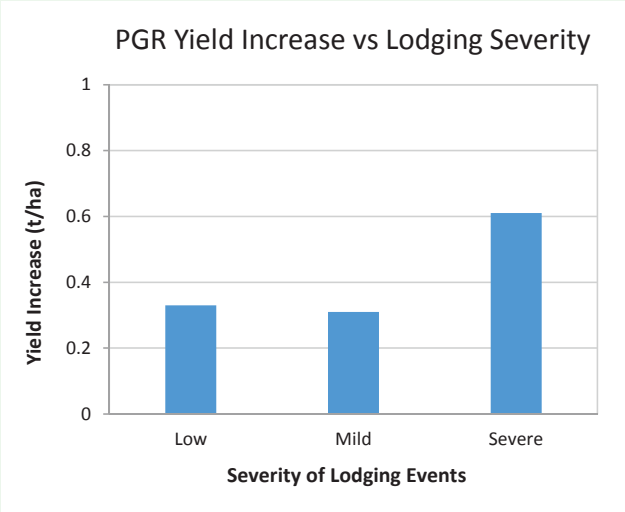
Six of the well irrigated, high sowing N experiments (mentioned above) experienced either zero or only mild lodging. Nevertheless, out of 166 comparisons in these six experiments, 86 showed a significant yield increase due to the application of the PGR mix, while just two showed a negative effect of the PGRs. The average yield increase was 0.32 t/ha across all of these experiments (Figure 14).

The largest yield response to PGRs were observed on heavily lodged fields with high sowing N.

Severe lodging was experienced in two of our high sowing N experiments: Gatton in 2013, and Spring Ridge in 2014. The use of the PGR mix in these experiments was associated with a 0.6 t/ha yield increase on average (Figure 14), with the most extreme example a 1.1 t/ha yield increase due to PGR application on EGA Bellaroi$^{\Phi}$ at Spring Ridge in 2014.

Daniel Moye shows the division between PGR treated Durum in the foreground and untreated Durum in the background.

FIGURE 14. The yield benefit gained by using the best practice PGR mix on well irrigated fields with high sowing N (greater than 120 kg N/ha), for a range of lodging event severity.



YIELD RESPONSES

The largest yield responses to PGRs were observed on heavily lodged fields with high sowing N.

PGRs can work in combination with in-crop N application to give even better protection against lodging.

Although the PGR mix didn't often increase yield on the low sowing N paddocks, the PGR mix reduced lodging in 50% of the comparisons we made in these canopy-managed fields. In a severe lodging event, growers may still experience a yield benefit by using both techniques at the same time. However if severe N stress has been induced through canopy management, it is probably advisable to relieve N stress through in-crop N application prior to application of the PGR in order to maximise the efficacy of the chemicals.

PGR application can affect grain quality.

Six PGR experiments from 2015 and 2016 were assessed for grain quality. At the experiment in Gatton in 2015 no difference was observed between PGR treated and untreated plots for HLW or protein, while screenings in Wallup$^{\Phi}$ were 0.5% worse in the PGR treated plots. However in the remaining experiments at Spring Ridge and Gatton, protein was more likely to increase and screenings were more likely to be lower in PGR treated plots (Figure 15). Protein increases ranged from 0.3 to 1.2%, while the reduction in screenings related to PGRs ranged from 0.3% up to 1.5%, although statistically significant increases were only observed in 25% of screenings comparisons, and 29% of protein comparisons. HLW was slightly more likely to be lower in PGR treated plots.

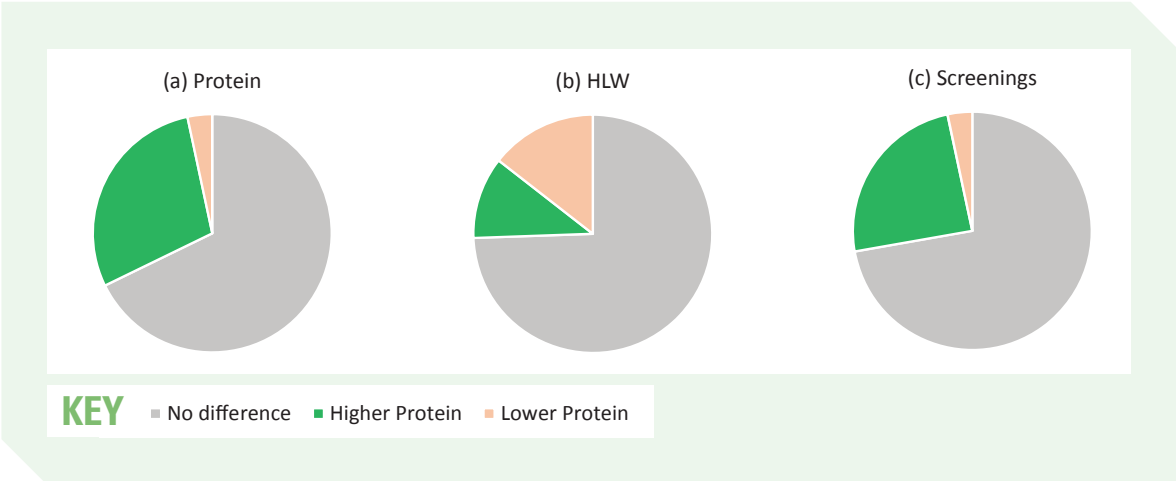
PGRs may have a negative effect on yield in partially irrigated fields or dryland crops.

Negative yield responses from PGR's have been observed in previous projects when dryland or partially irrigated crops encounter water or heat stress later in the season following application. This trend was also observed at one experiment in our project, at Brookstead in 2013, when the farmer was unable to fully irrigate the experiment due to the dry conditions and competing demands for irrigation water. At this site PGR application caused a 0.2 t/ha decrease in yield and a slight increase in screenings (untreated plots had 6% screenings on average, while PGR treated plots had 7% screenings). These results were observed on average across twelve mid to long season varieties including LRPB Lancer$^{\Phi}$, Mitch$^{\Phi}$ and EGA Gregory$^{\Phi}$. However, PGR application had no effect on yield for 12 quicker maturing varieties in a neighbouring experiment in the same paddock that received the same amount of irrigation.

PGRs won't always reduce lodging.

As discussed in Chapter 4, there is no silver bullet to stop lodging. Lodging risk is best reduced using a package of measures that includes irrigation strategies, variety selection and appropriate plant populations along with in-crop nitrogen application and/or PGRs. *The application of PGRs should be viewed similarly to that of a fungicide application – an 'insurance' measure that may not ultimately make a difference depending*

FIGURE 15. Proportion of PGR mix comparisons resulting in a statistically significant improvement for well irrigated paddocks with more than 120 kg/ha N at sowing for (a) grain protein, (b) hectolitre weight (HLW), and (c) screenings.



on how the season turns out. However, they could just be the difference that prevents growers from dealing with a heavily lodged crop that is lower yielding and difficult to harvest.

The results of our studies showed that in our high sowing N experiments, the PGR mix rarely stopped the crop from lodging altogether. However they often reduced the severity of lodging with 59 out of 147 comparisons in high sowing N experiments showing a significant lodging reduction following application of the PGR mix. ***Unexpectedly, we observed that PGRs caused significantly increased lodging in 5 out of 147 comparisons.*** Four of these occurred at Spring Ridge in 2014 when PGRs were used on LRPB Lancer$^{\Phi}$ or Mitch$^{\Phi}$, but did not adversely affect yield which was either no different or still higher in the PGR treated plots. This unusual event may have occurred because PGRs can increase yield in their own right, and this might occasionally cause lodging to be worse during grain filling due to the additional leverage this yield creates at the top of the plant. It may also occur because a crop that lodges earlier may have time to recover through stem straightening, while crops that lodge later may ultimately be more severely lodged because they do not have time to recover.

CANOPY MANAGEMENT IN ACTION

At a field day in Murgon in 2015, the Hamilton brothers opened up their farm 'Tindarra' to local irrigated growers. They shared how they had been using canopy management techniques to avoid lodging ever since 2008, when severe lodging caused significant yield losses and also prevented the fields from drying out to allow harvesting to resume after a significant rain event.

Fortunately, their good planning in 2015 meant they had sown lodging resistant varieties recommended by the project team (e.g. Mitch$^{\Phi}$, Wallup$^{\Phi}$, Suntop$^{\Phi}$), and their agronomic management included in-crop N application and PGR application. Two months after the field day when the photo was taken, they experienced another severe rain event, with harvest delayed by 6 weeks during which 300 mm of rain fell. Their fields did not lodge and still yielded 6.5 t/ha despite the significant amount of shattering caused by the delay in harvest.

LEFT to RIGHT: Gus Hamilton, Greg Hamilton, Darryl 'Dags' Stephens (from Tindarra, near Murgon, QLD), Dr Allan Peake (CSIRO) and Wayne Seiler (BGA Agriservices) standing in an irrigated crop of Wallup$^{\Phi}$, in October 2015. The crop did not lodge despite experiencing a harvest delay of six weeks, during which 300 mm of rain fell.

7. VISUALISING LODGING RISK IN IRRIGATED WHEAT

KEY POINTS

1. Inherent soil fertility is an important factor in determining lodging risk
2. Creating N rich and N deficient demonstration zones within your paddock can be used to visually assess paddock fertility
3. 'Greenseekers'® can be used to quantify crop growth and determine inherent paddock fertility by comparing NDVI readings from N rich and N deficient paddock zones.
4. Inherent paddock fertility can then be included with other lodging risk factors to assess crop lodging risk by using the lodging risk calculator on page 33.

As discussed in previous chapters, pre-sowing soil tests can help us understand the Nitrogen (N) status of the field and identify fields where in-crop N application or plant growth regulators (PGRs) can be used to reduce lodging risk.

However, the ongoing breakdown of soil organic matter releases N in a process known as mineralisation. This means a soil test taken well before sowing may not give an accurate indication of N status at sowing, particularly in wet conditions when mineralisation can occur rapidly and soil nitrogen is unstable and difficult to assess accurately. While soil tests can give an indication of paddock fertility through a measure of organic carbon, it won't determine how fast mineral N will be released from the residue of a rotation crop such as soybean or faba beans. And although growers may have the best intentions to take soil tests before sowing it is sometimes forgotten in the busyness of autumn harvesting and ground preparation.

How can we get an indication of lodging risk developing during the season, without a soil test?

There are two categories of lodging risk factors: those that the grower can control and those they cannot. Of these factors that the grower has some control over, the project results show that some have a greater influence on lodging risk than others. From this work and from feedback from advisers the following table gives an indication of some the key agronomic factors associated with lodging in irrigated crops (Table 6).

During interviews with regional agronomists, other factors also suspected as having influence on crop lodging were brought forward including; row orientation, basal P levels (both inherent and applied) giving vigorous early growth and seed depth. These factors have not been discussed in Table 6 as they were not able to be investigated using experiments during the course of the project.

TABLE 6. Factors associated with lodging risk deduced from experiments run in the project (higher star ratings confer greater influence over lodging risk)

FACTORS NOT UNDER THE GROWER'S CONTROL	LODGING RISK RATING	FACTORS UNDER THE GROWER'S CONTROL	LODGING RISK RATING
1. Inherent fertility – high fertility that is long standing for that paddock in the rotation without reference to fertiliser applied for the crop	*****	1. Varietal resistance to lodging – Wheat varieties have different root architecture and stem strengths that increase or decrease lodging risk	*****
2. Windy and wet weather (ear emergence to harvest)	*****	2. Irrigation (1) Irrigation timing in relation to expected weather conditions is a key factor in lodging risk (2) total irrigation applied increases yield potential and hence lodging risk	*****
		3. Total N rate applied – Higher N rates increase lodging risk particularly when superimposed on high inherent fertility	***(*)
		4. Nitrogen (N) timing - Earlier (at sowing) nitrogen application can increase lodging risk, particularly if inherent fertility is already high.	***
		5. Sowing date – Earlier sowing dates, particularly combined with high seed rates and longer season varieties can increase lodging risk.	**
		6. Seeding rate – Higher seed rates can increase lodging particularly combined with earlier sowing and inherent fertility.	**

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

Nick Poole from FAR Australia inspects lodged wheat in Central Queensland.

7.1

Assessing paddock fertility and potential lodging risk

Other than the variety and weather conditions during grain fill, ***one of the most influential factors giving rise to lodging in an irrigated wheat crop is the inherent fertility of the paddock.*** This is the fertility associated with the paddock that is independent of the fertiliser applied to the crop. Lodging risk is exacerbated when high levels of fertiliser are applied to crops that already have access to large quantities of available nitrogen and phosphorus from the soil without any fertiliser applied.

Higher inherent fertility can be visualised in the crop canopy at the start of stem elongation with crops showing more vigorous growth, higher shoot numbers, higher biomass and greener canopies. The link between crop density in terms of shoot number and Green Area Index (GAI) are already used in lodging risk tools in Europe.

The issue in northern Australian crops is complicated by the fact that they routinely receive N fertiliser at sowing which can mask the visual indicators of inherent fertility in the paddock. This is much less of an issue in Europe since crops are not fertilised with large amounts of N at sowing, so crop canopy images in early spring at GS30 are more indicative of the background N mineralisation and the inherent fertility of the paddock.

Methods for visualising potential lodging risk

1. Using N deficient and/or N rich strips to create a "visual indicator"

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

High inherent fertility. Where the inherent fertility of the paddock is very high there will be little or no difference in appearance between the N rich/deficient strips and remainder of the paddock when assessed in the spring.

Low inherent fertility. In contrast, where visual differences between the N rich / deficient strips and the paddock are pronounced the fertility will be lower.

Since high inherent paddock fertility has such a pronounced effect on lodging risk and irrigation increases that risk, crop canopy visual appearance at the beginning of stem elongation (GS30-31) is a key determinant of lodging risk and the likely need for an application of Plant Growth Regulators (PGRs).

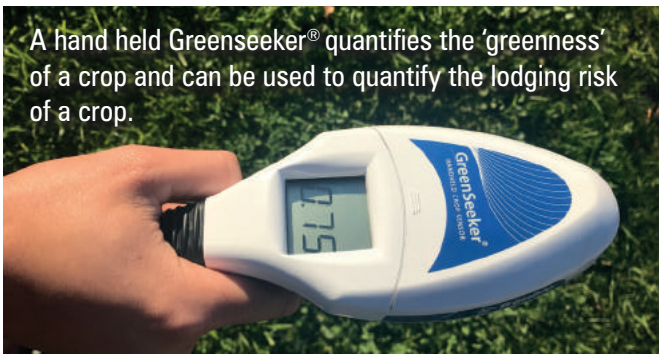
How can we measure the visual difference? The scale of this visual difference can be assessed either using visual observations by an experienced operator or using readouts from a hand held crop sensor such as Greenseeker®.

2. Using a Hand Held Greenseeker® to quantify Lodging Risk

Table 7 sets out three arbitrary categories of soil fertility on the basis of crop canopy appearance (recorded in northern region crops) at GS30-31 that illustrate the concept of visualising inherent fertility as an important lodging risk factor using a hand held Greenseeker®. The images show three different paddock fertilities and the visual difference between "N rich strips" or "N deficient" strips set up at sowing and the remainder of the paddock. The NDVI (Normalised Difference Vegetative Index) readouts from a hand held Greenseeker® enable us to quantify the relative difference between the images.

This is done by using NDVI readings from N rich and N deficient areas to calculate an NDVI response index as follows:

$$\frac{\textbf{NDVI reading (N rich area)}}{\textbf{NDVI reading (N deficient area)}} = \textbf{NDVI response index}$$

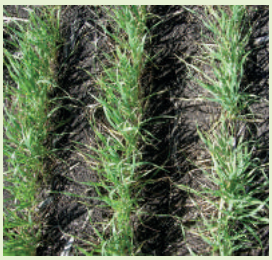


A hand held Greenseeker® quantifies the 'greenness' of a crop and can be used to quantify the lodging risk of a crop.

For example a value of 0.84 NDVI for the paddock divided by 0.83 NDVI for the N deficient strip set up at sowing, gives a NDVI response index of 0.84/0.83 = 1.012. In Table 7, three arbitrary response indices have been put forward. These can help estimate lodging risk and the need for subsequent PGR application when they are combined with variety lodging resistance ratings obtained from irrigated experiments with yield potential of 8-10 t/ha.

Clearly the highest risk scenarios for lodging are where high inherent fertility creates high crop canopy biomass independent of fertiliser applied (NDVI index at approximately 1.0). In contrast, higher NDVI response indices (1.2-1.5) illustrate less fertility in the paddock and therefore less risk of lodging, since crop canopy growth is more dependent on applied fertiliser alone.

TABLE 7. Different lodging risk scenarios based on Normalised Difference Vegetative Index (NDVI) response index from N rich or strips with no additional N applied, seen at GS30-31 in paddock scenarios with different fertility.

	HIGH FERTILITY PADDOCK No visual difference Response Index < 1.05	INTERMEDIATE FERTILITY PADDOCK Some visual difference Response Index = 1.05 – 1.20	LOW FERTILITY PADDOCK Strong visual difference Response Index < 1.20
NITROGEN RICH STRIP	 NDVI 0.84 High N Status	 NDVI 0.84 – High N status	 NDVI 0.73 High N status
NO NITROGEN ADDED	 NDVI 0.83 – No N Lodging occurred cv Mitch$^{\Phi}$ (MR)	 NDVI 0.74 No N Lodging did not occur cv Mitch$^{\Phi}$ (MR)	 NDVI – 0.50 No N Lodging did not occur cv Ventura$^{\Phi}$ (MS)
	NDVI Response Index = 1.01	NDVI Response Index = 1.14	NDVI Response Index = 1.46

MR - Moderately resistant to lodging, MS = Moderately Susceptible to lodging

7.2

Matching potential lodging risk to tactical management options

A lodging risk calculator has been developed to use the resources in this chapter (i.e. the inherent soil fertility calculator in Table 7) and other chapters (varietal lodging risk rating in Chapter 8) in combination with other information available to growers (e.g. soil test results, plant population). Using this information, it is possible to identify the management and environmental factors that apply to an irrigated wheat paddock in each row of the table below. The score in parentheses () given for each factor can be added up and related to the score in the interpretation notes below the table.

TABLE 8. Lodging risk calculator for fully-irrigated wheat fields.

INHERENT PADDOCK FERTILITY				High (+3)	Medium (+1)	Low (+0)		
SOIL + FERTILISER N AT SOWING (KG N /HA): extra risk for high fertility paddocks only	>350 (+3)	>250 (+2)	>150 (+1)					
PLANT POPULATION (plants/m^2 established)			>300 (+5)	250 - 300 (+4)	200 - 250 (+3)	150 - 200 (+2)	120 - 150 (+1)	< 120 (+0)
VARIETY LODGING RESISTANCE	S (+9)	MS - S (+7)	MS (+5)	MR - MS (+2)	MR (+1)	MR - R (+0)		
TEMPERATURES EXPERIENCED FROM SOWING TO GS30 (i.e. during tillering phase)				Much cooler than normal (+2)	Average (+0)	Much warmer than normal (-2)		
CLIMATE FORECAST FOR REMAINDER OF SEASON				La Nina (+2)	SOI Neutral, Rising, or Falling (0)	El Nino (-2)		

Lodging Risk Score Interpretation:

< 0 = Very low risk, yield potential likely to be reduced, consider earlier N application and/or increased irrigation.
0-2 = Low risk, proceed with intended irrigation and N management, consider PGR use.
3-4 = Moderate risk, advise use of PGRs to reduce lodging
5-7 = High risk, advise using PGRs as well as slightly reducing irrigation volumes to reduce yield potential
> 7 = Very high risk, advise using PGRs. Also advise reducing irrigation to limit yield potential to either:
(a) 6 t/ha (varieties with MS or higher lodging risk)
or (b) 7 t/ha (for varieties with MR-MS or lower lodging risk)

8. BEST VARIETIES FOR IRRIGATED PRODUCTION

KEY POINTS

1. All varieties have advantages and disadvantages for irrigated wheat production, so choose varieties carefully. Please consult QLD and NSW variety guides to fully evaluate variety suitability.
2. Varietal choice is a key factor in reducing lodging risk, but it is not a silver bullet for eliminating lodging. Other lodging control methods should be used in conjunction with resistant varieties to reduce lodging risk.
3. The most lodging resistant varieties may not achieve the highest quality grades (e.g. APH, Durum) and growers will need to weigh up their desire to avoid lodging against the potential gross margins of higher quality varieties with less lodging resistance.
4. LRPB Cobra$^{\Phi}$ and LRPB Dart$^{\Phi}$ are the two most lodging resistant varieties, but both of these varieties can still lodge under extreme lodging conditions.

Extensive variety testing has been conducted at Spring Ridge, Narrabri, Emerald, Gatton and Brookstead over the last five years. The results of the lodging screening experiments have been used to update the Queensland and NSW Variety Guide lodging ratings, and reported in GRDC update papers (see Chapter 11: Further Reading). The results are too numerous to fully reproduce in this booklet. However we have summarised findings on the best varieties in Table 9, and lodging risk ratings are presented for a wide range of varieties of different maturity in Table 10.

Varieties with the highest lodging resistance may not achieve the highest quality grades (e.g. APH, Durum), and growers need to weigh up their desire to avoid lodging against the potential gross margins available from higher quality varieties with less lodging resistance. Readers are also advised to consider additional variety attributes (particularly disease susceptibility) as detailed in the QLD and NSW wheat variety guides, before choosing a wheat variety.

Yield and grain quality results from irrigated experiments in 2014-2016 that included most of the varieties that rated MR-MS or better for lodging are presented in Figures 16-20 for readers who would like additional detail. These experiments were conducted using 'best-practice' agronomy which in all years involved plant populations of approximately 100 plants/m^2 and in-crop N application to supply at least 200 kg/ha of soil + fertiliser N by GS31-32. In 2014 and 2015, PGRs were also applied at approximately GS31-32. Longer season varieties were sown on an earlier sowing date, while quick maturing varieties were sown on a later sowing date (sowing date details are given in Chapter 9).

Note: when assessing the ability of a variety to achieve grain protein benchmarks, we suggest that readers should consider Figure 18, which lists the grain nitrogen uptake (i.e. protein x yield x a conversion factor of 1.75), an indicator of how well varieties extract N from the soil regardless of variation in grain yield.

TABLE 9. Recommended wheat varieties for irrigation in Queensland and northern NSW. Readers are advised to also consider additional variety attributes (particularly disease susceptibility) as contained in the QLD and NSW wheat variety guides before choosing a wheat variety.

MAXIMUM QUALITY CLASS	VARIETY	LODGING RATING	NOTES
APH	LRPB Dart$^{\Phi}$	R-MR	LRPB Dart$^{\Phi}$ is particularly quick maturing and has a slightly lower yield potential. Tended to have lower HLW and higher screenings than other quick varieties. Excellent lodging resistance, a good choice for paddocks with extremely high N levels.
	Wallup$^{\Phi}$	MR	Yields well at cooler locations and has high N recovery which allows it to achieve high protein concentrations as well as yield. Generally had lower screenings than most varieties of similar maturity but did have very low HLW at Spring Ridge in 2015 in a hot dry finish to the season. Wallup$^{\Phi}$ has short, upright stems that some growers prefer to use on wide row spacing, because it allows easier sowing of a double-crop in the inter-row spacing. Has sometimes lodged when sown early in the sowing window, so we recommend mid window sowing for Wallup$^{\Phi}$.
	Suntop$^{\Phi}$		Excellent yield potential across a range of environments, tillers prolifically. Does tend to have lower protein which is partly due to its higher yielding ability. N recovery is not as good as LRPB Spitfire$^{\Phi}$ or Wallup$^{\Phi}$.
	LRPB Crusader$^{\Phi}$		Similar to LRPB Dart$^{\Phi}$ with slightly more lodging susceptibility and a higher HLW on average. Achieved a QLD record irrigated yield of 8.2 t/ha at Brookstead in 2011.
	LRPB Spitfire$^{\Phi}$	MR-MS	Only included in the final two years of field experiments but was consistently high yielding with the highest protein and N uptake of the quick maturing varieties, and high HLW as well.
	LRPB Lancer$^{\Phi}$		Borderline 'MS' lodging rating, very high tillering ability. Recommended only for partial irrigation due to its higher lodging susceptibility. The best long-season option for APH quality, but lower yielding than non-APH long-season varieties.
	Kennedy$^{\Phi}$		Yields well in warmer environments such as Central Queensland and Lockyer Valley. Low tillering type, tends to have slightly lower screenings than some other quick varieties.
DURUM	EGA Bellaroi$^{\Phi}$	MR-MS	Similar yield potential to Caparoi$^{\Phi}$, high grain quality. Has slightly higher N recovery but lower HLW than Caparoi$^{\Phi}$.
	Caparoi$^{\Phi}$		Similar yield potential to EGA Bellaroi$^{\Phi}$, high grain quality. Has slightly lower N recovery but higher HLW than EGA Bellaroi$^{\Phi}$.
	DBA Aurora$^{\Phi}$	MS	Newly released varieties for which we only generated limited data. DBA Aurora$^{\Phi}$ has higher yield potential than most Durum varieties, but tends to have lower grain protein. DBA Lillaroi$^{\Phi}$ is rated by regional agronomists as having exceptional grain quality, similar to EGA Bellaroi$^{\Phi}$.
	DBA Lillaroi$^{\Phi}$		
OTHER	LRPB Cobra$^{\Phi}$	R-MR	Excellent yield potential and lodging resistance, has high levels of N recovery. Had highest yield but also the highest level of screenings at Spring Ridge in 2015 in a hot, dry finish.
	Livingston$^{\Phi}$	MR	Performs particularly well at Narrabri, and also had high yield at Spring Ridge in 2015 under late water stress. High N recovery rates.
	Mitch$^{\Phi}$		Good yield potential especially in partially irrigated situations, but does tend to have higher level of screenings in these situations. Tillers prolifically, lower N recovery than LRPB Cobra$^{\Phi}$ or LRPB Trojan$^{\Phi}$.
	Sentinel 3R$^{\Phi}$		Longer season type with excellent yield potential and high levels of N recovery. Good lodging resistance. The highest yielding variety at Spring Ridge in 2014.
	LRPB Trojan$^{\Phi}$	MR–MS	Excellent yield potential but less lodging resistance than LRPB Cobra$^{\Phi}$. Was the highest yielding variety in several experiments.

R - MR:.....*resistant to moderately resistant to lodging*
MR:.....*moderately resistant to lodging*
MR - MS:.....*moderately resistant to moderately susceptible to lodging*
MS:.....*moderately susceptible to lodging*
APH:.....*Australian Prime Hard (standards set by Wheat Quality Australia)*
HLW:.....*Hectolitre weight*

TABLE 10. Lodging risk rating+ and approximate variety maturity# for a range of varieties tested in QLD and Northern NSW.

	VARIETY MATURITY RATING#				
LODGING RATING+	**VERY QUICK**	**QUICK**	**MID**	**LONG**	**VERY LONG**
R-MR	LRPB Dart(p)		LRPB Cobra(p)		
MR	Livingston(p) LRPB Crusader(p) Condo(p)	Merinda(p) Suntop(p) Wallup(p)	Mitch(p)	Sentinel 3R (p)	
MR - MS		LRPB Spitfire(p) Kennedy(p) LRPB Impala(p)	LRPB Trojan(p) Lang(p) Sunguard(p) Elmore CL PLUS(p) **EGA Kidman** (p)* EGA Bellaroi(p) Caparoi(p)	LRPB Lancer(p) LRPB Gauntlet(p) LRPB Flanker(p)(p)	Sunzell(p)
MS	Sunmate(p)(p) Steel(p)	Hartog DBA Lillaroi(p)	DBA Aurora(p)	EGA Gregory(p) LRPB Viking(p) Kiora(p)	Suntime(p)(p) Strzelecki(p)
MS - S	Jandaroi(p)		Baxter(p) **LRPB Reliant** (p)*	EGA Bounty(p)	EGA Eaglehawk(p)
S			LRPB Orion(p)	EGA Burke(p) Sunvale(p) Hyperno(p)	

*+Variety lodging ratings were generated by the project team in the Better Irrigated Wheat Agronomy project, or the previous GRDC funded 'Achievable Yields for Irrigated Grains' project. #Maturity ratings are approximate as varietal maturity changes between environments. Check local variety guides and consult local agronomists to confirm maturity classification for specific environments. (p) Provisional rating developed on limited experimental data. *Lodging ratings not generated by either of these GRDC funded projects are listed in* **bold type** *as their lodging ratings may not accurately compare to other varieties in this table due to differences in screening environments and methods. Durum varieties are* underlined.

R - MR:.....*resistant to moderately resistant to lodging*
MR:.....*moderately resistant to lodging*
MR - MS:.....*moderately resistant to moderately susceptible to lodging*
MS:.....*moderately susceptible to lodging*
APH:.....*Australian Prime Hard (standards set by Wheat Quality Australia)*
HLW:.....*Hectolitre weight*

FIGURE 16. Yield for selected varieties with a lodging rating between R-MR and MR-MS from variety trials in 2014-2016 (a) longer season varieties (b) medium-quick varieties (c) quick varieties, and (d) Durum varieties. LSD = Least Significant Difference (95% certainty).

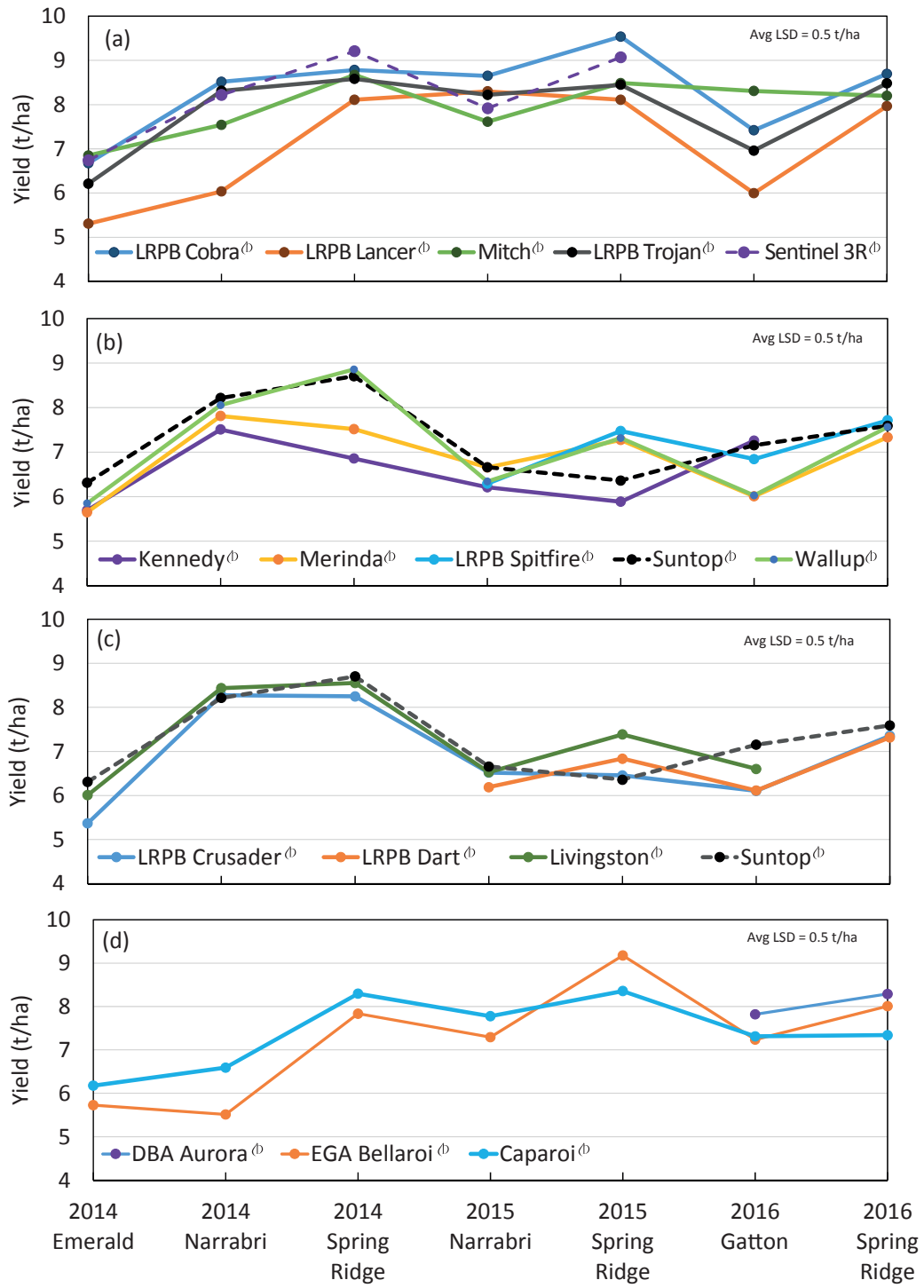


FIGURE 17. Protein for selected varieties with a lodging rating between R-MR and MR-MS from variety trials in 2014-2016 (a) longer season varieties (b) medium-quick varieties (c) quick varieties, and (d) Durum varieties. LSD = Least Significant Difference (95% certainty).

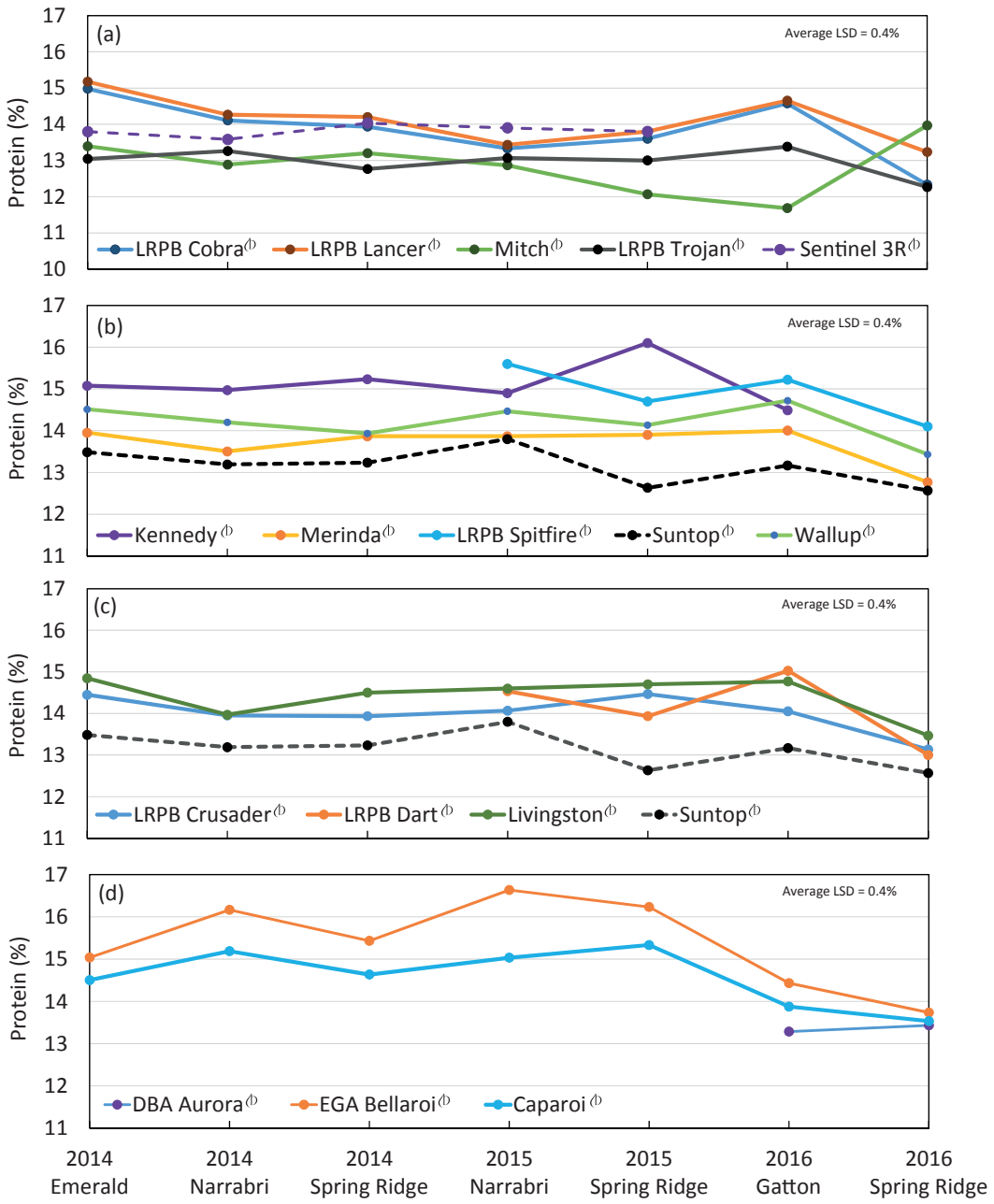


FIGURE 18. Grain nitrogen uptake (protein x yield x 1.75) for selected varieties with a lodging rating between R-MR and MR-MS from variety trials in 2014-2016 (a) longer season varieties (b) medium-quick varieties (c) quick varieties, and (d) Durum varieties. LSD = Least Significant Difference (95% certainty). **An LSD of 40 kg N/ha applies to the data in this experiment.

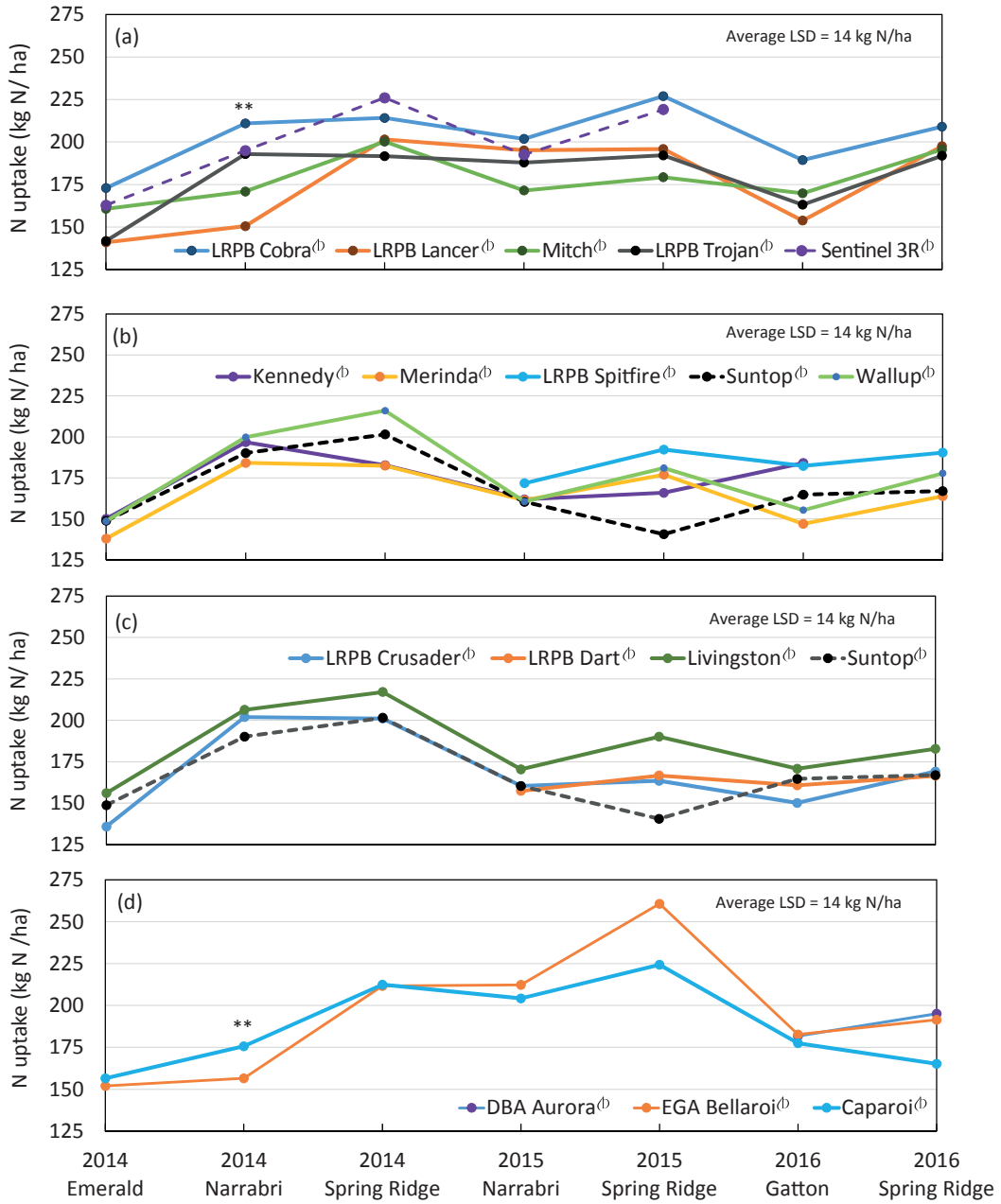


FIGURE 19. Hectolitre weight for selected varieties with a lodging rating between R-MR and MR-MS from variety trials in 2014-2016 (a) longer season varieties (b) medium-quick varieties (c) quick varieties, and (d) Durum varieties. LSD = Least Significant Difference (95% certainty).

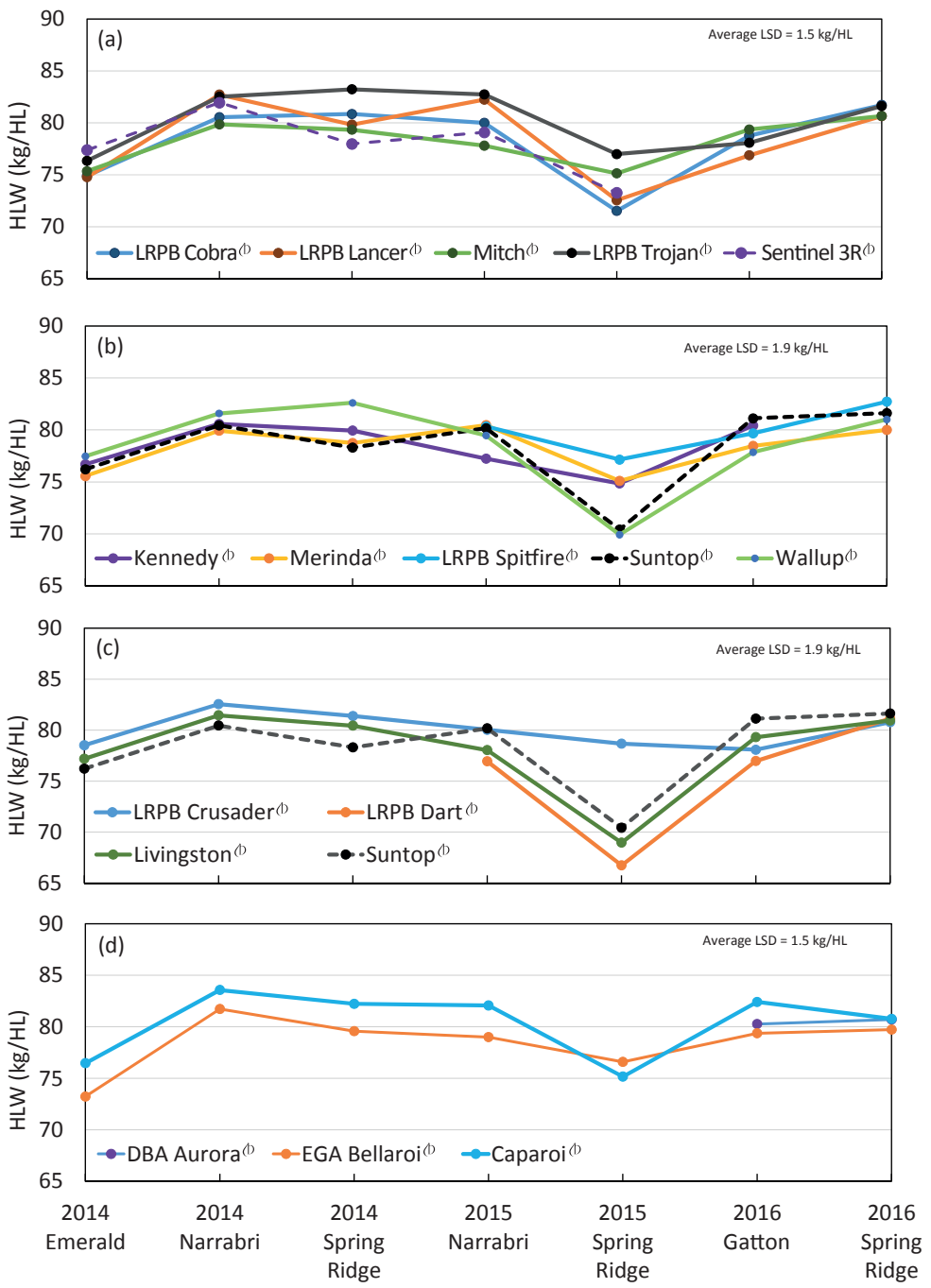
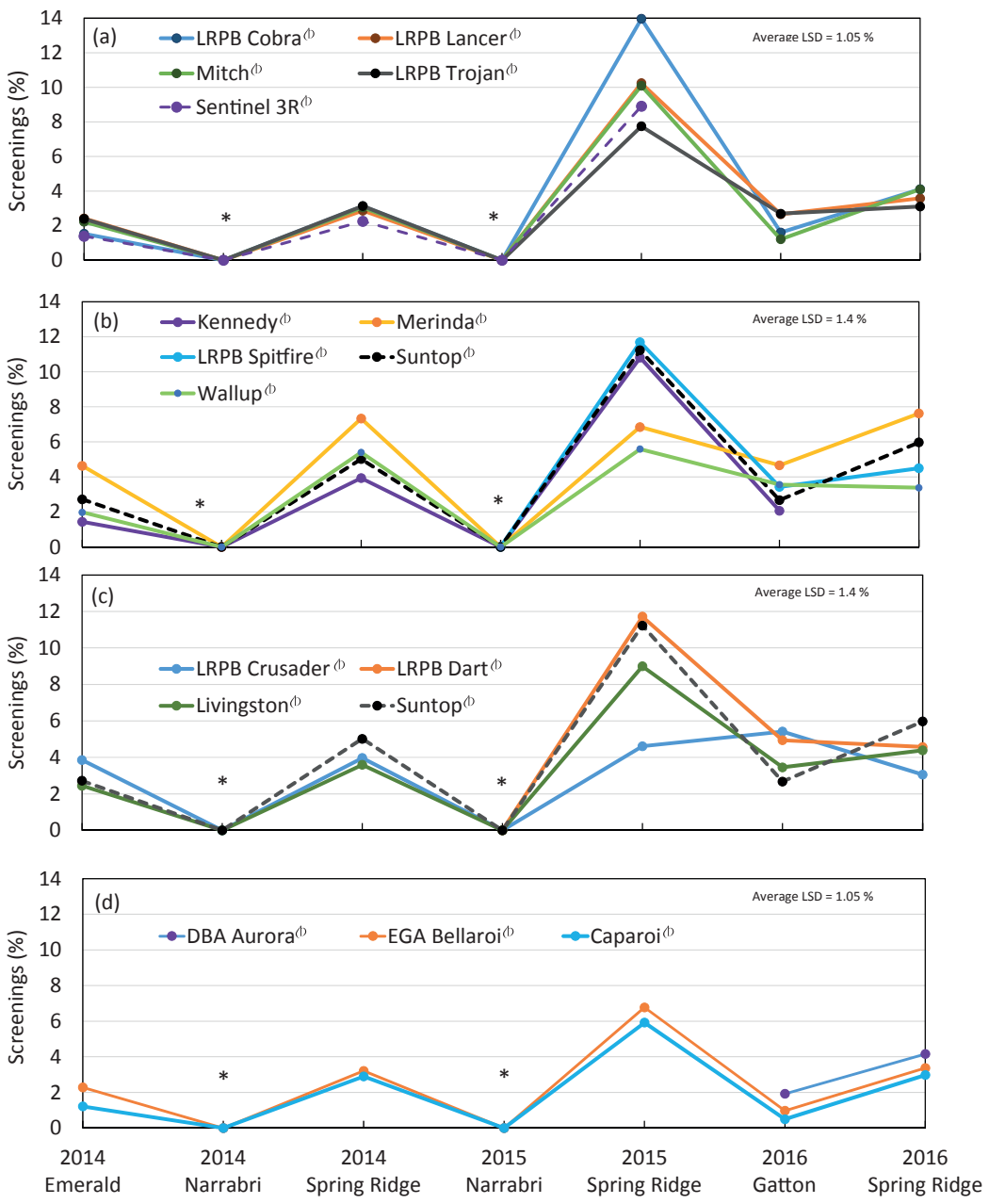


FIGURE 20. Screenings % for selected varieties with a lodging rating between R-MR and MR-MS from variety trials in 2014-2016 (a) longer season varieties (b) medium-quick varieties (c) quick varieties, and (d) Durum varieties.



9. WHAT IS THE BEST SOWING DATE FOR IRRIGATED WHEAT?

KEY POINTS

1. Earlier sowing increased yields by 0.4 t/ha on average with yield gains over 1 t/ha experienced in two experiments, although significant yield decreases were observed in two other experiments. No frosts were experienced at flowering during these trials.
2. Later sowing did not guarantee less lodging. Later sown crops may experience storms at earlier crop stages that are more susceptible to lodging damage.
3. Irrigated crops can take longer to reach flowering than dryland crops especially in dry seasons or regions, which means they can be sown slightly earlier and still flower at the same time as dryland crops.
4. Longer season varieties are typically sown early but tend to be highly lodging susceptible, and growers should reconsider growing such varieties under irrigation.

Sowing date is known to have a big impact on yield in dryland wheat cropping, with earlier sown crops likely to have higher yields as long as frost damage is avoided. However in high yielding wheat production regions such as Europe and New Zealand, early sowing is known to cause increased lodging risk. One of the aims of our project was to determine whether sowing later could be used to decrease the risk of lodging, without reducing yield.

From 2014 to 2016 we tested six of the highest yielding irrigated varieties for yield and lodging on an early and late sowing date, at Emerald, Gatton, Narrabri and Spring Ridge. The varieties were LRPB Cobra$^{\Phi}$, LRPB Trojan$^{\Phi}$, Kennedy$^{\Phi}$, EGA Bellaroi$^{\Phi}$, Caparoi$^{\Phi}$ and Suntop$^{\Phi}$. The first sowing date was between the 13th and 19th of May for all experiments except Narrabri in 2015 where it was delayed until 25th May due to operational difficulties. The second sowing date was eight days later at Gatton, two weeks later for Emerald and Narrabri, and three weeks later at Spring Ridge. The trials were grown using best practice techniques to avoid lodging (in-crop N application in 2014, and in-crop N application in conjunction with PGRs in 2015 and 2016).

On average, a yield gain of 0.4 t/ha was achieved by sowing earlier but it wasn't consistent across locations. As seen in Figure 21, a yield gain of 1 to 1.5 t/ha was obtained from the early sowing date at Narrabri and Spring Ridge in 2015. However, early sowing decreased yield by up to 1 t/ha at Narrabri and Spring Ridge in 2014, probably due to the higher levels of lodging experienced on the early sowing date in these experiments. It is important to remember however that no frost events occurred during the flowering period of these experiments.

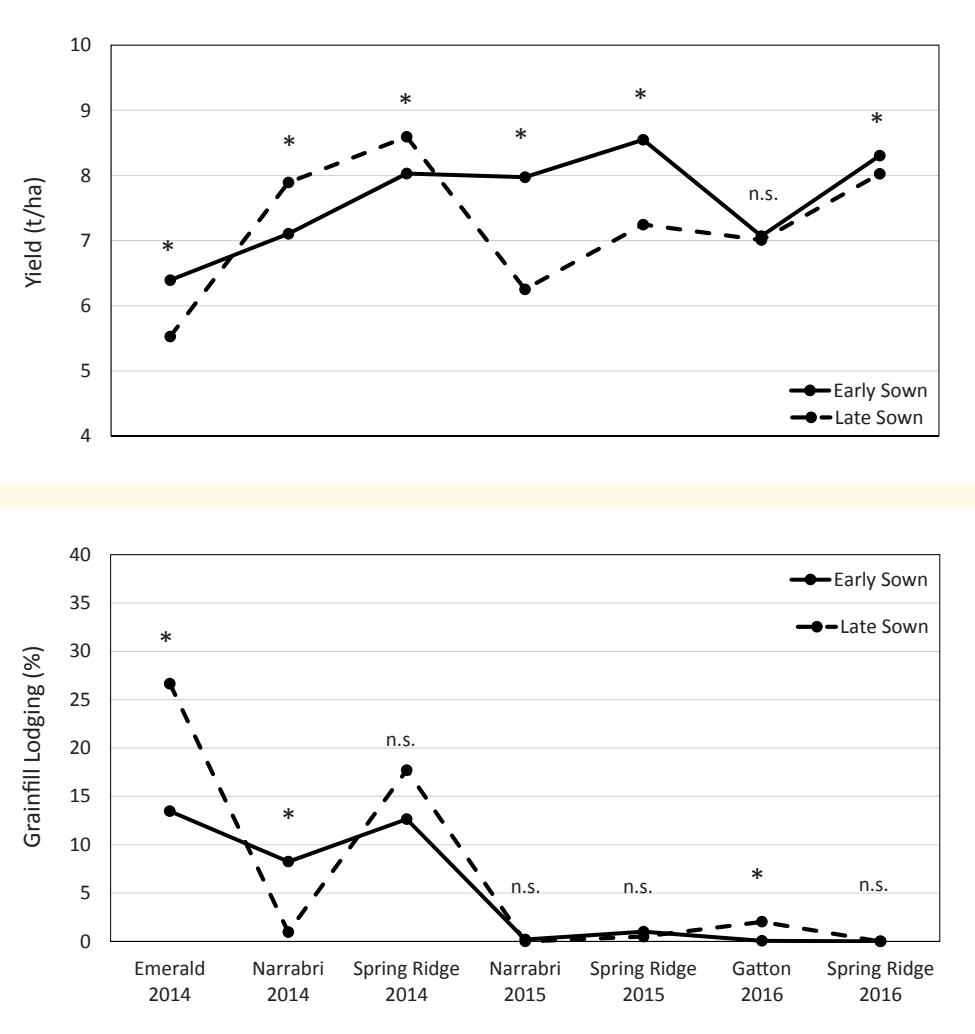
Later sowing did not guarantee less lodging. Significant lodging was only observed at 4 of these experiments (each of the 2014 experiments, and Gatton in 2016). However, it was interesting to observe that the early sowing date only experienced worse lodging in one experiment (Narrabri 2014), while the

late sowing date had significantly worse lodging in two experiments (Emerald 2014, and Gatton 2014). This result was unexpected because early sowing is known to increase lodging risk in high yielding production regions in Europe and New Zealand. Our explanation for this result is that spring storms caused lodging at an earlier stage of grain filling for these late sown experiments, which meant that lodging lasted for a longer period of time while the crop was green, and was therefore measured as being more severe.

Irrigated crops often have delayed flowering date compared to dryland crops, particularly in dry regions and seasons. This means that irrigated wheat can often be sown slightly earlier than dryland crops, and still flower at the same time. The largest differences will be seen in dry environments where water stress speeds up crop phenology of dryland crops while irrigated crops are unaffected.

Longer season varieties tend to be more lodging susceptible. The experiments above were conducted on a limited number of varieties that tended to be quick or medium maturity varieties, with MR-MS lodging risk or better. However, growers should be aware that if they chose to grow longer season, lodging susceptible varieties (see Table 10 in Chapter 8), that early sowing with such varieties would still be considered to have a high risk of lodging.

FIGURE 21. Average yield and lodging of six varieties sown on early and late sowing dates. n.s. = not significantly different. * = comparisons are significantly different with 95% certainty.



10. WHAT IS THE BEST ROW SPACING FOR IRRIGATED WHEAT?

KEY POINTS

1. Growers may get inconsistent results from narrow row spacing in irrigated wheat production
2. No yield benefit was gained by using the 25 cm row spacing when compared to the 38 cm row spacing at Gatton, a warmer short season environment that achieved lower yields. It is possible that 19 cm wide rows could have improved yields at Gatton if they had been tested.
3. When lodging was minimal, the 19 cm row spacing yielded 0.7 t/ha more than the 38 cm row spacing at Spring Ridge.
4. When lodging was severe and PGRs were applied, an increase of 0.4 t/ha was achieved using the 19 cm row spacing at Spring Ridge for five out of six varieties.
5. When lodging was severe and PGRs were not applied at Spring Ridge, the narrow row spacing caused a yield increase or decrease depending on the variety.
6. These results were obtained using a plant population of approx. 100 plants/m^2. Growers should be aware that a higher plant population would increase lodging risk and could cause different outcomes.

Many dryland growers now sow wheat with a row spacing as wide as 38 cm (15 inches), however the project team was often asked if a narrower row spacing can maximise yield in irrigated wheat fields.

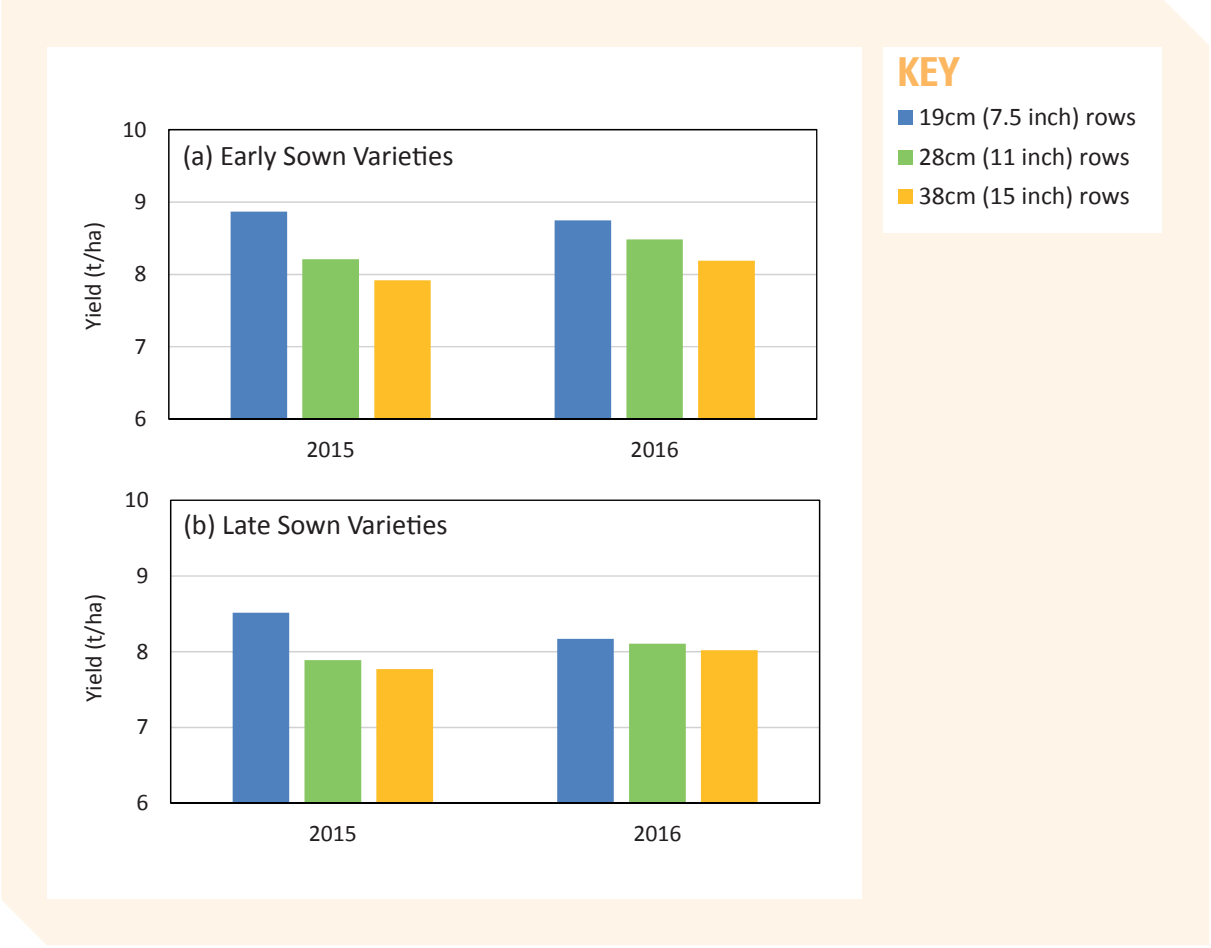
To examine this question, we conducted several row spacing experiments in the final three years of the project at Spring Ridge and Gatton. Alternative row spacings were tested with different agronomic regimes (plant growth regulators and the in-crop N application strategy) on a small number of varieties. Due to experimental limitations, only 25 and 38 cm (10 and 15 inch) row spacings were compared at Gatton, while 19, 28 and 38 cm (7.5, 11 and 15 inch) row spacings were compared at Spring Ridge. The plant population was always 100 plants/m^2, which meant that in the narrow-row crops the in-row plant population was lower (i.e. there were less plants per linear metre of row compared to the wider row spacing, but the same number of plants overall). Varieties were always sown on their recommended sowing date, such that quick maturing varieties were sown on the late sowing date, and long season varieties were always sown on the early sowing date described in Chapter 9. The results of these experiments demonstrated several valuable, general principles.

No yield benefit was observed from 25 cm rows at Gatton, QLD, where lodging was sometimes worse in the narrower rows. This was a surprising result as we had predicted that a short statured, quick maturing variety (such as Wallup$^{\Phi}$) would need a narrower row spacing to achieve maximum yield in a warm, short-season environment such as Gatton. But neither Kennedy$^{\Phi}$, Suntop$^{\Phi}$ nor Wallup$^{\Phi}$ showed a consistent yield benefit from being sown in 25 cm rows, when compared to

38 cm rows in either 2015 or 2016. The average yield of these experiments was 6.8 t/ha. Lodging was rated as mild and was significantly worse in the narrow row treatments when sowing N was high. It is possible that narrower rows (i.e. 19 cm) may have been necessary to provide a yield advantage at this environment, but we weren't able to test this row spacing at Gatton due to equipment limitations.

When lodging was minimal, a significant yield benefit was generally achieved using narrow rows at Spring Ridge, NSW. On average across two low lodging seasons (2015 and 2016) this yield benefit was relatively consistent in the earlier sown varieties (LRPB Lancer$^{\Phi}$ and Mitch$^{\Phi}$), where 28 cm rows had increased yield of 0.3 t/ha compared to 38 cm row spacing, while 19 cm rows had 0.75 t/ha greater yield compared to the 38 cm rows (Figure 22a). In the later season varieties (EGA Bellaroi$^{\Phi}$, LRPB Cobra$^{\Phi}$, LRPB Trojan$^{\Phi}$, Suntop$^{\Phi}$), the yield benefit was mainly confined to one year (2015) and the narrowest row spacing, with an additional 0.7 t/ha obtained from the 19 cm row spacing on average across varieties in 2015, but no significant benefit associated with the 25 cm row spacing (Figure 22b). EGA Bellaroi$^{\Phi}$ appeared to show greater response to the narrow row spacing as it also had a yield benefit of 0.7 t/ha associated with the 19 cm row spacing in 2016, when the other varieties did not. The mean yield of these experiments was 8.25 t/ha. These results were obtained consistently whether PGRs were applied or not.

FIGURE 22. Yield of alternative row spacing treatments at Spring Ridge in 2015 and 2016 when lodging was negligible (a) Average of long season varieties (Mitch$^{\Phi}$ and LRPB Lancer$^{\Phi}$) sown on the early sowing date, (b), average of quicker maturing varieties (EGA Bellaroi$^{\Phi}$, LRPB Cobra$^{\Phi}$, Suntop$^{\Phi}$, LRPB Trojan$^{\Phi}$) sown on the later sowing date.



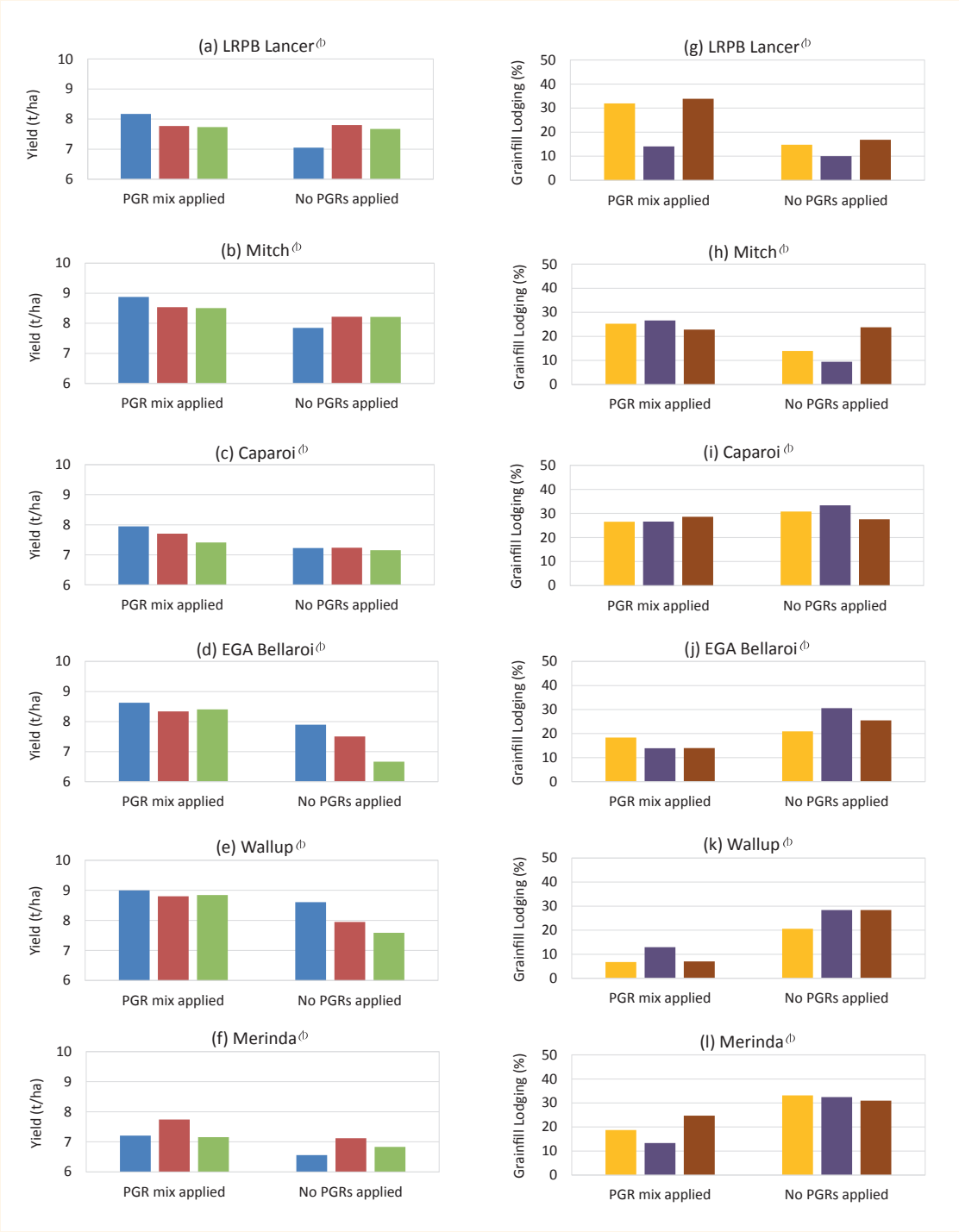
Mixed results were obtained at Spring Ridge in 2014 when lodging was severe. As seen in Figure 23(a,b) in 2014 when lodging pressure was high, 19 cm rows had a significant yield benefit of 0.4 t/ha compared to 38 cm rows when the PGR mix was used in conjunction with Mitch$^{\Phi}$ and LRPB Lancer$^{\Phi}$. As previously discussed in section 6.2, this was the comparison where we observed the unusual situation where lodging was worse when PGRs were applied. However when PGRs were not applied, there was actually a yield decrease of 0.5 t/ha associated with narrower rows for Mitch$^{\Phi}$ and LRPB Lancer$^{\Phi}$. Caparoi$^{\Phi}$ also showed improved yield as rows became narrower (Figure 23c) when PGRs were applied, but showed no response to row spacing when PGRs were not applied.

EGA Bellaroi$^{\Phi}$ and Wallup$^{\Phi}$ had different response patterns (Figure 23 d,e). While they showed a small yield gain associated with narrow row spacing when PGRs were used, they showed a larger yield gain when PGRs were not used, and this was associated with decreased lodging in the narrow row spacing (Figure 23 l,j). Merinda$^{\Phi}$ (Figure 23 f,k) had different response patterns to all the other varieties, having better yield when grown with the intermediate (25 cm) row spacing regardless of whether PGR's were used.

Why do the results vary between locations, varieties and with the severity of lodging? This is a difficult question to answer, but we have several possible explanations. One reason is that while lodging affects yield, it should be remembered that the reverse is also true. That is, yield can affect lodging, because a higher yielding crop is more at risk of lodging due to the increased weight at the top of each plant. This means that when changes in agronomic management improve yield potential (e.g. N fertiliser timing, row spacing, PGR application) the crop may eventually get to a tipping point where it lodges and yield begins to go down. Each variety differs for its lodging risk, so these agronomic changes 'interact' with the genetic factors that make each variety unique, and cause complex patterns of yield performance that are known as genotype x environment x management interaction (or GxExM).

In practical terms, it's difficult to assess the reasons for GxExM in terms we can understand without conducting detailed experiments. It could be that certain varieties are more susceptible to lodging on a wide row spacing because they develop greater lodging susceptibility based on their proximity to nearby plants in the same row. Other varieties may be more likely to lodge when their tillers are forced to stretch higher as they compete with other tillers for more sunlight, on a narrow row spacing. Some varieties might lodge more heavily when grown on a wide row spacing because there are less tillers surrounding each plant to prevent it from falling into the inter-row gap. These ideas are just theories, which if correct could interact with different growing season conditions in a way that means the response patterns might never be fully understood.

FIGURE 23. Yield (a-f) and grain fill lodging (g-l) of six varieties grown using different row spacing at Spring Ridge in 2014, when lodging was severe.



11. FURTHER READING

Communication publications

1. Peake A.S. (2016). **Practical suggestions for irrigated wheat growers: Lessons from eight years of on-farm research.** In Proceedings of the CCA AGM & Cropping Solutions Seminar, Moree, 4-5 May, 2016.

2. Peake A.S., Gardner, M., Bell, K., Poole, N., (2016). **The effect of sowing date, variety choice and N application timing on lodging risk and yield of irrigated wheat.** In GRDC Northern Region Grains Research Updates, Goondiwindi, 1-2 March, 2016

3. Peake A.S. and Fainges, J. (2015). **Understanding Lodging in Wheat: How to Measure it and Avoid it**. In Proceedings of the CCA AGM & Cropping Solutions Seminar, Griffith, 13-14 May, 2015.

4. Peake A.S., Gardner, M., Bell, K., Poole, N., Fainges, J. (2015). **Irrigated wheat agronomy x variety trials: 2014 Trial Update.** In GRDC Northern Region Grains Research Updates, Goondiwindi, 3-4 March, 2015.

5. Peake A.S., Gardner, M., Poole, N., Bell, K. (2014). **Beyond 8 t/ha: varieties and agronomy for maximising irrigated wheat yields in the northern region.** In: John Cameron (Ed), GRDC Adviser Updates 2015, Coonabarabran and Goondiwindi. ICAN Rural; 267-277.

6. Sykes, J, (2012). **Irrigated Wheat Best Practice Guidelines In Cotton Farming Systems.** Cotton Catchment Communities CRC and the Grains Research and Development Corporation. ISBN: [978-0-9872308-1-2] *http://www.cottoninfo.com.au/sites/default/files/documents/Irrigated_Wheat_publication.pdf*

7. Wigginton (Ed.) (2013). **Waterpak – a guide for irrigation management in cotton and grain farming systems.** Cotton Research and Development Corporation. ISBN: 1 921025 16 6. *http://www.insidecotton.com/jspui/handle/1/555?mode=full*

Scientific Publications

8. Peake, A.S., Bell, K.L., Carberry, P. S., Poole, N., Raine, S. R. (2016). **Vegetative nitrogen stress decreases lodging risk and increases yield of irrigated spring wheat in the subtropics.** Crop and Pasture Science, 67, 907-920.

9. Peake, A.S., Carberry, P.S., Raine, S.R., Gett, V., Smith, R.J. (2016). **An alternative approach to whole-farm deficit irrigation analysis: evaluating the risk-efficiency of wheat irrigation strategies in subtropical Australia.** Agricultural Water Management 169, 61-76.

10. Peake, A.S., Huth, N. I., Carberry, P. S., Raine, S. R., & Smith, R. J. (2014). **Quantifying potential yield and lodging-related yield gaps for irrigated spring wheat in sub-tropical Australia.** Field Crops Research, 158, 1-14.

11. Peake, A. S., Das, B. T., Bell, K. L., Gardner, M., Poole, N. (2017). **Do long season wheat cultivars maximise yield potential under irrigation in subtropical Australia?** Proceedings of the 18th Australian Agronomy Conference, Ballarat, Victoria.

ACKNOWLEDGEMENTS

We gratefully acknowledge the farmers of Australia who have provided much of the funding for this research through the Grain Research and Development Corporation. Funding from the Australian Federal Government and CSIRO is also gratefully acknowledged.

Northern region growers & agronomists are gratefully acknowledged for hosting experiments on farms and assisting with on-farm demonstration trials. In particular we would like to thank Greg Giblett, Derek Gunn, Angus Murchison, Gus Hamilton, Greg Hamilton, Tim Richards, Jamie Street, Peter Haslem, Jim Hunt, Hamish and Fraser Bligh, Drew Penberthy, Paul Castor, Jeremy Dawson, Graham Spackman, Jamie Iker, Josh Bell, Phil Lockwood, Steve Madden, Peter McKenzie, Bede Omara, Russel Wood, Ed Offner and Trevor Philp. These gentlemen assisted with field monitoring and farm visits and/or answered numerous questions to assist in constructing simulation scenarios that were relevant to growers of the northern grains region. Feedback from John Lacy, Dr Andrew Fletcher (CSIRO) and Douglas Lush (DAFQ) on the final draft of this best practice guide was also gratefully appreciated.

Statistical support from Michael Mumford (DAFQ) was helpful, professional, and vital to the success of the project. Additionally, Douglas Lush and Don Baills at DAFQ offered support each year tracking down seed stocks for hard-to-find varieties. We also thank Geoff Moore (National Variety Trials), Jon Hunt and Rob Presser (Kalyx Australia), Pauline Twidale (Pacific Seeds), Longreach Plant Breeding, Australian Grains Technologies, Gururaj Kadkol (NSWDPI), and Jason Able (Durum Breeding Australia and University of Adelaide) for their assistance in sourcing seed, often at short notice.

Technical support from Andy Hundt, CSIRO Narrabri was greatly appreciated, as was that of Steve Soderquist, Phil van Drie, Ryan Kearns, Greg Roberts and Terry Collins at CSIRO Gatton. Farm staff at the NSWDPI Breeza Research Station, the University of Sydney Plant Breeding Institute at Narrabri, and the DAFQ farms at Emerald and Kingsthorpe were also very helpful in conducting field experiments. The patient assistance of CSIRO Technical Staff in Toowoomba (John Lawrence and Ainsleigh Wixon) was also greatly appreciated.

CONTACT INFORMATION

If you have questions on the topics discussed in this publication, or any other questions regarding irrigated wheat production, please contact **Dr Allan Peake** at:

Email: **allan.peake@csiro.au**
Office: **07 4571 3212**
Mobile: **0429 881 137**

CSIRO

Australian Government
Grains Research and Development Corporation

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION