

Irrigated Wheat

Best Practice Guidelines
In Cotton Farming Systems



PRODUCED BY



IN PARTNERSHIP WITH



Department of
Primary Industries



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MAJOR REFERENCES

***Cereal Growth Stage Guides. There are two guides. The booklets are: Cereal Growth Stages (published September 2005) and Disease Management and Crop Canopies (published June 2009).

The booklets are designed to give growers greater confidence in identifying the important cereal growth stages and how they relate to the principles of disease management and canopy management. They can also be used to time the application of nitrogen fertiliser and plant growth regulator as recommended in this publication.

Cereal growth stages (GS) are used extensively in this publication.

To order each of the publications, please contact Ground Cover Direct - Freephone 1800 11 00 44.

To review go to:

- www.grdc.com.au/GRDC-Guide-Disease-Management-Crop-Canopies
- www.grdc.com.au/GRDC-Guide-Cereal-Growth-Stages

****NSW DPI Farm Budgets and Costs

The type of budget provided is the gross margin budget. Farm Enterprise budgets provide a guide to the relative profitability of similar enterprises and an indication of the different management practices used.

To review go to:

- www.dpi.nsw.gov.au/agriculture/farm-business/budgets

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A man wearing a light-colored hat and a blue and white checkered shirt is kneeling in a lush green wheat field. He is holding a small piece of wheat in his hands, inspecting it. The wheat stalks are tall and dense, with some showing signs of lodging (falling over).

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introduction

Research and extension projects were undertaken between 2007 and 2011 in partnership between: NSW Department of Primary Industries (NSW DPI), Cotton Catchment Communities CRC, DAFF Queensland, Grains Research & Development Corporation (GRDC), CSIRO, the Foundation for Arable Research (NZ) and Griffiths Agriculture.

The major projects were High Yielding Irrigated Grains in Cotton Farming Systems (HYIGCFS) and Achievable Yields (AY). Key recommendations have been developed from these projects to manage plant growth and to reduce the risk of lodging.

The HYIGCFS project focused on low soil-N (soil nitrogen) paddocks sown to wheat straight after cotton; while the

AY project focused on high soil-N/long fallow paddocks (similar to what was witnessed in 2008 when paddocks lodged badly).

This booklet has been compiled by the project supervisor John Sykes (contracted with NSW DPI) in collaboration with a number of northern NSW and Qld researchers: Brendan Griffiths (Griffiths Agriculture), Verity Gett, Rod Jackson, Tim Burley (NSW DPI), Graham Harris, Jose Payero (DAFF Queensland), Allan Peake (CSIRO), Nick Poole (Foundation of Arable Research NZ). It represents an opportunity taken to document research and commercial experience (since 2007) into the first set of best practice guidelines for irrigated wheat in cotton farming systems.



Sowing wheat into a trashy cotton stubble seed bed. 2008 Farm case study. **Photo V.Gett**

background

Planting cotton as a rotational crop with winter cereals (often wheat) is common practice in the northern growing region.

As early as 1998/99 a cotton grower showed that 70% of growers utilised a 1:1 or 2:1 cotton/wheat rotation. Since then the area sown to wheat has fluctuated depending on water availability, price received for cotton and wheat and disease management requirements. Overall crop yields have been low and inconsistent and growers have achieved poor profitability and reduced disease control in following cotton crops.

Before 2007, very little research had been done to develop management guidelines for irrigated wheat in the northern region. Irrigated information had been traditionally sourced from southern NSW. However, with the northern region being climatically different, that data was not entirely relevant. For example; the start to the northern autumn is milder and conducive to early vegetative growth (tillering). Spring is warmer with a shorter grain-fill period resulting in an increased demand for late-season nutrients and water.

In 2008, NSW was in the midst of a serious drought. A combination of low cotton prices and low water allocations along with high wheat prices ultimately saw cotton growers swapping to high-yielding irrigated wheat on their fallowed paddocks.

During the 2008 season many growers encountered a very wet establishment period, and many crops

were sown after a long fallow. Once these crops were watered-up in a high soil nitrogen (high-N) environment, most varieties performed poorly. A large percentage of crops produced massive biomass that was not transferred into grain yield (as a result of lodging) and large economic losses were suffered.

Researchers used a combination of on-farm monitoring, small plot trials, and computer modelling with the Agricultural Production Systems Simulator (APSIM) model to maximise yields. Computer modelling indicated that yields of 8t/ha are regularly achievable with a quick-maturing variety (such as Kennedy[®]) across most of the northern region (*Table 7*) but stipulates that this “does depend on weather conditions during a given year”.

Since 2007, some commercial crops have recorded high yields (8t/ha plus at Walgett, Springsure and Brookstead) to demonstrate lodging can be effectively managed.

Additionally, trial plots of wheat grown at the Agricultural Cotton Research Institute (ACRI) have yielded greater than 9t/ha in 2011.

It is now known that there are different but critical management decisions for growing high yielding irrigated wheat in high or low soil nitrogen paddocks. The key is to know the paddock’s starting soil-N level, and to then adjust water and nitrogen availability during the growing season.



Planting wheat following a fallow, 2008. Photo V.Gett

key project recommendations

The following are critical management findings that have been identified from recent research projects.

1. SOIL-N LEVEL

KEY POINT It is essential to conduct a nitrogen soil test in April/May before sowing. (See Appendix 1).

- Long fallow paddocks with high soil-N require careful management of canopy growth from establishment to avoid lodging
- Paddocks sown straight after cotton (low soil-N) are ideal to target maximum yield and manage early season canopy

2. ROW SPACING

KEY POINT 30cm row spacing is ideal (6 rows on a 1.8 metre bed).

- 15cm or 45cm row spacing (4 or 12 rows on a 1.8m bed) have, in small plot trials, yielded significantly less than 30cm spacing.



3. PLANT POPULATION

KEY POINT A population of 100-150 plants per square metre of bed or hill area is ideal in the northern region.

- Plant populations in irrigated paddocks are measured only on the hill or bed area. (See calculating plant populations page 7).
- Low plant populations of 50-100 plants per square metre of bed can achieve high yield levels but plants do not establish evenly.



4. SEEDBED PREPARATION

KEY POINT Seedbed preparation has a significant impact on seedling emergence and therefore yield potential.

- Planting into adequate soil tilth is critical.
- Every cotton seedbed must be pupae-busted after harvest.
- Tillage is then required to prepare a new seedbed that is free from clods and cotton stubble.
- The type of machinery used and the number of cultivations depends on the soil type and its structure.
- Prepare a seedbed that is in optimum condition for seed placement and emergence.

5. PLANT ESTABLISHMENT

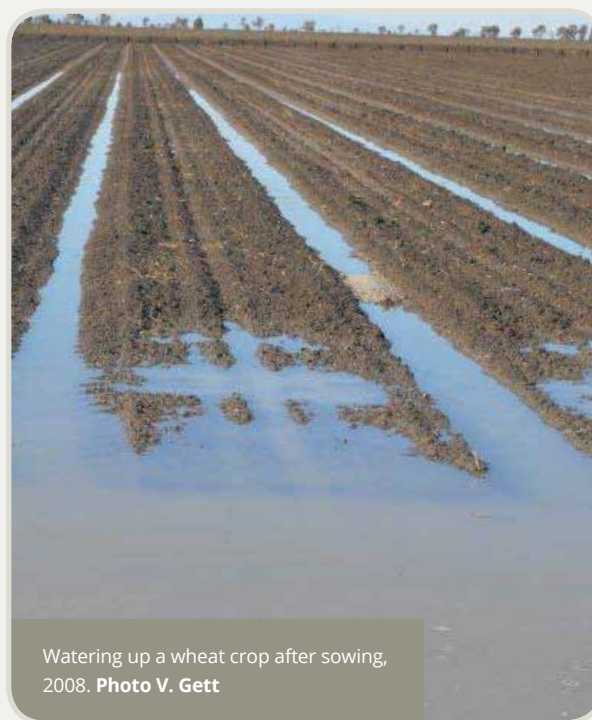
KEY POINT Once cotton harvest/bed preparation has been completed the best establishment scenario is a rain event that will provide sowing moisture, initiate seed germination and seedling.

This scenario is ideal in that it provides the best opportunity to achieve high yields (particularly if starting soil N levels are low). In this situation a uniform plant stand can be achieved; and the grower can then manage early season canopy growth and allow an irrigation to ensure secondary root development.

- Pre-irrigation is risky due to the need to delay sowing if rain occurs. However, establishment may be better in a pre-irrigated paddock than a paddock that is dry-sown and watered-up.
- If the profile is completely dry at sowing the only option is to plant shallow and water-up. This is the least desirable option, particularly if starting soil-N levels are very high.

Often, in the water-up situation, plants still do not achieve secondary root growth and require further irrigation during tillering- which may create

excessive early season biomass. This can create a crop that is predisposed to lodging, particularly if the starting nitrogen levels are in excess of the plant's requirements.



Watering up a wheat crop after sowing, 2008. Photo V. Gett

6. VARIETY CHOICE

KEY POINT On average durum wheat has consistently yielded 1t/ha higher than bread wheat in northern irrigated wheat trials (where the only irrigated research has been carried out on low soil-N sites).

- Durum varieties such as Bellaroi[®] and Caparoi[®] provided the highest yield potential and lodging resistance in 2011.
- Durum variety Hyperno[®] has high yield potential, but in trials demonstrated that it was prone to lodging.
- Quick maturing varieties such as Kennedy[®] and Longreach Crusader[®] are the most likely APH

(Australian Prime Hard) bread wheat varieties to achieve high yields, although Longreach Crusader[®] has shown significantly more lodging resistance than Kennedy[®] in high-N paddocks.

7. WATER BUDGETING

KEY POINT When undertaking a water budget; determine plant available water to a soil depth of 90cm.

- To maximise yield the wheat crop (from stem elongation stage) should access its entire soil water requirement from a soil depth of 90cm only.
- Depending upon in-crop rainfall, maximum yield may require between 3 to 5 subsequent spring irrigations.

8. SECONDARY ROOT GROWTH

KEY POINT The largest early season issue in the northern growing region is achieving adequate secondary root growth, post-sowing.

- Soil moisture status should be assessed at 25-30 days after emergence, and if necessary, a winter irrigation applied to ensure healthy secondary root development. However this is a management technique only to be used in low soil-N paddocks.
- Early secondary root development will enhance water and nutrient uptake.
- Dry soil moisture below the sowing depth of seed will prevent the growth of secondary roots.

9. SPRING IRRIGATION

KEY POINT Identify the fields' refill point to schedule irrigations and minimise water stress.

- Use of soil moisture monitoring equipment is recommended. Soil moisture data will help identify the refill point (usually when 50 per cent of plant's available water has been depleted) and allow irrigations to be timed between stem elongation (GS31) and the mid-dough stage (GS80) to minimise crop stress.
- At the mid-dough stage, soil moisture needs to be re-assessed to determine if a further irrigation is required.
- Correct timing of the last irrigation will ensure adequate grain fill and reduce the risk of lodging and harvesting delays.



A capacitance probe used in irrigation scheduling trial ACRI 2011 to schedule spring irrigations and measure water use. ACRI 2011. Photo V. Gett

10. LIMITED WATER AVAILABILITY

KEY POINT The best timing for a single in-crop irrigation of around 1 ML/ha is at early to mid-stem elongation.

- While head emergence is the most sensitive growth stage to a short severe water stress, the best timing for a single irrigation is one that spreads available water across 2-3 plant growth stages.

11. AVAILABLE SOIL PHOSPHORUS AT SOWING

KEY POINT In low soil-N post-cotton paddocks, starter fertiliser containing phosphorus will improve establishment.

- Sample representative paddocks to determine starting soil-N and P (N at 90cm depth, P at 20cm).
- For wheat grown after cotton use 10-20 kg P/ha as starter-fertiliser.

12. NITROGEN APPLICATION STRATEGY

KEY POINT At least 275 kg N/ha is required to grow 8t/ha of wheat.

- The success of nitrogen application depends on soil type, irrigation system, sowing soil moisture and rainfall and temperatures received at tillering.
- The minimum sowing soil-N required to achieve maximum yield varied in trials from 15 to 120 kg N/ha measured to a depth of 90cm.
- Nitrogen can be split-applied in low soil-N paddocks (some fertiliser will be required at sowing)
- In high-N soils nitrogen fertiliser requirements are more safely applied at stem elongation (growth stage 31) - ideally before a rainfall or irrigation event.

13. USE OF PLANT GROWTH REGULATORS (PGRS)

KEY POINT Use of PGRs is still being researched for wheat.

- PGR's have been effective in research trials when one application has been applied at stem elongation (GS31).
- PGR use is recommended in high soil-N paddocks when canopy growth is excessive.



Irrigated grains variety and irrigation frequency trial ACRI - irrigated and dryland plots replicated across the field. Photo V. Gett

- Carefully check label registration and follow label instructions.
- Alternative products may soon be available.
- Further research is required on single (versus split) application in combination with delayed N strategy.

14. DISEASE MANAGEMENT

KEY POINT The profitability of fungicide application increases in high-yielding irrigated wheat.

- A pre-planned strategy of fungicide application based on growth stage and emergence of the top three leaves provides greater margin returns when susceptible wheat cultivars are subject to disease.
- Where disease onset is early or where susceptible cultivars are grown with no up-front protection an application at GS31-32 may be needed. One application at GS39 may be sufficient.
- Consider an additional ear-emergence fungicide where stem rust (*Puccinia graminis*) is the primary disease target.
- Consider a first-flower spray where wheat or durum is at high risk of Fusarium head blight.

+ Calculating plant population on irrigation beds or hills (see key point 2):

For a 50 hectare block: select 6 common areas which are 25 metres in from the northern head ditch, southern head ditch, northern tail drain, and southern tail drain.

A 50 cm length on a 2 metre bed will give you a plant population for 1 square metre.

Total and average the samples to obtain plant population (plants per square metre).

If the bed width is 1.8 metres, reduce the average figure by 10%.

management checks

Once the decision is made to grow irrigated wheat, then management should focus on reducing the risk of lodging and maximising grain yield. A checklist is provided below to review if the crop is on target during the growing season.

Note: water and nitrogen application can be altered or managed differently during the season if a yield target needs to be adjusted from maximum (6-9t/ha) to reduced (<6t/ha) or vice versa.

Issue*	Management Check	Maximum Yield Checks	Reduced Yield Checks	Further Information Section*
Economics	- commodity price	High	Low	1
	- water availability	Full (5ML)	Low (2ML)	1/3
	- \$return/ML ****	High	Low	1
Paddock Suitability				
	- rotation requirement (cotton)	High	High	2
	- available soil nitrogen**	Low	High	1/2/4
	- available water (subsoil)	Good	Low	3
	- sowing moisture (topsoil)	Good	None	2
Seedbed Preparation				
	- lodging resistance (variety)	Good	Poor	2
	- furrow preparation	Good	Poor	3
	- seedbed preparation	Good	Poor	3
Plant establishment				
(GS10)***	- plant population+	100-150	50-100	2
	- winter irrigation	High	Low	3
Nitrogen and Irrigation				
(GS20)	- tiller number	300-500	<300	2/4
(G23)	- nitrogen application	maximum	reduce	1
(GS23-32)	- PGR	Possible	Unlikely	2/4
(GS35-45)	- spring irrigation	3-5	1-2	3
Disease Management				
(GS31)	- disease check (MR varieties)	Good	Poor	5
(GS39)	- fungicide application	1	1	5
(GS59)	- disease check	1		5

*See the relevant sections for more detailed information **See hints for interpreting soil N tests in the northern region - Appendix 1

See GRDC website for Cereal Growth Stages and Disease Management and Crop Canopies *See NSW DPI Farm Budget and Costs website

+See calculating plant populations on beds or hills page 7.



Example of planters set up to sow irrigated wheat into cotton stubble.
Photos V. Gett

irrigated wheat best practice guidelines

in Cotton Farming Systems

These guidelines are based on growers achieving maximum irrigated wheat yields (8t/ha plus).

Management adjustments to control lodging can be made prior to and during plant growth. A checklist has been provided on page 9 that is based on paddocks that have low soil-N (wheat grown straight after cotton harvest) or where there is high soil-N (wheat grown after a long fallow).

KEY POINT A paddock management strategy starts with soil testing for soil nitrogen in April/May each year.

See soil testing guidelines for nitrogen availability in Appendix 1.



Irrigated grains project field walk
Goondiwindi trial site 2008. Photo V. Gett



Brendan Griffiths,
Griffiths Agriculture



Tim Burley,
NSW DPI

1. nitrogen application

The most critical best practice guideline is to ascertain the paddock soil nitrogen level prior to planting irrigated wheat. Soil testing to 90cm for total shallow N (180cm for total deep N) is a practice that must be carried out. (See Appendix 1: Hints for interpreting N tests in the northern region). It is essential information from which realistic yield targets can be aimed at, and also vital to determining the amount and timing of nitrogen applied to the crop.

Case studies have shown a range of residual soil nitrogen levels in the northern region cotton / wheat system (Figure 9). A review of historical soil testing data has also confirmed the variability in residual soil nitrogen. Figure 1 represents soil test data for nitrogen (total N samples taken at 0-90 cm) collected from over 140 irrigated fields within the northern growing region during the period 2000-2010. Nitrogen levels present in these fields were highly variable ranging from as low as 18 kg N/ha and up to as high as 511 kg N/ha.

However there are two common scenarios of soil nitrogen availability in cotton paddocks:

1. Nitrogen will be required to be added to satisfy crop requirements.

2. Residual soil nitrogen levels will be in excess of crop requirements.

Fertiliser nitrogen is required to satisfy target yield

If yield target is maximised for wheat at 8t/ha plus, research has shown total crop requirements to be in excess of 275 kg N/ha of nitrogen (see Table 1).

As a guide aim to have 50-120 kg N/ha available at sowing, when targeting maximum yield. This can be either stored soil-N, applied fertiliser-N, or a combination.

To target maximum yield (8t/ha) a low soil-N paddock is ideal, principally because of the capacity to manage early season crop canopy.

If soil available N is low (<50 kg N/ha) – which is often the case when there is no fallow after cotton - then a higher level of starting nitrogen (120 kg N/ha) at sowing may be best for achieving maximum yield.

The remaining 80-150 kg N/ha can be applied at stem elongation (GS31) and 50 kg N/ha at flag leaf emergence (GS41).

In a cotton/wheat system there is a tight time-frame between the end of the cotton crop and the optimum planting date for irrigated wheat.

TABLE 1: Mean grain yield (t/ha) at 164 days after sowing (DAS) for 2011 nitrogen trial in wheat cv. Hyperno^b

No.	Treatment	Yield (t/ha) 164DAS	
1	Urea @ 385 kg/ha (177 kg N/ha) at Z31	6.6	D
2	Urea @ 385 kg/ha (177 kg N/ha) at planting	8.1	B
3	Urea @ 231 kg/ha (106 kg N/ha) at planting, urea @ 154 kg/ha (71 kg N/ha) at Z31	7.7	C
4	Urea @ 770 kg/ha (354 kg N/ha) at planting	9.4	A

p value: 0.000 LSD (P=0.38) Standard Deviation: 0.24 CV: 2.98

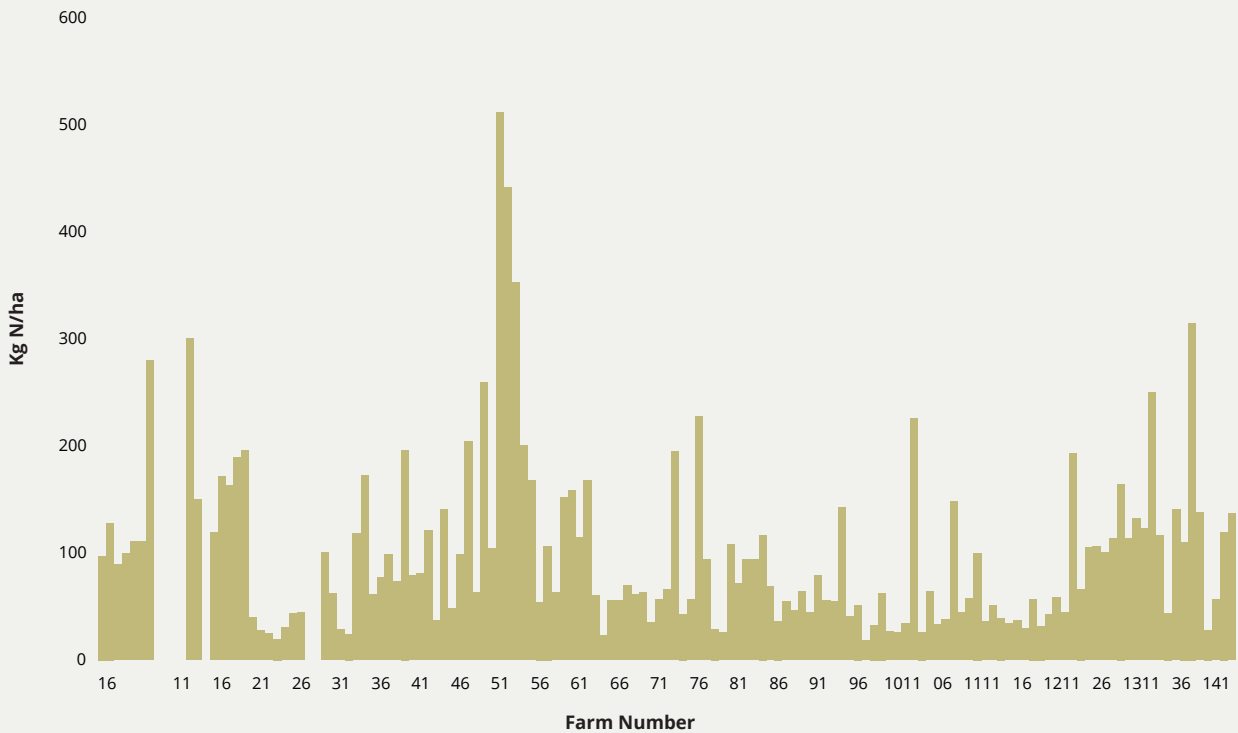
Source: B. Griffiths

Means within columns followed by the same letter are not significantly different at the 5% level according to least significant difference (LSD) test.



Farm case study 2008 - Irrigated wheat field with severe lodging as a result of a long fallow/high residual N situation. **Photo V. Gett**

FIGURE 1: Soil test data for nitrogen (total N samples 0-90 cm) collected from over 140 irrigated fields in the northern growing region 2000 - 2010.



Source: B. Griffiths Graph: T. Burley

Residual soil nitrogen is highly variable and is dependent on such factors as fertiliser strategy used in cotton crop production, baseline soil fertility, fallow length and rotation choice.



Nitrogen timing trial Narrabri
ACRI 2011. Photos B. Giffiths

There is often insufficient time to prepare a seedbed and so the option to pre-plant nitrogen is not available. Additionally as nitrogen (in excess of 20 kg N/ha) cannot be applied close to wheat seed (seedling burn) using a specialist nitrogen applicator rig at sowing is not practical. This means the options to apply nitrogen around sowing are:

1. Spreading: nitrogen may be applied as urea, spread on to the soil, post-sowing. This is often the cheapest and most practical method of applying N. Urea requires incorporation by rainfall within days of sowing (as urea is prone to loss as a result of volatilisation). Urea may be made less prone to volatilisation through the addition of products such as urease inhibitors (green urea).
2. Applying liquid nitrogen to the soil surface: there are various nitrogen based liquid fertilisers that may be applied to the soil surface - the majority require incorporation via rainfall. Products such as ammonium nitrate are less prone to volatilisation on grey and black clays. Ammonium nitrate is still available commercially in liquid form, although the solid granular form is no longer commercially available in agriculture.
3. Using overhead or subsurface irrigation to apply smaller amounts of irrigation and nitrogen during early crop growth.
4. Applying water-run urea or anhydrous ammonia in a flood irrigation system. This is an effective way of delivering in-crop N requirements, however any irrigation prior to or at sowing may reduce plant population. Additionally if in-crop rainfall is high, the crop may not be irrigated at the optimum time to ensure nitrogen availability when it is needed the most (stem elongation).

Residual soil nitrogen level is in excess of requirements for target yield

Prepared and/or fertilised fallow paddocks not planted to cotton can have excessive N levels. If maximum yield is targeted, nitrogen availability must be carefully managed. High soil-N will contribute to excessive early canopy growth and increase the risk of lodging. Residual soil nitrogen levels (above 275 kg N/ha) can be well in excess of crop nitrogen requirements. Project paddock surveys have shown residual soil nitrogen levels can at times be in excess of 500 kg N/ha (see *Figure 1 and Figure 9*).

If both nitrogen and plant-available-water are in excess of crop requirements at the vegetative stage crop lodging can be a problem.

In this situation the following management strategies can reduce the risk of lodging:

1. Apply no further N in crop.
2. Use irrigation management to manipulate canopy growth. Restrict irrigation water availability until stem elongation (GS31). Without rain this will reduce early season growth of biomass and tillers that contribute to crop lodging.
3. Use a plant growth regulator (PGR) at stem elongation (if irrigation management is not available as the only other option to minimise the impact of excessive early season vegetative biomass and tillering).

The nitrogen application strategies above must be used in combination with establishment and canopy management guidelines as a package to reduce early season growth and therefore lodging risk.



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2. establishment

Correct variety choice

Varietal performance will vary from year to year. For maximum yield potential (8t/ha plus) choose a variety with the best combination of yield potential, grain quality and disease resistance (see *annual Winter Cereal Management Guide–NSW DPI*).

There is little independent data on varietal performance under irrigation. Trial results from 2010 and 2011 showed significant differences between varieties with durum wheats averaging 1 tonne/ha higher in harvested grain yield than bread wheats (see *Figures 2a, 2b*).

Review available moisture, soil tilth, and planting equipment

Seedbed preparation and sowing method has a significant effect on seedling emergence and yield potential, particularly when watering-up.

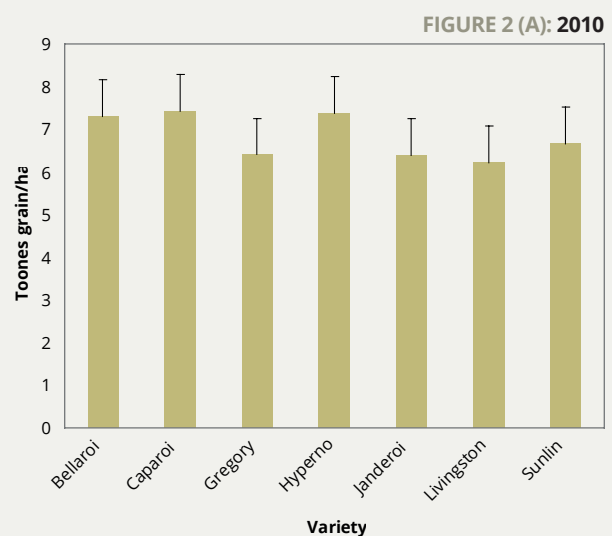
Following cotton (or another summer crop) the biggest challenge is having time to prepare a seedbed, and plant. All seedbeds must have tillage (after cotton root cutting and pupae destruction) to reduce clod size and improve seed to soil contact. The best establishment will occur when wheat is sown into moisture after rainfall. Pre-irrigation is not recommended. Irrigate up only to ensure optimum sowing time.

Case studies in 2008 identified establishment as being highly variable on cotton farms. When plant population was recorded across 25 on-farm research sites (Namoi Valley) the average establishment was 64%; with some sites as low as 30% and some as high as 90%. The constraints were identified as watering-up and spreading seed instead of planting.

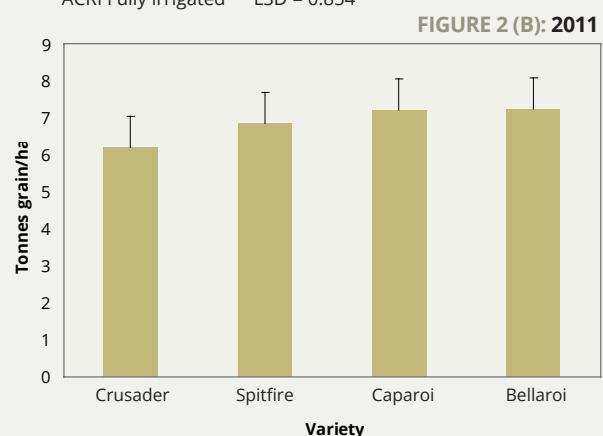
If available; planting equipment (tyne or disc) must have effective depth control and be calibrated to determine where and how much seed is being sown. Aim for an even germination through effective planter set-up, and adjust for soil conditions when sowing.

Research on the Liverpool Plains in 2011 showed that when irrigating-up after cotton (in a cloddy seed bed) durum wheat establishment was reduced by over 50%. This was not the case with bread wheat, where population increased when irrigating up (see *Table 2*).

FIGURE 2: Irrigated Grains Variety Trial ACRI



Source: V. Gett Irrigated Grains Variety Trial 2010
ACRI Fully irrigated LSD = 0.854



Source: V. Gett Irrigated Grains Variety Trial 2011
ACRI Fully irrigated LSD = 0.84

Variety trial ACRI 2010 demonstrating varying maturity dates of varieties. Sunlin approx. 10 days behind. **Photo V. Gett**



Establishment trial following cotton Federation Farm, at Narrabri 2008 - poorly established areas to left had seed spread compared to green areas where seed was sown. Photos V. Gett



Row spacing trial ACRI Narrabri 2011. Photo B. Griffiths

TABLE 2: Establishment Method Trial - Sowing into moisture Vs. water-up for durum and bread wheat varieties (Breeza NSW 2011). Emergence - plants/m².

Variety	Sow into moisture	Water-up
Gregory [Ⓛ]	81.2 b	109.3 a
Spitfire	82.8 b	129.5 a
Caparoi [Ⓛ]	89.2 A	34.3 B
EGA Bellaroi [Ⓛ]	89.2 A	30.8 B

Source: V. Gett LSD 30.76

Means within columns followed by the same letter are not significantly different at the 5% level according to Least significant difference (LSD) test.

Sow into moisture (pre-irrigation is not recommended as sowing can be delayed with rain)

Sowing into moisture provides the best plant-stand for irrigated wheat.

Growers will be faced with 3 possible scenarios

1. Planting into a full moisture profile. This is the most ideal scenario, as it provides the best opportunity for achieving high yields, particularly if starting soil-N levels are low. This allows early season crop canopy to be managed through nitrogen management.

2. Some soil moisture at sowing. Sow as long as is adequate for germination and some seedling growth. In low soil-N paddocks it is preferable to irrigate after the plants are established (GS10) in order to achieve secondary root development.
3. Dry soil profile at sowing. The only option here is to plant shallow and then water-up. This is the least desirable option, particularly if starting soil-N levels are very high. Sometimes in the water-up scenario, plants still do not achieve secondary root growth and require further irrigation during tillering. (This may create excessive early-season biomass and tillering, potentially predisposing the crop to lodging).

Select the correct row spacing

Row spacing can be altered to manipulate vegetative biomass and tillering.

In low soil-N paddocks the most appropriate row spacing is 30 cm, or 6 rows on a 1.8 metre bed. Wheat performs best at 30 cm row spacing as it responds well to plants more evenly distributed across the bed.

In high soil-N paddocks wider row spacing will increase intra-row competition, reduce tillering, and assist in the regulation of early season biomass during tillering.

Target 100-150 plants per square metre

In the northern region there is no need to plant high seed rates at optimum sowing times. The plant will adequately tiller with warmer temperatures after establishment.

A population of 100-150 plants per square metre is ideal. Populations of 50-100 plants per square metre with good tillering conditions and adequate in-season management have also achieved good yields on the Liverpool Plains.

TABLE 3: Row spacing trial, 2011 ACRI wheat cv. Hyperno[Ⓛ]

No.	Row Spacing	Plant Population (seeds/m ²)	Yield (t/ha) 164 Days After Sowing
1	0.15 (12 rows 1.8 m bed)	210	7.6 bc
2	0.30 (6 rows 1.8 m bed)		8.1 a
3	0.45 (4 rows 1.8 m bed)		7.8 ab
4	0.15 (12 rows 1.8 m bed)	308	7.2 c
5	0.30 (6 rows 1.8 m bed)		8.2 a
6	0.45 (4 rows 1.8 m bed)		7.8 ab

p value: 0.051 LSD (P=0.05): 0.54 Standard Deviation: 0.43 CV: 5.58

Source: B. Griffiths

Means within columns followed by the same letter are not significantly different at the 10% level according to least significant difference (LSD) test.

TABLE 4: Emergence Trial, 2011 ACRI (within row spacing trial, wheat cv. Hyperno[Ⓛ])

No.	Row Spacing	Plant Population (seeds/m ²)	Emergence (no./m ²) 29 Days After Sowing
1	0.15 (12 rows)	210 (target 150 seedlings/m ²)	161.4 b
2	0.30 (6 rows)		192.8 b
3	0.45 (4 rows)		159.2 b
4	0.15 (12 rows)	309 (target 220 seedlings/m ²)	245.3 a
5	0.30 (6 rows)		259.4 a
6	0.45 (4 rows)		251.1 a

p value: 0.000 LSD (P=0.05): 36.83 Standard Deviation: 24.44 CV: 11.55

Source: B. Griffiths

Means within columns followed by the same letter are not significantly different at the 5% level according to Least significant difference (LSD) test. See yield levels in Table 3.



Phosphorus rate response trial, Wee Waa, 2008 - plants from left (smallest to largest) - 0, 50, 100 kg MAP/ha. Table 5 below. Photo V. Gett

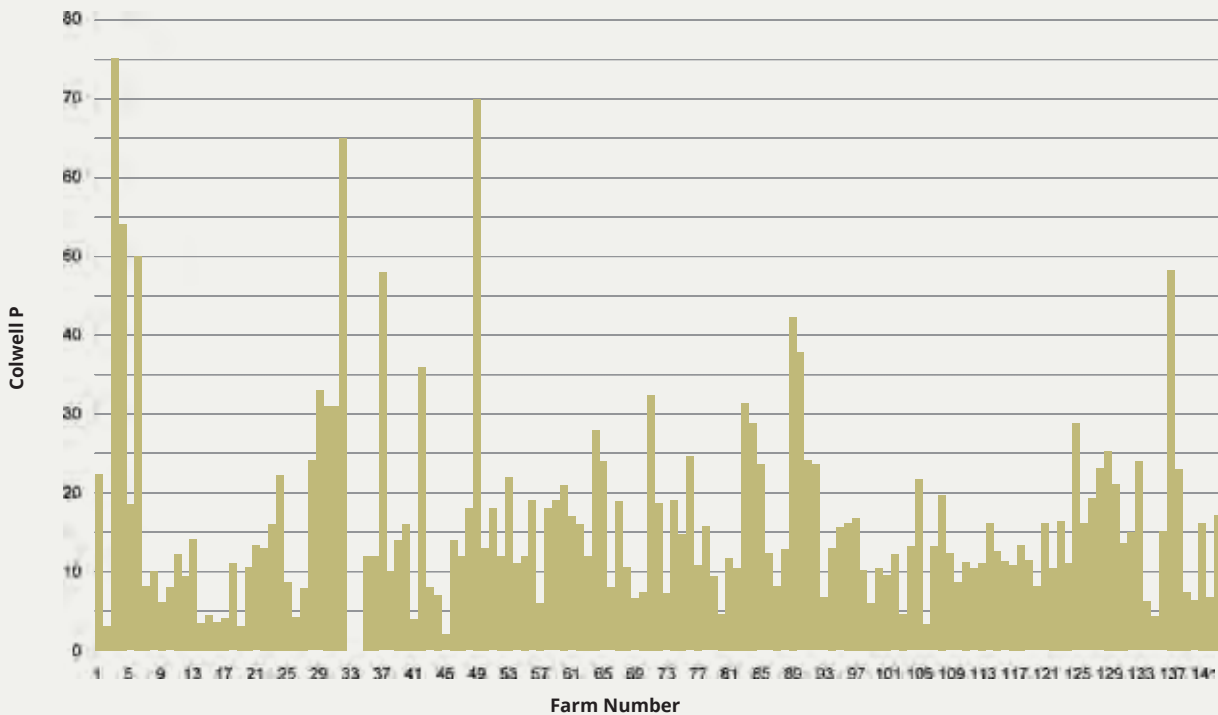
TABLE 5: Phosphorus Rate Trial, Wee Waa, 2008

	Plants/m ²	Shoots/m ²	Heads/m ²	Yield t/ha
0 kg MAP/ha	157 b	547 a	315 c	4.2 b
50 kg MAP/ha	173 ab	563 a	344 bc	4.2 b
100 kg MAP/ha	177 a	567 a	378 ab	4.4 ab
150 kg MAP/ha	180 a	591 a	424 a	4.7 a

Source: V. Gett

Note: Starting soil phosphorus Colwell P 46 ppm. Previous crop was wheat then fallow. Sunlin was planted on 1st June 2008, using 96 kg/ha. of seed, on 1 metre hills at 33cm spacing. 290 seeds / m² were sown with the aim to establish 150- 200 plants/m². The field was watered up, and received two in crop irrigations.

FIGURE 3: Phosphorus (Colwell P) collected from 140 irrigated fields in the northern growing region 2000 - 2010.



Source: B. Griffiths Graph: T. Burley

Residual soil phosphorus is highly variable and is dependent on such factors as fertiliser strategy used in cotton crop production, baseline soil fertility, fallow length and rotation choice.

Use Starter fertiliser

The level of available phosphorus present post-cotton harvest / pre-wheat planting in irrigated soils is highly variable. Historic soil testing data collected from over 140 irrigated fields 2000-2010 showed phosphorus levels ranging from 2 to 75 ppm (Colwell P) (see Figure 3).

Paddocks planted after cotton; such as wheat, might not have enough readily available phosphorus (even if P soil levels exceed 40 ppm) for best establishment. A starter fertiliser that contains phosphorus should be applied if targeting maximum yield. It is recommended to use 10-20 kgs P/ha as starter fertiliser. Research also indicates application of phosphorus produces more heads from tillers which subsequently leads to an increase in yield. (See Table 5 - Phosphorus Rate Trial, Wee Waa, 2008).

Sow at recommended/optimum sowing time

Sowing time is a management compromise that balances having the crop flowering soon after the last heavy frost, but still early enough to allow adequate grain fill before the heat in spring.

Yield drops 4-7% with each week of delay in sowing after the optimum time for a specific variety (Winter Crop Management Guide - NSW DPI).

Varieties also differ in the time they take from sowing to flowering. Select the sowing time for your variety that ensures it will flower after there is little chance (10%) of a frost occurring. (In the Namoi Valley this is after the first week of September.)

Some varieties sown too early will flower in late winter and be at risk to frost damage.



Sowing early (within the optimum range) is better suited to **low soil-N** paddocks where the canopy can be managed through delayed N application, and when irrigating-up.

Sowing late (within the optimum range) is an alternative strategy to reduce lodging in **high soil-N** paddocks.

Ensure secondary root development

Early secondary root development will increase the effectiveness of water and nutrient uptake. Secondary root growth normally starts between 25 and 30 days from emergence.

Dry soil-moisture below the sowing depth of seed will prevent the growth of secondary roots.

If the soil is relatively dry after plant emergence, then winter irrigation may be necessary in low soil-N paddocks. If there is available/uninterrupted moisture to one-metre depth, then winter irrigation should not be required.

However - if soil moisture is detected below a layer of dry soil then a quick flush of irrigation water after establishment should be applied to join up soil moisture and minimise deep drainage and water losses.

Overhead irrigation systems will have an advantage to ensure secondary root development, as the amount of water applied can be easily controlled.

To determine the need for flushing or winter irrigation use a push-probe to determine how wet the soil profile is at depth.

When to use plant growth regulators (PGRs)

Use of PGRs in wheat has not been common, however new PGRs are currently being evaluated and are undergoing registration for Australia (*see Table 6*).

The use of PGR's should only be considered for long fallow high soil-N paddocks where early biomass has been assessed as excessive.

Make an assessment of tiller numbers at GS25 before stem elongation. PGR application may be required if the tiller number exceeds 400, and plant growth is excessive.

Some PGR's reduce inter-node length and therefore increase stem strength.

From recent work undertaken there is evidence of increased yield from the use of PGRs.

TABLE 6: Plant growth regulator trial in wheat, 2011 ACRI cv. Gregory

No.	Treatment	Application timing	Yield (t/ha)	
			164DAS	
1	Untreated Check		5.0	bc
2	Product X* Treatment 2	GS31/32	5.2	ab
3	Product X* Treatment 3	GS31/33	5.3	ab
4	Product X* Treatment 4 + Cycocel®	GS31/34	5.9	a
5	Product X* Treatment 5	GS37/38	4.7	bc
6	Product X* Treatment 6	GS37/38	4.4	c
7	Product X* Treatment 7 + Cycocel®	GS37/38	4.9	bc

p value: 0.013 LSD (P=0.05): 0.75 Standard Deviation: 0.49 CV: 9.78

Source: **B. Griffiths**

Means within columns followed by the same letter are not significantly different at the 5% level according to least significant difference (LSD) test.

*Product X is in experimental use.



Rod Jackson,
NSW DPI



Graham Harris,
DAFF Qld



Allan Peake,
CSIRO

3. irrigation

Undertake a water budgeting exercise and set a yield target

Estimate at pre-planting how much crop can be grown with the available water and how much water is needed to achieve the required quantity and quality of production. Water availability will be influenced by:

- Plant-available water-capacity of the soil
- Starting soil moisture
- In-crop rainfall
- On-farm water allocations

Water demand is usually driven by the seasonal requirements of the crop for evapotranspiration (ET) purposes.

Crop water demand can vary year-to-year depending upon the prevailing weather.

For example, high temperatures and wind in spring will accelerate plant water-use considerably, leading to greater seasonal crop water use.

An internet site is available to review return per megalitre (using paddock specific information), at <http://www.apsim.info/IrrigationOptimiser> (google 'QPIF Irrigation Optimiser').

To obtain an irrigated wheat yield of 8t/ha or more, up to 550 mm of plant water use may be required – depending on location (see Table 7).

In grey cracking clays with no subsoil constraints, fully irrigated wheat will extract water to a maximum depth of 90cm.

As a rule of thumb, calculate water use from the top 90cm. 3-5 spring irrigations maybe required. However, the more heavily a crop is irrigated, the less it is able to take advantage of in-season rainfall which can be lost in runoff.

(See Table 8 for a worked water budgeting example).



Irrigated Grains Grower Workshop Wee Waa March 2009 - Workshopping irrigation optimiser web tool. Photo V. Gett

TABLE 7: Range of simulated maximum yield (t/ha) and evapotranspiration water use for 90% of years*, for quick maturing irrigated wheat (Kennedy^(b)) on 2m beds in the Northern Region, in the absence of lodging, disease, pest and frost damage.

Location	Range of Maximum Yield (t/ha)	Range of Maximum Evapotranspiration water use (mm)
Emerald	6.2 - 7.8	360 - 480
Dalby	7.0 - 9.5	430 - 550
St George	6.4 - 8.2	360 - 480
Goondiwindi	6.8 - 8.7	410 - 490
Walgett	6.7 - 8.3	420 - 500
Gunnedah	7.6 - 9.6	440 - 540

* (excludes the top 5% and bottom 5% of years). Source: A. Peake

TABLE 8: Irrigated Wheat Water Budgeting Example

Water Supply (ML)	
A. Proposed wheat production area (ha)	250
B. Total water available for wheat production ¹ (ML)	500
C. Irrigation efficiency (%) (if not measured for your system, refer to 2. below as a guide)	70
D. Irrigation water available to crop (ML) = B x (C/100)	350
E. Predicted in-season rainfall (mm) ² refer to 3. below	150
F. Rainfall efficiency (%)	75
G. Effective rainfall (mm) = E x (F/100)	113
H. Effective rainfall - proposed wheat production area (ML) = (G/100) x A	283
I. Starting soil moisture to 0.9m (ML/Ha) ^{3,4}	120
J. Estimated stored soil water for proposed wheat area (ML) = (I/100) x A	300
K. Total Available Water Supply (ML) =D+H+J	933

Crop Water Demand - Proposed Area (ML)	
Target Yield (T/Ha)	8
L. Average seasonal water requirement (mm)	500
M. Average Water Requirement (ML/Ha) = L/100	5
N. Estimated Total Crop Water Demand (ML) = L x A	1250
Water Deficit/Surplus (ML) = K – N	-317
Conclusion: An additional 317ML of on irrigation water allocation needs to be reassigned to the area proposed for high yielding irrigated wheat. If this is not possible then consideration needs to be given to reducing the planted area or reducing the target yield.	

1. Includes river water, groundwater and water currently stored on farm.
2. Common Irrigation system efficiency benchmarks: furrow 40-70%; border check 55-90%; Pivot or linear move low pressure 80%; drip 85%; spray line 80%; travelling gun 70%.
3. Assumptions or estimates of in-season rainfall need to be made in the context of risk management. A low risk strategy might be to budget on zero or minimal rainfall. Conversely a high risk strategy would be characterised by assuming rainfall at the 10 percentile or above (i.e. a very wet season).

Note if there is considerable variation in starting soil moisture between fields, or there are significant differences in soil type, then this water budgeting process may need to be carried out on an individual field basis.

4. If the field is coming out of fallow, starting soil moisture can be estimated using an online tool named HOWWET. It is freely available, and to run the program, the user follows simple menu prompts for details of site-location, soil type, stubble cover and initial soil water. Daily rainfall records for the fallow period are entered on a spread sheet and starting soil moisture is calculated automatically. For an explanation of what HOWWET is and what it can do, see: <http://www.derm.qld.gov.au/factsheets/pdf/land/l39.pdf>. The simplest method, albeit least accurate, is to use a push probe to determine how wet the soil profile is at depth, and estimate starting soil moisture as a percentage of plant available water capacity as depicted in Table 9.

Monitor soil moisture to time spring irrigations (for fully irrigated wheat crops) - Target yield >8t/ha

It is important to monitor soil moisture closely once secondary root depth has been completed (normally G31) (note key recommendation – winter irrigation).

In order to avoid crop stress, do not allow soil water to deplete beyond 50% of plant available water capacity (PAWC). This is commonly known as the 'refill point'. Once below 50% of PAWC, crops use more energy extracting the remaining soil moisture. Plant growth and yield potential will fall considerably if soils are allowed to dry down beyond this threshold. (See Table 9 and Figure 4).

Make sure water is available 2-3 days before the crop reaches its refill point. The reproductive growth phase typically coincides with an increase in atmospheric temperature and an acceleration of plant water use. (Any delay in water application can cause significant yield losses).

FIGURE 4: The relationship between average yield and soil water deficit used to trigger irrigation events, for fully irrigated APSIM wheat simulations at Narrabri (soil PAWC = 210mm).

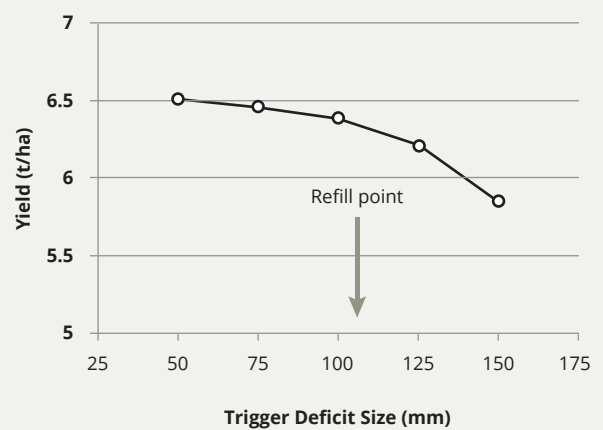


TABLE 9: Measured Wheat PAWC (mm) for typical soil types in northern NSW and Southern Queensland.

Soil description	NEW SOUTH WALES			QUEENSLAND		
	Location	PAWC to 0.9m (mm)	PAWC to 1.8m (mm)	Location	PAWC to 0.9m (mm)	PAWC to 1.8m (mm)
Black Vertisol	Breeza	183	282	Brookstead	168	273
	Moree	151	238	Jimbour	206	320
	Gurley	146	254	Macalister	188	308
	Ashley	111	117	Kaimkillenbun	236	332
	Croppa Creek	97	163	Wellcamp	170	245
	North Star	124	139	Greemnount	170	253*
	Spring Rldge	197	272	Tipton	197	269
Grey Vertisol	Croppa Creek	133	151	Goondiwindi	129	174
	Gurley	155	221	Brigalow	140	221
	Myall Vale	164	218	Jandowae	155	197
	Bekllata	180	249	Dalby	150	186
	Terry Hie Hle	167	221	Hopelands	147	210
	Merrah North	167	233	Warra	186	252*
	North Star	113	194	Yelarbon	156	237
Grey-Black Vertisol	Breeza	192	264			
	Boggabri	176	248			
Red Chromosol	North Star	107	153			

Source: APSIM Apsoil database - <http://www.apsim.info/Wiki/APSoil.aspx> Asterisk * denotes PAWC to 1.5m only



C probe used in irrigation monitoring trial ACRI 2011. Photo V. Gett

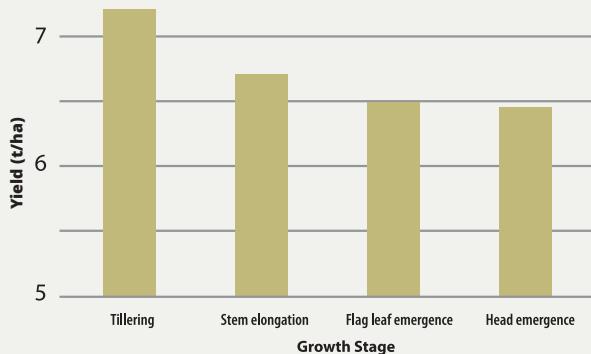
The period leading up to and including flowering is the most sensitive to water stress (Figure 6). Stress at this time will reduce the number of heads per plant, head length, and number of grains per head. It can also restrict further root growth. Yield losses from excessive water deficits at this time cannot be recovered by later irrigations.

Monitoring can be based on either soil moisture readings or weather information recording ET. Either will identify the critical refill point to start irrigation. When combined with knowledge of critical plant growth periods, each irrigation can be efficiently timed to achieve maximum yield.

The most common soil moisture monitoring device currently being used in the irrigated cotton and grains industries is the capacitance probe. Automatic logging and transmission of data to the home or office computer allows soil moisture to be monitored in real time.

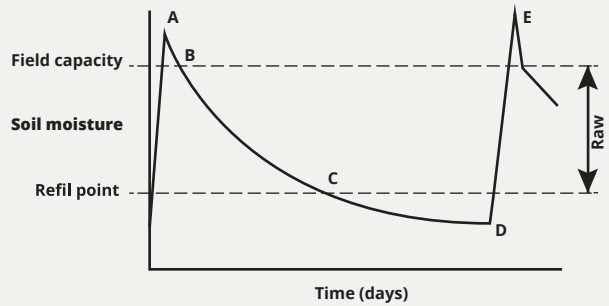
A refill point can be determined by analysing the soil drying cycle (see Figure 5).

FIGURE 6: Simulated yield of irrigated wheat crops that experience a severe, 10-day water stress at different growth stages, from a 40 year APSIM simulation (1970-2010) at Walgett.



Source: A. Peake

FIGURE 5: Soil drying cycle as measured by capacitance probe.



A to B Immediately after the initial irrigation, water exceeds the 'full point' and some water is rapidly lost to vertical drainage or run-off

B to C Water is held by the soil and is readily available to the crop, so there is unrestricted growth. Gradual decrease in water lost from the soil as it is taken up by the plant

C to D The readily available water has been used and the crop has difficulty extracting more. The daily use is lower and the crop is under stress

D to E Irrigation (or rain) has entered the profile after D

Soil moisture probes should be installed at a site representative of the irrigated area. Wheel tracks and areas where soil is compacted should be avoided, as should disturbed soil, outside rows, or areas near stunted or sick plants.

Ideally installation should occur well in advance of the first spring irrigation (25-30 days after plant emergence) as soil needs to consolidate around the capacitance tube for accurate soil moisture assessment.



Soil coring at ACRI Narrabri in 2011. Photo R. Jackson



Wheat grown in field weighing lysimeters at Kingsthorpe in 2009. A capacitance probe installed in the centre of the lysimeter measured profile soil moisture every 10cm. **Photo J. Payero**

Timing of the last irrigation

Correct timing of the last irrigation will ensure adequate grain fill and also reduce the risk of lodging and harvesting delays. It should be applied around the mid dough growth stage (GS80) if readily available water has been used to 60-90 cm soil depth.

Limited water options (for supplementary irrigated wheat crops) - Target Yield <6T/Ha

If there is a high probability of reduced water allocation and insufficient rainfall, then the yield target may need to be revised down, and supplementary irrigation strategies adopted.

Supplementary irrigated crops are 'water limited' i.e. not enough water is available to fully irrigate the area sown. Growers faced with this situation have two main choices: (1) to maximise production from the water available, or (2) to grow the largest area they can so that more of their farm gets the benefit of the wheat rotation crop.

Maximising crop water use efficiency

Growers wanting to achieve maximum production per ML of water should consider growing a smaller area of crop and irrigating it more heavily to achieve a higher yield. This strategy avoids the extra costs incurred in growing a larger area. Additionally, any irrigated crop

loses water through evaporation, and by growing a smaller area and targeting a higher yield, this evaporation loss is minimised across the farm.

The APSIM simulation model has been used to generate approximate guidelines for growers wishing to maximise their crop water use efficiency (CWUE). CWUE is defined as the amount of grain produced per unit of water used by the crop or lost to the farm through drainage and evaporation.

In general, maximum CWUE under irrigation is achieved when good soil moisture is available at sowing (or an irrigation has been applied at sowing) and then one or two supplementary spring irrigations are applied, (one irrigation in wetter districts such as the Liverpool Plains, and two irrigations in drier areas such as Emerald and Goondiwindi) (*Figure 7*).

However, additional irrigations could still return more than 1 tonne of grain per ML of irrigation water use once the maximum CWUE is achieved. Therefore, growers may achieve maximum profitability by applying additional spring-irrigations. The key consideration for growers is whether the yield gain from extra irrigation of the irrigated cropping area is more valuable than the cost of preparing, sowing and managing the additional paddocks, on which they could use the water as an alternative.



Irrigated grains variety and irrigation frequency trial ACRI - irrigated and dryland plots replicated across the field. **Photo J. Sykes**

Maximising productivity from a single irrigation

If a grower has a large area needing to be rotated with wheat as a disease break, then the best strategy may be to use a single irrigation on the cropping area to allow the maximum area to be sown to wheat.

Fortunately, wheat is quite an adaptable crop. It has a number of mechanisms that allow it to increase yield in response to better conditions. When rain falls (or an irrigation is applied) during a dry season, it is usually able to make use of the extra water regardless of crop stage. It can produce bigger leaves and store more energy during stem elongation, grow bigger heads during booting, set more grains during anthesis, and grow bigger grains during grain-filling.

While head emergence is the most sensitive growth stage to a short, severe water stress, the best timing for a single irrigation is probably the one which

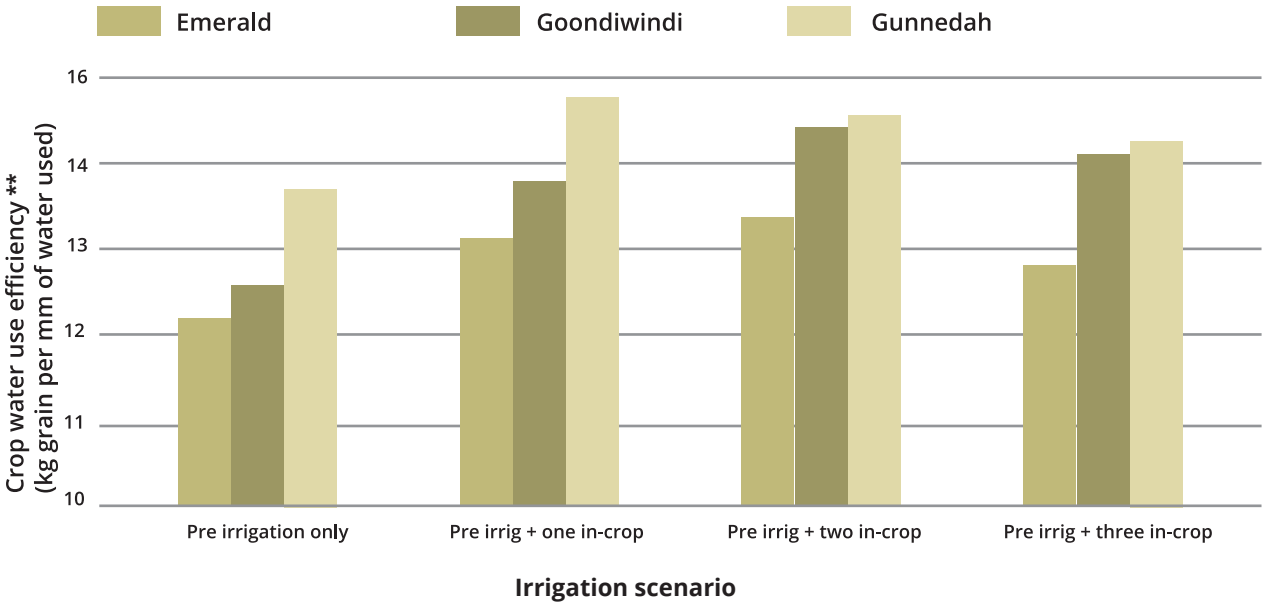
spreads the water across a number of growth stages and avoids a severe stress at any growth stage.

APSIM simulations suggest that in general, the best timing for a single in-crop irrigation of around 1ML/ha is from early stem-elongation through to flag-leaf emergence. It will still have time to help the crop develop a little more biomass, yet will also leave some soil water for flowering and early grain filling (*Figure 8*).

It should be remembered that these results have been obtained on average, from 40 years of weather data. The best timing of a single irrigation within individual seasons will vary depending on the timing of in-crop rainfall, and stored soil water at sowing.

If two irrigations (or 2ML/ha) is budgeted, then an irrigation may be applied at early to mid-stem elongation and again between flag-leaf and flowering.

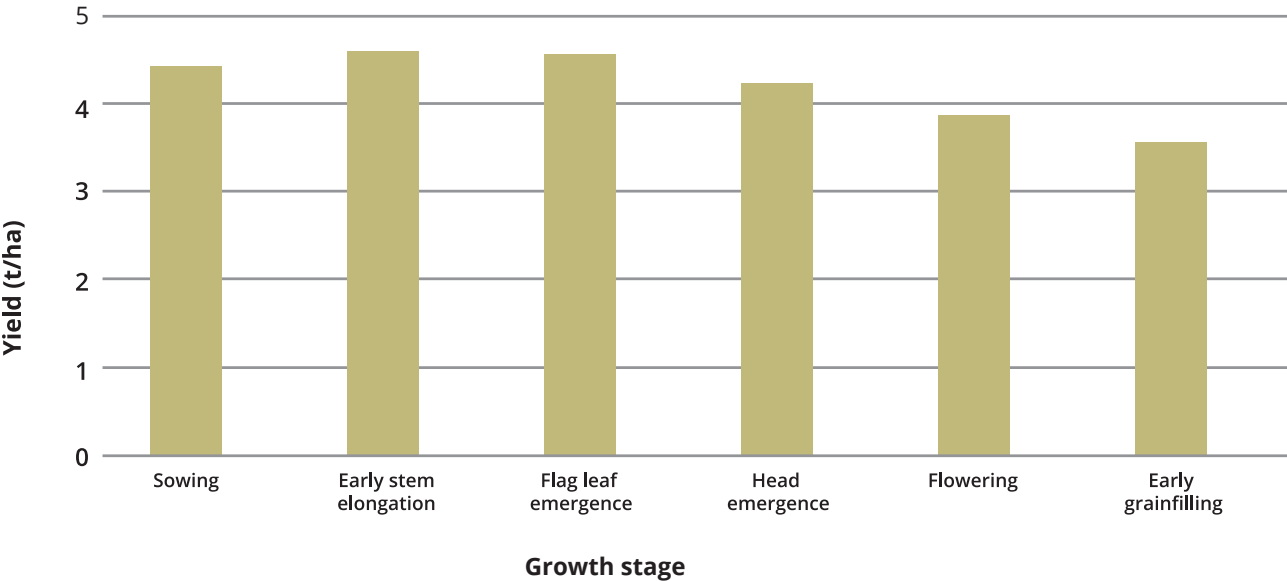
FIGURE 7: APSIM-simulated crop water use efficiency of various irrigation scenarios (using 0.9ML/ha irrigation events at 80% application efficiency) for Emerald, Goondiwindi and Gunnedah.



**Crop water use included soil evaporation, transpiration and deep drainage, but did not include runoff which was assumed to be recaptured on-farm.

Source: A. Peake

FIGURE 8: Simulated average yield after application of a 1.1 ML/ha irrigation at different growth stages, from a long-term APSIM simulation experiment at Goondiwindi.



**The simulations had a soil PAWC of 210 mm, and 65 mm of plant available water available at sowing in each year.

Source: A. Peake



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Nick Poole,
FAR

4. controlling lodging in high-N paddocks using canopy management techniques

Lodging can be a major problem

Lodging generally occurs in paddocks with high yield potential, when the top of the plant is so heavy and/or buffeted by wind that it buckles (stem lodging) or levers the root system out of wet soil (root lodging).

Lodging has the greatest impact on yield when it occurs during flowering or early grain-fill, as lodged crops don't intercept sunlight efficiently. Subsequently, the crop can then potentially set less grain, and/or produce smaller grains.

Severe lodging can also reduce yield or increase harvest costs through shattering, slower harvesting, and increased risk of sprouting.

Lodging is more likely to occur in paddocks with an extremely thick canopy at the beginning of stem elongation (GS31 - see *Figure 16 on page 37*). These crops tend to develop weaker surface roots and weaker stems.

Many irrigators have seen this on east-west configured

beds where the lodging (nearly always) occurs first on the southern side of the bed, where shading is greater due to the angle of the sun.

Canopy management techniques can reduce lodging risk. However it isn't possible to test all agronomic strategies, on all varieties, for every soil type and location. The techniques discussed here have not been widely tested on durum varieties. Therefore, it is recommended that growers should *always test new agronomy or varieties on a small scale first*.

Canopy management

Canopy management refers to any yield maximising technique that is used to manage the way a crop canopy develops.

For lodging-risk-reduction in high yielding wheat production in the northern region, the objective of canopy management is to 'hold the crop back' in the early growth stages. In this instance, canopy management for lodging-risk-reduction will typically involve the use of a number of agronomic strategies.



Nick Poole (FAR) inspects a lodged crop at Rolleston, Central Queensland in 2008. **Photo A. Peake**

Fourteen paddocks across the northern region were monitored in 2008, and the lessons learned from these paddocks are a good summary of canopy management techniques.

Test for soil nitrogen availability

The nitrogen requirement of an 8 t/ha wheat crop is approximately 275 kg N/ha, yet studies in 2008 showed that many long-fallow paddocks that lodged had well in excess of this amount of nitrogen available (see Figure 9 (a)).

It is therefore vital to test soil-N availability. If you have a high-N paddock, ensure that you use other canopy management techniques to minimise lodging-risk.

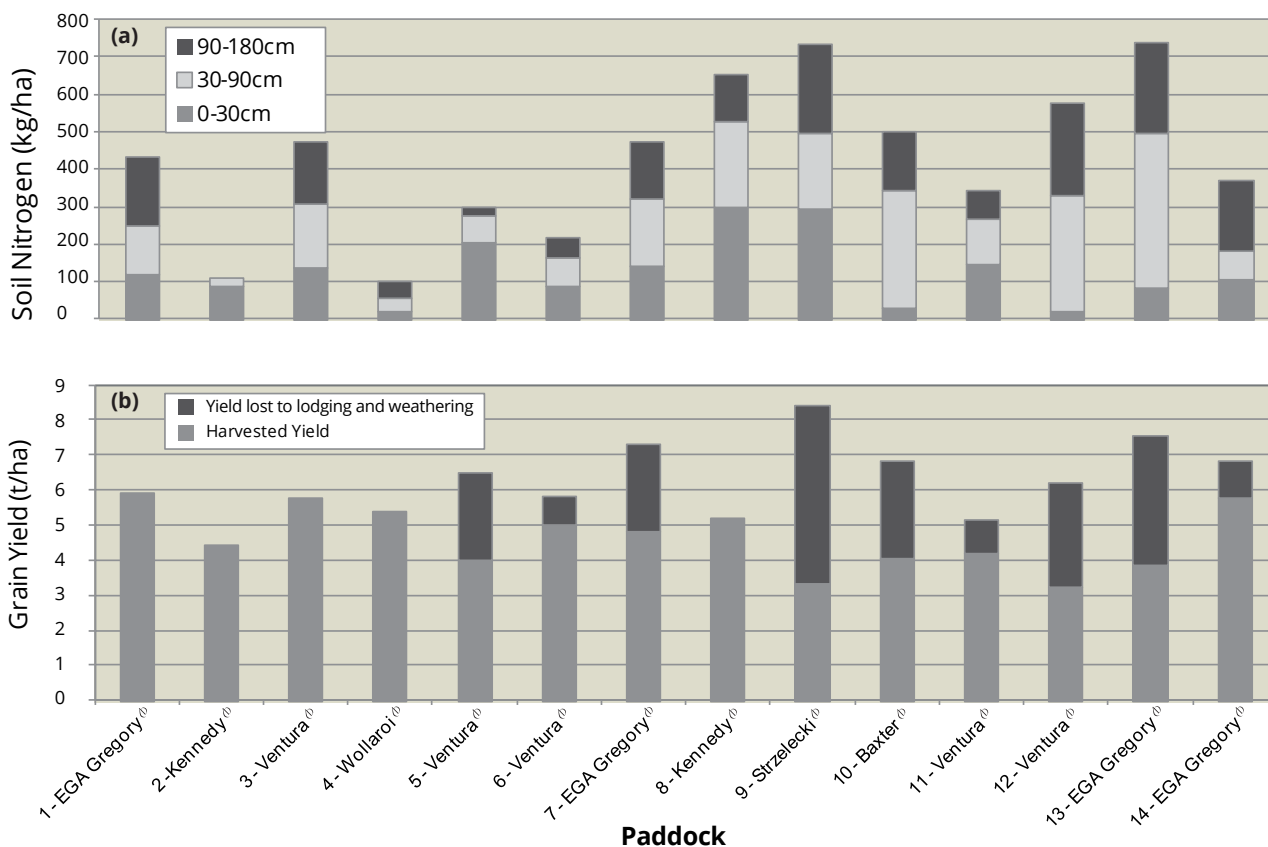
Some hints for interpreting nitrogen tests are provided at the end of this guide (Appendix 1).

Consider applying nitrogen 'in-season'

Trials across the northern region have shown that maximum yield can be achieved with varying amounts of nitrogen available to the crop either as soil or fertiliser N at sowing. This will depend on: variety, soil type, the severity of lodging, irrigation system and the timing of in-season N application.

It is impossible to make recommendations on a precise sowing-N target for all growers to aim at. However, there is a benefit in starting a wheat crop with less-than-the-full N requirement.

FIGURE 9: (a) Sowing soil nitrogen and (b) harvested yield and yield lost due to lodging for 14 paddocks monitored across the northern grain growing region in 2008.



Source: A. Peake

Decreased access to nitrogen during tillering reduces shading by decreasing leaf size and also reduces the production of unnecessary tillers, and thus can decrease lodging risk. But, if the nitrogen stress is too severe, and plant populations are low, it can decrease yield potential, by keeping tiller numbers too low.

Yields greater than 8t/ha can be achieved with as few as 400 tillers/m² at GS31 in the northern region in some cultivars, so this is a safe minimum tiller number to be aiming for at GS31.

As a general rule to growers, a high yielding irrigated wheat crop should aim to have roughly 50-120 kg N/ha available at sowing; whether as stored soil N, applied fertiliser-N, or a combination of both.

The availability of nitrogen to the developing wheat crop does change depending on moisture availability. If the soil is dry and little rain is received during tillering, a higher level of starting-N may be best for achieving high yields as it ensures maximum tiller development in dry years.

On the other hand if the soil is wet and/or regular rainfall is received during tillering, then larger amounts of sowing-N can cause the crop to develop excessive early biomass, and therefore increase lodging risk (see Figure 10).

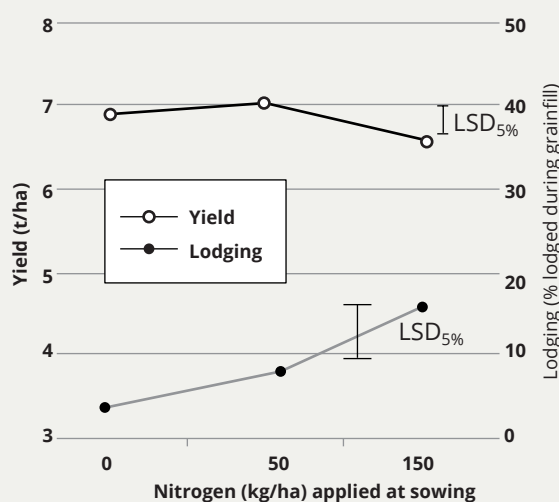
Applying the crop's entire N requirement before sowing may also make it harder to achieve high protein levels (see Figure 11). Early nitrogen application is used by the crop to produce excess biomass, and therefore less nitrogen will be available during grain fill.

A recommended starting point for the in-season application of nitrogen (when targeting high yields) is to apply and incorporate additional nitrogen at GS31 to ensure that 200 kg N/ha have been made available to the crop (this includes soil-N at sowing, and any fertiliser-N applied).

Then apply and incorporate another 75 kg N/ha when the flag leaf emerges.

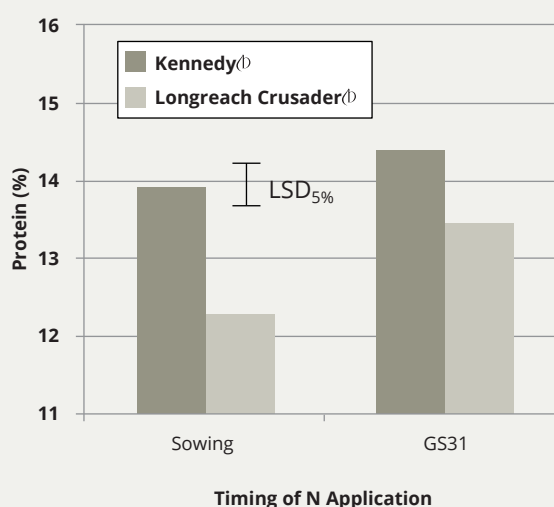
Obviously the success of the strategy is dependent on successful N incorporation in-season; to ensure the full N requirement is available once the flag leaf is fully emerged. However, this may be risky in flood irrigated fields, where growers may not wish to flood irrigate shortly after a rain event solely to incorporate N.

FIGURE 10: Yield and lodging scores for Kennedy[Ⓛ] (Gatton 2011) sown with three rates of fertiliser N incorporated into the bed.



Source A. Peake The soil contained just 15 kg N/ha before fertilising, and the trial was irrigated regularly during tillering.

FIGURE 11: Grain protein % for different timings of N application under irrigation for Longreach Crusader[Ⓛ] and Kennedy[Ⓛ], at Gatton 2011.



Source: A. Peake

Use lodging-resistant, short-season cultivars, especially on high-N paddocks

The worst lodged paddocks monitored in 2008 were sown to the bread wheats Strzelecki[Ⓛ], Baxter[Ⓛ] and EGA Gregory[Ⓛ], all of which are long season varieties (*Figure 9*).

In general, longer season varieties tend to be more lodging susceptible. This is probably because they have a longer tillering phase, making them more susceptible to excessive biomass development under good growing conditions. Additionally, they tend to be taller and hence develop a longer lever which is easier to topple in a lodging event.

Testing of a limited set of bread wheat varieties across environments in 2011 under high yielding conditions indicated that Kennedy[Ⓛ] and Longreach Crusader[Ⓛ] are two APH quality varieties that have good levels

of lodging risk resistance and high yielding ability, provided diseases are successfully controlled.

Longreach Crusader[Ⓛ] showed significantly more lodging-resistance than Kennedy[Ⓛ] in high- N paddocks. However Kennedy[Ⓛ] produced significantly better protein levels than Longreach Crusader[Ⓛ] at one location in 2011 (*Figure 11*), so it is important that growers test agronomic changes (including new varieties) on a small scale first.

The worst performing APH varieties in this testing were EGA Gregory[Ⓛ] and Lang[Ⓛ]. It may be advisable not to grow these varieties when attempting to achieve high yields, due to their high lodging risk.

Some Durum wheats also appear to have good levels of lodging resistance, and may have higher yield potential than bread wheats (*see Figures 2 (a) and 2 (b) on page 14*).



A susceptible variety lodges in a plot trial at Gatton, 2011.
Photo A. Peake



Root lodging in a paddock at St George, October 2008. Photo A. Peake

Calculate seeding rates using the 'bed-area' only

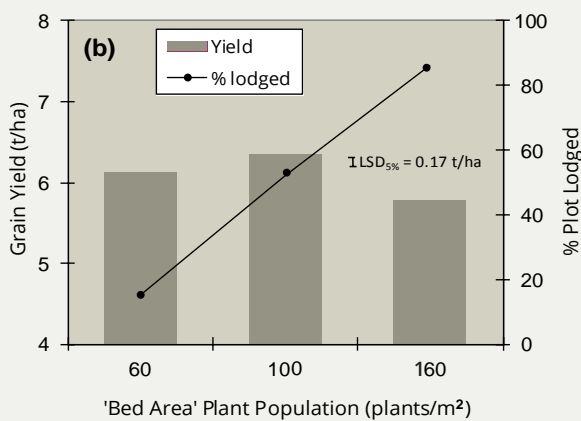
Many paddocks in 2008 had plant populations of 150-300 plants/m². Yet as observed in a crop of Hyperno[Ⓛ] at Boggabri in 2009 (see Figure 12) lodging risk increases with higher plant populations.

Only 100 plants/m² (and possibly less) on the bed-area is needed to achieve maximum yield on high nitrogen paddocks.

Late sown paddocks, or paddocks with low levels of starting soil-N, could benefit from slightly higher plant populations.

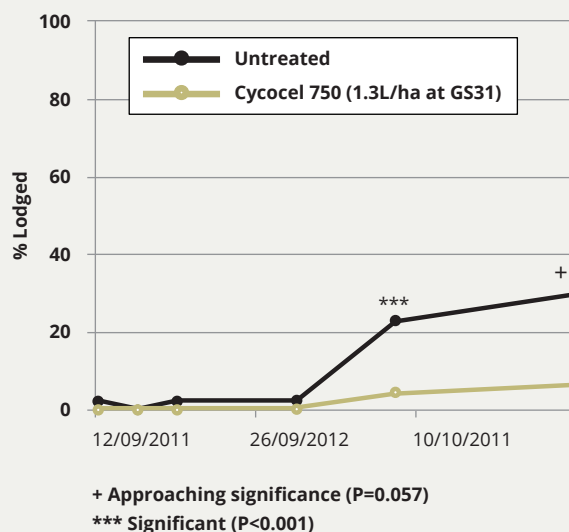
In 2008 some growers and contractors forgot to adjust seeding rates down to allow for the unplanted furrow in paddocks. Seed rate must be calculated for the area of bed only - and not unplanted furrows (see page 7 - Calculating plant populations for beds or hills).

FIGURE 12: Grain yield and lodging % in three plant populations for Hyperno[Ⓛ] grown at Boggabri on a high N paddock (300 kg N/ha to 90cm), 2009.



Source: A. Peake

FIGURE 13: The effect of Cycocel[®] 750A on lodging in Kennedy[Ⓛ], at Gatton (2011).



Source: A. Peake

Consider the use of plant growth regulators (PGRs)

PGRs are not readily available in this region, so while a number of products are used in NZ and Europe, at the time of publication only chlormequat chloride (Cycocel® 750A) is fully registered for lodging control in wheat in NSW, while it is temporarily registered in QLD. Full-registration applications have been submitted for Cycocel and other experimental products, that could see them fully available in both QLD and NSW soon, so growers should check for availability of new products with their supplier.

Little interest was shown in the use of PGRs in 2008, and none were used on monitored paddocks. However Cycocel 750A has been shown to reduce lodging risk in some circumstances (see Figure 13).

In this particular comparison, yield was not actually significantly greater in the treated plots despite the lodging reduction – probably because the lodging occurred too late in grain-fill to affect yield.

So while PGRs can reduce the risk of lodging, this will not necessarily always translate into a yield increase.

While new products are currently being trialled for

registration, growers should be aware that PGRs may have more effect on some varieties than others.

Later sowing and reduced irrigation scheduling can be used to reduce lodging risk; but may lead to reduced yield potential

Sowing later in the window can reduce yield potential. This may also reduce lodging risk as lower yielding paddocks have less weight at the top of the plant. On extremely late sown crops, there is less need to employ other lodging reduction techniques (especially delayed N application) that can reduce yield potential. This was observed at St George in 2008, where late sown Kennedy[®] on a very high-N paddock yielded 5t/ha, and did not lodge (paddock 8 in Figure 9).

In 2008, three monitored paddocks had more than 400 kg/ha of soil + fertiliser-N at sowing - yet did not lodge (paddocks 1, 3 and 8 in Figure 9). One was the late sown paddock, but the other two were supplementary irrigated paddocks (rather than fully irrigated paddocks). Yielding around 6t/ha, these paddocks (containing Ventura and EGA Gregory[®]) were irrigated sparingly, and managed to avoid lodging because they weren't pushed to achieve maximum yield.

Measuring light interception and leaf area index in a wheat experiment at Kingsthorpe in 2009. Photo J. Payero





Nick Poole,
FAR

5. disease management

Irrigating wheat increases the need for disease control in varieties that are disease susceptible

There are a number of inter-related reasons for this increase in disease risk:

1. Increasing available soil water increases green leaf retention in the crop canopy, which in turn provides disease a greater opportunity to affect green tissue during grain-fill.
2. Irrigating increases both canopy density - and subsequently humidity - which then encourages the development of all foliar diseases.
3. Applying higher levels of nitrogen to fulfill yield potential results in increased disease pressure through greater canopy density.

Pre-plant management options

Growers cannot influence the weather conditions surrounding disease build-up, but they are able to minimise potential disease epidemics by reducing disease inoculums by:

1. Destroying cereal volunteers that host rust over summer, particularly if the volunteers are susceptible to rust. Burning cereal residues harbouring stubble-borne-disease (such as yellow spot) will achieve similar effects.
2. Depriving the disease of a susceptible host, by selecting cultivars with greater resistance. This will minimise the impact of a given level of inoculum in the environment.

Variety Resistance

Selecting varieties with better disease resistance has two effects on the progress of a disease in the crop: it delays onset of the disease, and slows development of the disease.

The 2010 season gave rise to ideal conditions for many of the principal foliar diseases due to higher than average rainfall. The National Variety Testing (NVT) trials were not irrigated, however the yield response to fungicides in NSW NVT trials correlated very strongly to disease resistance rating (see Figure 14).

The responses indicated that given one of the best seasons for obtaining fungicide response, the economics of applying fungicides to moderately (MR) and resistant (R) cultivars were marginal when the principal disease was stripe rust.

However economic responses were obtained in cultivars with intermediate ratings of MR-MS (moderately resistant – moderately susceptible) along with more susceptible categories.

Resistance ratings of moderately resistant (MR) or resistant (R) are unlikely to give economic responses to fungicide application, unless the local inoculum loading is very high due to the presence of susceptible neighbouring crops - or - if there is a change of disease strain (pathotype).

Remember that while cultivar disease ratings give an excellent guide the ultimate management of the crop must be based on disease levels in the paddock particularly with an irrigated crop which is at higher risk.

Greater disease resistance <-----> **Greater disease susceptibility**

Later onset of disease

Less rapid development

Earlier onset of disease

More rapid development

Note: With Adult Plant Resistance (APR) in more resistant cultivars greater resistance to stripe rust can be exhibited at later growth stages.

Fungicides must be applied at the correct growth stage

Fungicides are an “insurance” strategy. To obtain the best results from their use, they have to be applied *before* the crop canopy becomes heavily infected, and particularly across the top three leaves of the canopy.

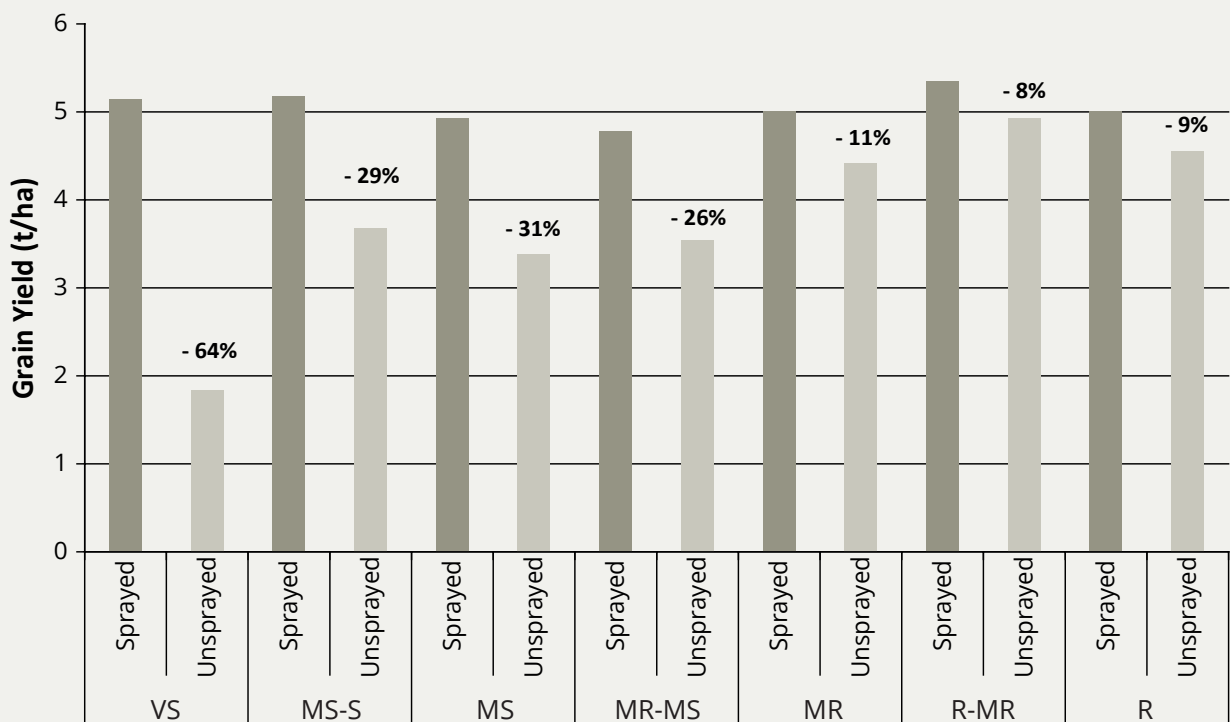
Foliar applied triazole fungicides (the most commonly used active ingredients in cereals) only move through the plant in one direction when applied to the crop. They travel in the xylem vessels of the leaf towards the leaf tip after uptake to the leaf and stem.

They work better as protectants than they do as curative or eradicator inputs. To best protect the top three leaves (*flag*, *flag-1* and *flag-2*), which are the main yield contributing leaves, fungicide application needs to be made between first node (GS31) and mid-booting (GS45) - the period in which these leaves emerge.

Application(s) made in this period should provide good protection against foliar diseases such as Stripe rust (*Puccinia striiformis*) and Yellow leaf spot or Tan Spot (*Pyrenophora tritici-repentis*).

FIGURE 14 Wheat Variety Response to Fungicide Application - 2010 NVT Trials.

Influence of wheat cultivar rating for stripe rust on fungicide response - NSW & NVT Cultivar Trials 2010.



VS-Very Susceptible, MS-Moderately Susceptible, MR-MS Moderately Susceptible-Moderately Resistant.

N.B. Cultivar ratings do change due to the impact of new pathotypes (see notes below). Therefore always manage stripe rust on the basis of what is observed in the paddock and remember that excessive inoculum pressure from neighbouring susceptible cultivars will lead to greater infection pressure in MR rated cultivars.

In 2010 the new pathotype Yr 17-27 was identified for the first time, meaning that if found in your region cultivars such as Livingston, Mira and EGA Ruby will not be resistant to stripe rust.

Securing green leaf retention

While fungicides are applied at stem elongation, the principal benefit is gained during the grain fill period (GS71 onwards), when fungicide use leads to greater green leaf retention (where disease has been controlled) in the treated crops. It is this effect of giving greater leaf area duration (LAD) that leads to the yield increase. In short – fungicide treated crops stay greener for longer.

In irrigated paddocks the grain fill period is not only more conducive to disease development continuing (larger canopy with higher humidity) but it also gives a far better opportunity for seeing the benefits of a fungicide application. This is because green leaf retention is naturally extended by greater soil water availability.

While the timing and number of fungicide sprays (*see strategy below*) depends on the time of disease onset, fungicides need to be applied in the period from first node to booting (GS31-45) in order to protect the three leaves of the crop canopy (*Flag, Flag-1 and Flag-2*), irrespective of disease.

Foliar fungicide timing & strategy

The key single timing for fungicide application in irrigated wheat crops is at flag leaf emergence on the main stem (GS39), since at this growth stage the top three leaves (on the main stem) are fully emerged.

However if stripe rust or yellow leaf spot infections occur earlier - at the start of stem elongation - (GS30-31) delaying a fungicide until flag leaf emergence will result in the loss of green leaf in the two leaves below the flag (*Flag-1 and Flag-2*).

Therefore, with early disease onset, a fungicide strategy for irrigated crops needs to be based on two fungicide applications in order to secure full protection of the top three leaves: one prior to flag leaf at first-to-second node (GS31-32) and a further application at flag leaf (GS39).

Remember: a single early fungicide applied at GS32 will not control disease in the two upper leaves, since the GS32 fungicide does not have the ability to protect leaves that are un-emerged at the time of application.

Though this might not be an issue in a dryland crop, it would be for an irrigated crop - where ideal conditions for disease are maintained for far longer by irrigation water.

The head-emergence fungicide timing (GS59) is optional and is most profitable when stem rust or Fusarium head blight is the target disease.

It serves the purpose of applying fungicide to the head (before infection occurs) and tops up the protection in the flag leaf following the earlier application at flag leaf emergence (GS39).

In longer season (southern) environments this spray can take on increased importance due to increased duration of grain fill under cooler conditions.

Use of up-front fungicides fluquinconazole (Jockey®) and flutriafol (Impact®)

With stripe rust, these fungicides will very often protect the crop until flag leaf - provided the up-front applications have been made at full rates. However it is important to point out that there may be little active ingredient remaining in the top two leaves at that stage.

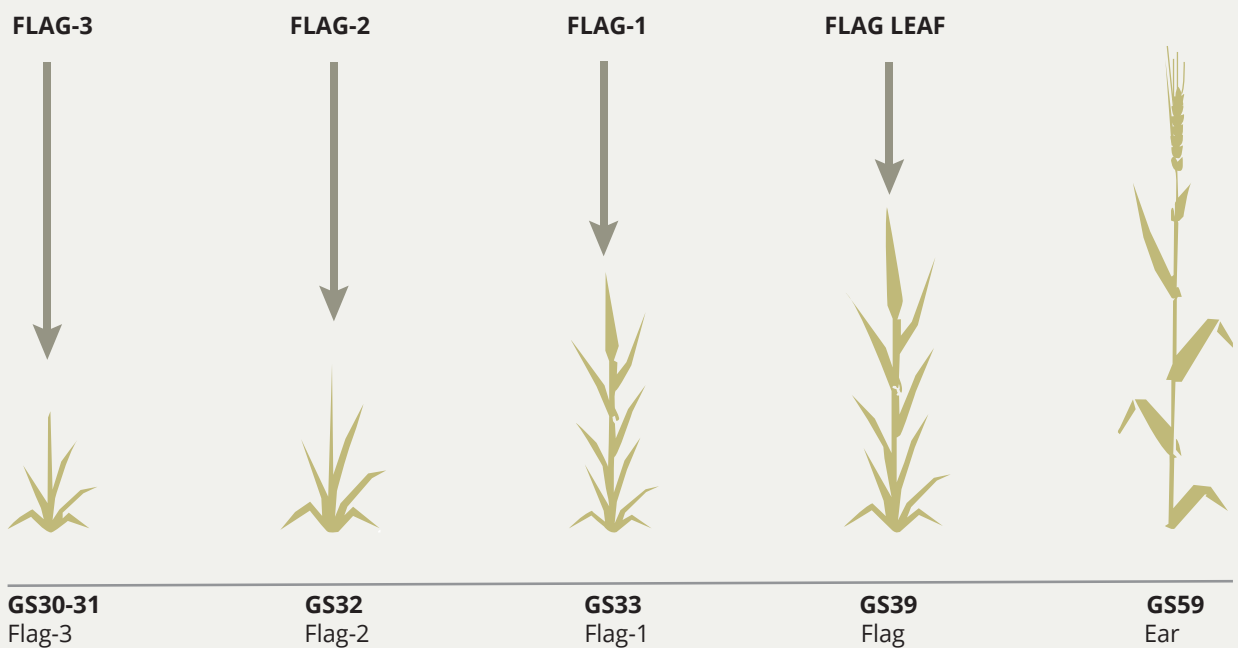
It takes 10-12 days before a new cycle of stripe rust becomes visible in the crop leaves, which may appear clean even though there is little protection in place. Where these up-front options have been employed aim to follow up and apply a foliar fungicide at flag leaf emergence (GS39).

Up-front measures need to be followed up in order to fully protect the top two leaves of the canopy during grain fill. But remember these up-front measures do not control all foliar diseases. Control of Yellow leaf spot (*Pyrenophora tritici-repentis*) is not achieved through the use of these up-front products.

Timing is critical to protect the top three leaves emerging in the crop

In order to obtain a clear picture of the growth stage of the crop, select the main stem from 5-10 plants (usually the longest stem or stem with the highest leaf ligule). Then split it with a knife in order to reveal the position of the embryo head and the length of nodes and internodes underneath. *See Figure 16 – or, alternatively check nodal growth (Figure 15).*

FIGURE 15: NODAL GROWTH: Growth stages marking the emergence of important leaves on the main stem (approximate relationship between nodes and top 4 leaf emergence).

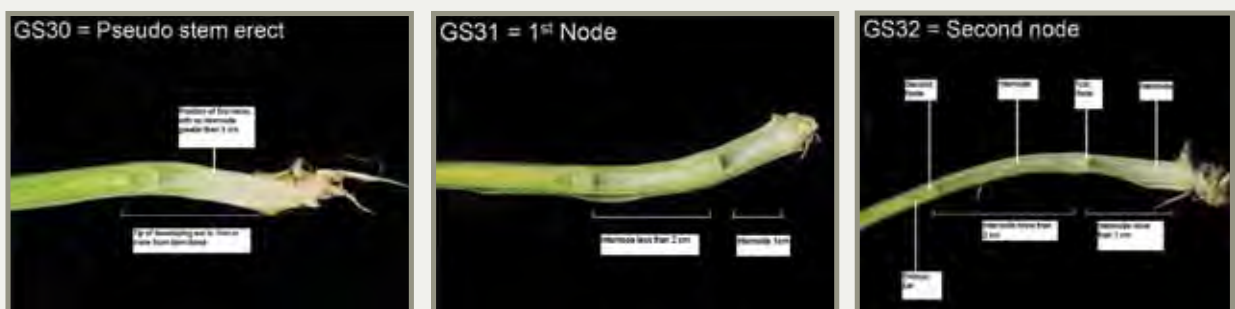


Though leaf dissection is the only sure way to check which leaf is emerging, nodal growth stages on the main stem give an approximate guide to leaf emergence and an easy way to identify fungicide timing by growth stage. Where crops are

subject to early disease onset, such as early stripe rust, an ideal timing for the first fungicide would be at the first to second node (GS31-32) since this growth stage coincides with the emergence of the first of the top three leaves (*flag - 2*).

FIGURE 16: Accurately Identifying Wheat Growth Stage 31.

Growth Stages of the main stem at early stem elongation defined by movement of the internal nodes, internodes and embryo ear.



Photos supplied by the Foundation for Arable Research.

appendix 1

Appendix 1: Hints for interpreting soil N tests in the northern region

STEP 1: Consider whether the data was collected appropriately.

At least eight cores should be bulked for a given soil type within a paddock. They should be taken at different points in the row configuration to ensure the sample is not biased, as N may still be partially banded due to band placement position or patterns of crop extraction. Additionally, cores should not be taken on recently fertilised paddocks, as it becomes very difficult to know just how much fertiliser N (which takes time to turn into plant-available-N) has been detected.

STEP 2: Arrange your information as per the worked example below.

Note that in the northern region, we focus on nitrate-nitrogen (NO₃-N) when soil testing. We don't usually consider ammonium-N results (NH₄-N) as they are unreliable and not usually important unless the pH is lower than 5.5, or above 8.5.

STEP 3: Ensure you have a correct estimate of bulk density.

Don't just use the example value of 1.2 g/cm³

unless you are sure it applies to your soil. A rough guide to bulk density is below, and soil information from your district may be available in the APSOIL database: <http://www.apsim.info/Wiki/APSoil.ashx>

Rough guide to bulk density in Vertosols

'Heavy' vertosols (PAWC ~ 290mm): they are likely to be black vertosols; the widest cracks are almost 3 inches wide when very dry. Bulk density is approximately 1.0 g/cm³ in the top 90cm, and 1.1 g/cm³ below 90cm.

'Medium' vertosols (PAWC ~ 250mm): these are likely to be grey or brown vertosols, the widest cracks are about 2 inches wide when very dry. Bulk density is approx. 1.2 g/cm³ in the top 90cm, 1.3 g/cm³ below 90cm.

'Light' vertosols (PAWC ~ 210mm): likely to be light brown, sandy textured vertosols, widest cracks are only 1 to 1.5 inches wide when very dry. Bulk density is around 1.4 in the top 90cm, and 1.5 to 1.6 below 90cm.

STEP 4: Do the calculations by following the worked example – note that your layer information and bulk density may be different to those used here

Depth Interval (cm below surface) EXAMPLE ONLY	Layer Thickness (cm) EXAMPLE ONLY	Bulk density (g/cm ³) EXAMPLE ONLY	Nitrate-N concentration (ppm or mg/kg both work out the same)	Available N for each layer (kg of N per hectare)
Calculation ⇒	A	B	C	A ÷ 10 x B x C
0-10	10	1.2	10	12
10-30	20	1.2	10	24
30-60	30	1.2	20	72
60-90	30	1.2	10	36
			Total shallow N	144 kg/ha
90-120	30	1.3	10	39
120-180	60	1.3	10	78
			Total deep N**	117 kg/ha
			TOTAL N	261 kg/ha

**Deep N is sometimes unavailable due to subsoil constraints, so detailed soil 'characterisation' can be necessary to determine if it will be available to the crop. From Peake et al. (2012) Agronomy for high yielding cereal environments: varieties, agronomic strategies and case studies, In GRDC Northern Region Grains Research Updates, Goondiwindi, 6-7 March, 2012.

further reading

Associated papers with detailed information from projects

- Peake A.S., and Angus J.F. (2009). Increasing yield of irrigated wheat in Queensland and Northern NSW. In GRDC Northern Region Grains Research Updates, Goondiwindi, 3-4 March, 2009. (Available on GRDC website)
- Peake A.S., Rebetzke G., Chapman S., Drecker F., McIntyre L., Hundt A. and Bell K. (2012). Agronomy for high yielding cereal environments: varieties, agronomic strategies and case studies. In GRDC Northern Region Grains Research Updates, Goondiwindi, 6-7 March, 2012. (Available on GRDC website)
- Griffiths B., Guppy C., Hulugalle N., Birchall C., Bailey L., (2011) Practical considerations and agronomic management for winter cereal cropping in the western regions of northern New South Wales and southern Queensland. (Available on GRDC website)
- Griffiths B., Gett V., Jackson R., Burley T., Harris G., Payero J. Addressing agronomic constraints in irrigated wheat production in the northern grain region. (Cotton CRC Science Review March 2012)
- Gett V. Establishing Irrigated Wheat following Cotton in Northern NSW. 16th Australian Agronomy Conference
- Jackson R., Griffiths B., Gett V., Burley T., Harris G. Improving irrigated wheat yields and water productivity in the northern cropping region of eastern Australia. (2012 IAL Conference)
- Scheer C., Grace P., Payero J.O. et al. Nitrous Oxide emissions from irrigated wheat in Australia: impact of irrigation management. Agriculture Ecosystems and Environment
- Payero J.O., Robinson G. and Harris G.A. Comparison of irrigation and nitrogen management strategies for wheat production in the Australian northern region. Field Crops Research
- Payero J.O., Harris G., Jackson R., (2012). Irrigation Guide for Wheat in the Australian Northern Region (WaterPak)

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