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GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

TRITICALE

SECTION 10

PLANT GROWTH REGULATORS AND CANOPY MANAGEMENT

PLANT GROWTH REGULATORS | CANOPY MANAGEMENT | CEREAL CANOPY MANAGEMENT IN A NUTSHELL

Plant growth regulators and canopy management

Key messages

- In Australian cereal production, plant growth regulators (PGRs) are mostly used with the intention of producing a smaller plant that is resistant to lodging, or they are applied with the intention of reducing excessive growth in irrigated broadacre crops.
- Trials have revealed mixed responses in crop yield following the application of PGRs.
- Canopy management includes a range of crop management tools to manage crop growth and development to maintain canopy size and duration to optimise photosynthetic capacity and grain production
- Canopy management starts at seeding—sowing date, variety, plant population and row spacing are fundamental. It is more than purely delaying nitrogen (N).
- So far, the best results for canopy management have been seen in early sown-long season varieties with high yield potential, which are very responsive to high nitrogen fertiliser inputs. [1]

10.1 Plant growth regulators

A plant growth regulator (PGR) is an organic compound, either natural or synthetic, that modifies or controls one or more physiological processes within a plant. They include many agricultural and horticultural chemicals that influence plant growth and development. PGRs are intended to accelerate or retard the rate of growth or maturation, or otherwise alter the behaviour of plants or their produce. [2] This influence can be positive, e.g. larger fruit or more pasture growth, or negative, e.g. shorter stems or smaller plant canopies. [3]

10.1.1 PGRs and triticale

The growth of triticale seedlings from seeds treated with three concentrations of the PGRs tetcyclacis and chlormequat, with or without drying after soaking has been investigated. Both tetcyclacis and chlormequat inhibited shoot growth. They reduced shoot-to-root ratios: first by restricting shoot growth (one week after treatment), and later by boosting root growth (eight weeks after transplanting). At the concentrations used, tetcyclacis was a more active PGR than chlormequat, and it promoted tiller production. Drying after soaking promoted root growth, retarded the elongation growth of seedlings, and enhanced some of the effects of the PGRs. [4]

In another study, seeds of triticale and barley were soaked in a range of dilutions of chlormequat. Germination was monitored and the growth of seedlings assessed for up to five weeks. Some concentrations of chlormequat produced seedlings with significantly more leaves on the main stem, more primary tillers, a greater leaf lamina area and a higher shoot dry weight. It is argued that these modifications could lead to an increased yield potential. [5]

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1 G McMullen (2009) Canopy management in the northern grains region: the research view. NSW Department of Primary Industries, http://www.nga.org.au/results-and-publications/download/31/australian-grain-articles/general-1/canopy-management-tactical-nitrogen-in-winter-cereals-july-2009-.pdf

2 PG Lemaux (1999) Plant growth regulators and biotechnology. Presentation, Western Plant Growth Regulator Society, http://ucbiotech.org/resources/biotech/talks/misc/regulat.html

3 D Jones (2014) Plant growth regulators. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Plant-growth-regulators

4 W Yang, REL Naylor (1988) Effect of tetcyclacis and chlormequat applied to seed on seedling growth of triticale cv. Lasko. Plant growth regulation 7(4), 289–301.

5 REL Naylor, PS Brereton, L Munro (1989) Modification of seedling growth of triticale and barley by seed-applied chlormequat. Plant growth regulation 8(2), 117–125.

10.1.2 PGRs in Australia

The use of PGR products in Australia has generally been relatively low. The principle reason for this is simply that crop responses are viewed as variable, and growers have not seen enough benefit in incorporating them into their cropping programs.

The use of PGR products in Australia has generally been relatively low. The principle reason for this is simply that crop responses are viewed as variable, and growers have not seen enough benefit in incorporating them into their cropping programs.

The most widely used PGRs in Australia have a negative influence on plant growth; i.e. they are applied with the intention of producing a smaller plant that is resistant to lodging or with the intention of reducing excessive growth in irrigated broadacre crops. Currently, there are four broad groups of PGRs in use in Australian crops. They are:

1. Ethephon, e.g. Ethrel®.
2. Onium-type PGRs, e.g. Cycocel®, the active ingredient of which is chlormequat (and Pix®, which is registered only for cotton).
3. Triazoles, e.g. propiconazole (which is registered as a fungicide, and not for use as a PGR).
4. Trinexapac-ethyl, e.g. Moddus®, Moddus® Evo.

The four groups of PGRs act by reducing plant cell expansion, resulting in, among other things, shorter and possibly thicker stems. If the stems are stronger and shorter, the crop is less likely to lodge.

Ethephon is applied from the stage of the flag leaf emerging (Z37) to booting (Z45), and reduces stem elongation through the increase in concentration of ethylene gas in the expanding cells.

The PGRs in groups two to four reduce crop height by reducing the effect of the plant hormone gibberellin. These are applied at early stem elongation (Z30–32).

The manufacturers of these products claim other benefits, too, including:

- Better root development that allows for increased root anchorage.
- Better root development that provides greater opportunity for water and nutrient scavenging.
- Possible improved grain quality.
- Reduction in shedding in barley.
- Increased harvest index (HI), the ratio between grain and total dry matter.
- Faster harvest speeds and reduced stress at harvest.

A combination of trinexapac-ethyl and chlormequat applied at growth stage 31 has been found to provide significant and consistent yield gains in wheat (11%) and barley (9%) under dry spring conditions. They also significantly reduced plant height, lessening the possibility of lodging in wetter seasons. [6] Overseas, chlormequat chloride has been found to inhibit gibberellin production, and has been recommended in winter and spring rye, wheat, oats, triticale and winter barley. [7]

Moddus® is registered for ryegrass seed crops, poppies and sugar cane. Moddus Evo®, an enhanced dispersion concentrate of Moddus®, is not currently registered but has been submitted to the Australian Pesticides and Veterinary Medicines Authority (APVMA) for registration to be used in Australian cereals.

An alternative to the chemical PGRs is grazing. It was demonstrated in the Grain and Graze project, which had study sites at a number of mixed-farming locations, that

6 W Long (2005) AC0003: Plant growth regulators and their agronomic and economic benefits to high yield potential cereal, pulse and oilseed crops. Final Report. Project ACC00003. GRDC, http://finalreports.grdc.com.au/ACC00003

7 BASF. How do PGR's work? http://www.agricentre.basf.co.uk/agroportal/uk/en/crop_solutions/cereals_5/lodging___canopy_managememt/canopy_management_in_cereals.html

MORE INFORMATION

Plant growth regulators

grazed treatments were regularly shorter than the non-grazed treatments, and grazed crops were less prone to lodging. [8]

10.1.3 Considering mixed results

In Australia, there have been mixed results in terms of PGRs' ability to increase yield and profits.

Take home messages:

- Crop responses to the use of plant growth regulators can be inconsistent.
- In general, yield responses, if any, are produced by the reduction in lodging rather than as a direct effect of PGRs (Photo 1).
- Plant growth regulators must be applied at the correct crop growth stage according to product directions, which can be well before any lodging issues are apparent.

Photo 1: *Severe lodging of a cereal crop (left).*

Source: Syngenta

The main commercial triticale varieties are relatively tall compared with newer wheat varieties, increasing the likelihood of lodging. In most of the newer varieties, however, lodging is not considered a problem. The likelihood of lodging is increased by high rates of nitrogen (N) fertiliser and under irrigated conditions. [9] PGRs may help to decrease the risk of lodging in triticale, but this has not yet been explored in Australia.

Attempting to grow high yielding irrigated crops requires high levels of inputs; this includes water and fertiliser, which can promote large vegetative crops with an increased risk of lodging. Lodging can result in reduced yields and difficult harvest. Plant growth regulators have been around for many years but results can be variable, even having negative effects on yield. The Irrigated Cropping Council (ICC) conducted trials in 2003 and 2004 that saw some reduction in lodging but little yield response. At the same time, trials on nitrogen management in cereals demonstrated that to achieve high yields, crops do not necessarily need heavy sowing rates and large amounts of nitrogen at sowing, with corresponding lush crop in early season prone to lodging. This has seen many growers adopt a topdressing strategy that supplies the crop with N when it needs it; i.e. from stem elongation onwards. Less vegetation at stem elongation promotes stronger stems, which can support a crop yielding 8 tonnes/ha.

A trial conducted at the ICC trial block in 2012 which aimed to grow 10 t/ha of wheat and barley was deliberately sown heavily and fertilised early, and sprayed with the plant growth regulator, Moddus® Evo, as lodging was likely to occur. The effect of the PGR was mixed: barley yields increased, but wheat yields did not, despite the crops not actually lodging. A repeat trial sown in 2013 saw some lodging control and, once again, a yield increase in barley.

8 D Jones (2014) Plant growth regulators. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Plant-growth-regulators

9 RS Jessop, M Fittler (2009) Triticale production manual: an aid to improved triticale production and utilization, in Improved triticale production through breeding and agronomy, Cooperative Research Centre for an Internationally Competitive Pork Industry, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

MORE INFORMATION

Mixed bag—dual purpose crops, PGRs and other local research—Tasmania Institute of Agriculture

GRDC: Plant growth regulators

GRDC: Plant growth regulators in broad acre crops

GRDC: PGRs and their agronomic and economic benefits to high yield potential cereal, pulse and oilseed crops

Online farm trials: Good things come in small packages: plant growth regulators in barley

Conclusions: The value of PGRs

PGRs may have a place in the management of high yielding crops. Unfortunately their effects are not consistent and the decision on whether to apply a PGR has to be made approximately three months before the lodging would be expected.

Alternative PGRs are available but are not yet registered for use on all crops or at rates and timings that would have a growth regulatory effect.

The yield improvements seen in barley in the ICC trials need further investigation, as the reason behind the increase is not clear. [10]

10.1.4 Case study: Moddus® Evo

Key points:

- Moddus® Evo reduces lodging and can increase yields.
- Application timing and concentration of Moddus® Evo is critical.
- Moddus® Evo should not be applied to plants under stress.
- Moddus® Evo has improved formulation stability and plant uptake.

Lodging is considered one of the biggest barriers to reliably achieving high yields in intensive cereal production in Australia. When favourable season conditions combine with traditional management practices in high input cereal production systems, lodging can result in significant reductions in yield and grain quality.

Moddus® (250 g/L trinexapac-ethyl) is used by cereal growers in a range of overseas countries including New Zealand, UK and Germany to reduce the incidence and severity of lodging and optimise the yield and quality of high yielding wheat, barley and oat crops. Moddus® Evo is an enhanced dispersion concentrate (DC) formulation, which has been developed to provide greater formulation stability and more effective uptake in the plant. With improved mixing characteristics and the potential to provide better consistency of performance, Moddus® Evo is currently submitted to the Australian Pesticides and Veterinary Medicines Authority (APVMA) for registration in Australian cereals.

GRDC and Syngenta, the manufacturer of Moddus®, undertook research to investigate the value of Moddus® applications to Australian cereals to reduce lodging and improve yields. [11]

Methods

The researchers conducted field trials across Australia from 2004 to 2011. They used a number of varieties, climatic conditions and geographical locations. They established small plots, typically 20–120 m^2 using a randomised complete block design, and incorporating three to six replicates.

They measured the effect of Moddus® application on plant growth, stem strength, stem-wall thickness, lodging, lodging score, and yield, and took grain-quality measurements.

Results

In the trials, overall improvements in yield were often correlated with a reduction in stem height, irrespective of whether lodging had occurred. Yield improvements through the reduction of lodging are well documented. What is less understood is the often-positive impact on yields with the use of Moddus® Evo in the absence of lodging.

Conversely during the course of the evaluation of Moddus® Evo on the yield enhancement and reduction in lodging, a few trials gave anomalous results, in

10 D Jones (2014) Plant growth regulators. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Plant-growth-regulators

11 LM Forsyth and K McKee (2013) Moddus Evo: controlling plant growth for reduced lodging and improved cereal yields. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Moddus-Evo-Controlling-plant-growth-for-reduced-lodging-and-improved-cereal-yields

MORE INFORMATION

GRDC: Moddus® Evo: Controlling plant growth for reduced lodging and improved cereal yields

which the application of Moddus® Evo did not improve yield. When the researchers examined these trials, they found that either environmental conditions during the lead-up to the application of the chemical were poor—with extensive frosting, drought, poor subsoil moisture—or there were nutrient deficiencies in the crop. As a result, they recommended that Moddus® Evo should only be applied to healthy crops with optimum yield potential. As well, the timing and concentration of Moddus® Evo applications is critical to produce the optimal yield improvements.

Moddus® Evo offers growers in environments conducive to lodging an in-season option to reduce the impact of lodging while allowing them to manage crops for maximal yields.

10.2 Canopy management

Key points:

- Canopy management starts at seeding: sowing date, variety, plant population and row spacing are fundamental. It is more than just delaying nitrogen.
- Correct identification of the key growth stages for input application is essential, particularly during early stem elongation when the key leaves of the crop canopy emerge.
- Knowledge of soil moisture status and soil nitrogen reserve and supply need to be taken into account in order to match canopy size to environment.
- Crop models can help integrate crop development, environmental conditions and nutrient status in order to make better canopy management decisions. [12]

What is canopy management?

The concept of canopy management has been primarily developed in Europe and New Zealand—both distinct production environments similar to those typically found in most grain producing regions of Australia.

Canopy management includes a range of crop management tools to manage crop growth and development to maintain canopy size and duration to optimise photosynthetic capacity and grain production. One of the main tools for growers to manage the crop canopy is the rate and timing of applied fertiliser N. The main difference between canopy management and previous N topdressing research is that all or part of the N inputs is tactically delayed until later in the growing season. This delay tends to reduce early crop canopy size but this canopy is maintained for longer, as measured by green leaf retention, during the grainfilling period. [13]

If the canopy is too thin, nitrogen timing is brought forward, if it is too thick nitrogen timing is delayed (Photo 2). Much of the change brought about by canopy management has been due to the adoption of lower plant populations and a greater proportion of nitrogen being applied later in the season.

12 GRDC (2009) Canopy management fact sheet, Grains and Research Development Corporation, https://grdc.com.au/uploads/documents/GRDC_CanopyManagement_4pp.pdf

13 G McMullen (2009) Canopy management in the Northern grains region—the research view. NSW DPI, http://www.nga.org.au/results-and-publications/download/31/australian-grain-articles/general-1/canopy-management-tactical-nitrogen-in-winter-cereals-july-2009-.pdf

Photo 2: *Example of controlled canopy cover—Kellalac wheat treated with the same level of nitrogen, sown 11 June at Gnarwarre (Geelong region) in Victoria (in high rainfall zone). The thinner crop canopy (left) yielded 6.18 t/ha and 12% protein; the thicker crop canopy (right) yielded 6.20 t/ha and 10.6% protein.*

Source: GRDC

Adopting canopy management principles and avoiding excessively vegetative crops may enable growers to ensure a better match of canopy size with yield potential as defined by the water available.

Other than sowing date, plant population is the first point at which the grower can influence the size and duration of the crop canopy, [14] and one of the main tools for managing the crop canopy is the rate and timing of applied fertiliser N.

If the canopy becomes too big, it competes with the growing heads for resources, especially during the critical 30-day period before flowering. This is when the main yield component (grain number per unit area) is set. Increased competition from the canopy with the head may reduce yield by reducing the number of grains that survive for grainfill.

After flowering, temperature and evaporative demand increase rapidly. If there is not enough soil moisture, the canopy dies faster than the grain develops, and results in small grain. Excessive N application and high seeding rates are the main causes of excessive vegetative production. Unfortunately, optimum N and seeding rates are season dependent. Under drought conditions, N application and seeding rates that would be regarded as inadequate under normal conditions may maximise yield, whereas higher input rates may result in progressively lower yields. Alternatively, in years of above average rainfall, yield may be compromised with normal input rates. The extreme of this scenario of excessive early growth is haying-off, where a large amount of biomass is produced, using a lot of water and resources. Then, later in the season, there is insufficient moisture to keep the canopy photosynthesising, and not enough stored water-soluble carbohydrates to fill the grain. Therefore, grain size and yield decrease.

To attain maximum yield, it is important to achieve a balance between biomass and resources. The main factors that can be managed are:

- plant population
- row spacing
- inputs of N
- sowing date
- weed, pest and disease control
- plant growth regulation, with grazing or specific plant growth regulator products

14 GRDC (2005) Cereal growth stages. Grains Research and Development Corporation, September 2005, https://grdc.com.au/uploads/documents/GRDC%20Cereal%20Growth%20Stages%20Guide1.pdf

Of these, the most important to canopy management are N, row spacing and plant population. [15]

Applying N or fungicide at stem elongation increases the opportunity to match input costs to the potential yield for that season. While seeding applications may still be required for healthy establishment, crop models help support decisions on application timing. Models such as APSIM and Yield Prophet® simulate growth stage and season.

Canopy management is not about a delayed N strategy, however, but starts at seeding by determining the correct plant establishment for the chosen seeding date and row spacing. This must also take into account available soil moisture and nutrients (Figure 1). [16]

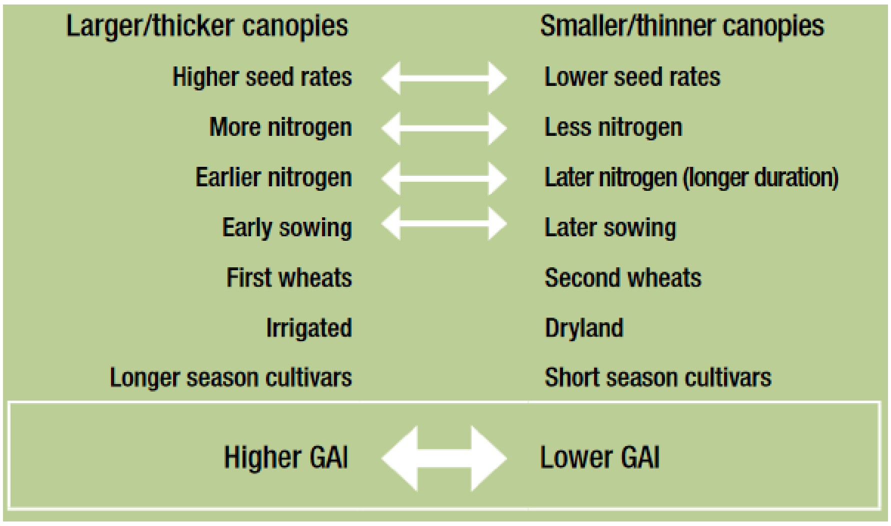

Figure 1: *Factors under grower control that influence canopy density, size and duration. GAI = Green area index (amount of green surface area).*

Source: GRDC

While N timing and rate are key components of successful canopy management, it is essential that they are considered in conjunction with the inter-related factors of:

- soil moisture
- soil nitrogen reserves
- seeding date
- seed rate and variety

To practice canopy management, it is important to understand the principal interactions between plant growth stages, available water and nutrients, and disease pressure. These interactions are complex but tools from simple visual indicators through to crop models can assist.

IN FOCUS

Canopy management—Inverleigh

Trials to inform canopy management guidelines were conducted in Inverleigh, Vic in 2007. Barley was sown on 13 June, following canola stubble. With high soil nitrogen reserves (203 kg/ha N, 0 = 90 cm) recorded at sowing, a small but significant response was observed to applied

15 N Fettell, P Bowden, T McNee, N Border (2010) Barley growth and development. PROCROP Series. NSW Department of Industry and Investment, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

16 GRDC (2009) Canopy management fact sheet, Grains and Research Development Corporation, https://grdc.com.au/uploads/documents/GRDC_CanopyManagement_4pp.pdf

nitrogen (0.21 t/ha at 50 kg/ha N and 0.23 t/ha at 100 kg/ha N) (Figure 2). There was a significant advantage to nitrogen timed during stem elongation (GS31–33) over nitrogen applied in the seedbed (Figure 3).

There was also a non-significant trend for the higher populations (193 plants/m^2) to be higher yielding than 100 plants/m^2 (0.21 t/ha mean advantage), with the highest yields in the trial recorded when the higher plant population was combined with GS31–33 nitrogen timings. At 50 kg/ha N, these timings produced malting grade qualities, with the exception of test weight, which was below 65 kg/ha in all treatments in the trial.

The best margins (after nitrogen and seed costs had been deducted) came from 190 plants/m^2, with nitrogen timed at GS31–33 at 50 kg/ha N. Interestingly, there was a greater response to 100 kg/ha N over 50 kg/ha N with the thinner crop canopy, leading to a significant interaction between N rate and plant population. However, higher plant populations with 50 kg/ha N still produced better margins. This may have correlated to a need to boost tillers in the lower plant population, but not in the higher population. [17]

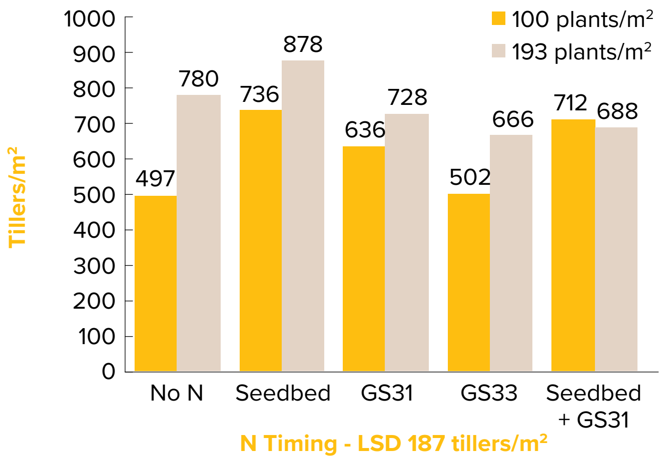

Figure 2: *Influence of different nitrogen timings and plant population on tiller/m^2.*

Source: Online farm trials

17 N Poole (2007) Defining guidelines for canopy management in barley for the different climatic regions of Australia: June sown Gairdner, Inverleigh, Victoria. Crop Agronomy Trials, http://www.farmtrials.com.au/trial/15841

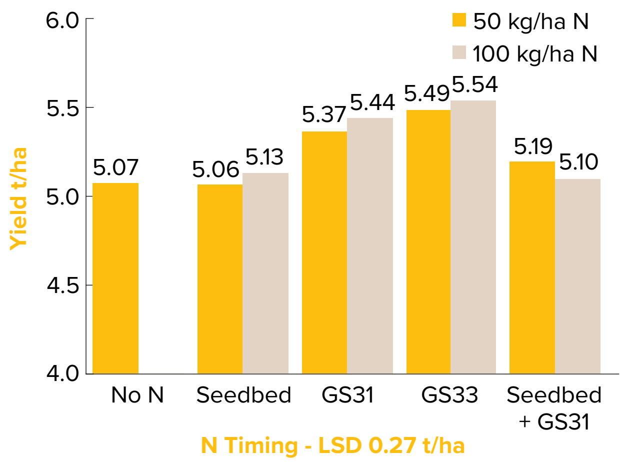

Figure 3: *Influence of different nitrogen timings and rates (mean of both plant populations) on yield (t/ha).*

Source: Online farm trials

10.3 Cereal canopy management in a nutshell

1. Select a target head density for your environment (350 to 400 heads per square metre should be sufficient to achieve optimum yield, even for a yield potential of 7 tonnes per hectare).
2. Adjust canopy management based on paddock nutrition, history and seeding time to achieve target head density.
3. Established plant populations (for wheat) of between 80 and 200 plants/m^2 would cover most scenarios.
4. Lower end of range (80–100 plants/m^2)—earlier sowings/high fertility and/or low yield potential low-rainfall environments.
5. Higher end of the range (150–200 plants/m^2)—later sowings, lower fertility situations and or higher rainfall regions.
6. During stem elongation (GS30–39), provide the crop with necessary nutrition (particularly N at GS30–33 pseudo stem erect–third node), matched to water supply and fungicides to:
    - maximise potential grain size and grain number per head
    - maximise transpiration efficiency
    - ensure complete radiation interception from when the flag leaf has emerged (GS39)
    - keep the canopy green for as long as possible following anthesis

Keeping tiller number just high enough to achieve potential yield will help preserve water for filling grain and increase the proportion of water soluble carbohydrates. The timing of the applied N during GS30–33 window can be adjusted to take account of target head number and can be employed where tiller numbers and soil nitrogen seems deficient for desired head number. Conversely, where tiller numbers are high and crops are still regarded as too thick, N can be delayed further until the second or third node (GS32–33), which will result in fewer tillers surviving to produce a head. Much of the research on topdressing nitrogen has focused on the role of in-crop

N to respond to seasons in which yield potentials have increased significantly due to above-average rainfall conditions. In these situations, research has shown that positive responses can be achieved, especially when good rainfall is received after N application. [18]

10.3.1 Setting up the canopy

Research has shown that extra tillers produced by more plants per unit area are more strongly correlated to yield, than extra shoots stimulated by increased nitrogen at seeding. [19]

Boosting tiller numbers with seeding nitrogen results in greater tiller loss between stem elongation and grainfill. This specifically occurs in two situations: low rainfall, short environments and when soil moisture is limited. In these situations, moisture and nutrient resources are used prior to stem elongation to produce biomass, which fails to contribute to grain yield. Indeed, diverting these resources to unsuccessful tillers limits the potential of surviving tillers.

Therefore, identifying the correct population for a particular sowing date, soil nitrogen reserve and region is the basis for setting up the crop canopy.

10.3.2 Soil moisture status

Under Australian conditions soil moisture has been identified as the biggest driver of the cereal crop canopy, both in terms of size and duration. Therefore, an understanding of how much water a soil can hold, and how much water a soil is holding at seeding and stem elongation is central to canopy management.

The start of stem elongation (GS30) is the pivotal point for managing the canopy with inputs, as from this point canopy expansion is rapid and soil nitrogen and water reserves can be quickly used.

If soil moisture is limited at the start of stem elongation, the ability to manipulate the crop canopy with nitrogen is limited; in many cases, the best canopy management is not to apply inputs such as nitrogen and fungicides.

By setting up a smaller crop canopy, modelling demonstrates that limited stored soil moisture can be reserved for use at grainfill, rather than being depleted by excessive early growth. However, in higher rainfall regions and in a good season, setting-up a small canopy may result in actual yield falling below potential.

Calculating potential yield and then plotting actual rainfall against decile readings for the region provides a broad picture of whether there will be sufficient soil moisture to consider additional nitrogen inputs at stem elongation.

The decision support tool Yield Prophet® and the Sirius Wheat Calculator (developed in New Zealand) offer simple tools to record and assess multiple options about the relationship between growing plants and the environment including available water and nutrients.

10.3.3 Soil nitrogen

It is important to have an understanding of soil N reserves to the depth of the rooting zone. Generally, 40–50 kg of N per hectare of soil-available N is required to feed a crop to stem elongation (GS30). Higher soil nitrogen reserves provide much more flexibility in managing the canopy, with tactical nitrogen applied during stem elongation.

Timing of deep-soil tests is important. Deep-soil nitrogen tests carried out in summer, several months before seeding may reveal less soil nitrogen than tests carried out after the autumn rain, when greater mineralisation will have occurred.

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18 N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, http://www.grdc.com.au/CanopyManagementGuide

19 GRDC (2009) Canopy management Factsheet, https://grdc.com.au/uploads/documents/GRDC_CanopyManagement_4pp.pdf

Providing soil moisture has not been limited or the crop has not been subject to waterlogging over winter, crop appearance at GS30–31 gives a reasonable indication of nitrogen reserves and the justification for nitrogen application at this stage.

However, it is difficult to use visual appearance unless you have a benchmark. This has led to the concept of the N rich strip (Photo 3). [20]

Photo 3: *A large difference in visual appearance: N-rich strip (110 kg N/ha at seeding) viewed at GS31, in trials planted on low soil N reserve (25 kg N/ha 0–90 cm). 443 tiller/m² under N-rich treatment (left) and 266 tillers/m² untreated (right).*

Source: GRDC

A useful guide that requires no sophisticated equipment is to apply an excess of nitrogen at sowing, for example 50 to 100 kg N/ha, to a small area of the paddock, approximately 2 m by 10 m.

During winter and spring by comparing crop vigour (tiller number) and greenness in these small N-rich areas with the rest of the crop, an indication of N supply can be obtained. The advantage of using the plant rather than depending totally on a soil test is that the plant is directly registering soil N supply rather than soil nitrogen reserve, which crop roots may not always be able to access.

This visual difference can be quantified by using crop sensors that measure the light reflectance from the crop canopy. By measuring the reflectance at the red and near-infrared wavelengths, it is possible to quantify canopy greenness using a number of vegetative indices, the most common of which is termed the Normalised Difference Vegetative Index (NDVI). This index gives an indication of both biomass present and the greenness of that biomass. This canopy sensing can be done remotely from aircraft/satellites or with a hand-held or vehicle-mounted sensor.

10.3.4 Seeding rate and date

Achieving the correct plant population is fundamental if sufficient tillers are to be set. Seeding rates need to be adjusted for seed size and planting date; if this does not occur the first step in controlling the canopy is lost.

How many plants are targeted depends on:

- region—as a general guide, drier regions sustain lower plant populations than wetter environments
- sowing date—earlier sowings require lower plant populations compared to later sowings, as the tillering window is longer and more tillers are produced per plant

Overall, earlier planting provides greater opportunities to manipulate the crop canopy during the stem elongation period: the plant's development periods are extended along with the earlier tillering period.

Row spacing

- Increased interest in no-till farming has created a trend for wider crop row spacing (Figure 4).
- In general, increasing row spacing up to 50 cm has minimal effect on cereal yield when yield potential is less than 2 tonnes per hectare.

20 GRDC (2009) Canopy management fact sheet, Grains and Research Development Corporation, https://grdc.com.au/uploads/documents/GRDC_CanopyManagement_4pp.pdf

- In higher rainfall areas, where cereal crops have higher potential yields, significant yield decreases have been recorded with wider row spacing (greater than 25 cm).
- The yields of broadleaf crops vary in their response to wider row spacing.
- Precision agriculture allows for easier inter-row sowing and fertiliser applications at wider row spacing. [21]

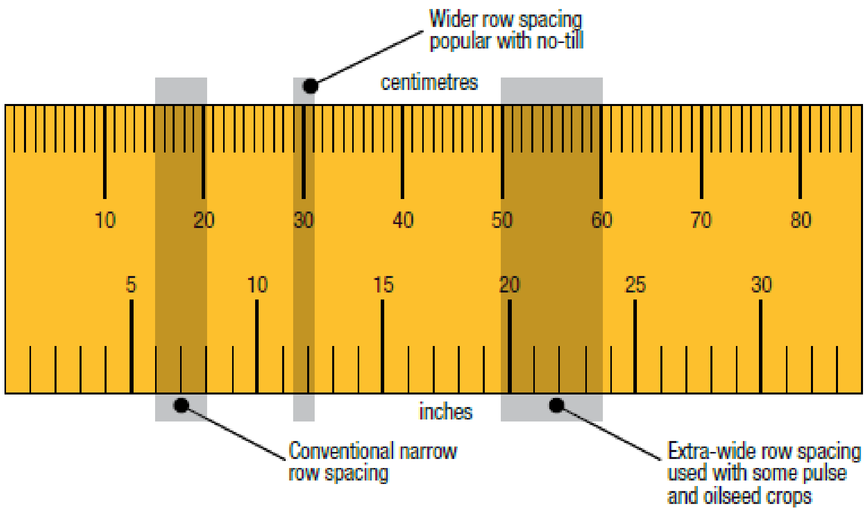

Figure 4: *Common row spacings in metric and imperial measurements.*

Source: GRDC

Yield

- There are a number of reasons why growers might wish to pursue wider row spacing in cereals; for example, residue flow, inter-row weed and disease control. However, in all project trials (2007–10) on wheat covering a wide range of rainfall scenarios, increasing row width reduced yield.
- The yield reduction in wheat was particularly significant when row width exceeded 30 cm.
- Crop row spacing is an important factor for weed competition (Photo 4).
- At row widths of 30 cm, the reduction in wheat yield compared to narrower 20–22.5 cm row spacing was dependent on overall yield potential.
- At yields of 2–3 tonnes per hectare, the yield reduction was negligible.
- At yields of 5 tonnes per hectare, the yield reduction was between 5–7%, averaging about 6%.
- Data from a single site suggests that rotation position may influence the yield response in wider row spacing in wheat. In wheat, wheat-on-wheat suffered less yield reduction with wider rows than an equivalent trial at the same site which was in wheat after canola. [22]

21 GRDC (2011) Crop placement and row spacing: southern region. Fact sheet. GRDC, https://grdc.com.au/Resources/Factsheets/2011/02/Crop-Placement-and-Row-Spacing-Southern-Fact-Sheet

22 N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, http://www.grdc.com.au/CanopyManagementGuide

Photo 4: *Narrow row spacing (left) and wide row spacing (right). The higher the yield potential, the greater the negative impact of wider rows on crop yields.*

Source: Weedsmart

Plant spacing

- Increasing row width decreases the plant-to-plant spacing within the row, leading to more competition within the row and reduced seedling establishment (for reasons that are not clearly understood).
- Increasing plant populations when using wider rows can be counterproductive with regard to yield, particularly where plant populations exceed 100 plants per square metre as a starting point.
- Limited data indicates that increasing seeding rates such that the average plant-to-plant spacing in the row drops below 2.5 cm are either negative or neutral in terms of grain yield.
- Planting seed in a band (as opposed to a row) will increase plant-to-plant spacing, but may increase weed germination and moisture loss through greater soil disturbance. [23]

Dry matter

- Wider row (30 cm and over) spacing reduced harvest dry matter relative to narrower rows (22.5 cm and under), with differences growing steadily (kilograms per hectare) from crop emergence to harvest, by which time differences were in the order of 1–3 t/ha depending on row width and growing season rainfall.
- The reduction in dry matter in wide rows was also significant at flowering (GS60–69), frequently 1 t/ha reduction when row spacing increased 10 cm or more over a 20 cm row spacing base. This could be important when considering harvesting for hay rather than grain. [24]

Grain quality

- The most noticeable effect of row width on grain quality was on protein; wider rows reduced yield and increased grain protein.
- Differences in grain quality were typically small in terms of test weights and screenings, with very small benefits to wider rows over narrow rows on some occasions. [25]

Nitrogen management

Nitrogen management has not been found to interact with row spacing; optimum N regimes for narrow row spacing
(22.5 cm or less) can be the same as for wider row spacing (30 cm or more). The greater nitrogen efficiency observed with stem elongation applied nitrogen was more important with narrow row spacing since higher yields lead to a tendency for lower protein. [26]

23 N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, http://www.grdc.com.au/CanopyManagementGuide

24 N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, http://www.grdc.com.au/CanopyManagementGuide

25 N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, http://www.grdc.com.au/CanopyManagementGuide

26 N Poole, J Hunt (2014) Advancing the management of crop canopies. GRDC, http://www.grdc.com.au/CanopyManagementGuide

10.3.5 In-crop nitrogen

Delaying N inputs from seeding to stem elongation (GS30–31) means they can be better matched to the season. In a dry spring, for example, no application may be warranted. In a spring with adequate rainfall to justify N application, project trials have shown stem elongation N to give yields equal or better than wheat crops grown with seeding N. However, applying N in advance of a rain front to ensure good incorporation has been found to be more important than exact growth stage. While GS31 should be the target growth stage for in-crop N application, the window can be expanded from GS25 to 31 in order to take advantage of rainfall. Even applications delayed until flag leaf can be successful where starting soil nitrogen is not too low (Figure 5).

Results from winter wheat cropping trials across Australia on the use of in-crop solid N at stem elongation show that where soil N reserves are low, N applied at stem elongation is not always the most appropriate strategy if yield is to be optimised.

Stem elongation N applications were found to be less appropriate with shorter season varieties and late sown crops. Drought conditions during the trial period (2006-08) has limited the results produced from trials. These trials assessed stem elongation N use in cereals grown on wider-row spacings: 300–350 mm compared to 175–200 mm. However, at the same seeding rate, moving to wider rows was found to reduce tillers per unit area and final ear population and yield, the latter by approximately 6% in the high rainfall zone. [27]

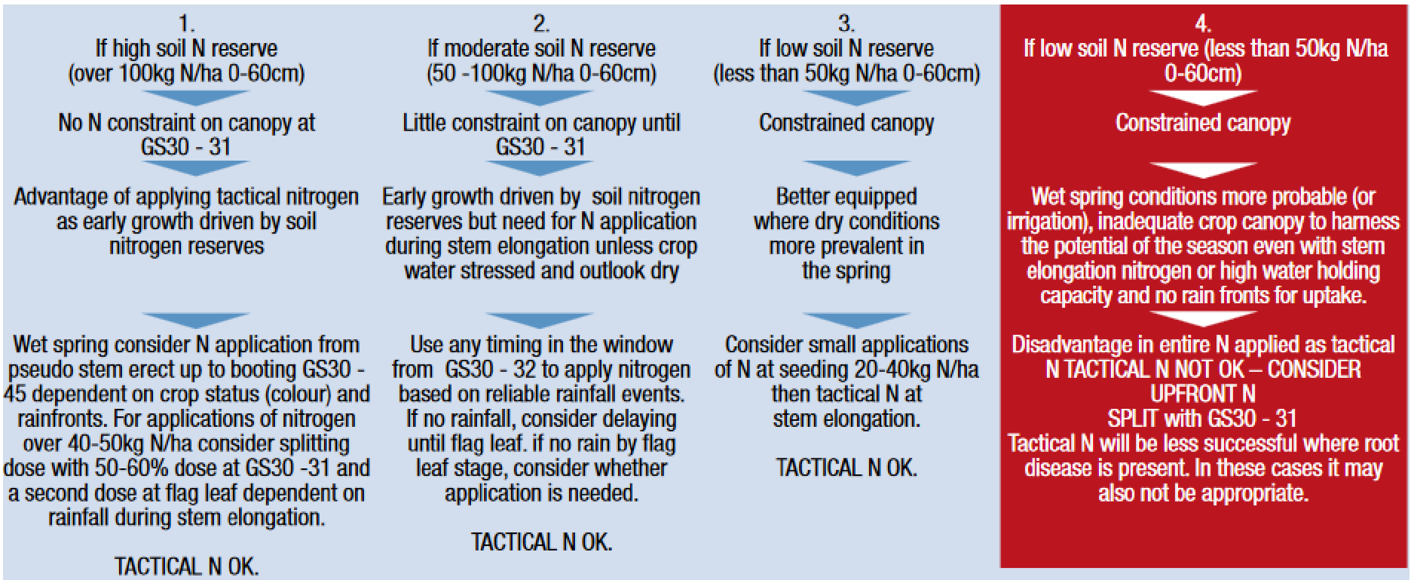

Figure 5: *Broad scenarios based on soil nitrogen level.*

Source: GRDC

10.3.6 Limitations of tactical nitrogen application

The main limitation to tactical N application is the ability to reliably apply N before a rain event, to enable roots to access soluble N in the root-zone. Predicted rain fronts may pass without yielding anything; therefore, dependably applying N throughout the season is risky.

Foliar N application is gaining popularity; however, this is only suitable for relatively low rates of N addition. Where higher N input is required, an efficient system to apply N into the wet soil profile after a rainfall event needs to be devised.

27 GRDC (2009) Canopy management fact sheet, Grains and Research Development Corporation, https://grdc.com.au/uploads/documents/GRDC_CanopyManagement_4pp.pdf

MORE INFORMATION

GRDC Fact Sheet: Canopy management

GRDC: Cereal growth stages guide

GRDC: Advancing the management of crop canopies

As technologies such as NDVI imaging and paddock management in zones become prevalent, the addition of N later in the crop cycle will become more relevant and will force the development of equipment to make such a system work.

Based on sound trials and paddock experience, the aim of improving the economic outcome at the end of the season through manipulation of the most costly input is taking shape. Adoption of these techniques would be further aided by development of efficient, in-soil N-application equipment. [28]

28 P McKenzie (2009) Canopy management in the northern grains region—the commercial view. Consultants Corner, Australian Grain, July 2009, http://www.nga.org.au/results-and-publications/download/31/australiangrain-articles/general-1/canopy-management-tactical-nitrogen-in-winter-cereals-july-2009-.pdf