SOUTHERN
AUGUST 2017

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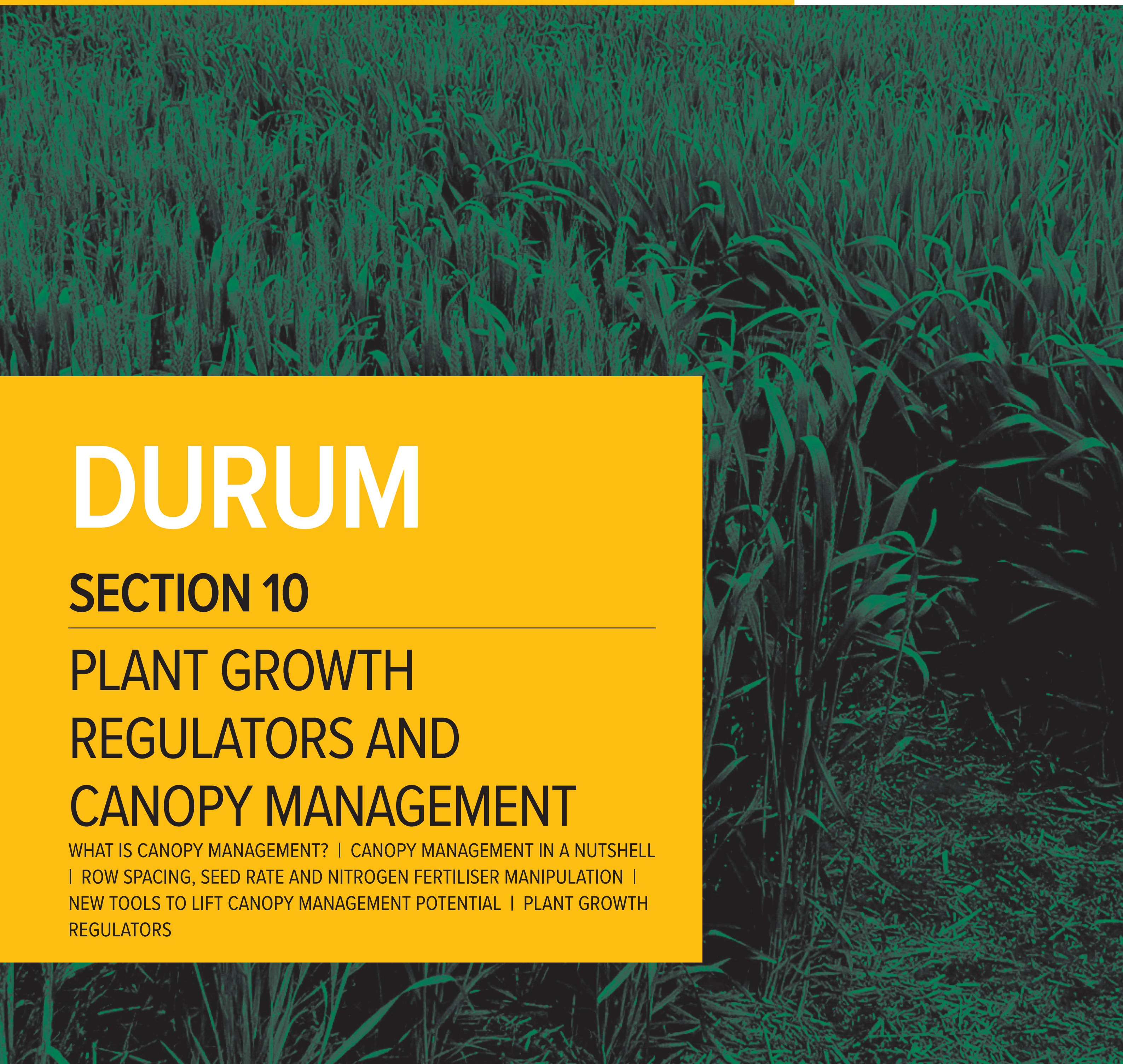

DURUM

SECTION 10

PLANT GROWTH REGULATORS AND CANOPY MANAGEMENT

Plant growth regulators and canopy management

Key messages

- Adopting canopy management principles and avoiding excessively vegetative crops may enable growers to better match 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.
- Upfront nitrogen increases tiller numbers and in many cases final ear number but may not necessarily increase yield.
- Crop responses to the use of plant growth regulators (PGRs) can be inconsistent.
- PGRs must be applied at the correct crop growth stage according to product directions, which can be well before any lodging issues are apparent.

10.1 What is canopy management?

Canopy management is managing the green surface area of the crop canopy in order to optimise crop yield and inputs. It is based on the premise that the crop's canopy size and duration determines the crop's photosynthetic capacity and therefore its overall grain productivity. [1]

Growth in cereals can be thought of in two distinct parts: 1) pre-flowering (pre-anthesis) growth, which is the growth of leaves, roots and stems before a crop flowers and sets yield potential; and 2) post-flowering growth, the majority of which goes into grain. The aim of canopy management is to get the balance right between pre- and post-anthesis growth to maximise grain yield, quality and harvestability in any given season. In drier environments crop canopies that produce excessive growth (tillers) by virtue of paddock fertility (soil nitrogen or applied nitrogen) use more of the water available pre-flowering, leaving less for grainfill. This may result in lower yields and poor grain size. Conversely, overly thin crop canopies that have adequate water available, produce insufficient crop canopy pre-flowering to fully take advantage of the water available for grainfill post-flowering. [2]

For more information on growth stages see Section 4: Plant growth and physiology.

Where this management system has been developed (principally in Europe and New Zealand) it has shifted grower focus from lush, thick crop canopies to thinner, more open, canopies (Photo 1). At its simplest, the technique could be represented by a simple comparison of crop canopies.

Growers practicing canopy management have target canopy sizes for specific growth stages, and nitrogen (N) management is tailored to adjust the crop to these targets. If the canopy is too thin, the timing of N fertiliser application is brought forward; if it is too thick, N timing is delayed. Soil moisture and expected rainfall for the remainder of the season are key factors to consider when deciding how much nitrogen to apply and when to apply it. In some seasons, several applications of nitrogen are required. Plant populations influence canopy development and management of plant populations in relation to sowing date can have a significant impact on crop biomass.

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

2 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

Photo 1: *Wheat grown in Victoria's high rainfall zone, near Geelong, treated with the same level of nitrogen. The crop on the left has a thinner crop canopy; it yielded 6.18 t/ha and 12.0% protein, compared to the thicker canopied crop on the right, which yielded 6.20 t/ha and 10.6% protein.*

Source: Grains Research and Development Corporation

In Photo 1, above, is an example of a thinner crop canopy (left) which yielded 6.18t/ha and 12% protein, and thicker crop canopy (right) which yielded 6.20 t/ha and 10.6% protein. The crop was Kellalac wheat, sown 11 June in Gnarwarre, Victoria (in the high rainfall zone); both paddocks were treated with same level of N.

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.

Canopy management includes a range of crop management tools for crop growth and development to maintain canopy size and duration and thereby optimise photosynthetic capacity and grain production. Other than sowing date, plant population is the first point at which the grower can influence the size and duration of the crop canopy [3] and 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 input is tactically delayed until later in the growing season. This delay tends to reduce early crop canopy size but the canopy is maintained for longer, as measured by green leaf retention, during the grainfilling period.

10.2 Canopy management in a nutshell

1. Select a target head density for your environment (350 to 400 heads/m^2 should be sufficient to achieve optimum yield even for 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 but durum crops should target the high end of sowing rates.
4. Lower end of range (80–100 plants/m^2): are appropriate for 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 and durum for weed competitiveness.

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

VIDEOS

WATCH: On-farm storage in the SA Mallee with Corey Blacksell.

WATCH: On-farm storage in SA—Linden Price

WATCH: Over the Fence: On-farm storage delivers harvest flexibility and profit

WATCH: Stay safe around grain storage

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:
7. maximise potential grain size and grain number per head;
8. maximise transpiration efficiency;
9. ensure complete radiation interception from when the flag leaf has emerged (GS39); and
10. 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. Earlier applications in the window (around GS30) can be employed where tiller numbers and soil N 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 less tillers surviving to produce a head. Further applications of nitrogen can be made as the crop progresses into booting (GS 45). Much of the research on topdressing N 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. [4]

10.2.1 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 has some risk. However, urea losses are extremely low during cold winter months and application of urea onto well -developed canopies assist in minimizing losses. Paddock trafficability is important, with an application of urea during or after a rainfall event onto wet soils being more beneficial to the crop than waiting for the next significant rainfall to occur and effectively applying the nitrogen at a later than optimum timing. Presswheel furrows can also aid nitrogen uptake as much of the fertiliser falls into the furrow where surface moisture levels are higher.

Foliar N application is gaining popularity; however, this is only suitable for relatively low rates of N addition and are generally more expensive. Foliar N applications are generally no more efficient than solid forms of nitrogen fertiliser. [5]

> *You can apply high rates in a liquid N form (i.e. UAN), with streaming nozzles, but there is a limit to how much N is actually taken in via the foliage. The remainder relies on root uptake. The advantage is that loss rates of a liquid N form are significantly lower than urea if you don't get sufficient rainfall to wash it in compared to urea. The downside is that UAN is generally a more expensive product per kg of N supplied.*

Agronomist's view

As technologies such as normalised difference vegetation index 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

4 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

5 Bill Long (2016). Personal communication.

taking shape. Adoption of these techniques in regions where winter rainfall is less frequent would be further aided by development of efficient, in-soil N application equipment. [6]

10.3 Row spacing, seed rate and nitrogen fertiliser manipulation

The traditional row spacing in much of southern Australia has been 15 to 20 cm (Figure 1). Greater adoption of no-till farming systems has increased interest in wider row spacing such as 30 to 50 cm, depending on the crop type and region. However, increasing row spacing is not always beneficial to yield. [7]

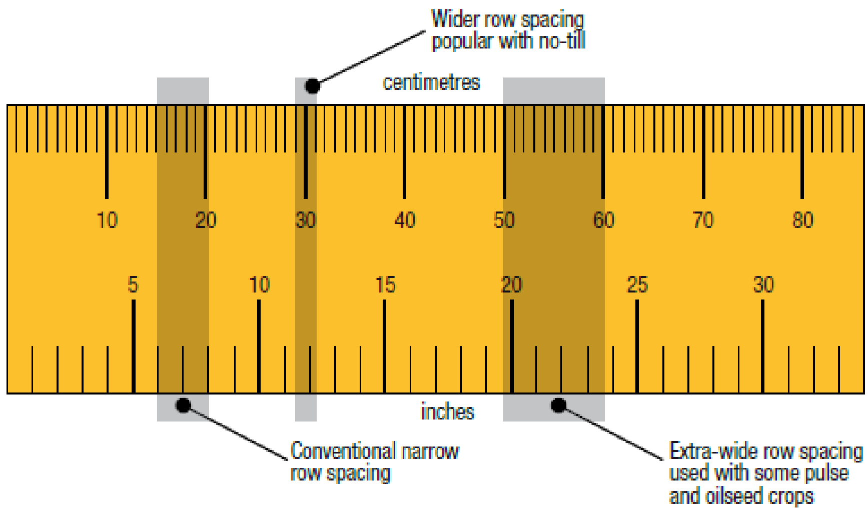

Figure 1: *Common row spacings in metric and imperial measurements.*

Source: Grains Research and Development Corporation

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 a series of canopy management trials (2007–10) on wheat covering a wide range of rainfall environments in Victoria, South Australia and New South Wales, increasing row width reduced yield.
- The yield reduction in wheat was particularly significant when row width exceeded 30 cm.
- 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 t/ha the yield reduction was negligible.
- At yields of 5 t/ha the yield reduction was between 5–7%, averaging about 6% (Photo 2).
- Data from a single site suggests that rotation position may influence the yield response in wider row spacing in wheat. Wheat after wheat suffered less yield reduction with wider rows than an equivalent trial at the same site which was in wheat after canola. [8]

6 Bill Long (2016). Personal communication.

7 GRDC (2011) Crop placement and row spacing fact sheet. Grains Research and Development Corporation, January 2011, https://grdc.com.au/Resources/Factsheets/2011/02/Crop-Placement-and-Row-Spacing-Southern-Fact-Sheet

8 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

Photo 2: *Narrow row spacing (left) and wide row spacing (right). The higher the yield potential, the greater the negative impact of wider rows on wheat 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) but most likely plant competition for resources such as light and water.
- Limited data indicates that increasing seeding rates, such that the average plant-to-plant spacing in the row drops below 2.5 cm, is 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. [9]

Dry matter:

- Wider row spacing (30 cm and over) reduced harvest dry matter relative to narrower rows (22.5 cm and under). From crop emergence to harvest, 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 a 1 t/ha reduction resulted 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. [10]

Grain quality:

- The most noticeable effect of row width on grain quality was on protein: wider rows increased yield and diluted 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. [11]

Nitrogen management

Nitrogen management did not interact with row spacing; optimum N regimes for narrow row spacing (22.5 cm or less) were the same as for wider row spacing (30 cm or more). The greater N efficiency observed with stem elongation applied N was more important with narrow row spacing since higher yields lead to a tendency for lower protein. [12]

9 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

10 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

11 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

12 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

10.3.1 Water and canopy management

Plants grow by intercepting solar radiation and must use water to do this. When plants are actively growing, they open the small holes (called stomata) on their leaf surfaces to let in carbon dioxide from the atmosphere, and this carbon dioxide is captured by the leaf's mesophyll cells and converted to dry matter through the process of photosynthesis. While the stomata are open, water evaporates from the mesophyll cell surfaces and escapes as vapour into the atmosphere. This process is called transpiration.

The amount of water a crop transpires per day is determined by the amount of leaf area a crop has per unit area of ground, water supply and the evaporative demand of the atmosphere (determined by the ambient temperature, solar radiation and wind). The amount of leaf area a crop has is measured as leaf area index (LAI) and is expressed in square metres of leaf area per unit of ground (m^2/m^2). For example, a crop with a LAI of 5.0 has 5 m^2 of leaf area per 1 m^2 of ground.

However, as the green area of the crop canopy is also composed of stems, leaf sheaths and the heads, the overall green area of canopy is described as the green area index (GAI). Cereal crops also have stomata on their stems, heads and leaf sheaths, and these areas contribute significantly to plant growth, particularly after anthesis. The rate at which plants are able to grow per unit of water transpired is called transpiration efficiency (TE), and is expressed as kilograms per hectare of dry matter per millimetre of transpiration (kg/ha/mm). Across a growing season, wheat plants generally have a TE for above-ground dry matter of between 50 and 60 kg/ha/mm. Factors that affect TE include nutrition (for example N stressed crops do not transpire as efficiently as crops with adequate N), the temperature and humidity of the atmosphere (the drier and warmer the atmosphere, the less efficient the plants) and the genetic make-up of the crop variety. [13]

10.4 New tools to lift canopy management potential

New tools to fight leaf diseases and respond to crop N needs have been developed for cereal growers in the high rainfall zone, following a three-year project by the Foundation for Arable Research.

Thirty-nine trials across the southern grains region showed that the use of crop sensors to assess the need for topdressed N at stem elongation have the potential to save up to $60/ha in fertiliser costs.

The trials showed a strong relationship between N uptake and sensor readings from late tillering to the third node, if appropriate test strips are used to calibrate the figures. This relationship is particularly useful to assess the degree of N available to the crop in spring. Linked with crop models in the future, it is envisaged that crop sensors could enable growers to better visualise the growth of their crops. The use of crop sensors may have a greater role where N applications are split. The sensor can be used after the first topdressing to determine whether a second application of N is warranted on parts of the paddock.

Trials in Tasmania found that for early sown (March or April), long season wheat, grazing before stem elongation prevented lodging and is more effective than other methods. However, in a wet spring, this was also associated with yield loss. The other factors found to reduce lodging were, in order of importance, variety choice, cutting sowing rates, applying plant growth regulators or delaying N. [14]

Key findings of the trials were:

- An average 6% yield penalty, but higher protein content, from wheat sown on 30 cm row spacing, compared with 20 or 22.5 cm, in crops yielding above 5 t/ha.

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13 GRDC (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

14 F Pritchard (2013) New tool lifts canopy management potential. Ground Cover Issue 105. Grains Research and Development Corporation, July 2013, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-105-July-August-2013/New-tool-lifts-canopy-management-potential

MORE INFORMATION

GRDC Canopy management guide

- Row spacing had little effect on yields for crops yielding 2 to 3 t/ha.
- Nitrogen requirements and optimal timing were the same, regardless of the row spacing.
- Ideally, growers should avoid planting seeds less than 2 cm apart within a row when sowing with wide rows, due to competition between plants.

10.5 Plant growth regulators

A plant growth regulator (PGR) is an organic compound, either natural or synthetic, that modifies or controls one or more specific physiological processes within a plant. PGRs are any substance or mixture of substances intended, through physiological action, to accelerate or retard the rate of growth or maturation, or otherwise alter the behavior of plants or their produce. [15]

PGRs are used to minimise crop lodging, shorten plant height and maximise yield, particularly in high N situations that promote heavy canopies. Attempting to grow high yielding irrigated crops requires high levels of inputs, including water and fertiliser, which can promote large vegetative crops that are prone to lodging. Lodging can result in reduced yields and difficulties in harvesting. PGRs have been around for many years but results can be variable and can have negative effects on yield in some circumstances.

Key points:

- Crop responses to the use of PGRs can be inconsistent.
- In Irrigated Cropping Council trials yield increases directly attributable to the use of PGRs have been measured in barley but not wheat. Other trials have demonstrated significant increases in wheat and barley yields in the absence of lodging.
- PGRs must be applied at the correct crop growth stage, which can be well before any lodging issues are apparent.

PGRs are chemicals which are used in various crops to manipulate the production of certain hormones, in particular gibberellic acid (GA) and ethylene (Ethephon). These hormones are produced by the plant at particular growth stages. By manipulating the amount of hormone produced by the crop, the plant height and stem strength can be influenced. Decreasing plant height and improving stem strength, reduces the amount of lodging and in some cases, increases Water Use Efficiency (WUE). [16] More recently, trinexipac ethyl has been registered for use in wheat and barley. Trials with this product demonstrate more consistent yield gains and reduced crop lodging as well as reduced head loss in barley. [17]

Inconsistent results from PRG applications

In a trial conducted in Narrabri, New South Wales, a combination of two PGRs increased yield by 16% when applied at GS31. Wheat was sown on 30 cm row spacings into a 2 m flat bed. Approximately 150 seedlings emerged and the site was irrigated via flood furrow. Nitrogen was applied at sowing (180 kg/ha) and the site had less than 30 kg/ha residual soil nitrate/90 cm soil. Despite no lodging being observed, a significant positive effect on yield was achieved using the products in this experiment when applied at the booting stage. This trend has been consistent through several experiments conducted using these products and mixtures. [18]

Another trial was conducted in 2006 at Benerembah, west of Griffith, to measure the influence of PGRs, varying N rates and application times on grain yield and quality

15 P Lemaux (1999) Plant growth regulators and biotechnology, http://ucbiotech.org/resources/biotech/talks/misc/regulat.html

16 B Haskins (2008) Durum wheat and barley canopy management, Hillston. New South Wales Department of Primary Industries, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/Durum-wheat-and-barley-canopy-management-Hillston.pdf

17 Bill Long (2016). Personal communication.

18 B Griffiths, L Bailey, C Guppy, N Hulugalle, C Birchall (2013) Managing resources and risk for 8 tonne cereal crops. GRDC Update Papers. Grains Research and Development Corporation, March 2013, https://grdc.com.au/Research-and-Development/%20GRDC-Update-Papers/2013/03/Managing-resources-and-risk-for-8-tonne-cereal-crops

MORE INFORMATION

Durm wheat and barley canopy management, Hillston.

Plant growth regulators

Plant growth regulators in broad acre crops

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

Good things come in small packages: plant growth regulators in barley

Mixed bag—dual purpose crops, PGRs and other local research—Tasmania.

of durum wheat on flood irrigation. Two durum wheat varieties (EGA Bellaroi⁄ and Jandaroi⁄) were planted using a small plot cone seeder at a sowing rate of 220 plants/m^2 (roughly 110 kg/ha). In the absence of lodging as with Bellaroi⁄, PGRs at DC31 actually reduced yield. When the crop lodged as it did in Jandaroi⁄, yield was maintained by using PGRs. In this trial PGRs were not economically viable, as they reduced or only maintained yield potential The researchers put these inconsistencies in yield and poor yield result down to poor seasonal conditions and suggest that PGRs may have a role in some season but not others. [19]

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 the PGR has to be made at 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. [20]

Until recently in Australia, the range of PGR's available to growers was limited to chlormequat chloride (wheat only) and ethephon (barley only) and the use of these products has generally been relatively low. The principle reason for this is simply that responses are viewed as variable and growers have not regularly seen the benefit of incorporating them into their management programs.

More recently a new PGR combination of trinexapac-ethyl and chlormequat applied at GS31 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. [21] 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. [22]

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 APVMA for registration in Australian cereals.

The purpose of this research was to investigate the value of Moddus® applications to Australian cereals to reduce lodging and improve yields.

19 IREC. Crop canopy management through nitrogen plant growth regulators. Farmer newsletter no. 175. Irrigation Research and Extension Committee,

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

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

22 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

Methods

Field trials were run across Australia from 2004 to 2011. A range of varieties, climatic conditions and geographical locations were used. Trials were established as small plots, typically 20–120m^2 using a randomised complete block design, incorporating 3–6 replicates.

Measurements were taken of the effect of Moddus® application on plant growth, stem strength, stem wall thickness, lodging, lodging score, yield, as well as grain quality measurements.

Results

Overall improvements in yield were often correlated with a reduction in stem height irrespective of whether lodging occurred or not. 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 there were a few trials with anomalous results, where Moddus® Evo application did not improve yield. When these trials were examined it was found that either environmental conditions during the lead up to the Moddus® Evo application were poor, with extensive frosting, drought, poor subsoil moisture profile or nutrient deficiencies within the crop. As a result Moddus® Evo should only be applied to healthy growing crops with optimum yield potential.

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. The timing and concentration of Moddus® Evo applications is critical to produce the optimal yield improvements. Moddus® should only be applied to healthy growing crops. Moddus® Evo is a new generation plant growth regulator offering improved yield potential to Australian cereals.

MORE INFORMATION

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