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GRDC

GROWNOTES™

SORGHUM

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

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What’s new

The GRDC GrowNotes are dynamic documents that are updated according to user feedback and newly available information.

This version of the GRDC Sorghum GrowNotes (updated December 2016) contains the following updates on original content published in July 2014:

Section A – Introduction

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- New podcast: Summer weed control - the latest: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2015/11/107-north
- New reference: N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

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- New reference: Sorghum agronomy to manage risk and improve yield in the western zone: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Sorghum-agronomy-to-manage-risk-and-improve-yield-in-the-western-zone
- New reference: Likely fit of summer and winter forage crop options in Central West farming systems: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Likely-fit-of-summer-and-winter-forage-crop-options-in-Central-West-farming-systems

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- New link: Is there an issue with sorghum following canola: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Is-there-an-issue-with-sorghum-following-canola
- New link: Differential response of wheat to retained crop stubbles: http://www.publish.csiro.au/cp/AR9900243

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- New reference: A Abunyewa, R Ferguson, C Wortmann, D Lyon, S Mason, R Klein (2010) Skip-row and plant population effects on sorghum grain yield. Agronomy Journal, 102(1), 296–302.
- New reference: J Whish, G Butler, M Castor, S Cawthray, I Broad, P Carberry, G Hammer, G McLean, R Routley, S Yates (2005) Modelling the effects of row configuration on sorghum yield, reliability in north-eastern Australia, Australian Journal of Agricultural Research, 56, 11–23.

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- New podcast: The Right Water - the missing ingredient in successful spraying: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2016/05/122-North

- New reference: GRDC funding tackles sorghum yield questions: https://grdc.com.au/Media-Centre/Media-News/North/2016/07/GRDC-funding-tackles-sorghum-yield-questions

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- New video: Weed control on paddock boundaries and fencelines: https://grdc.com.au/Resources/IWMhub/Weed-Webinars/Weed-control-on-paddock-boundaries-and-fencelines
- New link: Pre-emergent herbicides part of the solution but much still to learn: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Pre-emergent-herbicides-part-of-the-solution-but-much-still-to-learn
- New podcast: Summer weed control - the latest: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2015/11/107-north

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- New Link: Can high performance surface irrigation reduce nitrogen losses in broadacre cropping systems?: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Can-high-performance-surface-irrigation-reduce-nitrogen-losses-in-broadacre-cropping-systems

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- New podcast: Summer cropping: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2014/11/63-north
- New radio: Risk strategy likened to a big game of chess: https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-121-Mar-Apr-2016/Risk-strategy-likened-to-a-big-game-of-chess
- New link: Optimising performance of current northern cropping farming systems: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/09/Optimising-performance-of-farming-systems-current-and-potential-of-Northern-cropping-systems

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- New link: Sorghum yield risk vs starting soil moisture: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Sorghum-yield-risk-vs-starting-soil-moisture

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- New link: Managing the yield gap to achieve your yield potential in central west NSW: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Managing-the-Yield-Gap-to-achieve-your-yield-potential-in-central-west-NSW

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- New reference: Understanding and managing N loss pathways: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/06/Understanding-and-managing-N-loss-pathways

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- New podcast: Thrips worrying early summer crops: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2015/11/104-north

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- New link: All-seeing 'tractor' takes crop science to the future: https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-122-May-Jun-2016/All-seeing-tractor-takes-crop-science-to-the-future

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- High yielding sorghum and closing the yield gap: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/High-yielding-sorghum-and-closing-the-yield-gap

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- New video: https://grdc.com.au/Resources/IWMhub/Weed-Webinars/Managing-sorghum-injury-when-using-metolachlor-herbicides
- New link: GRDC Tips and Tactics: Managing frost risk - Northern Southern and Western Regions https://grdc.com.au/ManagingFrostRisk
- New reference: GRDC Tips and Tactics: Keeping sorghum safe: www.grdc.com.au/TT-KeepingSorghumSafe
- New reference: Sorghum agronomy to manage risk and improve yield in the western zone: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Sorghum-agronomy-to-manage-risk-and-improve-yield-in-the-western-zone
- New podcast: Optimising sorghum production: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2015/08/94-north

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- New link: Grain sorghum varietal reactions to heat stress and environment: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Grain-sorghum-varietal-reactions-to-heat-stress-and-environment

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- New link: Better profits from good soil water decisions (Goondiwindi): https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Better-profits-from-good-soil-water-decisions-Goondiwindi

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- New reference: Optimising sorghum genetics and management for targeted situations: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/06/Optimising-sorghum-genetics-and-management-for-targeted-situations
- New podcast: Optimising sorghum production: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2015/08/94-north
- New link: S Simpfendorfer & L Serafin (eds) (2016) Northern grains research results 2016. Research & Development – Independent Research for Industry, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/679102/Northern-grains-research-results-2016.pdf

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- New reference: Sorghum agronomy to manage risk and improve yield in the western zone: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Sorghum-agronomy-to-manage-risk-and-improve-yield-in-the-western-zone
- New section: Sorghum in the western zone

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- New link: RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. I. Overall changes in soil properties and trends in winter cereal yields. http://www.publish.csiro.au/SR/SR9860265

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- New reference: RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. http://www.publish.csiro.au/SR/SR9860281
- New link: SA Hossain, RC Dalal, SA Waring, WM Strong, EJ Weston (1996) Comparison of legume-based cropping systems at Warra, Queensland. 1. Soil nitrogen and organic carbon accretion and potentially mineralisable nitrogen. http://www.publish.csiro.au/SR/SR9960273
- New link: SA Hossain, WM Strong, SA Waring, RC Dalal, EJ Weston (1996) Comparison of legume-based cropping systems at Warra, Queensland. 2. Mineral nitrogen accumulation and availability to the subsequent wheat crop. http://www.publish.csiro.au/SR/SR9960289

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- New link: The what where and why of soil testing in the northern region: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/The-what-where-and-why-of-soil-testing-in-the-northern-region

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- New reference: Improving fertiliser decisions for P on the Western Downs: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Improving-fertiliser-decisions-for-P-on-the-Western-Downs
- New link: Phosphorus and potassium nutrition: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Phosphorus-and-potassium-nutrition
- New link: A calculator to assess the economics of deep placement P over time: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/A-calculator-to-assess-the-economics-of-deep-placement-P-over-time

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- Updated table: List of confirmed resistant weeds in northern NSW (current at February 2014).

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- New video: Weed control on paddock boundaries and fencelines: https://grdc.com.au/Resources/IWMhub/Weed-Webinars/Weed-control-on-paddock-boundaries-and-fencelines

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- New link: Emerging insect threats in northern grain crops: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Emerging-insect-threats-in-northern-grain-crops
- New information on how to recognise and monitor soil insects: https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects

- New podcast: Thrips worrying early summer crops: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2015/11/104-north

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- New link: High performance crop sequences for Southern Queensland: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/06/High-performance-crop-sequences-for-Southern-Queensland

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- New podcast: The Right Water - the missing ingredient in successful spraying: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2016/05/122-North
- New information on Charcoal rot: Disease control in summer crops and management strategies to minimise financial losses: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Disease-control-in-summer-crops-and-management-strategies-to-minimise-financial-losses

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- New podcast: Safe seed storage strategy: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2015/11/106-north
- New link: Part I Achieving great aeration results and Part II Silo recirculation as an aid to fumigation: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Part-I-Achieving-great-aeration-results-and-Part-II-Silo-recirculation-as-an-aid-to-fumigation

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- New link: GRDC Tips and Tactics: Managing frost risk - Northern Southern and Western Regions: http://www.grdc.com.au/GRDC-FS-N-Denitrification

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- New podcast: Boundary weed control and tactical agronomy: https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2014/06/41

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Introduction

A.1 Agronomy at a glance

- Sorghum requires a warm, summer growing period of about 4–5 months, with planting times usually between September and January.
- The crop is highly drought-tolerant, but responds well to rainfall, especially during head-forming and grainfill stages.
- Lodging is a major problem in many grain sorghum-producing areas and is usually associated with moisture stress. Use of lodging-resistant hybrids is recommended.
- It is now possible to adopt a practical integrated pest management (IPM) strategy that eliminates the use of chemical sprays for *Helicoverpa* and midge in most years.
- Adequate control of summer weeds (especially grasses) is necessary.
- Sorghum usually yields better than maize on soils of poor fertility.
- Control weeds within 4–5 weeks after planting or risk yield loss.
- Use no-till for dryland crops to increase soil moisture storage compared with conventional fallows.
- Set a target yield based on moisture availability.
- Be aware of the risks associated with growing sorghum after canola or mustard, because arbuscular mycorrhizal (AM) levels are at their lowest following these crops.
- Match the plant population and row spacing to the target yield. Uniformity is critical.
- Use nitrogen (N) fertiliser rates based on target yields, soil tests and/or previous crop yields and protein levels.
- Use effective weed control, especially for grasses.
- Consider previous herbicide applications for potential residues in the soil and herbicide resistance in weeds.
- Select at least two high-yielding hybrids that have the desired characteristics for your sowing conditions to spread production risk.
- To reduce the risk of ergot in northern New Sales Wales (NSW), plant crops so that they complete flowering by mid-March.
- Wide sowing windows occur for most areas. Avoid sowing too early (cold) or too late (ergot and frost). Aim to avoid flowering during the extreme heat of late December to late January.
- Monitor and if necessary control insects, especially wireworms (planting), midge (flowering), *Helicoverpa* and Rutherglen bug (grainfill).
- Use knockdown herbicides at the end of grainfill to hasten dry-down, improve harvesting and start the recharge of the fallow in dryland crops.
- Be prepared to dry grain from late sown crops. [1]

MORE INFORMATION

Graeme Hammer University of Queensland discusses the effect of high frequency hot days on sorghum. GRDC Podcast: 107 Summer weed control - the latest

1 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

A.2 Crop overview

Grain sorghum (*Sorghum bicolor* (L.) Moench) is the main summer grain crop in the northern grains region (Figure 1), and plays a key role in providing feed grains to the beef, dairy, pig and poultry industries. It is a good rotation crop, tolerating heat and moisture stress, and performing better than maize on soils with marginal potassium (K) levels. [2]

Grain sorghum is a major component of the dryland cropping system of north-eastern Australia. Approximately 60% of the Australian crop is grown in Queensland and the remainder in northern NSW. Grain sorghum is predominantly a summer season crop, with an extended season in higher latitudes including Central Queensland and further north.

The area of sorghum planted for grain in northern NSW is on average 160,000 ha and Queensland 470,000 ha annually. The main zones for sorghum production are the area east of the Newell Highway and the Liverpool Plains in NSW and the Darling Downs in Queensland. [3] Average farm yields vary around 2 t/ha and reflects the severity of constraints, as water stress during grainfilling is the common production environment.

Sorghum produced in Australia is used almost exclusively for feed, especially for cattle, pigs and poultry. None is used for human consumption and a significant market exists in the pet food industry. An export market of around 1 Mt exists, particularly to Japan, but the average amount exported is in the order of 300–500 kt. [4]

Grain sorghum was first grown in Queensland in 1938 and in NSW in 1940, using dwarf varieties introduced from the USA. Following the development of cytoplasmic male sterility in the 1950s in the USA, hybrid varieties were first grown commercially in Australia in 1962, and within 3 years, most farmers were growing the new hybrid varieties. [5]

A large variety of forage sorghum hydrids are available that can provide very rapid summer production (growth rates >100 kg/ha/d are typical). Biomass yields of >10 t DM/ha are reported at Trangie, 80 days after sowing. However, grazing should be initiated earlier (height 60–80 cm) to maximise forage quality, which declines rapidly as the crop develops. Forage sorghum also requires high levels of available N to optimise production and quality. Forage sorghum is better suited to cattle grazing than sheep, as it quickly gets too high for sheep grazing. The advantage of a forage sorghum over a grain sorghum in the farming system is that it could be terminated earlier (e.g. 70 days c.f. >100 days) after providing some grazing and allow the soil profile more time to refill. [6]

2 QDAF (2012) Overview of the sorghum industry. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/overview

3 L Serafin, G McMullen (2015) Sorghum agronomy to manage risk and improve yield in the western zone, GRDC Update Papers 31 July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Sorghum-agronomy-to-manage-risk-and-improve-yield-in-the-western-zone

4 QDAF (2012) Overview of the sorghum industry. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/overview

5 NSW DPI (2005) Grain sorghum. Agfact P3.3.5. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

6 L Bell (2015) Likely fit of summer and winter forage crop options in Central West farming systems, GRDC Update Papers 24 July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Likely-fit-of-summer-and-winter-forage-crop-options-in-Central-West-farming-systems

Figure 1: *Sorghum is the main summer grain crop in the northern grains region.*

A.2.1 Production and utilisation issues

The major limiting factor to production is water stress during grainfill. This results in reduced yield, causing lodging and reduced grain number and grain size.

The major insect pests are a complex of soil-borne insects, the sorghum midge (*Stenodiplosis sorghicola*) and cotton bollworm (*Helicoverpa armigera*). The major disease is sorghum ergot (*Claviceps africana*), which was first reported in Australia in 1996. Other diseases are sporadic and have relatively minor significance.

The major constraints to effective use as a feed grain include variable grain size, cost of processing (e.g. steam flaking), particularly for ruminants, and grain weathering.

These and other issues have been identified in conjunction with industry and dictate the direction of the sorghum research program in Australia.

Marketing

The sorghum trade is completely deregulated. Sorghum produced in Australia is used almost exclusively for feed—especially cattle, pigs and poultry—and this totals ~1.4 Mt (Figure 2). None is used for human consumption and a significant market exists in the pet food industry. There is a substantial export market for sorghum, especially to Japan. [7]

7 QDAF (2012) Overview of the sorghum industry. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/overview

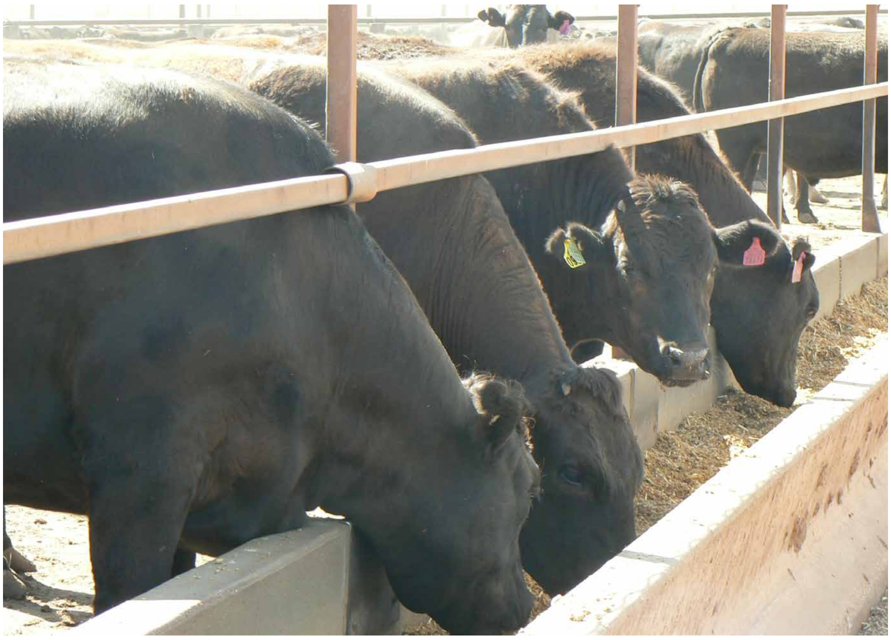

Figure 2: *Sorghum produced in Australia is used almost exclusively for feed.*

Photo: Rachel Bowman, Seedbed Media

A.3 Keywords

Grain sorghum, summer grains, dryland cropping, irrigation, feed grains, lodging, sorghum midge, *Helicoverpa*, ergot, lodging.

Planning/Paddock preparation

1.1 Paddock selection

MORE INFORMATION

GRDC Update Paper: Is there an issue with sorghum following canola

MORE INFORMATION

Crop & Pasture Science: Differential response of wheat to retained crop stubbles

MORE INFORMATION

http://www.dpi.nsw.gov.au/agriculture/broadacre/summer-crops/sorghum/sorghum/grain-sorghum

Grain sorghum, both dryland and irrigated, is usually grown on heavy clay soils with high water-holding capacity that are capable of supplying the plant with moisture through the warm growing season, even in the absence of rainfall.

Wherever possible, use no-till and controlled traffic for dryland crops, as these methods increase soil moisture storage more rapidly and deeply than random-trafficked, conventionally cultivated fallows. This increase in moisture storage, combined with reduced soil compaction, leads to increased yields and Water Use Efficiency. Use response cropping in favourable dryland areas to reduce the risk of deep moisture drainage. [1]

No-till sorghum following winter cereals consistently yields ~0.5 t/ha more than conventional crops because no-till fallows store about an extra 30 mm of plant-available water (Figure 1). Cereal stubbles also provide high levels of groundcover and maximise protection against soil erosion in predominantly summer-rainfall environments. Using no-till and minimum-till fallows enables crops to be sown up to 7 weeks after rain. This widens the planting window, increasing the likelihood of sowing at an optimum time. It can also mean the difference between planting a crop or not.

Successful sorghum crops have been grown immediately after winter pulse crops, provided the soil is wet to a depth of 1 m. Growing sorghum crops immediately following canola or mustard is not advised as these brassica crops can have a strong allelopathic [2] effect and can reduce arbuscular mycorrhizal fungi (AMF) levels. [3]

Figure 1: *No-till sorghum crops following winter cereals consistently yield ~0.5 t/ha more than conventional crops.*

1 NSW DPI (2005) Grain sorghum. Agfact P3.3.5. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

2 Allelopathy, Wikipedia, https://en.wikipedia.org/wiki/Allelopathy

3 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

MORE INFORMATION

http://www.publish.csiro.au/paper/AR9890255.htm

http://www.apsim.info/Documentation/TrainingManualsandResources/APSIMGeneralTrainingManual/CropRotations.aspx

http://www.regional.org.au/au/asa/2001/2/a/mccosker.htm

http://www.drylandcotton.com.au/wp-content/uploads/2012/02/Dryland-Cotton-Long-Term-Rotation-Option.pdf

1.2 Paddock rotation and history

CSIRO research examined long-term yields, nitrogen (N) uptake and responsiveness of grain sorghum following several crop rotation scenarios. Three lucerne rotations, an annual legume rotation, long fallowing, and continuous wheat growing were measured on a black earth and red clay in northern NSW.

The three lucerne rotations compared two methods of lucerne establishment (with or without a cover crop) and two methods of grazing management (short or extended grazing). There were large beneficial effects of lucerne leys on the first grain sorghum crop, whether they were measured as grain yield, N content of the foliage and grain, or N uptake.

The effect was much smaller in the second year but it increased in the third and fourth years, in direct relation to the rainfall during the sorghum flowering period. The effect was greater on the black earth than on the red clay, reflecting the much higher lucerne yields on the former soil.

Evidence indicated that the N contribution from lucerne after the first year was no greater than the N accumulated by long fallowing, and this was attributed to very low rainfall and lucerne yields during the 4-year ley period. The annual legume rotation suffered from drought and insect damage in most years, and following sorghum yields tended to be lower than those achieved by long fallowing.

Differences in the effects of establishment method and grazing management on total lucerne yields were reflected in the differences in subsequent grain sorghum yields. The largest differences were on the black earth, where extended grazing lowered the total yields of lucerne and subsequent grain sorghum. Sowing lucerne under wheat had little effect on total yields of lucerne or sorghum. [4]

1.3 Benefits of sorghum as a rotation crop

Sorghum is currently the most profitable grain crop in the higher rainfall areas of the northern grainbelt. If cotton prices improve, sorghum will still play a major part in an overall rotation strategy to diversify the summer crop planting and include a high-biomass input crop to help maintain soil organic matter levels.

A continuous sorghum-cropping system is likely to have more than twice the biomass (organic carbon) input than a wheat–long fallow–dryland cotton rotation.

In a higher rainfall farming system that includes dryland cotton, sorghum can be grown in the summer following cotton. If the winter season following cotton is dry, sorghum planting may be late rather than early, which reduces the chance of a double-crop change back to a winter crop. In years when there is average to good winter rain, it may be possible to plant dryland cotton after sorghum.

Profit margins show that sorghum may be almost as profitable as wheat in western growing regions if slightly more yield can be achieved to make up for a lower price.

Even if sorghum is not as profitable as wheat, there may be benefits in the cropping system. Having a summer crop as well as a winter crop spreads risk and the workload, which reduces demand for labour and machinery, and diversified farms can operate with smaller machinery. For example, a 2000-ha farm might need more than one planter and harvester if it grows only winter crop, whereas one machine may suffice if a significant area of summer crop is planted each year.

Rotation benefits can be substantial from a period of sorghum in a wheat-cropping system:

1. It can provide a disease break for wheat diseases, such as crown rot, and for nematodes.

4 ICR Holford (1989) Yields and nitrogen uptake of grain sorghum in various rotations, including lucerne, annual legume and long fallow. Australian Journal of Agricultural Research 40, 255–264, http://www.publish.csiro.au/paper/AR9890255.htm

MORE INFORMATION

http://www.grdc.com.au/uploads/documents/GRDC_Sorghum_HY.pdf

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2008/07/EXPANDING-THE-GRAIN-SORGHUM-INDUSTRY

http://www.grdc.com.au/~/media/9219D55FFB4241DC9856D6B4C2D60569.pdf

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2008/09/THE-RELATIVE-PERFORMANCE-AND-TARGETING-RELIABILITY-OF-SUMMER-CROPS-MAIZE-SUNFLOWERS-COMPARED-TO-GRAIN-SORGHUM

2. Control of difficult weeds, such as wild oats, sow thistle and fleabane, can be improved with summer–winter crop rotations.
3. Sorghum rotations can be used to help prevent herbicide resistance.
4. It is generally the highest biomass crop in the northern grains region, and carbon inputs can help to maintain soil organic matter. By comparison, a wheat–long fallow–dryland cotton system can deplete organic matter. [5]

1.3.1 The potential of sorghum in the western cropping zone

The Grains Research and Development Corporation (GRDC) is funding research trials into the potential of sorghum as a rotational crop for growers in north-western NSW.

Dryland grain sorghum production in north-western NSW is highly variable in terms of both area sown and tonnes produced. Typical farming systems are no-tillage and primarily winter-based with cereal-dominant rotations; this has led to major issues with crown rot (*Fusarium pseudograminearum*). Currently, the most reliable and profitable break crop is chickpeas; however, with concerns about *Pratylenchus thornei*, increasing herbicide resistance and climate variability, a profitable summer crop alternative is needed.

Sorghum producers in this area consider sorghum to be reasonably high risk, and in recent years have been disappointed in the lack of break crop benefits achieved when returning to wheat following sorghum.

Minimal dryland sorghum research has been conducted in this western zone (considered to be west of the Newell Highway) and has never focused on the interactions between crop management options, environmental conditions and hybrids. In the more favourable production areas in north-eastern Australia, research has shown that systems using skip configurations can reduce the risk of crop failure but often result in reduced yields (Whish *et al.* 2005) [6].

Commercially, the adoption of double skip-row sorghum has assisted in improving the reliability of sorghum in this zone. Under skip-row configurations, soil water in the unplanted area is conserved until later in the growing season when the crop is able to access these resources to fill grain (Abunyewa *et al.* 2010) [7]. There has been little research to validate this practice or determine appropriate plant populations and the impact of hybrids with differing traits such as tillering and staygreen on crop performance in the low-rainfall regions. In two high-yielding seasons, the impact of varying these three key factors, row configuration, plant population and hybrid type, was evaluated.

NSW Department of Primary Industries research shows that, on an early planting in high-yielding seasons where yield potential is >4.0 t/ha, solid plant configurations consistently produced the highest yields. Single-skip and super wide configurations produced yield results similar to each other but consistently lower than the solid plant. Double-skip configurations yielded considerably less than all other configurations under these conditions. The impact of configuration on grain yield in this study supports the findings of Whish *et al.* (2005) in higher yielding regions.

Populations of 30,000 plants/ha produced lower yields under the high-yielding seasons. Plant populations should target 50,000–70,000 established plants/ha. Commercially, populations of 70,000 plants/ha are not recommended, because no benefit was found over 50,000 plants/ha and additional seed costs would be incurred. The low tillering, high stay-green hybrids used in these experiments were unable to produce competitive yields in favourable seasons. Hybrids with moderate

5 P Wylie (2008) Managing sorghum for high yields—a blueprint for doubling sorghum production. GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Sorghum_HY.pdf

6 vJ Whish, G Butler, M Castor, S Cawthray, I Broad, P Carberry, G Hammer, G McLean, R Routley, S Yates (2005) Modelling the effects of row configuration on sorghum yield, reliability in north-eastern Australia, Australian Journal of Agricultural Research, 56, 11–23.

7 A Abunyewa, R Ferguson, C Wortmann, D Lyon, S Mason, R Klein (2010) Skip-row and plant population effects on sorghum grain yield. Agronomy Journal, 102(1), 296–302.

MORE INFORMATION

vArthur Gearon, grower at Chinchilla Queensland and GRDC northern panellist discusses the role of stay-green sorghum. GRDC Podcast: 122 The Right Water - the missing ingredient in successful spraying

MORE INFORMATION

https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Sorghum-agronomy-for-profit-in-the-western-zone

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf

to high levels of tillering responded more favourably to the improved seasonal conditions experienced in these 2 years.

On the Liverpool Plains in northern NSW, GRDC supported research conducted by the NSW Department of Primary Industries is examining the impact of plant population, row configuration, phosphorus and nitrogen (N) applications, hybrid selection and time of sowing on grain yield. [8]

Several trial sites have been established and monitored including Breeza and either Premer, Pine Ridge or Willow Tree depending on the season. Some clear results and recommendations have been generated from the Breeza trial over the past two years (2013–14 and 2014–15) which sorghum growers can use to help guide their future decision making on agronomic management.

Sowing in the 'ideal window' at the end of October–early November generated higher yields than the late sowing in December. In the 2013–14 season, the early sowing yielded 0.25 t/ha higher than the later planted crop.

Three hybrids were used, MR Buster, MR Scorpio and 85G33, with MR Buster included as a commercial check and the two other varieties as examples of recent release hybrids. Yield differences due to hybrid selection were small, with much larger yield differences resulting from varying crop nitrogen nutrition, row spacing, sowing time and plant density.

There was a noticeable response to N in the trials, with yield increasing in line with increases in the N rate at both times of sowing. In the earlier sown crops, the use of 200 kg N compared to nil nitrogen resulted in an additional 1.81 t/ha grain yield while in the late sown trials it resulted in an increase of 0.85 t/ha.

There was also a 1 t/ha increase in yield with the October plant as plant population increased from 50,000 to 75,000 plants/ha (3.01 t/ha versus 4.10 t/ha). However, there was no difference in yield between the 75,000 and 100,000 plants/ha treatments (4.1 t/ha and 4.17 t/ha). At the same time there was no significant response to varying population in the late sowing treatment (average yield 3.3 t/ha).

1.3.2 Sorghum preceding wheat

Benefits:

- cereal disease break
- control of problem weeds

Risks:

- The opportunity sorghum provides for the build-up of summer grass weeds could present a significant threat for subsequent summer fallows.
- Reduced groundcover of sorghum provides increased erosion risk in the following fallow. The crop choice following the sorghum, including cover crops, can help manage this issue.
- Planting dates for sorghum have been progressively earlier in the spring and this is reducing the benefit that the rotation has generally provided for managing wild oats. Wild oats are difficult to manage in sorghum and delayed planting is probably the best current option, but must be offset with early spray-out and a longer fallow period for the subsequent double crop (usually chickpeas). In recent years, the use of Dual Gold® in the winter fallow followed by at plant application has significantly improved the control of late germinating wild oats.

Research presented at the Australian Society of Agronomy Conference in 2012 examined the implications of a wheat–long fallow–sorghum–long fallow–wheat sequence (Verrell 2012). Sorghum is an important summer crop component of the northern NSW farming system. Traditionally, it is grown on a long fallow following wheat, then long-fallowed out to a durum or bread wheat crop. It can provide a break to cereal disease and can control problem weeds.

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8 GRDC (2016) GRDC funding tackles sorghum yield questions, https://grdc.com.au/Media-Centre/Media-News/North/2016/07/GRDC-funding-tackles-sorghum-yield-questions

Row spacing in sorghum varies greatly and increases as potential yield declines. High-yielding sites (>4 t/ha) can have row spacing from as low as 40–60 cm, whereas low-yielding sites (<3 t/ha) are generally planted with row configurations >1 m with skip or double-skip rows as options (Serafin & McMullen 2011).

Inter-row sowing has been shown to reduce the impact of crown rot and increase yield in a wheat–wheat sequence, and there was a need to examine whether the effect of row spacing and placement of sorghum and wheat crops would result in differences in grain yield in a 4-year crop sequence.

In this environment (high yield potential), narrow-row sorghum (40 cm) resulted in a higher yield (5.5 t/ha) than wide-row and double-skip configurations (average 4.7 t/ha), in what could be regarded as an above-average summer-rainfall season in 2009–10.

The biggest influence on the following wheat crop was the row-spacing configuration of the previous sorghum crop. Sowing sorghum in a double-skip arrangement resulted in a 1.0 t/ha yield advantage to the following wheat crop over wide-row sorghum and 1.6 t/ha over a narrow-row configuration. Wheat protein contents >12% suggest that the water-limited potential wheat yield was not inhibited by the amount of available N. However, it was clear that the wheat following the narrow-row sorghum had access to 40 kg less N than wheat following the double-skip sown sorghum.

The worst outcome for wheat yield was attributed to a row-placement system that kept sowing over the same row, year after year (4.41 t/ha). The best row-placement combination was sowing sorghum over the 2008 wheat rows, then sowing the 2011 wheat crop into the inter-row space (4.64 t/ha), meaning that the crop was sown into ground that did not have wheat sown in it for at least 4 years. This inter-row sowing strategy resulted in a 3% wheat yield advantage, on average, over continuous, on-row sowing. This is less than the 9% yield advantage reported by Verrell *et al*. (2005) in a chickpea–wheat–wheat system, but still supports the finding that inter-row sowing can provide a yield advantage to wheat.

Under conditions of high potential sorghum yields, the choice of sorghum row configurations and row placement strategies for both sorghum and the following wheat crop need to be considered in order to maximise yields and limit the impact of crown rot on wheat. [9]

MORE INFORMATION

http://www.regional.org.au/au/asa/2012/crop-production/8317_verrellag.htm

1.4 Disadvantages of sorghum as a rotation crop

Sorghum is recommended as a break crop in areas that have a winter-crop-dominated rotation, but the success is dictated by the amount of breakdown of the winter cereal stubble. Altering row configuration and population may improve the reliability of sorghum; however, it may also reduce the rate of decomposition of cereal stubble and reduce water accumulation during the fallow period and the break crop benefits. [10]

Sorghum planted on wide rows can hamper control of problematic grass weeds. Barnyard grass (*Echinochloa* spp.), liverseed grass (*Urochloa panicoides*) and more recently feathertop Rhodes grass (*Chloris virgata*) are the most common summer grass weeds of cropping in southern Queensland and northern NSW. They are also present in central Queensland.

These grasses are favoured in reduced-tillage systems, and have increased in prevalence in the last two decades. They are prolific seeders, are not consistently controlled with commonly used herbicides, and can be highly competitive. When uncontrolled, these weeds can reduce sorghum yields by 25–40%. [11]

MORE INFORMATION

http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/ngrt-results

9 AG Verrell (2012) Effects of row spacing and row placement on grain yield in a sorghum/wheat sequence under high rainfall. In: Proceedings 16th Australian Agronomy Conference. Australian Society of Agronomy/The Regional Institute Ltd, http://www.regional.org.au/au/asa/2012/crop-production/8317_verrellag.htm

10 G McMullen *et al.* (2013) Sorghum in the western zone—Row Configuration × Population × Hybrid—"Morialta", Mungindi 2012, Northern grains region trial results, pp. 76–80. Autumn 2013. NSW Department of Primary Industries http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/ngrt-results

11 QDAF Management of barnyard and liverseed grasses. Department of Agriculture, Fisheries and Forestry, Queensland, http://www.daff.qld.gov.au/__data/assets/pdf_file/0008/55277/Managing-barnyard-and-liverseed-grasses.pdf

1.4.1 Sorghum in crop sequences

Because of their ability to survive from season to season in infected stubble, the levels of the charcoal rot and Fusarium stalk rot pathogens in a paddock will generally increase with consecutive sorghum crops. Where charcoal rot has been a problem, sunflower, dryland soybean and mungbean crops should be avoided in future crop sequences for at least 3 years to reduce charcoal rot levels, and consideration should be given to growing winter crops in the crop sequence.

The role that other minor or potential hosts, e.g. chickpeas, play in the survival of the charcoal rot pathogen is unknown. Almost nothing is known of the ability of the *Fusarium* stalk rotting pathogens to survive in the northern region and the role that residue from non-hosts plays in their survival. However, it would be prudent to rotate out of sorghum to a known non-host crop, e.g. winter cereals and pulses or summer broadleaf crops, if Fusarium stalk rot has become an issue in a paddock.

Sorghum should not planted into, or adjacent to, paddocks where the previous winter cereal crop was affected by Fusarium head blight (Table 1). Crop sequences specifically designed to minimise the risk from leaf diseases are unlikely be effective, because of the airborne nature of the pathogen's spores. [12]

Table 1: *Significant pathogens shared by different crops in the northern region.*

Pathogen/Nematode	Common name	Sorghum	Maize	Sunflower	Summer pulses	Cotton	Winter cereals	Winter pulses
Pratylenchus thornei	root-lesion nematode	-	-	-	✓✓ m,s	-	✓✓	✓✓ c,f
Pratylenchus neglectus	root-lesion nematode	✓✓				nt	✓✓	✓✓ c
Fusarium graminearum	head blight	✓	✓✓	-	-	-	✓✓	-
Macrophomina phaseolina	charcoal rot	✓✓	✓✓	✓✓	✓✓ m,s,g	✓	-	✓
Sclerotinia sclerotiorum, S. minor	sclerotinia rot	-	-	✓✓	✓✓ s,m,g	-	-	✓✓ c,f,p
Sclerotium rolfsii	basal rot	✓	✓	✓	✓✓ s,g	✓	-	-
Fusarium verticillioides	fusarium stalk and cob rot	✓	✓✓	-	-	-	-	-
Fusarium semitectum	fusarium head blight and stalk rot	✓✓	✓	-	-	-	-	-

✓✓ - major disease; ✓ - recorded but generally minor disease; c=chickpeas; f=fababean; g=peanut; m=mungbean; p=field pea; s=soybean; nt=not tested

MORE INFORMATION

Arthur Gearon, grower at Chinchilla Queensland and GRDC northern panellist discusses the impact of charcoal rot on sorghum yield and management options. GRDC Podcast: 122 The Right Water - the missing ingredient in successful spraying

1.4.2 Long-fallow disorder

Soils naturally contain beneficial fungi that help the crop to access nutrients such as phosphorus (P) and zinc (Zn). The combination of the fungus and crop root is known as arbuscular mycorrhiza(e) (AM) (Figure 2). Many different species of fungi can have this association with the roots of crops. Many that are associated with crops also form structures called vesicles in the roots.

The severe reduction or lack of AM shows up as long-fallow disorder—the failure of crops to thrive despite adequate moisture. Ongoing drought in the 1990s and beyond has highlighted long-fallow disorder where AM have died out through lack of host plant roots during periods of long fallow. As cropping programs restart after dry years, a yield drop is likely from reduced AM levels, making it difficult for the crop to access nutrients.

12 GRDC (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Papers 13 September 2011

Long-fallow disorder is usually typified by poor crop growth. Plants seem to remain in their seedling stages for weeks and development is very slow.

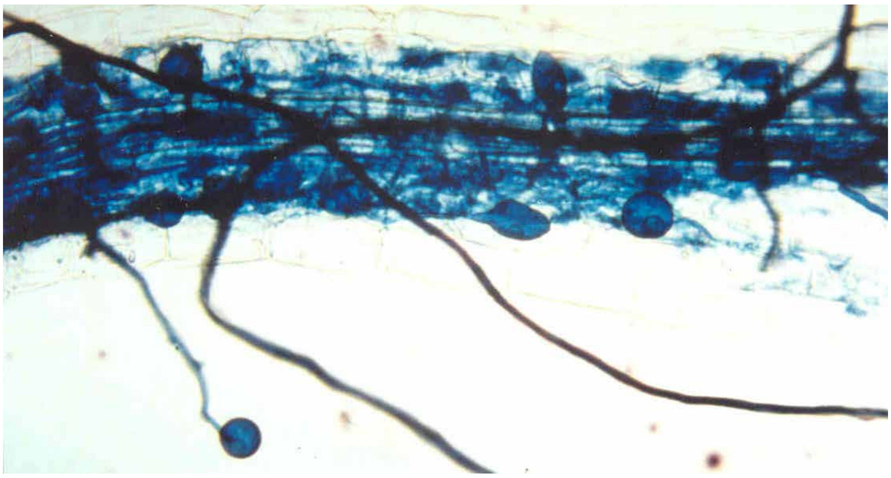

Figure 2: *Arbuscular mycorrhizae pictured in a wheat root.*

Photo: QDAF, Qld

MORE INFORMATION

http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/nutrition-vam

Benefits of good AM levels are:

- improved uptake of P and Zn
- improved crop growth
- greater drought tolerance
- improved soil structure
- greater disease tolerance

In general, the benefits of AM are greater at lower soil P levels because AM increase a plant's ability to access this nutrient. Sorghum has a medium dependency on mycorrhiza, and crops with higher dependency benefit more from AM (Table 2). [13]

Table 2: *Dependency of various crop species on mycorrhizae (value decreases as the phosphorus level of the soil increases).*

Mycorrhiza dependency	Potential yield loss without mycorrhiza (%)	Crops
Very high	>90	Linseed
High	60–80	Sunflower, mungbean, pigeon pea, maize, chickpea
Medium	40–60	Sudan grass, sorghum, soybean
Low	10–30	Wheat, barley, triticale
Very low	0–10	Panicum, canary grass
Nil	0	Canola, lupins

1.5 Fallow weed control

Paddocks generally have multiple weed species present at the same time, making weed-control decisions more difficult and often involving a compromise after assessment of the prevalence of key weed species. Knowing your paddock and controlling weeds as early as possible are important for good control of fallow weeds. Information is included below for the most common problem weeds; however, for advice on individual paddocks, you should contact your agronomist.

13 QDAF (2010) Nutrition—VAM and long fallow disorder. Department of Agriculture, Fisheries and Forestry Queensland, 14 Sept. 2010, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/nutrition-vam

MORE INFORMATION

Chris Preston University of Adelaide discusses strategies behind managing weeds around paddock boundaries and along fencelines. Video: Weed control on paddock boundaries and fencelines

MORE INFORMATION

GRDC Update Paper: Pre-emergent herbicides part of the solution but much still to learn

MORE INFORMATION

Michael Widrig QDAF discusses glyphosate resistant weeds and weed management strategy. GRDC Podcast: 107 Summer weed control - the latest

Benefits of fallow weed control are significant:

- Conservation of summer rain and fallow moisture (this can include moisture stored from last winter or the summer before in a long fallow) is integral to winter cropping in the northern region, particularly so as the climate moves towards summer-dominant rainfall.
- Modelling studies show that the highest return on investment in summer weed control is for lighter soils or in situations where soil water is present that would support continued weed growth. [14]

The Northern Grower Alliance (NGA) is trialing methods to control summer grasses. Key findings include:

1. Weeds resistant and tolerant to glyphosate are a major threat to our reduced-tillage cropping systems.
2. Although residual herbicides will limit recropping options and will not provide complete control, they are a key part of successful fallow management.
3. Double-knock herbicide strategies (sequential application of two different weed control tactics) are useful tools but the herbicide choices and optimal timings will vary with weed species.
4. Other weed-management tactics can be incorporated, e.g. crop competition, to assist herbicide control.
5. Cultivation may need to be considered as a salvage option to avoid seed bank buildup.

Double-knock strategies

Double-knock refers to the sequential application of two different weed-control tactics applied in such a way that the second tactic controls any survivors of the first. Most commonly used for pre-sowing weed control, this practice can also be applied in-crop. [15]

Consider the species present, interval timing and water rate. For information on double-knock tactics, download the GRDC fact sheet (Effective double knock herbicide applications Northern Region) from http://www.grdc.com.au/Resources/Factsheets/2012/09/Herbicide-Application-fact-sheet-Effective-Double-Knock-Herbicide-Applications-Northern-Region.

Double-knock herbicide strategies are useful tools for managing difficult-to-control weeds, but there is no ‘one size fits all’ treatment.

The interval between double-knock applications is a major management issue for growers and contractors. Shorter intervals can be consistently used for weeds where herbicides appear to be translocated rapidly (e.g. awnless barnyard grass) or when growing conditions are very favourable. Longer intervals are needed for weeds where translocation appears slower (e.g. fleabane, feathertop Rhodes grass and windmill grass).

Critical factors for successful double-knock approaches are for the first application to be on small weeds and to ensure good coverage and adequate water volumes particularly when using products containing paraquat. Double-knock strategies are not fail-proof and rarely effective for salvage weed-control situations unless environmental conditions are exceptionally favourable.

Important weeds in northern cropping systems

Weed management, particularly in reduced-tillage fallows, has become an increasingly complex and expensive part of cropping in the northern grains region. Heavy reliance on glyphosate has selected for species that were naturally more glyphosate-tolerant or has selected for glyphosate-resistant populations. The four key weeds that are causing major cropping issues are:

1. awnless barnyard grass (ABYG) (*Echinochloa colona*) (Figure 3)

14 GRDC (2012) Summer fallow—make summer weed control a priority. GRDC Fact Sheet January 2012

15 C Borger, V Stewart, A Storrie. Double knockdown or ‘double knock’. Department of Agriculture and Food Western Australia

2. flaxleaf fleabane (*Conyza bonariensis*)
3. feathertop Rhodes grass (FTR) (*Chloris virgata*)
4. windmill grass (*Chloris truncata*)

Awnless barnyard grass

Figure 3: *Awnless barnyard grass. Barnyard grass can be difficult to control in northern farming systems.*

Photo: Rachel Bowman, Seedbed Media

This has been a key summer grass problem for many years. It is a difficult weed to manage for at least three main reasons:

1. Multiple emergence flushes (cohorts) each season
2. Easily moisture-stressed, leading to inconsistent knockdown control
3. Glyphosate-resistant populations increasingly being found

Key points

- Glyphosate resistance is widespread. Tactics against this weed must change from glyphosate alone.
- Utilise residual chemistry wherever possible and aim to control 'escapes' with camera spray technology.
- Try to ensure that a double-knock of glyphosate followed by paraquat is used on one of the larger early summer flushes of ABYG.
- Restrict Group A herbicides to management of ABYG in-crop and aim for strong crop competition.

Resistance levels

Prior to summer 2011–12, there were 21 cases of glyphosate-resistant ABYG. Collaborative surveys were conducted by NSW Department of Primary Industries (DPI), Department of Agriculture, Fisheries and Forestry Queensland (QDAF) and NGA in summer 2011–12 with a targeted follow-up in 2012–13. Agronomists from the Liverpool Plains to the Darling Downs and west to areas including Mungindi collected ABYG samples, which were tested at the Tamworth Agricultural Institute with Glyphosate CT at 1.6 L/ha (a.i. 450 g/L) at a mid-tillering growth stage. Total application volume was 100 L/ha.

The main finding from this survey work was that the number of 'confirmed' glyphosate-resistant ABYG populations had nearly trebled. Selected populations were also evaluated in a separate glyphosate rate-response trial. The experiment showed that some of these populations were suppressed only when sprayed with 12.8 L/ha.

Growers can no longer rely on glyphosate alone for ABYG control.

Residual herbicides (fallow and in-crop)

A range of active ingredients is registered in summer crops, e.g. metolachlor (e.g. Dual Gold®) and atrazine, or fallow, e.g. imazapic (e.g. Flame®), and these ingredients provide useful management of ABYG. The new fallow registration of isoxaflutole (Balance®) can provide useful suppression of ABYG but has stronger activity against other problem weed species. Few (if any) residuals give consistent, complete control. However, they are important tools that need to be considered to reduce the weed population exposed to knockdown herbicides, as well as to alternate the herbicide chemistry being employed. Use of residuals together with camera-spray technology (for escapes) can be an effective strategy in fallow. Growers and agronomists need to understand the plant-back implications of the residual herbicide options they choose to employ.

Double-knock control

This approach uses two different tactics applied sequentially. In reduced-tillage situations, it is frequently glyphosate first followed by a paraquat-based spray as the second application or 'knock'. Trials to date have shown that glyphosate followed by paraquat has given effective control, even on glyphosate-resistant ABYG. Note that most effective results will be achieved from paraquat-based sprays by using higher total application volumes (100 L/ha) and finer spray quality and by targeting seedling weeds.

Several Group A herbicides, e.g. Verdict® and Select®, are effective on ABYG but should be used in registered summer crops such as mungbeans. Even on glyphosate-resistant ABYG, a double-knock of glyphosate followed by paraquat is an effective tool. In the same situations, there has been little benefit from a Group A followed by paraquat application. Note that Group A herbicides appear more sensitive to ABYG moisture stress. Application on larger, mature weeds can result in very poor efficacy.

Timing of the paraquat application for ABYG control has generally proven flexible. The most consistent control is obtained from a delay of ~3–5 days, when lower rates of paraquat can also be used. Longer delays may be warranted when ABYG is still emerging at the first application timing; shorter intervals are generally required when weed size is larger or moisture stress conditions are expected. High levels of control can still be obtained with larger weeds, but paraquat rates will need to be increased to 2.0 or 2.4 L/ha.

Flaxleaf fleabane

Figure 4: *Flaxleaf fleabane.*

Photo: QDAF, Qld

There are three main species of fleabane in Australia: *Conyza bonariensis* (flaxleaf fleabane) (Figure 4), *C. canadensis* (Canadian fleabane) and *C. albida* (tall fleabane). There are two varieties of *C. canadensis*: var. *canadensis* and var. *pusilla*. Of the three species, flaxleaf fleabane is the most common across Australia. [16]

For more than a decade, flaxleaf fleabane has been the major weed-management problem in the northern cropping region, particularly in reduced-tillage systems. Fleabane is a wind-borne, surface-germinating weed that thrives in situations of low competition. Germination flushes typically occur in autumn and spring when surface soil moisture levels stay high for a few days. However, emergence can occur at nearly all times of the year.

An important issue with fleabane is that knockdown control of large plants in the summer fallow is variable and can be expensive due to reduced control rates.

Key points

- Utilise residual chemistry wherever possible and aim to control 'escapes' with camera spray technology.
- This weed thrives in situations of low competition; avoid wide row cropping unless effective residual herbicides are included.
- 2,4-D and fluroxypyr followed by paraquat are crucial tools for consistent double-knock control.
- Successful growers have increased their focus on fleabane management in winter (crop or fallow) to avoid expensive and variable salvage control in the summer.

16 M Widderick, H Wu. Fleabane. Department of Agriculture and Food Western Australia

MORE INFORMATION

http://www.glyphosateresistance.org.au/register_summary.html

https://www.agric.wa.gov.au/grains-research-development/fleabane

Resistance levels

Glyphosate resistance has been confirmed in fleabane. There is great variability in the response of fleabane to glyphosate, with many samples from non-cropping areas still well controlled by glyphosate, whereas fleabane from reduced-tillage cropping situations shows increased levels of resistance. The most recent survey has focused on non-cropping situations, with a large number of resistant populations found on roadsides and railway lines where glyphosate alone has been the principal weed management tool employed.

Residual herbicides (fallow and in-crop)

One of the most effective strategies to manage fleabane is the use of residual herbicides during fallow or in-crop. Trials have consistently shown good efficacy from a range of residual herbicides commonly used in sorghum, cotton, chickpeas and winter cereals. There are now at least two registrations for residual fleabane management in fallow.

Additional product registrations for in-crop knockdown and residual herbicide use, particularly in winter cereals, are still being sought. A range of commonly used, winter cereal herbicides exists with useful knockdown and residual fleabane activity. Trials to date have indicated that increasing water volumes from 50 to 100 L/ha may help the consistency of residual control, with application timing to ensure good herbicide–soil contact also important.

Knockdown herbicides (fallow and in-crop)

Group I herbicides have been the major products for fallow management of fleabane, with 2,4-D amine the most consistent herbicide evaluated. Despite glyphosate alone generally giving poor control of fleabane, trials have consistently shown a benefit from tank mixing 2,4-D amine and glyphosate in the first application. Amicide® Advance at 0.65–1.1 L/ha mixed with Roundup® Attack at a minimum of 1.15 L/ha and then followed by Nuquat® at 1.6–2.0 L/ha is a registered option for fleabane knockdown in fallow. Sharpen® is a product with Group G mode of action. It is registered for fallow control when mixed with Roundup® Attack at a minimum of 1.15 L/ha but only on fleabane up to a maximum of six leaves. Currently, the only in-crop knockdown registration is for Amicide® Advance at 1.4 L/ha in either wheat or barley.

For more information on label rates, visit www.apvma.gov.au.

Double-knock control

The most consistent and effective double-knock control of fleabane has included 2,4-D in the first application followed by paraquat as the second. Glyphosate alone followed by paraquat will result in high levels of leaf desiccation but plants will nearly always recover.

Timing of the second application in fleabane is generally aimed at ~7–14 days after the first application. Increased efficacy is obtained when fleabane is actively growing or if rosette stages can be targeted. Although complete control can be obtained in some situations, e.g. summer 2012–13, control levels will frequently reach only ~70–80%, particularly when targeting large, flowering fleabane under moisture-stressed conditions. The high cost of fallow double-knock approaches and inconsistency in control level of large, mature plants are good reasons to focus on proactive fleabane management at other growth stages.

Feathertop Rhodes grass

Figure 5: *Feathertop Rhodes grass.*

Photo: Rachel Bowman

Feathertop Rhodes grass (Figure 5) has emerged as an important weed-management issue in southern Queensland and northern NSW since ~2008. This is another small-seeded weed species that germinates on, or close to, the soil surface. It has rapid, early growth rates and can become moisture-stressed quickly. Although FTR is well established in central Queensland, it remains largely an 'emerging' threat further south. Patches should be aggressively treated to avoid whole-of-paddock population explosions.

Key points

- Glyphosate alone or glyphosate followed by paraquat has generally poor efficacy, especially on more advanced plants.
- Utilise residual chemistry wherever possible and aim to control 'escapes' with camera spray technology.
- A double-knock of Verdict™ followed by paraquat can be used in Queensland prior to planting mungbeans where large spring flushes of FTR occur.
- Treat patches aggressively, even with cultivation, to avoid paddock blowouts.

Residual herbicides (fallow and in-crop)

This weed is generally poorly controlled by glyphosate alone even when sprayed under favourable conditions at the seedling stage. Trials have shown that residual herbicides generally provide the most effective control, a similar pattern to that seen with fleabane. Currently registered residual herbicides are being screened and offer promise in both fallow and in-crop situations. The only product currently registered for FTR control is Balance® (isoxaflutole) at 100 g/ha for fallow use.

Double-knock control

Although a glyphosate followed by paraquat double-knock is an effective strategy against ABYG, the same approach is variable and generally disappointing for FTR management. By contrast, a small number of Group A herbicides (all members of the 'fop' class) can be effective against FTR but need to be managed within a number of constraints:

- Although they can provide high levels of efficacy on fresh and seedling FTR, they need to be followed by a paraquat double-knock to get consistent high levels of final control.
- Group A herbicides have a high risk of selection for resistance, again requiring follow-up with paraquat.

- Many Group A herbicides have plant-back restrictions to cereal crops.
- Group A herbicides generally have a narrower range of weed growth stages for successful use than herbicides such as glyphosate, i.e. Group A herbicides will generally give unsatisfactory results on flowering and/or moisture-stressed FTR.
- Not all Group A herbicides are effective on FTR.

For information on a permit (PER12941) issued for Queensland only for the control of FTR in summer fallow situations prior to planting mungbeans, see www.apvma.gov.au.

Timing of the second application for FTR is still being refined, but application at ~7–14 days generally provides the most consistent control. Application of paraquat at shorter intervals can be successful, when the Group A herbicide is translocated rapidly through the plant, but has resulted in more variable control in field trials. Good control can often be obtained up to 21 days after the initial application.

Windmill grass

Figure 6: *Windmill grass.*

Photo: Maurie Street

Whereas FTR has been a grass weed threat coming from Queensland and heading south, windmill grass (Figure 6) is more of a problem in central NSW but is spreading north. Windmill grass is a perennial, native species found throughout northern NSW and southern Queensland. The main cropping threat appears to be from the selection of glyphosate-resistant populations, with control of the tussock stage providing greatest management challenges.

Key points

- Glyphosate alone or glyphosate followed by paraquat has generally poor efficacy.
- Preliminary data suggest that residual chemistry may provide some benefit.
- A double-knock of quizalofop-p-ethyl (e.g. Targa®) followed by paraquat can be used in NSW.

Resistance levels

Glyphosate resistance has been confirmed in windmill grass, with three documented cases in NSW, all west of Dubbo. Glyphosate-resistant populations of windmill grass in other states have all been collected from roadsides, but in central west NSW, two were from fallow paddock situations.

Residual herbicides (fallow and in-crop)

Preliminary trials have shown a range of residual herbicides with useful levels of efficacy against windmill grass. These herbicides have potential for both fallow and in-crop situations. No products are currently registered for residual control of windmill grass.

Double-knock control

Similar to FTR, a double-knock of a Group A herbicide followed by paraquat has provided clear benefits compared with the disappointing results usually achieved by glyphosate followed by paraquat. Constraints apply to double-knock for windmill grass control similar to those for FTR.

For information on a permit for NSW only for the control of windmill grass in summer fallow situations, visit www.apvma.gov.au.

Timing of the second application for windmill grass is still being refined, but application at ~7–14 days generally provides the most consistent control. Application of paraquat at shorter intervals can be successful, when the Group A herbicide is translocated rapidly through the plant, but has resulted in more variable control in field trials and has been clearly antagonistic when the interval is ≤1 day. Good control can often be obtained up to 21 days after the initial application. [17]

MORE INFORMATION

http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS102/Herbicide-resistance-in-summer-grasses

http://www.nga.org.au/module/documents/download/225

1.6 Fallow chemical plant-back periods

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop.

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods, e.g. sulfonylureas (chlorsulfuron). Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the 'Protection of crops etc.' heading in the 'General Instructions' section of the label. [18]

For more information, see the NSW DPI publication 'Weed control in summer crops' at www.dpi.nsw.gov.au/pubs/wcsc.

MORE INFORMATION

www.apvma.gov.au

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

http://www.caws.org.au/awc/2002/awc200210871.pdf

1.7 Crop establishment

Apart from moisture stress, poor crop establishment and weed competition are usually the major factors that significantly reduced sorghum yields. The following recommendations should help to improve crop establishment and crop yields.

Uniform establishment and accurate depth placement of seed is essential. Precision planters can achieve both of these, when correctly managed. Planters should be in small enough sections to follow the paddock undulations with large-diameter depth wheels located within the frame and tines or discs mounted on parallelogram planter units.

Narrow points or discs are better suited to no-till and minimum-till conditions and work very well in free-flowing soils, but excessive planting speeds will reduce establishment.

In moist seedbeds, the seed should be placed no more than 3 cm deep; depths greater than this will reduce emergence. In dry seedbeds using moisture seeking for deep-furrow planting, the seed is also placed 5 cm deep. In this instance, the seed

17 R Daniel (2013) Weeds and resistance—considerations for awnless barnyard grass, *Chloris* spp. and fleabane management. Northern Grower Alliance, http://www.nga.org.au/module/documents/download/225

18 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-in-conservation-farming-systems.pdf

may be 10–12 cm below the original soil surface. Seeding practices that leave furrows above the seed are at risk of damage from storm rainfall. High-intensity rainfall can fill furrows with water; the damage from this type of event can be 3-fold:

1. Short term waterlogging can increase the risk of seedling diseases and slow the emergence.
2. Chemical damage. Water can carry herbicides used at planting into the furrow, concentrating them in the seed zone; combined with waterlogging, stands can be dramatically reduced.
3. Water flow into the furrow can also carry soil. This, combined with soil swelling, can increase the actual seed depth. This can reduce the emergence percentage depending on the depth and the above-mentioned stresses.

Press-wheels are essential not only to improve establishment but also to help control soil insect pests of germinating and emerging sorghum, including true and false wireworms. Use press-wheel pressures of 4–6 kg per cm width of press-wheel for conventional seedbeds and 6–10 kg for no-till and minimum-till seedbeds. Use pressures at the higher end of the range when sowing moisture is marginal, seed is deeply planted or soil insects are present. Use pressures at the lower end of the range when soils are hard-setting or surface-crusting. Crop establishment is improved when the shape of the press-wheel matches the shape of the seed trench. [19]

MORE INFORMATION

http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/summer-crop-production-guide

1.8 Soil moisture

1.8.1 Dryland

Planting sorghum with <1 m of wet soil reduces the likelihood of high yields, increases the risk of crop failure and places a greater reliance upon in-crop rain to produce an economic yield.

Crops sown on heavy clay soils with 1.5 m of wet soil and receiving 100 mm of effective in-crop rain should yield at least 3.5 t/ha, but crops starting with 1 m of wet soil plus 50 mm of effective rain will yield only ~1.3 t/ha. After the initial 100–110 mm of soil water is used, sorghum can produce grain at an approximate rate of 15 kg/ha.mm available soil water.

MORE INFORMATION

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Impact-of-stored-water-on-risk-and-sowing-decisions-in-western-NSW

http://www.regional.org.au/au/asa/2006/poster/water/4587_routleyr.htm

Using this Water Use Efficiency (WUE) estimate, producers with good management practices should be achieving long-term average yields in the Quirindi area of 5–6.8 t/ha; Gunnedah, Inverell and Tamworth districts 3.5–4.0 t/ha; Moree and Narrabri districts 2.5–3.0 t/ha; and Coonamble–Walgett districts 2.0–2.5 t/ha. [20]

For dryland production, fallow moisture storage is maximised by no-tillage and good stubble cover.

Many trials have shown that sorghum grown using no-tillage yields ~25% higher than sorghum on land that has been cultivated, providing nutrient supply is adequate for the higher yields.

Fallow trials at Billa Billa (Thomas 2000) provide an example of this yield gain, where for six sorghum crops grown between 1988 and 1995, grain yield improved from 2.48 t/ha when cultivated to 3.05 t/ha with no-till, an increase of 23%.

At Biloela in 1992, sorghum was double-cropped on wheat after 240 mm of rain was received in November and December. Rainfall between sowing and harvest was 62 mm, of which 50 mm fell prior to flowering. This meant that the crop had a dry finish. Grain yield for no-tillage was 2.4t/ha, compared with 1.27t/ ha for cultivated treatments.

19 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

20 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

It was noted as unlikely that the tillage over 3 months resulted in this large yield difference. The response is attributed, at least in part, to the long-term effects of 10 years of no-tillage on the soil.

After 20 years of different tillage treatments, this trial area is showing ongoing benefits in soil health and yield of crops. Three crops have been grown using no-tillage, with the yield on land no-tilled for 20 years almost 90% higher than for crops grown using no-tillage but on land cultivated for 20 years (2.7 t/ha average yield *v.* 1.43 t/ha; Freebairn 2006).

As well as fallow storage, moisture utilisation during the growth of the sorghum crop is likely to be optimised by no-tillage. A higher level of groundcover will reduce runoff and slow evaporation.

Farmers have also found that no-tillage provides a much greater chance of using moisture-seeking planting for an early plant of sorghum on land fallowed from wheat.

Moisture stays closer to the surface, and in some cases it has been possible to plant sorghum in September, many weeks after the last fall of rain. [21]

1.8.2 Irrigation

An understanding of sorghum crop development and the environmental drivers of crop development is crucial if managers are to maximise the crop performance through irrigation. Irrigation timing is a critical part of irrigation management in grain sorghum, and whereas meeting the evaporative demand is also important, it can result in poor WUE if the irrigation is applied at the wrong time. In more favorable growing areas, strategic irrigations at key growth stages can result in very high yields and WUE.

Grain sorghum growth stages

The growth cycle of grain sorghum can be broken into three main stages (Figure 7):

1. Early growth: stages 0–2 or emergence to 5 leaves fully emerged
2. Vegetative growth: stages 3–5 or 8 leaves fully emerged to booting
3. Early grainfill; stages 6–7.5 or flowering to milky dough approximately 65–85 days after emergence [22]

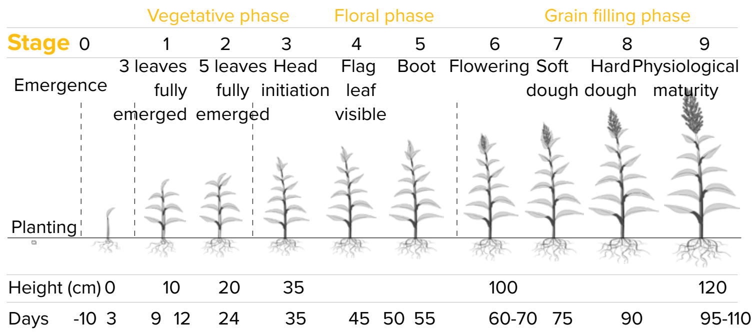

Figure 7: *Growth stages of sorghum.*

Quantities of water required for full irrigation of a sorghum crop will vary depending on seasonal and soil conditions; however, budget on 1.4 ML/ha (delivered to the field) for a pre-irrigation and three irrigations of 1.2 ML/ha during the growing season. The timing of the first irrigation in the absence of irrigations should be at flowering

21 P Wylie (2008) Managing sorghum for high yields—a blueprint for doubling sorghum production. GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Sorghum_HY.pdf

22 T Philp (2011) Irrigated grain sorghum agronomy; irrigation timing. GRDC Update Papers 7 September 2011

MORE INFORMATION

http://www.ausgrain.com.au/Back%20Issues/195jfgrn10/22-sowing.pdf

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/THE-ECONOMICS-OF-SOWING-DECISIONS-AND-LIMITED-SOIL-WATER

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/MODELING-THE-PROFIT-AND-RISK-OUTCOMES-OF-A-RANGE-OF-SOIL-WATER-TRIGGERS-AND-CROPPING-AREA-INTENSITIES-GOONDIWINDI

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GRDC Update Paper: Can high performance surface irrigation reduce nitrogen losses in broadacre cropping systems?

and 10–14 days later during early grainfill. Irrigated yields should be in the vicinity of 10–12 t/ha. [23]

1.9 Yield and targets

1.9.1 Seasonal outlook

Queensland Alliance for Agriculture & Food Innovation (QAAFI) produces regular, seasonal outlooks for sorghum producers. These high-value reports are written in an easy-to-read style and are free. For more information, visit https://qaafi.uq.edu.au/industry/crop-outlook.

For tips on understanding weather and climate drivers, including the Southern Oscillation Index (SOI), visit the Climate Kelpie website. Case studies of 37 farmers across Australia recruited as Climate Champions as part of the Managing Climate Variability R&D Program can also be accessed at the Climate Kelpie website.

Australian CliMate is a suite of climate analysis tools delivered on the web, iPhone, iPad and iPod Touch devices. CliMate allows you to interrogate climate records to ask questions relating to rainfall, temperature, radiation, and derived variables such as heat sums, soil water and soil nitrate, and well as El Niño Southern Oscillation status. It is designed for decision makers such as farmers whose businesses rely on the weather.

Download from the Apple iTunes store at https://itunes.apple.com/au/app/australian-climate/id582572607?mt=8 or visit http://www.australianclimate.net.au

One of the CliMate tools, '*Season's progress?*,' uses long-term (1949 to present) weather records to assess progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and with all years. *It* explores the readily available weather data, compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons.

Crop progress and expectations are influenced by rainfall, temperature and radiation since planting. *Season's progress?* provides an objective assessment based on long-term records:

- How is the crop developing compared to previous seasons, based on heat sum?
- Is there any reason why my crop is not doing as well as usual because of below-average rainfall or radiation?
- Based on season's progress (and starting conditions from HowWet–N?), should I adjust inputs?

For inputs, *Season's progress?* asks for the weather variable to be explored (rainfall, average daily temperature, radiation, heat sum with base temperatures of 0, 5, 10, 15 and 20°C), a start month and a duration.

As outputs, text and two graphical presentations are used to show the current season in the context of the average and all years. Departures from the average are shown in a fire-risk chart as the departure from the average in units of standard deviation. [24]

The Bureau of Meteorology has recently moved from a statistics-based to a physics-based (dynamical) model for its seasonal climate outlooks. The new system has better overall skill, is reliable, allows for incremental improvements in skill over time, and provides a framework for new outlook services including multi-week/monthly outlooks and the forecasting of additional climate variables. [25]

MORE INFORMATION

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

http://www.grdc.com.au/uploads/documents/GRDC_Water%20Use%20Efficiency%20.North%20version%20231009.pdf

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf

http://www.moreprofitperdrop.com.au/wp-content/uploads/2013/10/WATERpak-4_2-Irrigated-Sorghum-best-practice.pdf

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http://www.climatekelpie.com.au/understand-climate/weather-and-climate-drivers/queensland#ElNino

http://www.climatekelpie.com.au/ask-a-farmer/climate-champion-program

MORE INFORMATION

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Seasonal-climate-outlook-improvements-changes-from-historical-to-real-time-data

www.australianclimate.net.au

23 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

24 Australian CliMate—Climate tools for decision makers, www.australianclimate.net.au

25 J Sabburg, G Allen (2013) Seasonal climate outlook improvements changes from historical to real time data. GRDC Update Papers 18 July 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Seasonal-climate-outlook-improvements-changes-from-historical-to-real-time-data

MORE INFORMATION

Jeremy Whish CSIRO discusses target yield, soil water and planting in a dry year. GRDC Podcast: 063 Summer cropping

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Strategies for managing risk. Ground Cover Radio 121: Risk strategy likened to a big game of chess

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Ground Cover Issue 121: Risk strategy likened to a 'big game of chess'

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GRDC Update Paper: Optimising performance of current Northern cropping farming systems

1.9.2 Water Use Efficiency (WUE)

The WUE is the measure of a cropping system's capacity to convert water into plant biomass or grain. It includes the use of water stored in the soil and rainfall during the growing season.

WUE relies on:

- the soils ability to capture and store water;
- the crop's ability to access water stored in the soil and rainfall during the season;
- the availability of water at key growth stages;
- the crop's ability to convert water into biomass; and
- the crop's ability to convert biomass into grain (harvest index). [26]

Converting water into grain

Crop factors indicate how a plant converts water into grain.

Using an average WUE factor of 15 (for every mm of water taken up by the plant, the crop will produce 15 kg grain/ha) for sorghum and assuming the plant uses all the rain that falls, a yield of ~1.7 t can be achieved from 115 mm of in-crop rainfall on average. A wide range of WUE has been measured in grain sorghum, from 7 to 25 kg/mm. The amount of water available is important, but equally important is the timing; other abiotic factors such as heat at key development stages can have major effect.

However, much of this rainfall will be lost from the system via evaporation, or in some cases, runoff. The amount lost is hard to predict and depends on the intensity of the rainfall, the soil dryness at the time of the rainfall event, and the length of time that radiation is reduced from cloud cover and crop cover. On average, ~50–75% of this water will be lost from the system. This changes the scenario from 1.7 t/ha to ~0.4–0.8 t/ha.

Water stored during the fallow is the second source of crop water supply. Stored water is of higher value than rainfall because it is available when the plant needs it, provided reserves are sufficient. In terms of risk management, the greatest value of stored water is in knowing the quantity available for crop production, even before the crop is planted, when decisions are being made. It is also why managing fallow stubble cover and weeds is so important.

Using the above example where the goal is to produce a crop in the region of 2.6–3 t/ha, the analysis of rainfall shows an 80% chance of growing at least 0.4–0.8 t on rainfall alone; therefore, the crop needs to derive the additional 2.2–2.6 t of planned production using the soil water reserves. With the crop factor of 15 kg grain/ha.mm water, this suggests that 140–170 mm of soil water will be required. In rough terms, 150 mm soil water should achieve a 20% return on input costs, or better, 8 years in 10.

The efficiency of production may actually be a lot lower (or higher) depending on seasonal rainfall distribution and crop stage. An alternative approach, which does take into consideration the vagaries of seasonal rainfall distribution and amount, temperature, radiation and soil condition, is to use simulation modelling tools such as APSIM, or its derivatives Yield Prophet™ or Whopper Cropper. These tools all use probability to describe the riskiness of particular actions such as planting on a particular date. Figure 8 shows an APSIM output prepared for Rowena, looking at an October planting.

26 GRDC (2009) Converting rainfall to grain. Northern Region. GRDC Water Use Efficiency Fact Sheet, http://www.grdc.com.au/uploads/documents/GRDC_Water%20Use%20Efficiency%20North%20version%20231009.pdf

MORE INFORMATION

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Strategies-for-improving-wateruse-efficiency-in-western-regions-through-increasing-harvest-index

http://www.grdc.com.au/Resources/Factsheets/2010/02/Water-Use-Efficiency-North

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GRDC Update Paper: Sorghum yield risk vs starting soil moisture

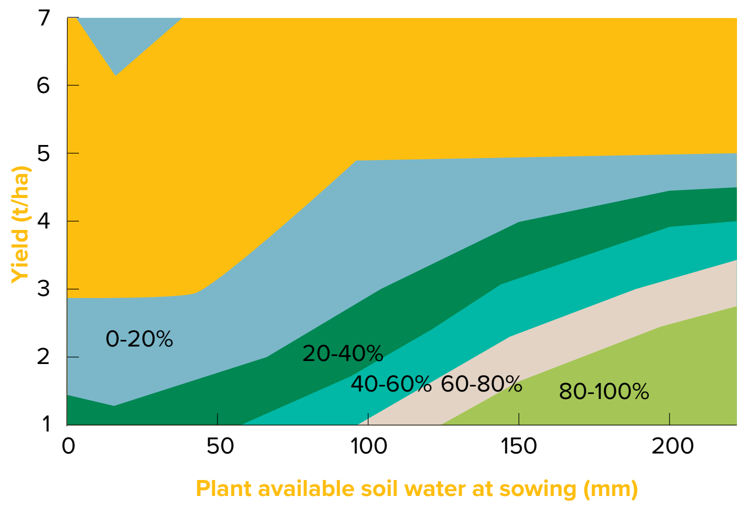

Figure 8: *Rainbow chart showing the probability (colours) of achieving a particular yield (y-axis) based on starting soil water conditions (x-axis). Moving left to right: red, 0%, yellow 0–20%, green 20–40%, light blue 40–60%, dark blue 60–80%, pink 80–100%.*

Figure 8 supports the back-of-envelope calculation suggesting that 150 mm of starting water is the minimum required to achieve a yield of 3 t in 5 years in 10, whereas with 200 mm of stored water the probabilities improve to 6–8 years in 10.

Different sowing strategies can be used to reduce the risk of a failed crop. Skip-row planting maintains a high plant density within the crop row, forcing the plants to experience early competition that limits tillering. As the plants approach grainfill, the limited number of tillers are filled from the spared water in the skip, ensuring the crop is finished. The advantage of skip-row is that it helps ensure a yield and prevents crop failure. However, the downside is that yield is capped because of the lack of tillers, so the crop cannot take full advantage of good rain and will yield less than a solid crop configuration when not under stress. High pricing may also be a consideration.

If the outlook is poor, reducing the area planted is also a way of hedging bets and reducing the risk and expense of a failed crop. However, growing a non-profitable crop as part of a rotation can be tolerated, provided the benefits of the crop to the overall farm system are justified. Reducing weeds, managing herbicide resistance and reducing disease inoculum are benefits of crop rotation that are not easily measured and not considered when using simple WUE calculations or crop model simulations.

Deciding whether to plant is difficult; experience and intuition are valuable components of this decision. However, by following some of the approaches presented here, the decision can be made more transparent and justifiable. By thinking about the consequences of the planting decision on future crops, and how this crop fits into the overall whole farm system, the best decision will be made. [27]

The French–Schultz approach

In southern Australia, the French–Schultz model is widely used to provide growers with a benchmark of potential crop yield based on available soil moisture and likely in-crop rainfall.

27 J Whish (2013) Impact of stored water on risk and sowing decisions in western NSW. GRDC Update Papers 23 July 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Impact-of-stored-water-on-risk-and-sowing-decisions-in-western-NSW

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GRDC Update Paper: Managing the Yield Gap to achieve your yield potential in central west NSW

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http://www.grdc.com.au/~/media/607AD22DC6934BE79DEAA05DFBE00999.pdf

In this model, potential crop yield is estimated as:

Potential yield (kg/ha) = WUE (kg/ha.mm) × [crop water supply (mm) – estimate of soil evaporation (mm)]

where crop water supply is an estimate of water available to the crop, i.e. soil water at planting plus in-crop rainfall minus soil water remaining at harvest.

In the highly variable rainfall environment in the northern region, it is difficult to estimate in-crop rainfall, soil evaporation and soil water remaining at harvest. However, this model may still provide a guide to crop yield potential (see Tables 3 and 4).

The French–Schultz model has been useful in giving growers performance benchmarks—where yields fall well below these benchmarks, it may indicate something wrong with the crop's agronomy or a major limitation in the environment. There could be hidden problems in the soil such as root diseases, or soil constraints affecting yields. Alternatively, apparent underperformance could be simply due to seasonal rainfall distribution patterns, which are beyond the grower's control. [28]

Table 3: *Typical parameters that could be used in the French–Schulz equation.*

Crop	WUE (kg/ha.mm)	Soil evaporation (mm)
Wheat	18	100
Chickpea	12	100
Sorghum	25	150

Table 4: *Effect of soil water threshold for planting on system Water Use Efficiency (SWUE) and other system performance parameters.*

System:	Conservative	Moderate	Aggressive
Planting threshold (mm)	150	100	50
Number of crops	35	45	72
Crops/year	0.69	0.88	1.41
Total grain produced (t/ha)	141	172	197
Average yield (t/ha)	4.04	3.82	2.73
Average cover (%)	40%	49%	55%
SWUE (kg/ha.mm)	4.55	5.53	6.32
% rainfall ending up as:			
Transpiration	21%	26%	32%
Evaporation	56%	55%	55%
Run-off	18%	16%	11%
Drainage	5%	3%	2%

This table presents the results of a simulation modelling analysis for a cropping system at Emerald from 1955 to 2006

Challenging the French–Schultz model

Application of the French–Schultz model for the northern region has been challenged in recent times.

In the wheat-belt of eastern Australia, rainfall shifts from winter-dominated in the south (South Australia, Victoria) to summer-dominated in the north (northern NSW and Queensland). The seasonality of rainfall, together with frost risk, drives the choice of cultivar and sowing date, resulting in a flowering time between October in the south and August in the north.

28 GRDC (2009) Converting rainfall to grain. Northern Region GRDC Water Use Efficiency Fact Sheet, http://www.grdc.com.au/~/media/607AD22DC6934BE79DEAA05DFBE00999.pdf

In eastern Australia, wheat crops are therefore exposed to contrasting climatic conditions during the critical period for grain formation, i.e. a window of about 20 days before and 10 days after flowering, which affects yield potential and WUE.

Understanding how those climatic conditions affect crop processes and how they vary from north to south and from season to season can help growers and consultants to set more realistic target yields across sites, locations and seasons (Figure 9).

Researchers have analysed some of the consequences of the shift from winter to summer rainfall between southern and northern regions in terms of implications for management and breeding. They advise caution on the use of simple rules of thumb (French–Schultz) for benchmarking WUE, and discuss the importance of more integrative and dynamic modelling approaches to explore alternatives to increase WUE at the single-crop and whole farming-systems level, i.e. $/ha.mm.

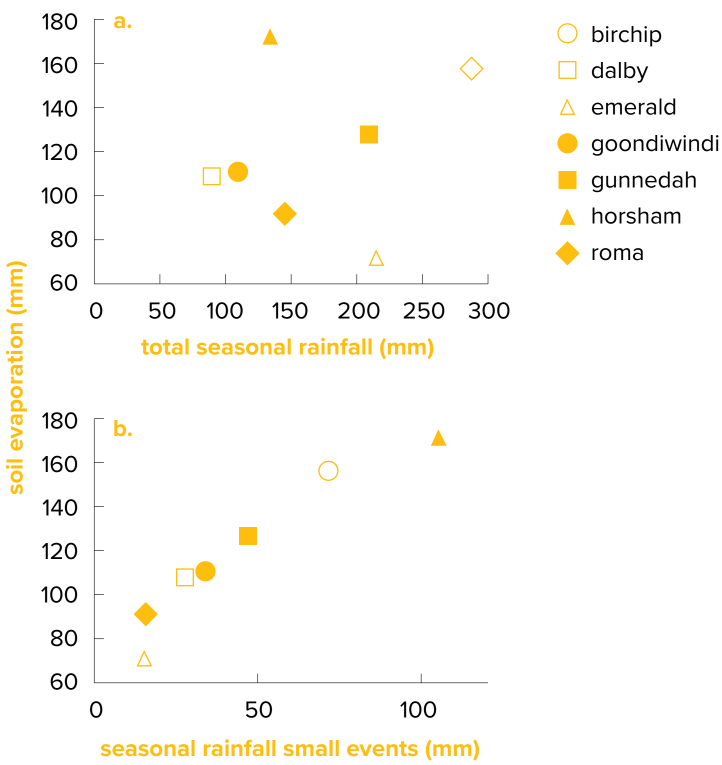

Figure 9: *Simulated soil evaporation is (a) unrelated to seasonal rainfall and (b) closely related to rainfall in small events (i.e. ≤5 mm).*

MORE INFORMATION

https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2008/06/Farming-systems-design-and-water-use-efficiency-WUE-Challenging-the-French-Schultz-Wue-model

1.9.3 Nitrogen-use efficiency (NUE)

Although sorghum is a C4 crop [29] and uses N, CO_2, solar radiation and water more efficiently than most C3 crops, N as a nutrient is still one of major factors limiting crop yield. Depending on soil N fertility, applications to commercial grain sorghum crops can vary from 0 to 150 kg N/ha.

As yield increases and if there is a shortfall of N, grain protein will decline, sometimes by as much as 6 percentage points. The total N requirement of an 8 t/ha sorghum crop at a grain protein level of 6.5% is 142 kg N, compared with 190 kg N at 10%

29 C4 carbon fixation. Wikipedia, http://en.wikipedia.org/wiki/C4_carbon_fixation

protein. It is generally thought that the maximum yield is achieved with grain protein at 9–10%, and that at lower levels yield is compromised by a lack of N.

Variable responses to the application of N fertiliser have previously been observed in sorghum, with differences attributed to climatic, soil and genotypic factors across seasons and locations. Part of this yield variation is associated with differences in the capability of the soil to supply N and in the efficiency of recovery of applied N fertiliser. The other component contributing to the variable yield response to fertiliser-N is the N requirement for yield determination. The N requirement is dependent on the yield expectation in a given environment as determined by climate, management and cultivar. There is a need to determine the minimum N requirement for a given yield level so as to maximise NUE (defined as grain yield per unit N uptake). Nitrogen uptake in excess of that required for yield determination results in lower NUE and is associated with increased stem and grain N concentration.

Sorghum is currently one of the most profitable crops in the higher rainfall areas of the northern grains belt. Profit margins suggest that sorghum may be almost as profitable as wheat in western growing regions if slightly more yield can be achieved to make up for a lower price. Nitrogen inputs represent a large input cost within the gross margin for sorghum; however, the lack of protein premiums means that luxurious N applications directly reduce profitability. [30]

MORE INFORMATION

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Agronomic-and-economic-responses-of-sorghum-to-nitrogen-nutrition

Nitrogen loss pathways

Nitrogen can be lost from cropping soils via downwards, sidewards or upwards movement.

Downward movement of nitrate [NO_3^-] via leaching is a greater problem in lighter textured soils than in the medium–heavy clays dominating the northern grains zone, but previous research has demonstrated some N losses, albeit small on an annual scale, can occur via this pathway. [31]

Sideways movement can occur rapidly through erosion of organic matter rich topsoil during intense rainfall events, or more slowly through lateral subsoil movement of nitrate-N in soil water.

The main upwards N loss pathways consist of gaseous losses through either ammonia volatilisation or denitrification of nitrate.

In 2012–15, six experiments with isotope-labelled (15N) urea fertiliser were conducted in northern NSW and a further 11 in southern Queensland, all focussed on measuring the fate of applied N fertiliser in summer sorghum. The use of 15N allowed researchers to trace the fate of urea-N applied to the soil from sowing through to harvest. [32]

Between 56 and 100% of the applied N was found in the soil and plant at harvest, with in-season rainfall (both timing and amount) and soil C and N status having a major impact on the seasonal loss potential.

Avoiding unnecessarily high N rates, delaying or splitting N fertiliser so that peak N availability coincides with peak crop N demand, and relying on residual N from legume rotations all significantly reduced gaseous N losses from dryland sorghum, although the effectiveness of any management strategy varied with seasonal conditions.

Nitrification inhibitor-coated urea significantly reduced nitrous oxide emissions in all studies, but did not improve grain yields enough to justify the additional cost on an agronomic basis.

30 M Gardner *et al.* (2013) Agronomic and economic responses of sorghum to nitrogen nutrition. GRDC Update Papers 18 July 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Agronomic-and-economic-responses-of-sorghum-to-nitrogen-nutrition

31 M Bell, G Schwenke, D Lester (2016) Understanding and managing N loss pathways, GRDC Update Papers 22 June 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/06/Understanding-and-managing-N-loss-pathways

32 M Bell, G Schwenke, D Lester (2016) Understanding and managing N loss pathways, GRDC Update Papers 22 June 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/06/Understanding-and-managing-N-loss-pathways

Depending on the season, delaying/splitting N applications gave either no yield benefit (dry season) or a significantly greater yield (good in-crop rainfall). Much of the unused N after a dry season remained in the soil and, provided loss events were not experienced during the fallow, significantly benefited the following crop.

1.9.4 Short-fallow options

In northern NSW–southern Queensland, chickpeas are the most popular double-crop option after sorghum. Chickpeas are relatively tolerant of atrazine residues and are slower to use stored soil water. This double-crop system with chickpeas also has environmental benefits by enabling chickpeas to be grown on sloping soils without the same degree of soil erosion during the following summer fallow period.

Mungbeans may be included in the rotation as a double-crop option as a short fallow (6 months) following sorghum. They can also be grown immediately following winter cereal harvest, or after a long fallow (18 months) from a winter cereal crop. When planting into sorghum stubble, Atrazine residues are most likely to be a concern. The rate used will determine the plant-back safety, with 9 months being adequate at lower rates.

Like mungbeans, soybeans are a short-duration, summer-growing grain crop. Soybeans also commence flowering in ~45 days, but are slower to mature than mungbeans, taking 130–140 days to harvest. As a summer grain legume, soybeans are well suited to growing in rotation with a range of crops including sorghum, winter cereals, canola, cotton and maize.

Most soil types in central west NSW are suited to soybean growing. Like mungbeans, soybeans do not tolerate waterlogging. Warm, moist seedbeds with good drainage provide the best start for soybean establishment. Where furrow irrigation is used, high hills are required to minimise waterlogging. Crusting soils can also create problems for emerging soybean plants, because of epigeal germination (i.e. the soybean leaves must be able to push their way through to the soil surface). Removing stubble from the plant line in dryland, no-till situations will also assist establishment. [33]

1.10 Nematode status of the paddock

In the northern grains region, the predominant root-lesion nematode (RLN), *Pratylenchus thornei,* costs the wheat industry A$38 million annually. [34] Including the secondary species, *P. neglectus*, RLN is found in three-quarters of fields tested.

Resistance and susceptibility of crops can differ for each RLN species, and sorghum is resistant to *P. thornei* but susceptible to *P. neglectus*. [35]

1.10.1 Nematode testing of soil

It is important to have paddocks diagnosed for plant parasitic nematodes so that optimal management strategies can be implemented. Testing your farm will tell you:

- if nematodes are present in your fields and at what density
- which species are present

It is important to know which species are present because some crop-management options are species-specific. If a particular species is present in high numbers, immediate decisions must be made to avoid losses in the next crop to be grown. With low numbers, it is important to take decisions to safeguard future crops. Learning that

MORE INFORMATION

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Summer-crop-options-for-the-central-west-mungbeans-soybeans?highlight=sorghum

http://www.grdc.com.au/~/media/9219D55FFB4241DC9856D6B4C2D60569.pdf

http://www.regional.org.au/au/asa/1998/9/280cox.htm

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/146690/err-20-Farming-Systems-in-the-Northern-Cropping-Region-of-NSW--An-Economic-Analysis-Region-of-NSW-An-Economic-Analysis.pdf

http://espace.library.uq.edu.au/view/UQ:159371

http://livestocklibrary.com.au/handle/1234/21419

MORE INFORMATION

https://www.grdc.com.au/~/media/B4063ED6F63C4A968B3D7601E9E3FA38.pdf

http://www.soilquality.org.au/factsheets/root-lesion-nematode-in-queensland

33 L Jenkins (2012) Summer crop options for the central west—mungbeans & soybeans. GRDC Update Papers 10 April 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Summer-crop-options-for-the-central-west-mungbeans-soybeans?highlight=sorghum

34 GM Murray, JP Brennan (2009) The current and potential costs from diseases of wheat in Australia. GRDC Report, https://www.grdc.com.au/~/media/B4063ED6F63C4A968B3D7601E9E3FA38.pdf

35 K Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet, http://www.soilquality.org.au/factsheets/root-lesion-nematode-in-queensland

a paddock is free of these nematodes is valuable information because steps may be taken to avoid future contamination of that field. [36]

Testing of soil samples taken either before a crop is sown or while the crop is in the ground provides valuable information.

1.10.2 Effects of cropping history on nematode status

Root-lesion nematode numbers build up steadily under susceptible crops and cause decreasing yields over several years. Yield losses >50% can occur in some wheat varieties, and up to 20% in some chickpea varieties. The amount of damage caused will depend on:

- the numbers of nematodes in the soil at sowing
- the tolerance of the variety of the crop being grown
- the environmental conditions

Generally, a population density of 2000 RLN/kg soil anywhere in the soil profile has the potential to reduce the grain yield of intolerant wheat varieties.

A tolerant crop yields well when high numbers of RLN are present (the opposite is intolerance). A resistant crop does not allow RLN to reproduce and increase in number (the opposite is susceptibility).

Growing resistant crops is the main tool for managing nematodes. In the case of crops such as wheat or chickpeas, choose the most tolerant variety available and rotate with resistant crops to keep nematode numbers at low levels. Information on the responses of crop varieties to RLN is regularly updated in grower and QDAF planting guides. Note that crops and varieties have different levels of tolerance and resistance to *Pratylenchus thornei* and *P. neglectus*.

For more information, download '*Management of root-lesion nematodes in the northern grain region at* http://www.daff.qld.gov.au/__data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf

Summer crops have an important role in management of RLN. Research shows when *P. thornei* is present in high numbers, two or more resistant crops in sequence are needed to reduce populations to low enough levels to avoid yield loss in the following intolerant, susceptible wheat crops. [37]

For more information on nematode management, see GrowNotes Sorghum 8. Nematodes.

1.11 Insect status of paddock

1.11.1 Insect sampling of soil

It is important to monitor and control soil-dwelling insects such as wireworms at sowing. [38]

Soil-dwelling insect pests can seriously reduce plant establishment and populations, and subsequent yield potential.

Soil insects include:

- cockroaches
- crickets
- earwigs

MORE INFORMATION

https://sites.google.com/site/crownanalyticalservices/home

http://www.sardi.sa.gov.au/products__and__services/entomology/diagnostic_services/predicta_b

http://www.daff.qld.gov.au/__data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf

MORE INFORMATION

https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Summer-crop-decisions-and-root-lesion-nematodes

MORE INFORMATION

Melina Miles QDAF describes germinating seed bait technique for checking insect populations prior to sowing. GRDC Podcast: 104 Thrips worrying early summer crops

36 QDAF (2009) Root lesion nematodes—management of root-lesion nematodes in the northern grain region. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/__data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf

37 K Owen, T Clewett, J Thompson (2013) Summer crop decisions and root-lesion nematodes. GRDC Update Papers Bellata 16 July 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Summer-crop-decisions-and-root-lesion-nematodes

38 NSW DPI (2005) Grain sorghum. Agfact P3.3.5. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

- black scarab beetles
- cutworms
- false wireworm
- true wireworm

Different soil insects occur under different cultivation systems and farm management can directly influence the type and number of these pests:

- Weedy fallows and volunteer crops encourage soil insect build-up.
- Insect numbers decline during a clean long fallow from lack of food.
- Summer cereals followed by volunteer winter crops promote the build-up of earwigs and crickets.
- High levels of stubble on the soil surface can promote some soil insects because of a food source, but this can also mean that pests continue feeding on the stubble instead of germinating crops.
- No-tillage encourages beneficial predatory insects and earthworms.
- Incorporating stubble promotes black field earwig populations.
- False wireworms are found under all intensities of cultivation but numbers decline if stubble levels are very low.

Control measures against soil insects are normally applied at sowing. Since different insects require different control measures, the species of soil insects must be identified before planting.

Soil sampling by spade

1. Take a number of spade samples from random locations across the field.
2. Check that all spade samples are deep enough to take in the moist soil layer (this is essential).
3. Hand-sort samples to determine type and number of soil insects.
4. Spade sampling is laborious, time-consuming and difficult in heavy clay or wet soils.

Germinating-seed bait technique

Immediately following planting rain:

1. Soak insecticide-free crop seed in water for at least 2 h to initiate germination.
2. Bury a dessertspoon of the seed under 1 cm of soil at each corner of a 5 m by 5 m square at five widely spaced sites per 100 ha.
3. Mark the position of the seed baits, as large populations of soil insects can destroy the baits.
4. One day after seedling emergence, dig up the plants and count the insects.

Trials have shown no difference in the type of seed used for attracting soil-dwelling insects. However, use of the type of seed to be sown as a crop is likely to indicate the species of pests that could damage that crop.

The major disadvantage of the germinating-grain bait method is the delay between the seed placement and assessment.

Detecting soil-dwelling insects

Soil insects are often difficult to detect as they hide under trash or in the soil. Immature insects such as false wireworm larvae are usually found at the moist–dry soil interface.For current chemical control options see the websites of Pest Genie Australia or APVMA. [39]

MORE INFORMATION

http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects

http://www.pestgenie.com.au/

http://www.apvma.gov.au/

39 QDAF (2011) How to recognise and monitor soil insects. Queensland Department of Agriculture, Fisheries and Forestry, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects

PODCAST

The GEKKO phenotyping tractor is being used by the University of Queensland as a remote sensing vehicle that can drive over trial sorghum plots during different growth stages and compile a composite picture for high definition 3D profiles of the plant canopy. Ground Cover Radio 122: All seeing tractor takes crop science to the future

MORE INFORMATION

Ground Cover Issue 122: All-seeing 'tractor' takes crop science to the future

Pre-planting

2.1 Hybrid sorghum characteristics

Selecting the right hybrid will depend on the location and season prospects. Growing two or three hybrids with slightly different characteristics can help spread your production risk.

2.1.1 Hybrid maturity

Select hybrids with a maturity length suitable for the local climatic conditions. With good to average dryland conditions on the North West Slopes and Liverpool Plains, the medium–slow to medium-maturity hybrids are recommended. On the North West Plains, the medium to medium–quick hybrids are recommended, depending on subsoil moisture storage. Growers need to select on highest yield potential and reliability, which includes the appropriate agronomic traits.

In northern NSW, quick-maturity hybrids take ~66 days from planting to the start of flowering, medium-maturity hybrids ~73 days, and slow-maturity hybrids ~80 days. The time a hybrid takes to flower will vary, depending on temperature. At Moree, for example, medium-maturity hybrids planted in early October take ~80 days to flower but when planted in mid-November only take ~60 days. At Spring Ridge, medium-maturity hybrids planted in early November flower in ~80 days compared with 65 days if sown during late November. [1]

As a rule, medium–late maturing sorghums are higher yielding, particularly under conditions of good moisture and nutrients. However, as moisture conditions become more limiting, the earlier maturing hybrids have greater yield reliability. Slower maturing hybrids generally give higher yields than quick-maturing hybrids when moisture and nutrients are not limiting. When moisture is limiting, the quicker maturing hybrids may offer better reliability. The choice of maturity will therefore depend on conditions at planting (e.g. soil type, stored water) and grower's attitude to risk (Figure 1). [2]

1 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

2 QDAF (2011) Sorghum—planting information. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/planting-information

MORE INFORMATION

GRDC Update Paper: High yielding sorghum and closing the yield gap

Figure 1: *Growing two or three sorghum hybrids spreads production risk.*

Photo: Loretta Serafin, NSW DPI

2.1.2 Yielding ability

Choose hybrids that have a high yielding ability under a range of seasonal conditions, and grow more than one hybrid each season. Trial hybrids on your farm over several seasons and grow those that perform best on average.

NSW DPI researchers investigated six key agronomic practices; row spacing, plant population, hybrid selection, nitrogen (N) and phosphorus (P) nutrition and time of sowing at two locations on the Liverpool Plains during the growing seasons of 2013–14, 2014–15 and 2015–16. [3]

In each season, trials were conducted at two locations, the NSW DPI Research Station at Breeza and in commercial sorghum paddocks at Pine Ridge (2013–14), Willow Tree (2014–15) or Premer (2015–16) in the respective seasons.

Key points

- Time of sowing can have large impacts on final crop yield, however being able to identify when to plant depending on the season is not possible.
- Nitrogen nutrition had the largest impact on crop yield across the three seasons.
- Hybrid performance varied between seasons and sowing times, however there was no consistent pattern of which hybrid yielded the best. [4]

2.1.3 Lodging and disease resistance

Lodging can be a problem in all dryland growing areas. Select hybrids with good lodging resistance where moisture stress is likely during the latter stages of grainfill. Moisture stress is the most common cause of lodging. Fusarium and charcoal stem rots are often associated with lodging, leading to plant death and considerable yield loss. Crops that remain green with some available soil moisture during grainfill are generally less prone to lodging. Northern Grower Alliance (NGA) trials in 2010–11

3 L Serafin, G McMullen (2016) High yielding sorghum and closing the yield gap, GRDC Update Papers 21 July 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/High-yielding-sorghum-and-closing-the-yield-gap

4 L Serafin, G McMullen (2016) High yielding sorghum and closing the yield gap, GRDC Update Papers 21 July 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/High-yielding-sorghum-and-closing-the-yield-gap

showed that applications of glyphosate pre-harvest exacerbated the proliferation of *Fusarium*, resulting in the potential for increased lodging.

Agronomic practices such as no-till, stubble retention and controlled-traffic farming, all of which aim to store more fallow and in-crop rainfall, will to help reduce lodging. The use of wide or skip-rows, especially in the North West Plains, will also help.

These practices allow medium-maturity hybrids with higher yield potential to be grown.

Lodging is rarely a problem on fully irrigated crops, but can occur in specific varieties in partially irrigated crops that are stressed during the later stages of grainfill or following desiccation.

2.1.4 Sorghum midge resistance

Most hybrids have some level of resistance to sorghum midge.

Newly released hybrids are tested for their midge resistance by the Industry Testing Group, comprising Department of Agriculture, Fisheries and Forestry Queensland (QDAF) and seed companies (Figure 2, Table 1). Resistant hybrids have significantly reduced the need to spray for midge. [5]

Figure 2: *Hybrids are assessed and given a midge rating.*

5 QDAF (2011) Sorghum—planting information. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/planting-information

MORE INFORMATION

http://www.grdc.com.au/Research-and-Development/Major-Initiatives/The-Sorghum-Midge-Tested-Scheme

https://www.pacificseeds.com.au/products/grain-sorghum.html

http://www.heritageseeds.com.au/products/hgs-114-grain-sorghum

http://www.pioneer.com/web/site/australia

http://www.nuseed.com.au/AU/Home

http://www.pacificseeds.com.au/images/stories/brochures/lowresforweb.pdf

Table 1: *The Industry Testing Group assigns midge resistance (MR) ratings from 1 to 7 (current top rating).*

Hybrid	MR rating	Seed company
HGS-102	6	Heritage Seeds
Enforcer	6	Nuseed
MR-Apollo	6	Pacific Seeds
MR-Eclipse	6	Pacific Seeds
MR-Taurus	6	Pacific Seeds
MR-Scorpio	6	Pacific Seeds
HGS-114	6	Heritage Seeds
85G33	5	Pioneer
Dominator	5	Nuseed
Venture	5	Nuseed
Pacific MR 43	5	Pacific Seeds
84G99	5	Pioneer
MR-Bazley	4	Pacific Seeds
Liberty White	4	Nuseed
MR-Buster	4	Pacific Seeds
84G22	4	Pioneer
85G08	4	Pioneer
Tiger	3	Nuseed

Ratings can range from 1 (no resistance) to 8+ (practical field immunity; some new hybrids)

2.1.5 Organophosphate insecticide reaction

Some hybrids have a phytotoxic reaction to organophosphate (OP) insecticides. This causes symptoms from spotting to intense purpling of leaves and stems. When crops are likely to be sprayed with OP insecticides, it is suggested to grow tolerant hybrids with a rating of 4–5 to reduce possible yield losses. See Table 2 and consult seed companies for hybrid ratings. [6]

6 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

Table 2: *Sorghum hybrid characteristics 2011—see key below for ratings.*

Company	Hybrid	Maturity	Height	Standability	Sorghum midge[A]	OP reaction[B]	Head type	Irrigation suitability
Nuseed	Venture	MQ	M	5	5	CC	SO	Yes
	Tiger	M	M	5	3	CC	SC	Yes
	Dominator	M	M	5	5	MIN	O	Yes
	Liberty White	M	M	5	4	MIN	SO	Yes
	Enforcer	MS	M	4	6	MIN	O	Yes
Pacific Seeds	MR Eclipse	MQ	M	4	6	MIN	SO	Yes
	Pacific MR43	M	MT	4	5	MIN	O	Yes
	MR Buster	M	M	5	4	SEV	SO	Yes
	MR Bazley	M	M–S	5	4	CC	SC	Yes
	MR Apollo	ML	M	5	6	CC	SO	Yes
	MR Scorpio	M	M	4.5	6	CC	SO	Yes
	MR Taurus	MQ	M	5	6	CC	SO	Yes
Pioneer	85G33	MQ	S–M	5	6	NA	SO	Yes
	84G99	M	M	5	5	MIN	O	No
	85G22	M	M	5	4	MIN	SO	Yes
Heritage Seeds	HGS-102	M	M	5 (charcoal rot 6)	7	8 (minimal)	SO	Yes
	HGS-114	M	M–S	5.5 (charcoal rot 6.5)	6	9 (minimal)	SO	Yes

The information presented in this table was kindly supplied by seed companies and is not based on DPI data. Only varieties commercially available in NSW and Queensland are listed. Consult seed companies before final selection of sorghum hybrids for particular markets and for particular localities

[A]Midge rating is the factor by which a hybrid's midge resistance exceeds that of a fully susceptible hybrid (rating 1). For example, if it is cost-effective to control 2 midges/head in a rating 1 hybrid, then cost-effective control in a rating 7 hybrid occurs when there are 14 midges/head.

[B]Joint seed company approved ratings based on visible leaf damage only. Ratings may not reflect possible yield losses due to the chemical.

Key for Table 2

Maturity	Height	Standability	Midge resistance	OP reaction	Head type	Irrigation suitability
Medium–**Q**uick **M**edium **M**edium **S**low	**S**hort **M**edium **M**edium **T**all	**1** Poor **2** Fair **3** Good **4** Very Good **5** Excellent	**1** Susceptible **2** Low **4** Moderate **6** Very high **7** High **8+** Excellent **P** Preliminary	**SEV** Severe **MOD** Moderate **MIN** Minimal **CC** Consult Company	**O**pen **S**emi-**O**pen **S**emi-**C**ompact **C**ompact	Company recommendations

MORE INFORMATION

http://www.hsrseeds.com.au/grain-sorghum.aspx

http://www.pacificseeds.com.au/products/sorghum.html

http://www.pioneer.com/CMRoot/International/Australia_Intl/web_content/media/summer.pdf

http://www.daff.gov.au/__data/assets/pdf_file/0007/2281228/sorghum.pdf

2.2 Safe rates of fertiliser sown with seed

Care must be taken when applying nitrogenous fertilisers at planting. Release of ammonia from the fertiliser can damage the germinating seedling if applied with the seed at planting. Table 3 details the safe rates for application with the sorghum seed at planting.

Table 3: *Safe rates (kg/ha) of some nitrogen fertiliser products sown with sorghum seed at planting.*

Row spacing (cm)	N applied	Urea	DAP	MAP Starterfos
18	25	54	130	200
25	18	39	90	138
50	9	20	45	69
75	6	13	30	46
100 (1-m rows)	4.5	10	23	35
150 (single-skip)	3.0	6.7	15	20
200 (double-skip)	2.3	5	11	17

Rates in Table 3 should be reduced by 50% for very sandy soil sand may be increased by 30% for heavy-textured soils or where soil moisture conditions at planting are excellent.

Rates should be reduced by 50% when planting equipment with narrow-slit openers is used (the fertiliser concentration is increased around the seed).

Rates may be increased by 50% when airseeders are used operating at high pressures with wide openers. Airseeders spread the fertiliser bands when operating at high pressures, reducing the fertiliser concentration around the seed. [7]

2.3 Sprouted grain and feed quality

Premium Grains for Livestock Program (PGLP) research shows that sprouting has little or no effect on feed value, provided the grain is not contaminated with fungal growth.

Trials showed that the energy content of sprouted grains for animals was not decreased, and in some circumstances may be increased, compared with non-sprouted grain. The effects of germination were particularly favourable for a barley sample fed to broiler chickens and sorghum fed to cattle.

PGLP was funded by GRDC, Meat and Livestock Australia (MLA), Australian Pork Limited (APL), Rural Industries R&D Corporation (RIRDC), Australian Egg Corporation Limited (AEC), Ridley AgriProducts and Dairy Australia (DA). The project which carried out by the several research organisations across Australia and coordinated by researcher Dr John Black, John L Black Consulting, Warrimoo, NSW.

There was no detrimental effect of sprouting on the energy value of grains for animals; however, the effects of storage on the possible deterioration of sprouted grain or of mycotoxins that may develop needed to be examined.

The research analysed sprouted sorghum samples collected from the Moree district of NSW that had been significantly downgraded at the grain depot. The starch content and *in vitro* fermentation and digestion were compared with the mean values from all other sorghum samples. Results suggested that the starch content and nutritional value of sorghum were unaffected by sprouting.

As part of the trials, grain was fed to sheep, pigs, broiler chickens and layers. A comparison of available energy content and total available energy intake suggested the sprouted sorghum was not substantially different from the other sorghum samples examined.

Two cultivars each of wheat and barley and three cultivars of sorghum were also germinated for periods of 16–48 h and germination was ceased by drying. Germination for these periods did not alter the starch content of the grains, but reduced significantly the falling number values, which measure the degree of starch breakdown by the grain enzyme amylase.

Germination did not affect the microbial fermentation of starch. However, the rate of starch digestion appeared to increase, with a significant increase in total acid and lactic acid production with all grain species. These results indicate that germination increases the accessibility of both rumen microbial and animal digestive enzymes to starch, and increases the rate of starch digestion for all cereal species examined. [8]

For more details on weather-damaged or mouldy grains, see GrowNotes Sorghum 15. Marketing.

MORE INFORMATION

http://www.grdc.com.au/Media-Centre/Media-News/Misc/2013/03/sprouted-sorghum--feed-quality-not-dampened

http://ses.library.usyd.edu.au/handle/2123/5441

https://www.grdc.com.au/uploads/documents/2010ASGCEditedPapersPDF/Lawrence_Feedlot_edited_paper.pdf

http://www.brahman.com.au/technical_information/nutrition/fastSlowGrains.html

7 QDAF (2011) Sorghum— nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

8 R Bowman (2013) Sprouted sorghum: feed quality not dampened. GRDC Media Centre, http://www.grdc.com.au/Media-Centre/Media-News/Misc/2013/03/sprouted-sorghum--feed-quality-not-dampened

Planting

3.1 Seed treatments

Herbicides containing the active ingredient metolachlor (Dual®, Dual Gold®, Primextra® and Primextra Gold®) can seriously damage sorghum plants. When there is a need to use these herbicides for weed control, it is necessary to 'safen' the sorghum seed by pre-plant seed treatment with the seed-safener, Concep® II. Check labels on all seed treatment products for recommended treatment sequences and procedures. [1] Pacific Seeds Elite seed and Pioneer Hi-Bred Betta Strike Plus seed are both pre-applied with Concep® II.

Factors increasing the chance of sorghum injury

- rainfall or irrigation between planting and emergence wetting down to the seed zone, especially where waterlogging occurs.
- light/sandy/gravel soils
- germinating seedling under stress (e.g. waterlogging, cold shock, insect damage)
- maximum application rates
- marginal soil temperature at planting
- defined planting furrows that with rainfall, act to concentrate herbicide over the crop row
- shallow planting depth

Factors reducing the chance of sorghum injury

- high quality seed, treated with Concep® II seed safener
- Concep® II seed safener applied within the past 18 months
- closing up of the planting slot to avoid herbicide coming into contact with the sorghum seed
- excellent crop agronomy [2]

3.2 Time of sowing

Early plant sorghum currently offers a more attractive proposition to growers in the western zone (west of the Newell Highway) than late plant sorghum, mostly for logistical and rotational reasons. [3] The preferred planting time for the Moree and Narrabri districts is late September through to early October, and for Gunnedah, Inverell and Tamworth districts, mid-October to late November (Table 1). Planting at the beginning of these windows is often more successful in minimising moisture stress during flowering; however, the earlier planted crops are more likely to suffer from cold conditions as seedlings. Early plantings have the advantage of early maturity and harvest enabling the opportunity of double-cropping (often to chickpeas) after favourable midsummer rains (Figure 1).

November can be a difficult month for planting sorghum in northern NSW and southern Queensland. It often means heat stress conditions during flowering and

MORE INFORMATION

http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/planting-information

http://www.grdc.com.au/uploads/documents/2010ASGCPowerPointPresentationsPDF/Keller_FusariumInSorghum_slides.pdf

www.apvma.gov.au

VIDEOS

Mark Congreve ICAN discusses the factors that influence crop injury. Video: Managing sorghum injury when using metolachlor herbicides

MORE INFORMATION

GRDC Tips and Tactics: Managing frost risk - Northern Southern and Western Regions

1 QDAF (2011) Sorghum—planting information. Department of Primary Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/planting-information

2 GRDC (2016) Keeping sorghum safe, GRDC Tips and Tactics, www.grdc.com.au/TT-KeepingSorghumSafe

3 L Serafin, G McMullen (2015) Sorghum agronomy to manage risk and improve yield in the western zone, GRDC Update Papers 31 July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Sorghum-agronomy-to-manage-risk-and-improve-yield-in-the-western-zone

PODCAST

Loretta Serafin NSW DPI discusses sorghum trials in northern NSW aimed at optimising profitability. GRDC Podcast: 094 Optimising sorghum production

early grainfill, although summer weather is notoriously erratic. Yields can be variable because of erratic summer weather, but are generally average or better.

Planting before early January so that the crops finish flowering by mid-March may reduce the risk of sorghum ergot infection. January-planted, midge-resistant hybrids with good soil moisture and nutrition can still have good yield potential despite being slower to dry-down and more prone to midge damage.

Planting after mid-December on the Liverpool Plains increases the risk of 'incomplete pollination' caused by night temperatures falling to <13°C during flowering, thereby reducing yield in some of the more susceptible hybrids. Sowing after 10 January is not recommended because of the risk of the sorghum not reaching physiological maturity before an early first frost event.

Table 1: *Suggested sowing times for sorghum in NSW.*

Region	Early plant												Late plant														
	Aug.				Sept.				Oct.				Nov.				Dec.				Jan.				Feb.		
Week:	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3
NW plains						>	●	●	●	●	●	●	<				>	>	●	●	●	●	<				
NW slopes, Liverpool Plains									>	●	●	●	●	●	<		>	●	●	●	●	<					
Central west											>	●	●	●	●	●	<										
Southern irrigation areas											>	●	●	●	●	●	<										
Western Downs					>	●	●	●	●	●	●	●	●	●	●	<			>	●	●	●	●	<			
Central Downs							>	●	●	●	●	●	●	●	●	<			>	●	●	●	●	<			
Northern Downs							>	●	●	●	●	●	●	●	●	<			>	●	●	●	●	<			
Southern Downs									>	●	●	●	●	●	●	●	●	●	●	●	<						
Callide Dawson			>	●	●	●	●	●	●	●	<								>	●	●	●	●	●	●	<	
Southern Highlands			>	●	●	●	●	●	●	●	<								>	●	●	●	●	●	●	<	
Northern Highlands	>	●	●	●	●	●	●	●	●	●	<								>	●	●	●	●	●	●	●	<

> Earlier than ideal, but acceptable; ● optimum sowing time; < later than ideal, but acceptable

Figure 1: *Consider soil temperatures prior to sorghum planting.*

Sorghum should be planted when the soil temperature at 09:00 (9 am) EST at the intended seed depth (~5 cm) is at least 16°C (preferably 18°C) for 3–4 days consecutively and the risk of frosts has passed. Soil temperatures usually reach 16°C in early October at Moree and mid-October at Gunnedah. These same planting rules apply in the central west of NSW.

Planting into cold soils slows emergence, reduces germination and establishment, and increases susceptibility to seedling blight. Low soil and air temperatures slow plant growth and reduce nutrient uptake (especially phosphorus), inducing purpling in some hybrids. Very early planted paddocks frequently have to be replanted. Note that some hybrids do have better cold tolerance than others. [4]

In Queensland, sorghum planting time varies from September to January, depending on planting rains and soil temperature early in the season.

Crop failures are likely in central and southern regions from very early plantings in August–September, due to cold conditions at emergence, and very late plantings in February–March, due to cold conditions during crop ripening. Planting at the early end of the range is preferred to avoid midge problems and to allow the option to double-crop a winter crop if sufficient rainfall is received.

Best yields usually follow October plantings. These crops usually miss insect damage by midge. With late crops, midge will need to be managed by selecting midge-

4 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

MORE INFORMATION

http://www.australianoilseeds.com/__data/assets/pdf_file/0006/7791/1989_Survey_of_Sorghum_and_Sunflower_Establishment_in_Central_Highlands.pdf

MORE INFORMATION

G Hammer, S Chapman, V Singh, C Nguyen, E van Oosterom, G McLean, B Zheng, D Jordan (2015) Grain sorghum varietal reactions to heat stress and environment, GRDC Update Papers 24 July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Grain-sorghum-varietal-reactions-to-heat-stress-and-environment

resistant sorghum hybrids and/or with the use of insecticide sprays. Generally, mid-season hybrids are the best overall performers.

Sorghum ergot disease risk can also be minimised by planting from mid-October to mid-January in southern Queensland, so that flowering occurs between mid-December and mid-March, when the probability of ergot developing in sorghum florets is lowest. For more detail on this disease and its management, see GrowNotes Sorghum 9. Diseases.

In central Queensland, use quick-maturing hybrids for rain-grown spring plantings. For the main summer planting (late December to mid-February), plant slow-maturing hybrids early and the quicker maturing hybrids later to improve yield reliability.

At soil temperatures of 15°C, sorghum takes 11–14 days to emerge. At 17°C, it takes only 7–10 days. [5]

3.2.1 The effect of temperature on yield

Collaborative research funded by the Grains Research and Development Corporation (GRDC) and led by the University of Queensland has examined the sowing-date effects on yield and high temperature risk in sorghum.

The superiority of early or late sowing varies from year to year depending on how the season develops. Researchers argue that the best growers can do is to estimate the risks of what might happen for different scenarios given historical climate data.

The APSIM model provides the best technology for doing this, and the sorghum model has been updated to incorporate the latest scientific knowledge on the physiology of crop growth and development (Hammer *et al.* 2010). Researchers can now simulate risks associated with changes in genetics (G) and management (M) across environments (E)—the G × M × E landscape—with increased confidence by using the model with historical climate records (or with climate-change scenarios).

Researchers have looked at the effects of sowing date on yield chances and considered how this is affected by moisture conditions and occurrences of high temperature. Results are given for Goondiwindi, but could be reproduced for other sites (Figure 2). [6]

5 QDAF (2011) Sorghum—planting information. Department of Primary Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/planting-information

6 G Hammer *et al.* (2011) Sowing date effects on yield and high temperature risk in sorghum. GRDC Update Papers 6 September 2011

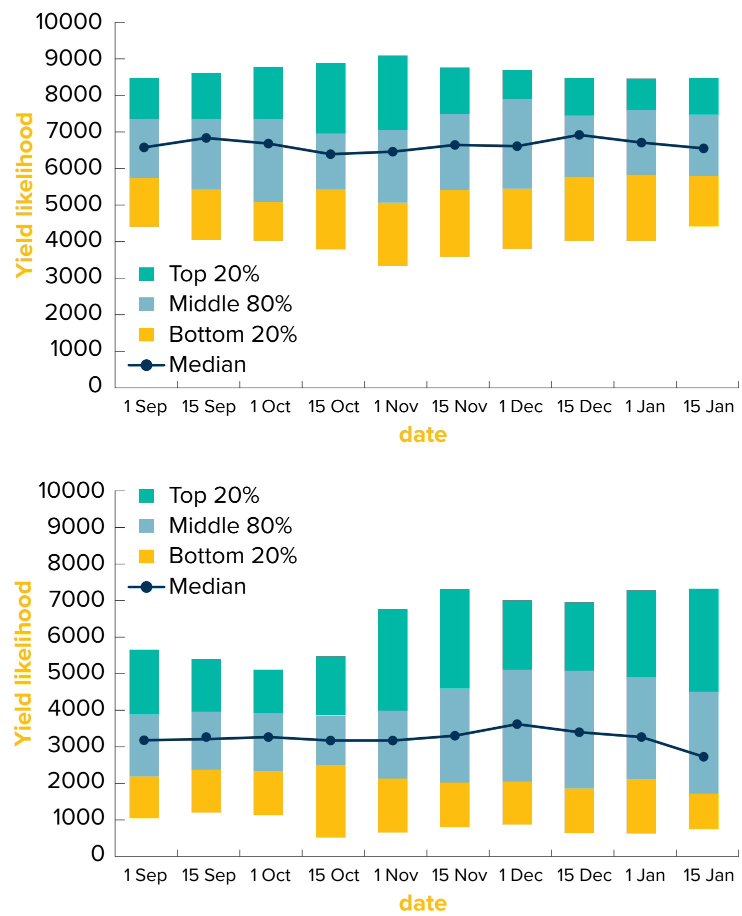

Figure 2: *Yield likelihood v. sowing date at Goondiwindi assuming either a full profile (top panel) or 100 mm available water at sowing (bottom panel). The blue line joins the median (50/50) yield and the bars indicate the range of yield in 80% of years. The best and worst 10% are not included. The 80% of years are broken into the best 20% (top, green), middle 40% (yellow), and worst 20% (bottom, red) of those years.*

3.2.2 Maximising yield potential

Early planting of sorghum can help to avoid hot weather. It also raises a compromise between soil temperatures for good sorghum emergence and trying to avoid heat and achieve better Water Use Efficiency (WUE).

Heat affects sorghum in several ways:

- It reduces the time from emergence to flowering.
- High night temperatures result in higher respiration levels and less efficient photosynthesis.
- Temporary wilting occurs during the heat of the day.
- Severe temperatures can affect head development.

The combination of these factors reduces WUE, resulting in the crop using more water in hot weather to grow the same yield.

The effect of heat has implications for planting time. The effect of delay in planting time for wheat is well documented, with a halving of WUE from ~12 kg/ha.mm at the

MORE INFORMATION

http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/managing-for-dry-times

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

http://www.grdc.com.au/uploads/documents/GRDC_Sorghum_HY.pdf

MORE INFORMATION

GRDC Update Paper: Better profits from good soil water decisions (Goondiwindi) optimum planting date in May, to 6 kg/ha.mm for wheat planted in late July (WUE calculated without subtracting evaporation).

Sorghum is not as greatly affected by heat as wheat, but there are similar effects. The estimated WUE of sorghum from an early planting at Dalby is 16 kg/ha.mm, which drops by 33% to 10.8 kg/ha.mm in December (Figure 3).

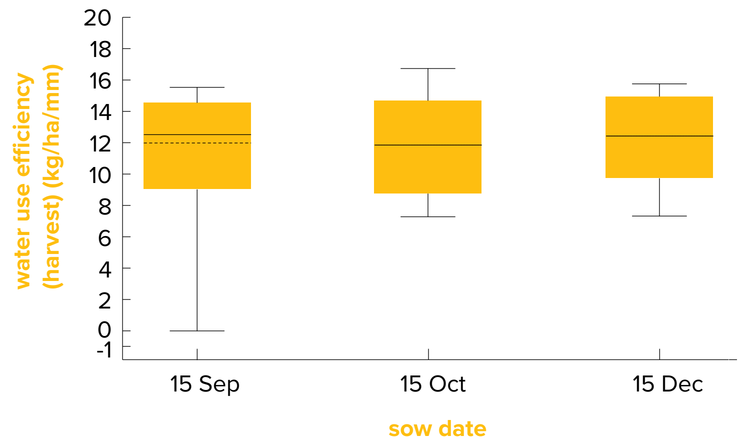

Figure 3: *Simulated Water Use Efficiency (WUE, kg/ha) for three planting dates at Dalby. Soil water 290 mm, medium-maturity planted at 6 plants/m. Note mean WUE slightly higher on the September plant but with more variability.*

Source: Whopper Cropper

By selecting cold-tolerant varieties and using good insecticide treatment and accurate shallow planting of seed with disc planters, sorghum can be established at much lower temperatures than the 17–18°C generally recommended. Sorghum will still emerge at much lower temperatures; it will just take longer and is more prone to disease and insect attack.

Another reason that soil temperatures may not be very useful guide is that they only reflect the weather over the past few days, whereas what is important is the temperature over the week or two after planting.

The alternative to using soil temperatures is to plant according to the expected end of the frost season in a particular locality and paddock on the farm. This means sorghum planting might start around the second week in September in western areas (e.g. Moree and Roma), allowing 10 days for emergence before the end of the frost period.

Around Dalby, the earliest start of a planting period with reasonable risk is around the third week in September, and at Warwick, a week or two later.

Attempting to plant as early as possible means replanting may be needed on occasions, but this will usually be when there is rain soon after planting under cold conditions. The benefit is likely to be better crops in 9 years out of 10.

Key points

- Optimum WUE for sorghum planted in September at Dalby is 16 kg/ha.mm. This is estimated to fall by 33%, to 10.8 kg/mm, for a mid-December planting.
- There is a conflict between ideal soil temperatures and getting the crop in early to avoid heat.
- Cold soil planting is less of a problem with modern planters and insecticides.

- Sorghum will establish at much lower temperatures than the 17–18°C that is generally recommended. [7]

3.2.3 Matching sorghum hybrids and management to site and seasonal conditions

Yield in sorghum is not just agronomy or hybrid choice, what really matters is to understand how to match hybrids and management to sites and expected seasonal conditions.

Substantial opportunities exist to increase productivity by providing growers access to hybrids with a wider range of trait characteristics. [8]

Queensland researchers conducted on farm trials at 19 locations across Queensland investigating the performance of twelve commercial and experimental hybrids representing the major types available, with variations in density and row spacing. More than 2000 plots were planted between 2014 and 2016. Hybrid types were defined by the maturity and tillering characteristics of the hybrids. Maturity in the hybrids varied from 55 to 62 days to flowering; and from 106 to 113 days to maturity. High and low tillering hybrids produced 3.5 and 2.5 tillers per plant (at flowering); though both types produced around 2.1 heads per plant at maturity. [9]

Results from the first season of agronomy trials showed almost a two-fold increase in yield that could be achieved by better matching agronomy to hybrid type across the tested sites. These findings question the idea that agronomy outweighs genetics in sorghum yield; and emphasises that what really matters is to understand how to match hybrids and management to sites and expected seasonal conditions.

- For the high yielding environments, the highest yields were obtained with higher tillering and later maturity hybrids planted in solid configurations at medium to high plant populations.
- In the medium yielding environments, highest yields were obtained with medium tillering and medium maturity hybrids planted in solid configurations at medium to high plant populations.
- In the low yielding environments, highest yields were obtained with low tillering and earlier maturity hybrids planted in solid configurations at low plant populations.

Download the GRDC Update paper from: https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/06/Optimising-sorghum-genetics-and-management-for-targeted-situations

3.3 Targeted plant population

3.3.1 Row spacing

Solid plant rows (75 or 100 cm) typically outyield skip-rows or wide rows under good growing conditions; therefore, solid planting is more appropriate with high-yielding, irrigated crops and/or high rainfall environments. Skip-row configurations are more advantageous in low-moisture, lower yielding dryland situations.

Advantages of solid rows decrease rapidly as soil moisture reserves decline, especially in more marginal areas. Table 2 is a useful guide to determine which row spacing is more appropriate for a particular target yield in a dryland situation.

MORE INFORMATION

Loretta Serafin NSW DPI discusses sorghum trials in northern NSW aimed at optimising profitability. GRDC Podcast: 094 Optimising sorghum production

S Simpfendorfer & L Serafin (eds) (2016) Northern grains research results 2016. Research & Development – Independent Research for Industry, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/679102/Northern-grains-research-results-2016.pdf

7 P Wylie (2008) Managing sorghum for high yields—a blueprint for doubling sorghum production. GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Sorghum_HY.pdf

8 D Jordan, D Rodriguez (2016) Optimising sorghum genetics and management for targeted situations GRDC Update Papers 21 June 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/06/Optimising-sorghum-genetics-and-management-for-targeted-situations

9 D Jordan, D Rodriguez (2016) Optimising sorghum genetics and management for targeted situations GRDC Update Papers 21 June 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/06/Optimising-sorghum-genetics-and-management-for-targeted-situations

Skip-rows are a useful method of conserving water during the vegetative stage of a crop for use at flowering and grainfill. This term 'skip-row' indicates that the row configuration is changed by 'skipping' or not planting rows. This management strategy has been used with peanuts, cotton and maize, as well as sorghum. When discussing row spacing for sorghum (and some other crops, such as cotton), it is useful to refer to Table 3.

Skip-row or wide-row configurations are most effective when starting soil water levels are good, with the wide areas between rows acting as a buffer for poor or variable in-crop rainfall. In more marginal, western dryland areas, growers could regard wide rows or skip-rows as mandatory and consider either single-skip or double-skip rows. These wider rows improve risk management by increasing yield stability and greatly reducing the risk of crop failure. However, in high-yielding environments or seasons, resulting in 1.0 m, solid-plant yields of ≥5 t/ha, yield loss of 10–40% (compared with solid plant) would be expected if wide-row or skip-row configurations are used. The optimum row spacing based on yield expectations is shown in Table 2.

Agronomic management is very important if sorghum is planted on wide or skip-row configurations. Plant population should be the same as solid planting on an area basis (same number of plants/ha).

Uniform (as opposed to patchy) plant establishment within rows will maximise the water use between the wide rows, and good stubble management (groundcover) is necessary to reduce water and soil loss in the skip areas. Effective weed control before and during the season is critical, otherwise the advantages of the wider rows will be lost. Wide rows (>150 cm) allow inter-row cultivation or shielded spraying for weed control.

The yields from skip-row spacing in wet seasons may be less than from solid planting; however, research indicates that in some instances where chickpeas are double-cropped following skip-row sorghum, the gross margin was higher than where the chickpeas were double-cropped out of solid-plant sorghum. These results will obviously depend on both summer and winter seasonal conditions and the relative crop commodity prices. [10]

MORE INFORMATION

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2003/09/Population-density-studies-in-sorghum-and-wheat

Table 2: *Match row spacing to expected yield.*

Expected yield	Optimum row spacing
>4 t/ha	≤0.75 m, solid plant
3–4 t/ha	≤1.0 m
<3 t/ha	≥1.0 m or skip-rows

Table 3: *Row configurations used to plant sorghum.*

Row configuration	Rows planted
0.75 or 1.0 m, solid plant	All rows planted on row spacing 0.75 or 1.0 m
1.5 m, solid plant	All rows planted on row spacing 1.5 m
Single skip	Two rows planted, one row unplanted (1.0 m)
Double skip	Two rows planted, two rows unplanted (1.0 m)

10 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

MORE INFORMATION

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/431279/Sorghum-yields-in-the-western-zone.pdf

VIDEOS

To view Paul Castor (MCA Goondiwindi Pty Ltd) highlighting the benefits and potential issues for growing summer crops on narrow rows for greater crop competition with weeds, visit: http://www.grdc.com.au/Media-Centre/GRDC-Gallery/Video/loACpykKja0.

3.3.2 Plant population

Even though target plant populations vary with conditions, the uniformity of the established plant population is always extremely important. The plant population targeted depends on the depth of soil moisture at planting and the likely growing conditions (Table 4). Under dryland situations, lower tillering hybrids should be planted at slightly higher populations.

Consider re-planting when populations are <12,000–15,000 plants/ha, especially with quick-maturity or low-tillering hybrids.

In skip-row situations, aim for plant populations similar to those for good dryland moisture conditions. [11]

Table 4: *Recommended sorghum plant populations.*

Growing conditions	Target population/m^2
Dryland	
Good conditions	4–6
Average conditions	3.5–5.5
Marginal conditions	3–4
Irrigation	
Supplementary	5–10
Full	10–15

Research conducted 2010–15 at sites west of the Newell Highway suggests plant populations should be targeted in the range of 30–50,000 plants/ha where the expected yield is 2.0 t/ha or greater. Where expected yields are less than 2.0 t/ha, plant populations as low as 15,000 plants/ha can provide slight improvements in yield compared to 30,000 and 50,000 plants/ha. [12]

3.3.3 Skip-row sorghum

In the drier sorghum-growing areas, skip-row planting configurations have been used to improve sorghum's reliability.

Outstanding results sometimes occur in dry seasons, where skip-row sorghum can produce a yield of ~2 t/ha while there has been no harvest of sorghum on 1-m rows.

Growing sorghum using skip-row configurations involves the suppression of early plant growth; this is likely to make more water available at flowering. Sorghum roots take time to extract moisture from the inter-row space of wide rows, which further delays the onset of moisture stress.

However, the reduction in plant biomass as a result of skip-row configurations will reduce grain yield as the potential yield increases to >2.5 t/ha.

Four trials conducted as part of the GRDC Western Farming Systems project present a typical range of outcomes. In two of the trials, at Billa Billa and Bungunya, there was no difference between 1-m row spacing of sorghum and single-skip and double-skip row spacings, where there is a gap of 2 m and 3 m, respectively, on each side of two sorghum rows. The mean yields of these two trials were 2.8 and 2.7 t/ha, respectively.

At Croppa Creek, with higher yields, the 1-m sorghum and single-skip sorghum yielded 5.5 t/ha, but the double skip yielded less, at 4.5 t/ha.

The fourth trial, harvested at Billa Billa in 2002, had the reverse trend, whereby double-skip sorghum showed a slightly better yield (of 2.8 t/ha) than sorghum in 1-m rows, which yielded 2.6 t/ha.

11 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

12 L Serafin, G McMullen (2015) Sorghum agronomy to manage risk and improve yield in the western zone, GRDC Update Papers 31 July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Sorghum-agronomy-to-manage-risk-and-improve-yield-in-the-western-zone

In central Queensland, 11 trials conducted between 2001 and 2004 showed yield benefits from wide rows when sorghum yields were <3 t/ha. Of 11 trials, five showed a gain, three trials showed a penalty from using wide rows and three trials showed no difference (Collins *et al.* 2006).

Long-term modelling for central Queensland showed that 1-m rows would produce greater yields in more years than wide rows (Collins *et al.* 2005). However, since 1990, when yield potential has been lower than the long-term average, this analysis showed a benefit in yield slightly in favour of wide rows.

Modelling of sorghum at Dulacca (Hammer 2001) suggested a lower yield threshold of 2 t/ha as a penalty for double-skip rows. In this analysis, the ratio of sorghum yield for double-skip rows to that of solid planting was 88% at 3 t/ha and 75% at 4 t/ha.

An important aspect of wide-row sorghum is that when planted closer together in the row, sorghum does not tiller as much and will produce less vegetative growth. This can be an advantage in dry years and help to ration the water. However, plant stand is often less in wide rows, and if it is too low, the yield penalty in better years can be considerably more than at higher population levels.

Several trials have demonstrated that the optimum plant population is higher in wide rows than narrow rows (Thomas *et al.* 1981). In a trial at Condamine, Bidstrup (2001) demonstrated a fall in yield potential as the plant population increased for 75-cm rows, whereas there was an increase in yield as plant population increased for 150-cm rows.

It is important to consider row spacing in conjunction with determining plant population.

Because farmers across most of the northern grainbelt are targeting average yields of >3 t/ha, they should generally use a row spacing of 1 m with a low plant population of 35,000–40,000 plants/ha in western areas, and increase plant populations with increasing yield potential.

When moisture reserves are low or yield potential is in doubt, wide-row sorghum may provide a more reliable outcome.

In higher yielding situations, row spacings >1 m with plant populations of 60,000–80,000 are a good compromise, although on the Liverpool Plains, 55,000 plants/ha is recommended for dryland production. This is to avoid yield loss in drier years. The effect of temperature on tillering drives target populations across the northern region; populations generally increase when moving north, because increasing temperatures lower tillering.

Although row spacings <1 m may improve yield in some situations, this is mostly due to increased tillering, which can be compensated for by higher population. However, moisture remains the limiting factor in most years, and too many plants or too many tillers (with narrow rows) can have negative effects in years that turn out to be below average. [13]

MORE INFORMATION

http://www.grdc.com.au/uploads/documents/NL40%20V3.pdf

http://www.regional.org.au/au/asa/2012/crop-production/8317_verrellag.htm

http://www.queenslandcountrylife.com.au/story/3608450/the-secrets-to-sorghum-success/

3.4 Calculating seed requirements

When calculating planting rates, allow for an extra 20–25% for establishment losses when planting into a very good seedbed on heavy black soil using press-wheels, and 40–50% when seedbed conditions are fair or when press-wheels are not used (Table 5). Obtain the number of seeds per kg and the germination percentage from the bag.

To determine the planting rate (kg seed/ha):

(Required number of plants/m^2 × 10,000) ÷ (seeds/kg × germination % × establishment %)

13 P Wylie (2008) Managing sorghum for high yields—a blueprint for doubling sorghum production. GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Sorghum_HY.pdf

Example calculation:

(40 (target plant population/m^2) × 10,000) ÷ (30,000 (seeds/kg) × 0.90 (germination %) × 0.75 (establishment %)) = 1.98 kg seed/ha [14]

Approximate number seeds/kg = 26,000–30,000 (refer to bag label for an exact count).

Germination percentage

Average germination is 90%. Minimum prescribed percentage is 80%. Refer to bag label for the exact figure.

Table 5: *A guide to field establishment percentage.*

Planter type	Establishment range
Precision planter	60–75%
Airseeder/combine with press wheels	50–60%
Airseeder/combine without press wheels	35–55%

3.5 Sowing depth

MORE INFORMATION

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

It is necessary to plant seed only deep enough to give it moisture to germinate and allow its roots to grow down through moist soil into subsoil moisture, ahead of the drying front. [15]

Correct seed placement is essential, however, to ensure that the seed is planted deep enough into moisture to germinate and allow its roots to grow down through moist soil into subsoil moisture. Research agronomists recommend planting depth is 50–75 mm into moisture. [16] However, in practice, some agronomists on the Liverpool Plains recommend no more than 30 mm planting depth where moisture has been identified, as deeper planting is only advantageous under high temperatures and drying conditions.

3.6 Sowing equipment

Establishment of grain sorghum has improved in recent years, with better planters and improved insecticide treatments that have residual effects on insects that eat the emerging seedling as well as the seed.

Conventional planters in combination with untreated seed in the past have typically resulted in only 40–50% of seeds becoming established as plants, but with the use of disc planters, press-wheels and modern insecticides, 70–80% establishment is commonly achieved.

Airseeders and a toolbar fitted with single-disc openers have provided an economical option and performed well in planting sorghum. Extra benefits of precision spacing may occur; these include higher yields, better evenness and improved competition with weeds. Sorghum's ability to tiller does allow it to compensate for variation in plant population and plant spacing. Although this ability is better than that of maize or sunflowers, uniform spacing should always remain the goal.

Under favorable conditions, seeding depths >7.5 cm reduce emergence; depths >10 cm may result in a complete failure.

Depth of sorghum planting should be varied in response to moisture and temperature. Planting should be as shallow as possible (~5 cm) under cool soil

14 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

15 QDAF (2011) Sorghum—planting information. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/planting-information

16 NSW DPI (2005) Grain sorghum. Agfact P3.3.5. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

temperatures, with depth increasing under hot, dry conditions. Sorghum has been observed to have better emergence at 8–10 cm depth under high temperatures, which rapidly dry out the soil surface.

In the 1980s, various treatments, including seed soaking and water injection, were trialled by farmers in attempts to improve sorghum establishment.

Radford and Nielsen (1985) trialled the effects of press-wheels, seed soaking and water injection at nine sites in southern and central Queensland. Although press-wheel compaction hastened and improved the emergence of sorghum in all situations, seed soaking and water injection had little effect on hastened emergence and no effect on the final emergence.

The authors concluded that press-wheel compaction at 4 Newtons per mm width of press-wheel is generally recommended for sorghum sowing. [17]

Sorghum is the most widely grown, no-tillage summer crop on the Liverpool Plains and on the floodplains near Dalby. It tolerates compacted subsoil and can stand high press-wheel pressure at planting. Good grass control in the crop is essential to achieve high yields, but this can be expensive with herbicides. Some farmers are now using shielded sprayers and knockdown herbicides prior to planting. The longer the paddock is under no-tillage, the easier it is to establish the following crops. [18]

3.6.1 Moisture-seeking planting

Sorghum has been successfully sown into deep soil moisture several weeks after rain, in early spring. There is a conflict between sowing shallow because temperatures are cold and having to dig deep to find moisture. There is also a problem in getting disc planters to plant deeply.

One way to assist disc planters to plant deeper for moisture seeking is to remove soil in front of the disc units, using a tine or trash-wippers. Often it will only need a small amount of dry soil to be removed to allow the disc opener to penetrate to moisture.

The disc opener generally does not need to plant as deeply as a tine because it does not mix wet and dry soil.

Leaving a significant trench over the seed can be a disadvantage if rain falls while the sorghum is emerging. It can be particularly significant if residual herbicides have been used at planting. The rain will concentrate the herbicide in the seed trench and may reduce the establishment of the sorghum under cool conditions.

Provided the seed is not too deep, raking a little loose soil over the seed trench can help reduce this problem. It can also help to stop the seed trench drying out and cracking when conditions are tough. Some farmers fit chains or mounted harrows behind the planter to bring some loose soil back over the row. [19]

3.6.2 Strip tillage

Strip tillage is a new technique being trialled that some agronomists believe should have merit in the following situations:

- on sodic soils where crop establishment is difficult
- where the stubble burden from the previous cereal crop is heavy, causing hair pinning and poor seed/soil contact

17 P Wylie (2008) Managing sorghum for high yields—a blueprint for doubling sorghum production. GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Sorghum_HY.pdf

18 QDAF (2011) Sorghum—planting information. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/planting-information

19 P Wylie (2008) Managing sorghum for high yields—a blueprint for doubling sorghum production. GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Sorghum_HY.pdf

Plant growth and physiology

4.1 The sorghum plant

The sorghum plant's botanical name is *Sorghum bicolor* (L.) Moench, and it is a member of the Poaceae family.

It is a perennial, tropical C4 grass capable of growing beyond physiological maturity of the grain. The hybrids available for grain production may be either determinate or indeterminate in setting the number of tillers for grain production. Although they can vary, most hybrids grow to ~1 m in height. A sorghum plant produces two ranks of single leaves in alternate positions on the stem. The leaves have overlapping sheaths, long, broad blades and, with the exception of the lowest leaf, pointed tips.

Sorghum usually has a dominant stem and, depending on the hybrid and the plant population, several tillers. A vigorous fibrous root system supports the plant and provides water and nutrients for shoot growth.

In the absence of subsoil constraints, sorghum roots can extract water to a depth of 1.8 m.

The sorghum head is a many-branched panicle, with small seeds ~4 mm in diameter. Current hybrids have either an open or a closed panicle, and the number of seeds per head varies. Seed weight typically ranges from 24,000 to 37,000 seeds/kg. Seed typically contains 7–12% protein. Although colour of the seed coat varies from white through to brown, red is the most commonly grown colour in Australia. [1]

4.2 Plant growth stages

Sorghum is a perennial tropical grass with a growing season of 115–140 days. The rate of growth depends upon temperature and moisture primarily, but it can also be influenced by soil fertility, insect and disease damage. [2] The optimum temperature range for growth is 12–34°C.

Growth rates are very sensitive to temperature and moisture, as well as soil fertility and insect and disease damage. The roots grow at ~2.5 cm/day.

Sorghum has 10 recognisable growth stages that can be used to plan irrigation, desiccation, insect scouting and insect control. Leaves are counted when the collar (where the leaf blade and leaf sheath attach) can be seen without cutting the plant apart. [3]

1 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

2 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

3 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre/summer-crops/sorghum/sorghum/grain-sorghum

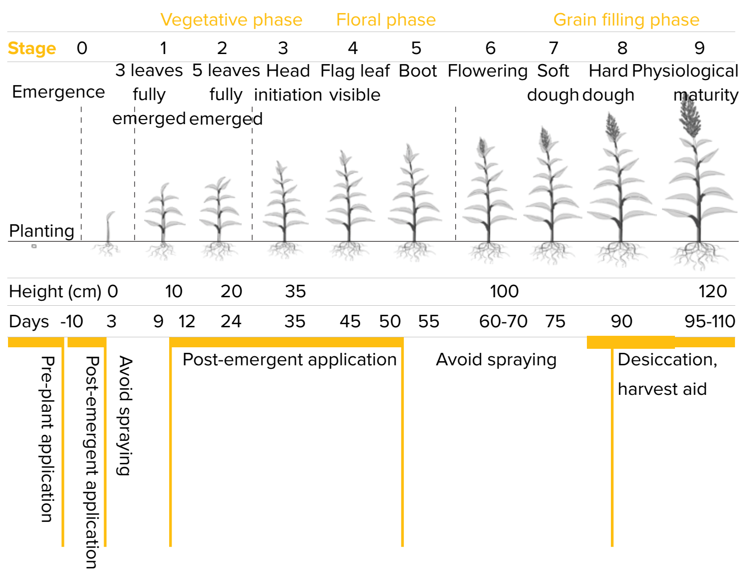

Figure 1: *Sorghum growth stages.*

1. Stage 0. Germination

Emergence usually occurs within 3–10 days of planting. Under warm temperatures, adequate soil moisture, good seed vigour and normal sowing depth, the time taken from planting to emergence is closer to 3 days. Sorghum has hypocotyl emergence, meaning a shoot emerges from the seed and pushes through the soil surface.

Under cold soil temperatures, it takes longer for the shoot to emerge and the risk of insect or disease attack is higher. [4]

Conditions for germination include a temperature range 16–18°C (and rising), soil moisture near field capacity, seed depth of ~5 cm and a seedling vigour percentage >90%.

The seed provides the seedling with nutrients and food reserves. The hypocotyl or young shoot extends from the seed, taking up water. At around day 5, a fibrous root system begins to form from the hypocotyl. During this period, the seed must be protected against soil insect attack. If conditions turn cool and wet, fungal diseases such as pythium may cause losses through seedling death. [5]

2. Stage 1. Three-leaf stage

The growing point is still below the soil surface. This stage will usually begin ~10 days after emergence. Following shoot emergence, leaves will progressively unfold. [6]

3. Stage 2. Five-leaf stage

This occurs ~21 days after emergence. The growing point is still below the soil surface. At the 5-leaf stage, the root system is rapidly expanding and roots produced at the lower nodes may push the lower leaf off the plant. The lowest (first) leaf always has a rounded tip, in contrast to the pointed tips of later leaves.

4 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

5 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

6 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

During this stage the yield potential is set. If water, sunlight or nutrients are limiting, yields can be restricted. Dry matter production occurs at nearly a constant rate between this stage and maturity. [7]

4. Stage 3. Growing point differentiation

The growing point changes from vegetative (leaf-producing) to reproductive (head-producing) ~30 days post-emergence.

At this stage the total number of leaves has been determined and the potential head size will soon be defined. Around 30% of the total leaf area will have developed, correlating to ~one-third of the time taken between planting and physiological maturity. This equates to 7–10 leaves, with the lower 1–3 leaves being possibly lost. Following growing-point differentiation, stalk or culm growth increases rapidly. Nutrient uptake is also rapid. This rapid growth allows sorghum plants to be very competitive against weeds for the rest of the season. [8]

5. Stage 5. Boot stage

Leaf area is now at a peak, providing maximum light interception. The head, still enclosed in the flag leaf sheath, is almost developed to full size. The peduncle has begun to elongate and will result in the head becoming visible from the flag leaf sheath. Potential head size is determined. Stressful conditions from lack of moisture or herbicide damage at this stage may stop the head completely growing from the flag sheath. Head death can occur earlier than booting under extreme moisture stress in combination with high temperatures. The sorghum plant will preferentially favor carrying through the primary tiller. Head death can occur earlier than booting under extreme moisture stress in combination with high temperatures. This failure will hinder complete pollination at flowering. [9]

6. Stage 6. Flowering

The peduncle rapidly elongates, pushing the head through the flag leaf sheath. Half-bloom is usually defined as the stage when 50% of the heads in the paddock are 50% flowered; however, it may also relate to an individual plant. The time required from planting to 50% flowered depends on the hybrid as well as the environment. Modern hybrids usually take 55–80 days, which represents 50–70% of the time between planting and physiological maturity.

Sorghum is primarily self-pollinated. Flowering begins at the top and proceeds downward requiring 4–5 days for the whole head to flower. The time a hybrid takes to start flowering depends largely on temperature. For example, a medium-maturity hybrid planted in the cooler, early October period at Moree flowers in ~80 days. However, if planted in the warmer mid-November period, it flowers in 60 days.

Severe moisture stress and/or very high temperatures during flowering can result in pollen-blasting and poor head-fill. Pollen-blast can be an issue at temperatures >36°C. Low night temperatures <13°C can reduce pollination in some hybrids.

Once pollination has occurred, seeds will begin to form, taking ~30 days to reach full development. Visually, the seeds become rounded, up to around 4 mm in size, and will then start to change colour. The final colour varies from white with hybrids such as Liberty White through to red or brown in most sorghum hybrids. [10]

7. Stage 7. Soft dough

Soft dough is the stage after approximately half the grain dry weight has accumulated. Following an increase in culm weight after flowering, the culm decreases in weight as the grain rapidly forms. This period includes the time the grain is of soft as well as medium dough consistency.

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7 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

8 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

9 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

10 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

As dry matter accumulation is similar across hybrids, the length of this period will strongly influence grain yield, with the longer maturing hybrids outyielding the quicker maturing lines. This holds as long as the plants are not subjected to moisture stress or frost during this period. [11]

8. Stage 8. Hard dough

Approximately 75% of the grain dry weight has accumulated by hard dough stage. Nutrient uptake is essentially complete. Some lower leaves may now have been lost. [12]

9. Stage 9. Physiological maturity

The grain is said to be physiologically mature when a black spot appears at the point where the seed attaches the plant. At this time, the seed is fully mature and will not gain any more nutrients or moisture from the plant (Figure 2). The moisture content is usually ~30% at this time.

If using desiccation, this is the optimum time to apply a registered herbicide to kill the plant, preventing additional moisture use. [13]

Figure 2: *Ripe sorghum grain.*

The length of time between physiological maturity and harvest depends on a number of factors including whether desiccation is used and environmental conditions such as temperature. [14]

The plant has reached maximum total dry weight and maximum grain weight. Physiological maturity can be determined by the formation of a dark spot on the grain on the opposite side from the embryo—otherwise known as black-layer formation. While the seeds develop, nutrients and moisture flow through a series of tubes from the parent to the seed.

Once the grain reaches its maximum size, these tubes become permanently blocked off. This is because the water in the seed during the soft and hard dough stages is displaced with starch, until water can no longer move in. The seed therefore dries out, typically from ~30% down to 10% or air-dry level. The black layer appears first in the seeds at the top of the head. [15]

MORE INFORMATION

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/summer-crops/sorghum/general/summer-crop-production-guide

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/431278/Sorghum-Spray-Out-Timing.pdfa

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11 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

12 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

13 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

14 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

15 NSW DPI (2005) Grain sorghum. Agfact P3.3.5, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/146355/grain-sorghum.pdf

Nutrition and fertiliser

A balance of soil nutrients is essential for profitable yields. Fertiliser is commonly needed to add the essential nutrients phosphorus (P), potassium (K), sulfur and zinc. Lack of other micronutrients may also limit production in some situations.

Knowing the nutrient demand of crops is essential in determining nutrient requirements. Soil testing and nutrient audits assist in matching nutrient supply to crop demand. [1]

MORE INFORMATION

RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 265–279.

5.1 Declining soil fertility

The natural fertility of cropped agricultural soils is declining over time, and so growers must continually review their management programs to ensure the long-term sustainability of high quality grain production. Paddock records, including yield and protein levels, fertiliser test strips, crop monitoring, and soil and plant tissue tests all assist in the formulation of an efficient nutrition program.

Pasture leys, legume rotations and fertilisers all play an important role in maintaining and improving the chemical, biological and physical fertility of soils, fertilisers remain the major source of nutrients to replace those removed by grain production. Fertiliser programs must supply a balance of the required nutrients in amounts needed to achieve a crop's yield potential. The higher yielding the crop, the greater the amount of nutrient removed. Increasing fertiliser costs means growers are increasing pulses within their crop rotation and even the use of ley pastures to complement their fertiliser programs and possibly boost soil organic matter.[2]

5.1.1 Soil organic matter

Soil organic matter (SOM) is a critical component of healthy soils and sustainable agricultural production. Growers understand that crops grown in healthy soils perform better and are easier to manage. Soil organic matter is '*all of the organic materials found in soils irrespective of its origin or state of decomposition*' [3] that is anything in or on the soil of biological origin, alive or dead. It is composed mainly of carbon (approximately 60%) as well as a variety of nutrients (including nitrogen, phosphorus and sulfur). It is difficult to actually measure the SOM content of soil directly so we measure the soil organic carbon (SOC) content and estimate SOM through a conversion factor:

Soil organic matter (%) = organic carbon (%) × 1.72

It is important to understand the role of plants in the SOM cycle. Photosynthesis is the process by which plants take in carbon dioxide (CO_2) from the atmosphere, combine with water taken up from the soil, and utilising the energy from the sun, form carbohydrate (organic matter) and release oxygen (O_2). This is the start of the SOM cycle. When the leaves and roots (carbohydrate) die they enter the soil and become SOM. These residues are decomposed by soil organisms which provides them with the energy to grow and reproduce. The SOM cycle is a continuum of different forms (or fractions) with different time frames under which decomposition takes place. Over time SOM moves through these fractions; particulate, humic and resistant fractions. As

1 P Matthews, D McCaffery, L Jenkins (2013) Winter Crop Variety Sowing Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/aboutus/news/all/2013/2013-wcvsg

2 QDAF (2010) Nutrition management. Overview. Department of Agriculture, Fisheries and Forestry Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/overview

3 JA Baldock, JO Skjemstad (1999) Soil organic carbon/Soil organic matter. In KI Peverill, LA Sparrow, DJ Reuter (eds). Soil analysis: An interpretation manual. CSIRO Publishing, Collingwood Australia.

SOM decomposes carbon is released from the system along with any nutrients that are not utilised by the microorganisms. These nutrients are then available for plants to utilise. Eventually a component of these residues will become resistant to further decomposition (resistant fraction Figure 1).

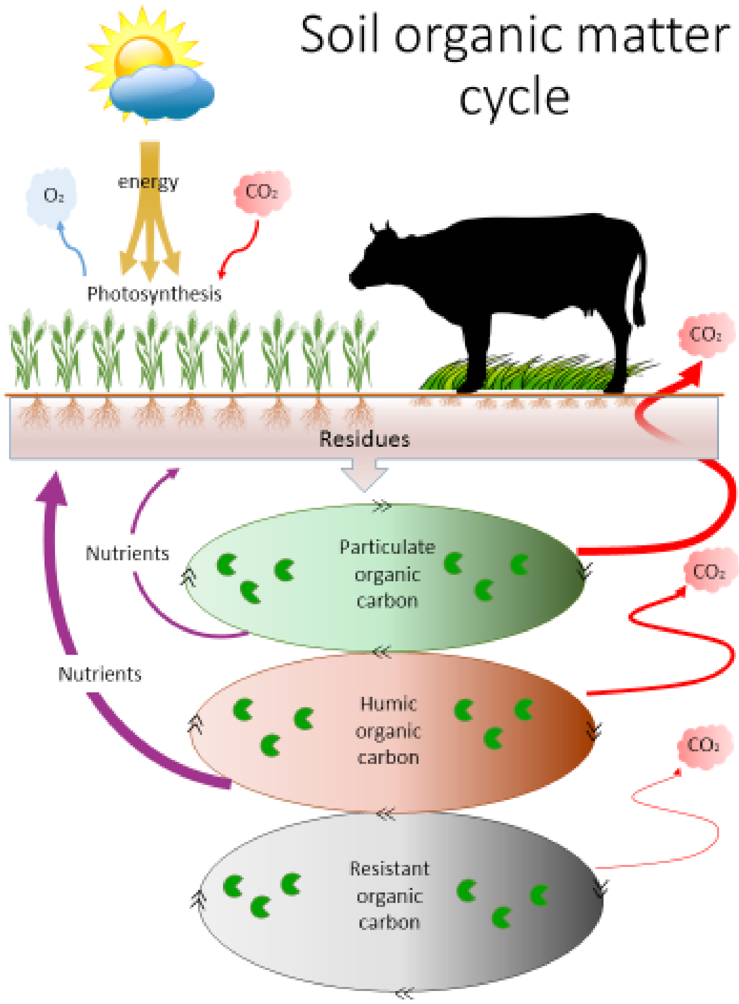

Figure 1: *Organic matter cycle.*

Source: J Gentry, QDAF

Organic matter is fundamental to several of the physical, chemical and biological functions of the soil. It helps to ameliorate or buffer the harmful effects of plant pathogens and chemical toxicities. It enhances surface and deeper soil structure, with positive effects on infiltration and exchange of water and gases, and for keeping the soil in place. It improves soil water-holding capacity and, through its high cation-exchange capacity, prevents the leaching of essential cations such as calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na). Most importantly, it is a major repository for the cycling of nitrogen and other nutrients and their delivery to crops and pastures.

Australian soils are generally low in SOM. Initial SOM levels are limited by dry matter production (and so climate) for each land type/location. SOM levels have declined under traditional cropping practices. On-farm measures (sampled 2012–15) from over 500 sites in Queensland and northern NSW confirm that soil organic matter, measured as soil organic carbon, declines dramatically when land is cleared and continuously cropped. This decline affects all soils and land types but is most dramatic for the brigalow–belah soils because their starting organic carbon levels are so high (Figure 2). [4]

4 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

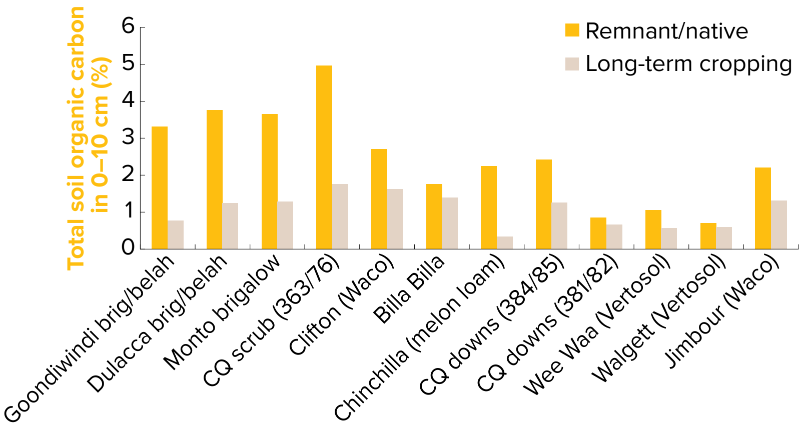

Figure 2: *The decline of soil organic carbon in long-term cropping systems.* [5]

Declining levels of SOM have implications for soil structure, soil moisture retention, nutrient delivery and microbial activity. However, probably the single most important effect is the decline in the soil's capacity to mineralise organic nitrogen (N) to plant-available N. Past research (1983) has shown that N mineralisation capacity was reduced by 39–57%, with an overall average decline of 52% (Figure 3). [6] This translated into reduced wheat yields when crops were grown without fertiliser N.

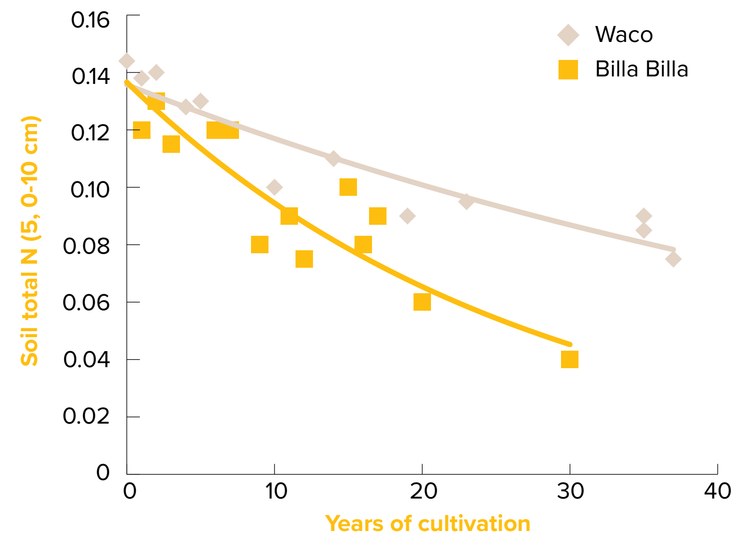

Figure 3: *Graph of decline in soil total N with years of cropping. The decline was greater for the Billa Billa soil (clay content 34%) than the Waco soil (clay content 74%).*

Source: based on Dalal & Mayer (1986a,b) [7]

5 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

6 RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 281–292.

7 RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 281–292.

5.1.2 Current situation

Soil organic carbon levels are simply a snapshot of the current balance between inputs (e.g. plant residues and other organic inputs) and losses (e.g. erosion, decomposition) constantly happening in each soil and farming system. The decline over time is overwhelmingly driven by the extent of fallowing in our farming systems. Most fallow rain in the northern region (as much as 75–80% in a summer fallow) is lost as runoff or evaporation. This wasted rain does not grow dry matter to replenish the organic matter reserves in the soil. However, increasing moisture in the fallowed soil continues to support microbial decomposition. This helps accumulate available nitrogen for the next crop, but reduces soil organic carbon. The soil organic matter and carbon levels will continue to decline until they reach a new lower level that the dry matter produced by the new farming system can sustain. Put simply,

'Crops may make more money than trees and pastures, but do not return as much dry matter to the soil.'

Total soil organic carbon levels vary within a paddock, from paddock to paddock and from region to region. Comprehensive sampling was under taken throughout the northern region, with over 900 sites sampled and analysed for total organic carbon at 0–10 cm depth. These results varied enormously across sites. The average was 1.46% however it varied from under 0.5% to over 5% (Figure 4). [8] A selection of these data from representative soil types throughout the northern grains region clearly indicates how soil carbon levels can be significantly different due to soil type (Figure 5). [9]

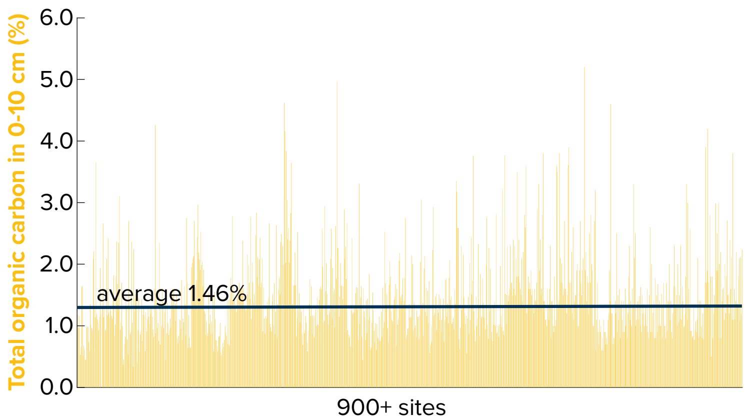

Figure 4: *Soil organic carbon levels on mixed farms within the GRDC Northern Region.* [10]

8 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

9 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

10 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112_117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

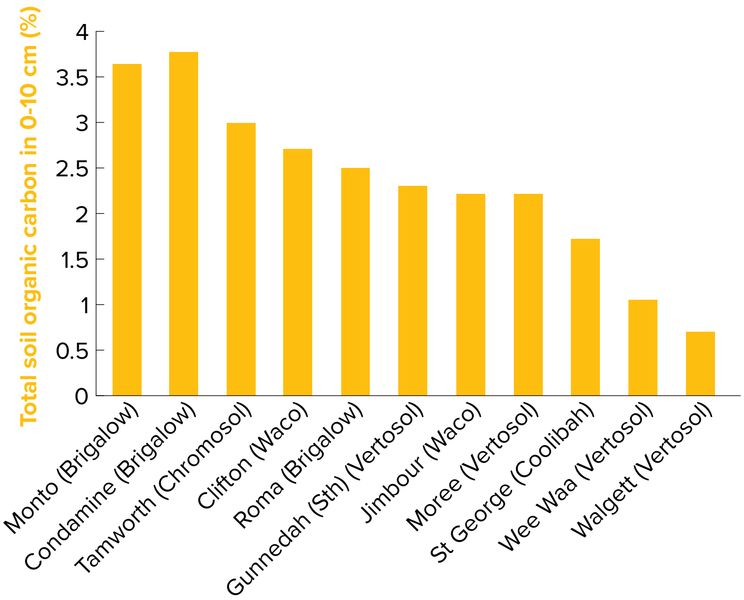

Figure 5: *Impact of land-type on total soil carbon levels (0–10 cm) across the northern region.* [11]

5.1.3 Options for reversing the decline in soil organic matter

Soil organic matter is an under-valued capital resource that needs informed management. Levels of SOC are the result of the balance between inputs (e.g. plant residues and other organic inputs) and losses (e.g. erosion, decomposition, harvested material) in each soil and farming. [12] So maximising total dry matter production will encourage higher SOC levels, and clearing native vegetation for grain cropping will typically reduce SOC and SOM levels. [13]

Modern farming practices that maximise Water Use Efficiency for extra dry matter production are integral in protecting SOM. Greater cropping frequency, crops with higher yields and associated higher stubble loads, pasture rotations and avoiding burning or baling will all help growers in the northern region to maintain SOM.

Research in the past has shown the most direct, effective means of increasing SOM levels is through the use of pastures, however these pasture have to be productive. A grass only pasture will run out of N especially in older paddocks, which is normally the reason why these paddocks are retired from cropping. As a result, a source of nitrogen is required to maximise dry matter production, this can be supplied via a legume or N fertiliser. The rotation experiments of I. Holford and colleagues at Tamworth, NSW and R. Dalal and colleagues in southeast Queensland provide good evidence of this (Table 1).

The greatest gains in soil carbon and nitrogen, relative to the wheat monoculture, were made in the 4-year grass–legume ley, with increases of 550 kg total N/ha and 4.2 t organic C/ha. The chickpea–wheat rotation fared no better than the continuous wheat system. The shorter (1–2-year) lucerne and annual medic leys resulted in marginal increases in soil organic C and N (Table 1).

MORE INFORMATION

SA Hossain, RC Dalal, SA Waring, WM Strong, EJ Weston (1996) Comparison of legume-based cropping systems at Warra, Queensland. 1. Soil nitrogen and organic carbon accretion and potentially mineralisable nitrogen. Australian Journal of Soil Research 34, 273–287.

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SA Hossain, WM Strong, SA Waring, RC Dalal, EJ Weston (1996) Comparison of legume-based cropping systems at Warra, Queensland. 2. Mineral nitrogen accumulation and availability to the subsequent wheat crop. Australian Journal of Soil Research 34, 289–297.

11 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

12 FC Hoyle, JA Baldock, DV Murphy (2011) Soil organic carbon: Role in rainfed farming systems. In PG Tow, I Cooper, I Partridge, C Birch (eds). Rainfed farming systems. Springer, pp. 339–361.

13 RC Dalal, RJ Mayer (1986) Long term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Australian Journal of Soil Research 24, 281–292.

Clearly, time and good sources of both carbon and nitrogen are required to build up SOM, which is exactly what the 4-year grass–legume ley provided. Nitrogen was supplied via N_2 fixation by the lucerne and annual medic in the pasture, with most of the carbon supplied by the grasses, purple pigeon grass and Rhodes grass. There were no inputs of fertiliser nitrogen in any of the treatments in Table 1. [14]

Table 1: *Effects of different rotations on soil total N and organic C (t/ha) to 30 cm and as gain relative to continuous wheat.*

Rotation	Wheat crops	Soil total N		Organic C	
		0–30 cm	Gain	0–30 cm	Gain
Grass/legume ley 4 years	0	2.91	0.55	26.5	4.2
Lucerne ley (1-2 years)	2-3	2.56	0.20	23.5	1.2
Annual medic ley (1-2 years)	2-3	2.49	0.13	23.1	0.8
Chickpeas (2 years)	2	2.35	0.00	22.0	0.0
Continuous wheat 4 years	4	2.36	-	22.3	-

Source: Hossain et al. 1996a

Further research was initiated in 2012 to identify cropping practices that have the potential to increase or maintain soil organic carbon and soil organic matter levels at the highest levels possible in a productive cropping system. Paired sampling has shown that returning cropping country to pasture will increase soil carbon levels (Figure 6). However, there were large variations in carbon level increases detected, indicating not all soil types or pastures preform the same. Soil type influences the speed by which carbon levels change, i.e. a sandy soil will lose and store carbon faster than a soil high in clay. As too does the quality and productivity of the pasture, maximising dry matter production by ensuring adequate nutrition (especially in terms of nitrogen and phosphorus) will maximise increases in soil carbon over time. Current research in Queensland being undertaken by the Department of Agriculture, Fisheries and Forestry (QDAF) is indicating that the most promising practice to date to rebuild soil carbon stocks, in the shortest time frame, is the establishment of a highly productive pasture rotation with annual applications of nitrogen fertiliser, however, adding an adapted legume is also effective. [15]

14 D Herridge (2011) Managing legume and fertiliser N for northern grains cropping. Revised 2013. GRDC, https://grdc.com.au/uploads/documents/Managing-N-for-Northern-Grains-Cropping.pdf

15 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

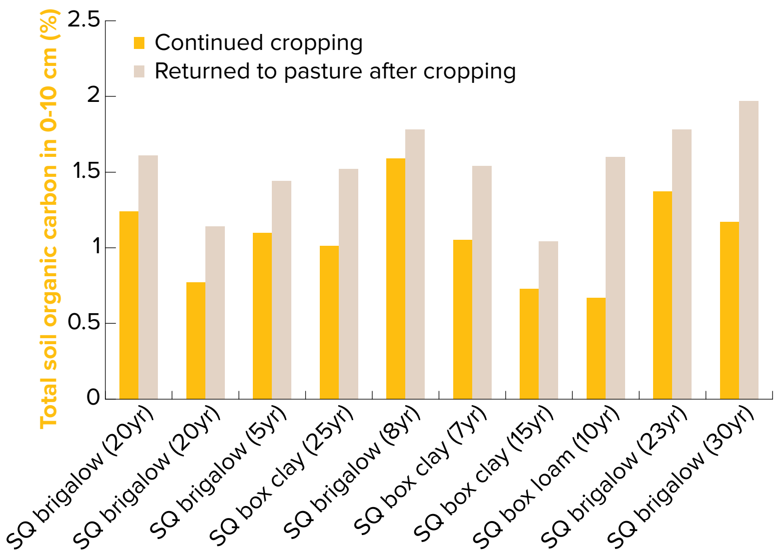

Figure 6: *Total organic carbon comparisons for croplands resown to pasture.* [16]

Impact of fertiliser N inputs on soil

If the rates of fertiliser N are sufficiently high, the effects can be positive. In the Warra experiments, both soil organic C and total N increased marginally (3–4%) over an 8-year period when no-till, continuous wheat, fertilised at a rate of 75 kg N/ha, was grown. This is in contrast with decreases of 10–12% in soil organic C and N in the non-fertilised, continuous wheat and chickpea–wheat plots. The result was much the same in NSW Department of Primary Industries experiments in northern NSW. At the Warialda site, for example, SOM increased during 5 years of cropping but only where fertiliser N had been applied to the cereals.

It is clear from the above examples that building SOM requires N. It works in two ways. First, the fertiliser or legume N produces higher crop/pasture yields and creates more residues that are returned to the soil. Then, these residues are decomposed by the soil microbes, with some eventually becoming stable organic matter or humus. The humus has a C/N ratio of about 10:1, i.e. 10 atoms of C to 1 atom of N. If there are good amounts of mineral N in the soil where the residues are decomposing, the C is efficiently locked into microbial biomass and then into humus.

If, on the other hand, the soil is deficient in mineral N, then more of the C is respired by the soil microbes and less is locked into the stable organic matter. [17]

5.2 Crop removal rates

Nitrogen (N) is the main nutrient required for good sorghum yields, with total requirements of 85 kg N for a yield of 3.5 t/ha, 130 kg N/ha for a yield of 5.2 t/ha, and 150 kg N/ha for a yield of 6 t/ha.

Phosphorus removed in grain for a 5.2 t/ha crop is in the vicinity of 12 kg of P, which equates to 60 kg of mono-ammonium phosphate (MAP). In practice, such a high rate may not be needed. The recommended rate will depend upon the soil test level and the recent history of P application.

16 QDAF (2016) Queensland Grains Research – 2015. Regional Research Agronomy Network. Department of Agriculture, Fisheries and Forestry Queensland, pp. 112–117, http://www.moreprofitperdrop.com.au/wp-content/uploads/2016/08/RANsTrials2015-screen.pdf

17 D Herridge (2011) Managing legume and fertiliser N for northern grains cropping. Revised 2013. GRDC, https://grdc.com.au/uploads/documents/Managing-N-for-Northern-Grains-Cropping.pdf

MORE INFORMATION

S Simpfendorfer & L Serafin (eds) (2016) Northern grains research results 2016. Research & Development – Independent Research for Industry, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/679102/Northern-grains-research-results-2016.pdf

If the soil test (bicarbonate-extractable or Colwell P) is >15, then there is a low probability of sorghum responding to P fertiliser. This critical value is half that of wheat, reflecting the efficiency with which sorghum is able to extract P from the soil. Sometimes there is an early response to P, but as the root system and arbuscular mycorrhizae (AM) develop, this can disappear.

In a mixed sorghum and wheat cropping system, it may be worthwhile fertilising the wheat crop and not the sorghum, depending on the nutrient status and removal.

The use of P fertiliser is also recommended under cold-start conditions if soil phosphate levels are marginal.

Phosphorus fertiliser is usually applied with the seed, but the suggested maximum rate of MAP on sorghum planted on clay soils in 1-m rows is 35–40 kg/ha. This 'safe' rate should be reduced on loamy soils. If more P needs to be applied than this, it should be put on away from the seed, either in a separate mix with the N fertiliser or in a separate band.

One of the most economical and effective ways to supply P to sorghum crops is to use feedlot manure (Figure 7). One tonne of aged manure contains about 7 kg of P, which means that an application of 8 t/ha will supply 56 kg P/ha, enough for four or five crops of sorghum, and more if the soil P levels are reasonably high and the strategy is to apply about 7–10 kg P/ha.year.

Feedlot manure also applies large quantities of potassium (K) and sulfur (S), which will ensure that there are no deficiencies relating to these nutrients. The N component of the feedlot manure adds to the value. In a good summer season, about half of the total N should be released during the first crop. If 8 t/ha of manure is applied, this means that, of the 128 kg of N in this manure, about 64 kg should be available to the sorghum crop and could be deducted from the fertiliser requirement.

Figure 7: *Feedlot manure supplies large quantities of potassium and sulfur.*

MORE INFORMATION

http://www.grdc.com.au/uploads/documents/GRDC_Sorghum_HY.pdf

http://aciar.gov.au/files/node/320/mn2_pdf_78177.pdf

https://www.pioneer.com/home/site/ca/template.CONTENT/products/sorghum/production-manual/guid.AE3799A5-A380-492A-B5DF-1D49E8B1735B

In subsequent years, the extra N release should be considered a bonus, which may boost yields in a good year. In this way, manure applications can provide a little extra reserve of N in an organic form, which can help boost yields in a wet summer. Nitrogen removal at given target yields in northern grains districts is shown in Table 2.

For farms within 60 km of a feedlot, the cost of manure is typically about $22–25/t spread on the paddock, which makes manure good value compared with the equivalent cost of N and P (total $43). If K is of use, the value of nutrients in manure is >$50/t. [18]

18 P Wylie (2008) Managing sorghum for high yields—a blueprint for doubling sorghum yields. GRDC, http://www.grdc.com.au/uploads/documents/GRDC_Sorghum_HY.pdf

MORE INFORMATION

GRDC Update Paper: The what where and why of soil testing in the northern region

MORE INFORMATION

http://www.grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2014/01/024

MORE INFORMATION

https://grdc.com.au/Media-Centre/Media-News/North/2013/11/In-crop-nitrogen-key-to-summer-sorghum-yields

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Agronomic-and-economic-responses-of-sorghum-to-nitrogen-nutrition

Table 2: *Yield targets and nitrogen removal for grain sorghum*

	Soil moisture (mm)	In-crop rainfall (mm)	Water Use Efficiency	Target yield (t/ha)	kg N/ha removed
Cool areas, better soils (Darling Downs–Liverpool Plains)	160	250	15	6.15	102
In-between areas with brigalow and box soils	150	250	13	5.20	87
Hotter areas, Moree, Condamine, Roma	130	205	10	3.35	61

5.3 Soil testing

Soils should be tested every 3–5 years as part of a nutrient-monitoring program. Actual fertiliser usage should be determined using soil testing, in conjunction records of grain production and grain quality for individual paddocks. Soil test results should be interpreted by experienced, accredited specialists. [19]

Always carry out N tests to the estimated rooting depth of the crop in question. [20]

5.4 Nitrogen

Sorghum responds to the application of N fertilisers. Numerous trials across northern NSW have demonstrated the likely yield benefits, on average 1.8 t/ha, from the application of 80 kg N/ha at or prior to sowing and in short fallow situations; in sorghum following sorghum this was up to 2.9 t/ha.

Research by NSW DPI and the Northern Grower Alliance (NGA) has evaluated the effect of applying N in crop. Results from the 2007–08 season showed that crop yield could be maintained if N is applied post emergence up to the 7-leaf stage.

The contribution of a pulse crop or pasture to soil N largely depends on the quantity of dry matter produced and levels of nodulation. However, as a guide, compared with a previous sorghum crop, cowpea and mungbean crops may leave up to an additional 40 kg/ha of soil N, whereas soybeans and pigeon peas may leave 25–50 kg N/ha.

Nitrogen budgeting can also be used to determine the N requirements of a crop and can be calculated as described below (see section 5.4.3 'Crop nitrogen requirements'). The quantity of N required to grow the crop is about twice the quantity removed in the grain. [21]

5.4.1 Nitrogen supply

The crop N requirement can be supplied from the following sources:

- N in the soil as nitrate
- N mineralised through the growing season
- N applied as fertiliser

Mineralisation rates will depend on age of cultivation, soil organic matter status (see section 5.1.1) and seasonal conditions. Consult your advisor to gain a mineralisation estimate.

The crop N requirement not supplied by the soil from either soil nitrate reserves or mineralisation should be applied as fertiliser (Table 3).

19 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

20 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

21 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

Where a grain legume was the previous summer crop

The contribution of previous summer grain legumes to soil N levels is very erratic, ranging from actual depletion to an increase of up to 40 kg N/ha. Growers are advised to adopt a conservative approach and treat as for other summer crops unless previous experience shows otherwise. With good plant growth but little removal of N in grain (i.e. with low yield), the loss of soil N under cropping will be less with a grain legume than with other crops. [22]

Soil nitrate-N is estimated by soil testing to 100 cm depth and from the cropping history, especially the grain yield and protein content of the previous crop. Using the above example, if only 80 kg/ha of nitrate-N was available in the soil, then a further 80 kg N/ha would be needed. The protein content of grain is a good indicator of the adequacy of N supply to a crop, as shown in Table 4. [23]

Table 3: *Nitrogen rates (kg N/ha) for sorghum, as influenced by crop rotation, on the Liverpool Plains.*

	Dryland sorghum target yield		
Previous crop	**4 t/ha**	**6 t/ha**	**Irrigated sorghum**
Sorghum, sunflower, cotton	100	140	180
Cowpea, mungbean	60	120	–
Soybean	–	–	100
Long fallow, winter cereal	80	120	150
Long fallow, faba beans	30	90	120
Long fallow, chickpeas	45	100	–
Lucerne (good stand)	0	0	–

Nitrogen-fertiliser application rates should be based on your target yield, seasonal expectations and previous paddock history. Application rates will vary considerably from area to area. On the Darling Downs, higher rates are generally used than on the Western Downs or in central Queensland, because the country has been farmed considerably longer, the soils are capable of storing more plant-available moisture, and yield expectations are generally higher. However, the same principles apply in all areas—if the available N is low at planting then adequate N fertiliser must be applied to achieve your yield goal. [24]

5.4.2 Low grain protein, the signal of nitrogen deficiency

The grain protein content of sorghum can be used as a reliable indicator of the N supply available for that particular sorghum crop. Table 4 summarises the relationship between grain protein and N supply. [25]

22 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

23 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

24 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

25 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

Table 4: *Using sorghum grain protein as an indicator of season nitrogen (N) supply.*

Sorghum grain protein (@13.5% moisture)	Indicated N supply
<9.0%	Acute N deficiency. Grain yield would almost certainly increase with increased N supply (e.g. N fertiliser). Protein percentage will also increase if N supply is adequate for optimum season yield.
9.0–10.0%	Marginal N deficiency. Grain yield may increase and protein will increase with increasing N supply.
>10.0%	Nitrogen not limiting yield this season. Higher N supply may increase grain protein. Producing higher protein percentage by adding extra N is only economical if high protein premiums exist.

5.4.3 Crop nitrogen requirements

The amount of N removed from the paddock in harvested grain can be calculated as:

N removed (kg N/ha) = yield (t/ha) × protein (%) × 1.6

As a rule, twice this amount of N is required to grow the crop. The following formula that can be used to estimate the N requirement of a sorghum crop:

N required (kg N/ha) = yield goal (t/ha) × protein (%) × 3.2

The N supply required to produce a range of yield and protein levels is given in Table 5.

Table 5: *Available soil nitrogen (N) needed for expected yield and grain protein levels.*

Yield (t/ha)	Grain protein				
	8%	9%	10%	11%	12%
2.0	51	58	64	70	77
2.5	64	72	80	88	96
3.0	77	86	96	106	115
3.5	90	101	112	123	134
4.0	102	115	128	141	154
4.5	115	130	144	158	173
5.0	128	144	160	176	192
6.0	154	172	192	212	230
7.0	180	202	224	246	268
8.0	204	230	256	282	308

Available soil N = current soil N (soil test) + estimated mineralisation between the time of testing and harvest

5.4.4 Nitrogen fertiliser application

Nitrogen fertiliser can be applied in a number of forms, the most common being anhydrous ammonia (82% N) and urea (46% N). The choice usually depends on price, availability, and ease and convenience of use.

Care must be taken when applying nitrogenous fertilisers at planting. Release of ammonia from the fertiliser can damage the germinating seedling if applied with the seed at planting. Table 6 details the safe rates for application with the sorghum seed at planting.

MORE INFORMATION

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Agronomic-and-economic-responses-of-sorghum-to-nitrogen-nutrition

https://grdc.com.au/Media-Centre/Media-News/North/2013/11/In-crop-nitrogen-key-to-summer-sorghum-yields

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/Nutritional-interactions-of-N-P-K-and-S-on-the-Darling-Downs

Table 6: *Safe rates (kg/ha) of some nitrogen (N) fertiliser products sown with sorghum seed at planting.*

Row spacing (cm)	N applied	Urea	DAP	MAP Starterfos
18	25	54	130	200
25	18	39	90	138
50	9	20	45	69
75	6	13	30	46
100	4.5	10	23	35

Rates should be reduced by 50% for very sandy soil and may be increased by 30% for heavy-textured soils or where soil moisture conditions at planting are excellent.

Rates should be reduced by 50% when planting equipment with narrow slit openers is used (the fertiliser concentration is increased around the seed).

Rates may be increased by 50% when airseeders are used and operating at high pressures with wide openers. Airseeders spread the fertiliser bands when operating at high pressures, reducing the fertiliser concentration around the seed. [26]

MORE INFORMATION

GRDC Update Paper: Phosphorus and potassium nutrition

5.5 Phosphorus

Sorghum is much more tolerant of low soil P levels than is wheat or barley. Soils with <10 µg/g (ppm) of bicarbonate-extractable P are likely to respond to P. Responses to starter fertilisers are likely in Moree, Tamworth and parts of the Liverpool Plains. [27]

Summer cereal crops generally are not as responsive to P as are wheat and barley. Soil P levels need to be quite low (<15 mg/kg of bicarbonate-extractable P on the Darling Downs, <10 mg/kg on the Western Downs and central Queensland) before consistent responses to P fertiliser occur. Deficiency symptoms include stunted plants and reddening of lower stems. Using a BSES-P test in addition to the traditional bicarbonate-extractable P test will improve the accuracy of identifying P responsive sites.

Fertiliser placement in a band with the seed is important because P movement in the soil is very limited. Application rates vary from 5 to 10 kg P/ha depending on soil type and district.

MORE INFORMATION

GRDC Update Paper: A calculator to assess the economics of deep placement P over time

Research on the Western Downs suggests the strongest responses to deep P in grains (wheat and sorghum) occurred when post-planting rainfall allowed the establishment of secondary roots and tillers, which are the main pathways to plant P uptake and increased yields. In wet years when the topsoil was readily accessible, or in extremely dry years, responses were more limited. [28]

MORE INFORMATION

http://www.grdc.com.au/GRDC-FS-PhosphorusManagement

Applying phosphate fertiliser can induce zinc (Zn) deficiency, either by interference with Zn uptake or by relative dilution of Zn concentration in the plant by the large increase in production caused by phosphate application. A small amount of Zn applied with the phosphate overcomes the problem.

Phosphorus deficiency is more likely to occur after a long fallow due to low numbers of AM fungi in the soil. AM fungi are the beneficial soil fungi that help plant roots to take up both P and Zn. [29]

MORE INFORMATION

GRDC Update Paper: Changing nutrient management strategies in response to declining background fertility

26 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

27 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

28 M Bell, D Lester (2015) Improving fertiliser decisions for P on the Western Downs, GRDC Update Papers 31 July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Improving-fertiliser-decisions-for-P-on-the-Western-Downs

29 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

5.6 Zinc

Sorghum frequently responds to Zn on the heavy alkaline clay soils. Good yield responses have been obtained in northern NSW from starter fertilisers containing 2.5% Zn applied at 40–100 kg/ha. For longer term responses lasting 5–6 years, Zn oxide should be applied at ~15 kg/ha and incorporated into the seedbed well before sowing. Foliar sprays have also become a popular option for applying Zn. [30]

Yield responses to Zn from trial work and grower experience are common in many areas (i.e. the Darling Downs and Liverpool Plains). Zinc plays a vital role in a plant's ability to use N and transform it into yield and protein. Zinc is, therefore, a vital element to the plant and it should not be overlooked in a balanced crop-nutrition program.

Zinc deficiency is not easy to detect, but response to Zn fertiliser occurs frequently on old cultivation on heavy clay soils with high soil pH and/or high P levels. Soil erosion, soil structural problems (e.g. hardpans) and root diseases can all increase the likelihood of Zn deficiency. The availability of Zn to many crops is increased by the presence of AM in the soil. Crops grown after long fallows or other events that deplete soil AM population will be most at risk of suffering Zn deficiency. [31]

5.6.1 Critical levels for zinc

Soil pH <7.0: 0.4 mg/kg (DTPA-extractable Zn)
Soil pH >7.0: 0.8 mg/kg (DTPA-extractable Zn)

On the Western Downs, the deficiency is usually associated with low soil Zn test (<0.4 mg/kg), high soil pH (>8) and low organic carbon (<0.7%).

Zinc can be applied directly to the soil (Zn sulfate monohydrate), as a component of a starter fertiliser, as a foliar spray (Zn sulfate heptahydrate) or as a seed dressing. Zinc sulfate monohydrate should be applied at least 4 months before planting at 10–20 kg/ha, which will provide enough Zn for 5–8 years. [32]

5.6.2 Sulfur

Sulfur responses are widespread on the eastern and southern Darling Downs. Deficiencies have also occurred on the Anchorfield and Haselmere soil types of the central Darling Downs and in areas of the Jimbour plain. It is prevalent on basaltic black earth soils that have been intensively farmed for ≥20 years, particularly if they have been eroded, waterlogged or irrigated, and especially where double-cropping is practiced. Soil S levels in the intensively farmed districts east of the range tend to be low, especially where gypsum and/or S-containing fertilisers have not been used regularly.

Soil test levels <4 mg S/kg (0–10 cm) are indicative of likely S response. A rate of 8–10 kg S/ha is normally adequate. A deep soil test to 120 cm may give a better indication of profile S supply.

Gypsum at the rate of 200–400 kg/ha every 3 years is the cheapest source of S. [33]

5.7 Potassium

Potassium deficiency rarely occurs in the sorghum-growing areas of Queensland except in the South Burnett. However, there is the potential for the deficiency to occur on some of the older farming soils, particularly on the Darling Downs.

30 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

31 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

32 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

33 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

Because of the gradual decline in soil K levels with crop removal and historically low fertiliser application rates, some situations (particularly red soils) require K fertiliser applications. However, crops also vary in their response to improved soil K levels. Generally, winter cereal responses have been low to moderate unless gross deficiencies occur. Yields of rain-grown cereals such as maize and sorghum are less likely to respond to K applications than yields of grain legumes (soybeans and navy beans) and peanuts under conditions of marginal soil K status.

Potassium fertilisers cannot be placed in direct contact with seed at rates required. Fertilisers should be applied by side-banding at planting, combine-drill pre-plant in fallow, or broadcast and cultivated in fallow or prior to preceding crop. [34]

5.8 Subsoil constraints

Subsoil salinity is quite common in the brown, grey and black clay soils in northern NSW. Salinity is the salt concentration in the soil solution. Whereas previous research from experimentally imposed salt levels had indicated that grain sorghum is tolerant of salinity, more recent research in northern NSW indicates that grain sorghum is much more sensitive to salinity.

The recent research showed a rapid decline in plant growth and yield as soil salinity increased, i.e. when electrical conductivity (EC, saturated extract) increased from 2 to 5 dS/m. Anecdotal reports from growers and agronomists agree with these experimental results that where there is subsoil salinity, root exploration by grain sorghum into these saline layers is greatly reduced.

In addition to subsoil salinity, subsoil sodicity is reasonably common in northern NSW. A sodic soil has an excess of exchangeable sodium ions attached to clay particles. This excess of ions affects the physical characteristics of a soil by causing dispersion. When a clay soil disperses with water, the clay particles swell, as they are no longer bound together, and this minimises drainage through the soil pores (spaces). A dispersive soil sets hard when dry.

Subsoil sodicity restricts rooting depth. It therefore restricts crop access to water and nutrients. Surface sodicity results in surface sealing and reductions in water infiltration and may cause waterlogging on the surface or inhibit emergence. [35]

34 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

35 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

Weed control

Weeds are estimated to cost Australian agriculture A$2.5–4.5 billion per annum. Consequently, any practice that can reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry. See more at www.grdc.com.au/weedlinks. [1]

Weed control is essential if growing the crop on summer rainfall, and to prevent weed seeds from contaminating the grain sample at harvest. Weed management should be planned well before planting and options considered such as chemical and non-chemical control. [2]

The Grains Research and Development Corporation (GRDC) supports integrated weed management. Download the Integrated Weed Manual.

Weed control is important, because weeds can:

- rob the soil of valuable stored moisture
- rob the soil of nutrients
- cause issues at sowing time, restricting access for planting rigs (especially vine-type weeds such as melons, tarvine or bindweed, which wrap around tines)
- cause problems at harvest
- increase moisture levels of the grain sample (green weeds)
- contaminate the sample
- prevent some crops being grown where in-crop herbicide options are limited, i.e. broadleaf crops
- be toxic to stock
- carry disease
- host insects

MORE INFORMATION

https://grdc.com.au/Resources/IWMhub/Section-2-Agronomy-to-enhance-weed-management

6.1 Planning your weed control strategy

1. Know your weed species. Ask your local adviser or service provider or use the Sydney Botanic Gardens plant identification service, which is free in most cases (see link).
2. Conduct in-crop weed audits prior to harvest to know which weeds will be problematic the following year.
3. Ensure wheat seed is kept from a clean paddock.
4. Have a crop-rotation plan that considers not just crop type being grown but also what weed control options this crop system may offer, e.g. grass control with triazine-tolerant (TT) canola.

MORE INFORMATION

The Royal Botanic Gardens Plant Identification & Botanical Information Service: https://www.rbgsyd.nsw.gov.au/science-conservation/plant-id-disease-diagnostic-services

6.2 Herbicide resistance

Herbicide resistance is an increasing threat across Australia's northern grain region for both growers and agronomists. Already 14 weeds have been confirmed as herbicide-resistant in various parts of this region, and more have been identified at risk of developing resistance, particularly to glyphosate.

MORE INFORMATION

GRDC Fact Sheet: Group A Herbicides in Fallow

1 GRDC (2005) Weed Links, Integrated weed management. GRDC, www.grdc.com.au/weedlinks

2 QDAF (2012) Wheat—planting information. Department of Agriculture, Fisheries and Forestry, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/planting-information

In northern NSW, 14 weeds are confirmed resistant to herbicides of Group A, B, C, I, M or Z (see Table 1). As well, barnyard grass, liverseed grass, common sowthistle and wild oat are at risk of developing resistance to Group M (glyphosate) herbicides (see Table 2). Glyphosate-resistant annual ryegrass has been identified within ~80 farms in the Liverpool Plains area of northern NSW. [3]

Table 1: *List of confirmed resistant weeds in northern NSW (current at November 2016).*

Weed	Herbicide group and product/chemical (examples only)	Areas with resistance in NSW	Future risk	Detrimental impact
Wild oats	A. Topik® and Wildcat® B. Atlantis® Z. Mataven®	Spread across the main wheat-growing areas. More common in western cropping areas	Areas growing predominantly winter crops	High
Paradoxa grass	A. Wildcat®	North and west of Moree	Areas growing predominantly winter crops	High
Awnless barnyard grass	C. Triazines M. Glyphosate	Mainly between Goondiwindi and Narrabri	No-till or minimum tilled farms with summer fallows	High Very high
Charlock, black bindweed, common sowthistle, Indian hedge mustard, turnip weed	B. Glean®, Ally®	Spread across the main wheat growing areas	Areas growing predominantly winter crops	Moderate
Annual ryegrass	M. Glyphosate B. Glean® A. Verdict®	Group M widespread in Liverpool Plains. Group A and B resistance in central west NSW	Areas with predominantly summer fallows. Winter cropping areas	High High
Fleabane	M. Glyphosate	Spread uniformly across the region	Cotton crops and no-till or minimum tilled systems	Moderate
Wild radish	I. 2,4-D amine	Central west NSW	Continuous winter cereal cropping	High
Windmill grass	M. Glyphosate	Central west NSW	Continuous winter cropping and summer fallows	High
Liverseed grass	M. Glyphosate	A few isolated cases	No-till or minimum tilled systems	Moderate
Sowthistle	M. Glyphosate	Liverpool Plains	Winter cereal dominated areas with minimum tillage	High
Feather-top Rhodes grass	M. Glyphosate	Widespread, more common in the north	No-till or minimum tilled systems, sorghum and cotton crops	High

Table 2: *List of potential new resistant weeds in northern NSW (as at November 2016).*

Weed	Herbicide group and product/chemical (examples only)	Future risk	Detrimental impact
Barnyard, liverseed and windmill grasses	A. Verdict® L. Paraquat	No-till and minimum tilled systems	Very high Very high
Common sowthistle	I. 2,4-D amine	Winter cereals	High
Paradoxa grass	B. Glean®, Atlantis®	Western wheat growing areas	High
Other brassica weeds including wild radish	B. Glean®,, Ally®	Areas growing predominantly winter crops	Moderate
Annual ryegrass	L. Paraquat	Areas with predominantly summer fallows	Very high
Wireweed, black bindweed, melons and cape weed	I. 2,4-D amine, Lontrel®, Starane®	Areas growing predominantly winter crops	High
Fleabane	I. 2,4-D amine	Cotton crops and no-till or minimum tilled systems	Very high
Other fallow grass weeds	M. Glyphosate	No-till or minimum tilled systems	High

3 A Storrie *et al.* Managing herbicide resistance in northern NSW, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/155148/herbicide-resistance-brochure.pdf

Testing services

For testing of suspected resistant samples, contact:

Charles Sturt University Herbicide Resistance Testing
School of Agricultural and Wine Sciences
Charles Sturt University
Locked Bag 588
Wagga Wagga, NSW 2678
02 6933 4001
http://www.csu.edu.au/weedresearchgroup/herbicide-resistance

Plant Science Consulting
22 Linley Ave
Prospect, SA 5082
0400 664 460
info@plantscienceconsulting.com.au
www.plantscienceconsulting.com

6.2.1 Be a WeedSmart farmer

Figure 1: *WeedSmart logo.*

The Australian grain industry stands at the crossroads with two options. Which direction will it take?

One road is for every grower to make herbicide sustainability their number one priority so that it influences decision-making and practices on all Australian grain farms. Armed with a clear 10-point plan for what to do on-farm, grain growers have the knowledge and specialist support to be WeedSmart.

On this road, growers are capturing and/or destroying weed seeds at harvest. They are rotating crops, chemicals and modes of action. They are testing for resistance and aiming for 100% weed kill, and monitoring the effectiveness of spray events.

In addition, they are not automatically reaching for glyphosate, they do not cut on-label herbicide rates, and they carefully manage spray drift and residues. Growers are planting clean seed into clean paddocks with clean borders. They use the double-knock technique and crop competitiveness to combat weeds.

On this road, the industry stands a good chance of controlling resistant weed populations, managing difficult-to-control weeds, prolonging the life of important herbicides, protecting the no-till farming system and maximising yields.

The other option is for growers to think resistance is someone else's problem, or an issue for next year, or something they can approach half-heartedly.

If herbicide resistance is ignored, it will not go away. Managing resistance requires an intensive but not impossible effort. Without an Australia-wide effort, herbicide

MORE INFORMATION

www.weedsmart.org.au

VIDEOS

Richard Daniel, NGA Discusses Herbicide Resistance Tactics: http://www.weedsmart.org.au/bulletin-board/rethinking-weed-control/

resistance threatens the no-till system, land values, yields and your hip pocket. It will drive down the productivity levels of Australian farms.

Jump on board WeedSmart and take the road of least resistance. [4]

6.2.2 Ten ways to weed out herbicide resistance

1. Act now to stop weeds from setting seed.
   - » Destroy or capture weed seeds.
   - » Understand the biology of the weeds present.
   - » Remember that every successful WeedSmart practice can reduce the weed seedbank over time.
   - » Be strategic and committed—herbicide resistance management is not a 1-year decision.
   - » Research and plan your WeedSmart strategy.
   - » You may have to sacrifice yield in the short term to manage resistance—be proactive.
   - » Find out what other growers are doing, and visit www.weedsmart.org.au.
2. Capture weed seeds at harvest. Options to consider are:
   - » Create and burn narrow windrows.
   - » Produce hay where suitable.
   - » Funnel seed onto tramlines or silage in controlled traffic farming (CTF) systems.
   - » Use a green or brown manure crop to achieve 100% weed control and build soil nitrogen levels.
3. Rotate crops and herbicide modes of action:
   - » Look for opportunities within crop rotations for weed control.
   - » Understand that repeated application of effective herbicides with the same mode of action (MOA) is the single greatest risk factor for evolution of herbicide resistance.
   - » Protect the existing herbicide resource.
   - » Remember that the discovery of new, effective herbicides is rare.
   - » Acknowledge that there is no quick chemical fix on the horizon.
   - » Use break crops where suitable.
4. Test for resistance to establish a clear picture of paddock-by-paddock weed status:
   - » Sample weed seeds prior to harvest for resistance testing to determine effective herbicide options.
   - » Visit the WeedSmart website, www.weedsmart.org.au or www.ahri.uwa.edu.au for more information on herbicide-resistance survey results.
   - » Collaborate with researchers by collecting weeds for surveys during the double-knock program (northern region).
5. Aim for 100% weed control and monitor every spray event:
   - » Stop resistant weeds from returning into the farming system.
   - » Focus on management of survivors in fallows (northern grains region).
   - » Where herbicide failures occur, do not let the weeds seed. Consider silage, chipping, fallowing or brown manuring the paddock.
   - » Patch-spray areas of resistant weeds only if appropriate.
6. Do not automatically reach for glyphosate:
   - » Use a diversified approach to weed management.
   - » Consider post-emergent herbicides where suitable.

4 WeedSmart, http://www.weedsmart.org.au

- » Consider strategic tillage.

7. Never cut the on-label herbicide rate and carefully manage spray drift and residues:
   - » Use best management practice in spray application. The GRDC has produced a series of Fact Sheets, available at www.grdc.com.au.
   - » Consider selective weed sprayers such as WeedSeeker or WeedIt.
8. Plant clean seed into clean paddocks with clean borders:
   - » It is easier to control weeds before the crop is planted.
   - » Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds.
   - » A recent Australian Herbicide Resistance Initiative (AHRI) survey showed that 73% of grower-saved crop seed was contaminated with weed seed.
   - » The density, diversity and fecundity of weeds are generally greatest along paddock borders and areas such as roadsides, channel banks and fence lines.
9. Use the double-knock technique:
   - » Double-knock is the use of any combination of weed control that involves two sequential strategies; the second application is designed to control survivors of the first method of control used.
   - » Access GRDC research results at www.grdc.com.au or www.nga.org.au.
10. Employ crop competitiveness to combat weeds:
    - » Consider narrow row spacing and seeding rates.
    - » Consider twin-row seeding points.
    - » Use barley and varieties that tiller well.
    - » Use high-density pastures as a rotation option.
    - » Consider brown manure crops. [5]

MORE INFORMATION

www.weedsmart.org.au

http://www.ahri.uwa.edu.au

https://grdc.com.au/Resources/IWMhub/Section-1-Herbicide-resistance

6.3 Benefits of sorghum for weed control

Crop rotation, especially with summer crops, can be an effective means of managing a spectrum of weeds that result from continuous wheat cropping.

The use of rotations that include both broadleaf and cereal crops may allow an increased range of chemicals—say three to five MOAs—or non-chemical tactics such as cultivation or grazing. For the management of wild oats, the inclusion of a strategic summer crop such as sorghum means two winter fallows, with glyphosate an option for fallow weed control. Grazing and/or cultivation are alternative, non-chemical options.

Where continuous summer cropping has led to development of Group M resistant annual ryegrass, a winter crop could be included in the rotation and a Group A, B, C, D, J or K herbicide used instead, along with crop competition and potential harvest management tactics.

For summer grasses, consider a broadleaf crop such as mungbean, because a Group A herbicide and crop competition can provide good control.

Strategic cultivation can provide control for herbicide-resistant weeds and those that continue to shed seed throughout the year. It can be used to target large mature weeds in a fallow, for inter-row cultivation in a crop, or to manage isolated weed patches in a paddock. Take into consideration the size of the existing seedbank and the increased persistence of buried weed seed, but never rule it out.

Most weeds are susceptible to grazing. Weed control is achieved through reduction in seed-set and competitive ability of the weed. The impact is optimised when the timing of the grazing occurs early in the life cycle of the weed. [6]

5 WeedSmart, http://www.weedsmart.org.au

6 GRDC (2012) Herbicide resistance, http://www.grdc.com.au/Media-Centre/Hot-Topics/Herbicide-Resistance

6.4 Herbicides explained

6.4.1 Residual *v.* non-residual

Residual herbicides remain active in the soil for an extended period (months) and can act on successive weed germinations. Residual herbicides must be absorbed through the roots or shoots, or both. Examples of residual herbicides include imazapyr, chlorsulfuron, atrazine and simazine.

The persistence of residual herbicides is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics.

6.5 Pre-emergent herbicides

Choosing herbicides for weed control will depend on the specific weed species present in the paddock and the crop being grown. Consult your agronomist to discuss specific strategies.

Good weed control management in summer crops such as sorghum is essential for the production of high-yielding and profitable crops.

Weeds lower crop yields by competing for soil water, nutrients, space and light. In dryland crops where water is often severely limited, competition for water is the most critical factor in reducing yields. For irrigated crops, competition for light and nutrients is more important. Cropping options can also be restricted by the difficulty or inability to control weeds in some crops, such as burrs and thornapples in sunflower.

Growers should aim to reduce weed numbers and keep them low with an ongoing control program. Management practices that combine all of the available methods are the key to successful weed control.

Weed control starts in the previous crop or pasture where weeds should not be allowed to set seed. No single herbicide will control all weeds. Combinations of herbicides and/or cultivations may be needed. A missed herbicide spray or tillage operation can seriously reduce the effectiveness of a weed control program.

Control of weeds along fences, contour banks, waterways, irrigation channels and other non-cropped areas is also important. [7]

6.6 Tactics within the farming system

- Crop rotation—a well managed rotation in each paddock with broadleaf and cereal crops alternated is a very useful weed control technique. For example, grasses are more easily and cheaply controlled by chemicals in broadleaf crops, while broadleaf weeds are easier to control in cereal crops. In northern NSW, alternating of summer and winter crops is an important weed control strategy. Good crop rotation management can substantially reduce the overall cost of chemical weed control.
- Haymaking or silage-making—these fodder conservation methods can be effective in reducing weed burdens as weed seeds are removed from the paddock in the hay or silage.
- Pasture management techniques including pasture topping by mowing or using herbicides, spray-grazing, strategic heavy grazing or burning and can play a role in weed control programs.
- Good agronomic practices such as using weed free seed and timely sowing with optimal plant populations and adequate nutrition contribute to good weed control management.

VIDEOS

Chris Preston University of Adelaide discusses strategies behind managing weeds around paddock boundaries and along fencelines.

Video: Weed control on paddock boundaries and fencelines

7 http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/weed-control/summer

- Timely cultivation is a valuable method of killing weeds and preparing seedbeds. Most growers use varying combinations of mechanical and chemical weed control to manage their fallows or stubbles.
- Fallow weed control—the basis of a successful dryland summer crop is a weed free fallow. No-till and minimum-till fallows have become the norm, no-till has enabled crops to be sown at the optimum time and to be sown when it is too dry to sow into a cultivated fallow. Also, no-till has often reduced operating costs to less than those for cultivated fallows, with significant machinery and tractor-time savings.

Opportunity double-cropping following winter cereals has succeeded where there is sufficient soil moisture. In no tillage systems, stubble retention is vital for improving soil structure, reducing soil erosion and degradation, storing soil moisture and having a wetter seedbed. Farmers have moved away from cultivating fallows to minimum and no tillage by substituting knockdown and residual herbicides. [8]

6.7 Pre-plant and pre-emergent weed control

Pre-plant or pre-emergent weed control of grasses is essential in sorghum and maize and preferable in broadleaf crops. Similarly, broadleaf weed control is preferable at this stage. In seeking flexible cropping options, farmers are often avoiding the use of residual herbicide, especially for grass control. [9]

6.8 Post-emergent weed control

Weeds should be removed from: sorghum and maize within three to four weeks of emergence to prevent yield loss; soybeans within four to seven weeks of planting; sunflower within two to three weeks of emergence. Adzuki bean, mungbean and pigeon pea are more sensitive to weeds than soybeans. Similarly, millets are more sensitive to weeds than sorghum.

The extent of yield reduction depends on the weed species, weed and crop density and the size of weeds when control measures are applied. The stage of weed and crop growth are vital factors when planning successful post-emergent herbicide use. Read herbicide labels carefully for these details and information on optimum conditions for spraying. [10]

Significant yield losses occur if weeds are not killed until 4–5 weeks after planting. For effective control of most weeds, apply atrazine either before planting, at planting or immediately after planting. Apply Primextra® Gold, Dual® Gold or other metolachlor products as a pre-emergent spray for grass control, especially liverseed grass. Treat seed with Concep®II seed safener when using Primextra® Gold, Dual® Gold or other S-metolachlor products.

No-till and minimum-till fallowed crops where atrazine and glyphosate have been used, should have excellent weed control at planting and during crop growth. These fallows conserve more soil moisture and should improve the chances of planting crops at the optimum time.

Atrazine residues prevent the planting of crops other than sorghum or maize for 18 months after application of 2.5–6.5 L/ha of atrazine 500 g/L, 1.4–3.3 kg/ha of atrazine 900 g/kg or more than 3.2 L/ha of Primextra® Gold. Check the herbicide label. Where residues occur on soils with a pHCa greater than 7, a small field test, pot test or an analytical test should be done before planting susceptible crops. Pennisetum forages, white french millet, faba bean, chickpea and cowpea (in order of decreasing tolerance) may tolerate limited residues. Most other crops are highly sensitive. Herbicide resistance is an emerging problem in most grain producing areas. Producers should target their weed control carefully so that the correct rate

8 http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/weed-control/summer

9 http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/weed-control/summer

10 http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/weed-control/summer

and timing of application is achieved and rotate herbicide groups. This is particularly important for harder to kill weeds such as barnyard grass, liverseed grass, fleabane and bindweed. [11]

6.8.1 Avoiding crop damage from residual herbicides

When researching the residual activity and cropping restrictions following herbicide application, the herbicide label is the primary source of information and it should be read thoroughly. The information below provides an explanation of how herbicides break down and extra notes on some specific herbicides used in broadacre cropping.

What are the issues?

Some herbicides can remain active in the soil for weeks, months or years. This can be an advantage, as it ensures good long-term weed control. However, if the herbicide stays in the soil longer than intended it may damage sensitive crop or pasture species sown in subsequent years.

For example, chlorsulfuron (Glean®) is used in wheat and barley, but it can remain active in the soil for several years and damage legumes and oilseeds.

A real difficulty for growers lies in identifying herbicide residues before they cause a problem. Currently, we rely on information provided on the labels about soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, or if testing is possible, it is too expensive to be part of routine farming practice. Once the crop has emerged, diagnosis is difficult because the symptoms of residual herbicide damage can often be confused with, and/or make the crop vulnerable to, other stresses, such as nutrient deficiency or disease. [12]

An option for assessing the potential risk of herbicide residues is to conduct a bioassay involving hand planting small test areas of crop into the field in question.

Which herbicides are residual?

The herbicides listed in Table 3 all have some residual activity or planting restrictions.

MORE INFORMATION

Hear US herbicide residue specialist Dr Dale Shaner explain the effects soil-applied herbicides to crop residues: http://www.grdc.com.au/Media-Centre/GRDC-Gallery/Video/3tnKn3qn4BA

For a recording of Dr Shaner's full GRDC webinar '*Stubble and soil binding of pre-emergent herbicides*' (13 Dec. 2013), visit: https://grdc.com.au/Resources/IWMhub/Weed-Webinars/Stubble-and-soil-binding-of-pre-emergent-herbicides.

11 http://www.dpi.nsw.gov.au/agriculture/broadacre-crops/summer-crops/sorghum/general/summer-crop-production-guide

12 DEPI (2013) Avoiding crop damage from residual herbicides, Department of Environment and Primary Industries Victoria, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

Table 3: *Active constituent by herbicide group(may not include all current herbicides).*

Herbicide group	Active constituent
Group B: Sulfonylureas	Chlorsulfuron (Glean®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®), triasulfuron (Logran®)
Group B: Imidazolinones	Imazamox (Raptor®), imazapic (Flame®), imazapyr (Arsenal®)
Group B: Triazolopyrimidines (sulfonamides)	Florasulam (Conclude®)
Group C: Triazines	Atrazine, simazine
Group C: Triazinones	Metribuzin (Sencor®)
Group C: Ureas	Diuron
Group D: Dinitroanilines	Pendimethalin (Stomp®), trifluralin
Group H: Pyrazoles	Pyrasulfotole (Precept®)
Group H: Isoxazoles	Isoxaflutole (Balance®)
Group I: Phenoxycarboxylic acids	2,4-Ds
Group I: Benzoic acids	Dicamba
Group I: Pyridine carboxylic acids	Clopyralid (Lontrel®)
Group K: Chloroacetamides	Metolachlor
Group K: Isoxazoline	Pyroxasulfone (Sakura®)

How do herbicides break down?

Herbicides break down via chemical or microbial degradation. The speed of chemical degradation depends on the soil type (clay or sand, acid or alkaline), moisture and temperature. Microbial degradation depends on a population of suitable microbes living in the soil to consume the herbicide as a food source. Both processes are enhanced by heat and moisture. However, these processes are impeded by herbicide binding to the soil, and this depends on the soil properties (pH, clay or sand, and other compounds such as organic matter or iron).

For these reasons, degradation of each herbicide needs to be considered separately and growers need to understand the soil type and climate when trying to interpret recropping periods on the product label for each paddock. [13]

How can I avoid damage from residual herbicides?

Select a herbicide appropriate for the weed population you have.

Make sure you consider what the recropping limitations may do to future rotation options.

Users of chemicals are required by law to keep good records, including weather conditions, but particularly spray dates, rates, batch numbers, rainfall, soil type and pH (including different soil types in the paddock). In the case of unexpected damage, good records can be invaluable.

If residues could be present, choose the least susceptible crops (refer to product labels). Optimise growing conditions to reduce the risk of compounding the problem with other stresses such as herbicide spray damage, disease and nutrient deficiency. These stresses make a crop more susceptible to herbicide residues. [14]

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13 DEPI (2013) Avoiding crop damage from residual herbicides, Department of Environment and Primary Industries, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

14 DEPI (2013) Avoiding crop damage from residual herbicides, Department of Environment and Primary Industries Victoria, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

Group B: Imidazolinones

The imidazolinones are very different from the sulfonylureas, as the main driver of persistence is soil type, not soil pH. They tend to be more of a problem on acid soils, but carryover does occur on alkaline soils. Research has shown that in sandy soils, such as on the Eyre Peninsula, they can break down very rapidly (within 15 months in alkaline soils), but in heavy clay soils in Victoria they can persist for several years. Breakdown is by soil microbes. Oilseeds are most at risk. Widespread use of imidazolinone-tolerant canola and wheat in recent years has increased the incidence of imidazolinone residues.

Group C: Triazines

Usage of triazines has increased to counter Group A resistance in ryegrass, in particular in triazine-tolerant canola. Atrazine persists longer in soil than simazine. Both generally persist longer on high pH soils, and cereals are particularly susceptible to damage. Recent research in the US indicates that breakdown rates tend to increase when triazines are used regularly, as the number of microbes able to degrade the herbicide can increase. This may mean that breakdown can take an unexpectedly long time in soils that have not been exposed to triazines for some years.

Group D: Trifluralin

Trifluralin tends not to leach through the soil, but it can be moved into the seedbed during cultivation or ridging. Trifluralin binds strongly to stubble and organic matter and is more likely to be a problem in paddocks with stubble retention. Be particularly careful with wheat, oats and lentil. Barley is more tolerant. Use knife-points to throw soil away from seed and sow deep; not suited to disc seeders.

Group H: Isoxazoles

Persistence in acid soils (pH <7) has not been fully tested, but research has shown that isoxazole persistence is expected to be longer than the label recommendations for legume crops and pastures. Isoxazoles will also persist longer in clay soils and those with low organic matter. Cultivation is recommended prior to recropping.

Group I: Phenoxys

Clopyralid and aminopyralid can be more risky on heavy soils and in conservation cropping as they can accumulate on stubble. Even low rates, they can cause crop damage up to 2 years after application. They cause twisting and cupping, particularly for crops suffering from moisture stress.

2,4-D used for fallow weed control in late summer may cause a problem with autumn-sown crops if plant-back periods are not observed. Changes have been made to the 2,4-D label recently and not all products can be used for fallow weed control—check the label.

The label recommends that you not sow sensitive crops, especially canola, until after a significant rainfall event. Oilseeds and legumes are very susceptible to injury from 2,4-D.

Group K: Metolachlor

Metolachlor is used in canola crops. The replanting interval is 6 months. [15]

15 Dual Gold® herbicide, http://www.herbiguide.com.au/Descriptions/hg_Dual_Gold.htm

Group K: Pyroxasulfone

Pyroxasulfone relies on microbial degradation, which is favoured by in-season rainfall. Label plant-back periods are important particularly for oats, durum wheat and canola. Residues will lead to crop stunting. [16]

For more information, visit www.apvma.gov.au.

MORE INFORMATION

Syngenta Quick-Test: http://www.plantscienceconsulting.com

http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/weed-control-winter-crops

www.apvma.gov.au

6.9 In-crop herbicides: knockdowns and residuals

When selecting a herbicide, it is important to know crop growth stage, weeds present and plant-back period. For best results, spray weeds while they are small and actively growing. Herbicides must be applied at the correct stage of crop growth, or significant yield losses may occur. Check product labels for up-to-date registrations and application methods.

How to get the most out of post-emergent herbicides:

1. Consider application timing—the younger the weeds the better. Frequent crop monitoring is critical.
2. Consider the growth stage of the crop.
3. Consider the crop variety being grown and applicable herbicide tolerances.
4. Know which species were historically in the paddock and the resistance status of the paddock (if unsure, send plants away for a 'Syngenta Quick-Test' (see link).
5. Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought or, for some chemicals, cloudy/sunny days. This is especially pertinent for frosts with grass-weed chemicals.
6. Use the correct spray application:
    - Consider droplet size with grass-weed herbicides, water volumes with contact chemicals and time of day.
    - Observe the plant-back periods and withholding periods.
    - Consider compatibility if using a mixing partner.
    - Add correct adjuvant.

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

6.10 Post-emergent herbicide damage

Crop yield can be compromised by damage from herbicides, even when products are applied according to the label rate.

Factors that can contribute to herbicide damage are:

- crop variety grown
- weather conditions at time of application
- mixing partner
- growth stage of crop
- nutritional status of crop

16 DEPI (2013) Avoiding crop damage from residual herbicides, Department of Environment and Primary Industries Victoria, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

Insect control

Sorghum is susceptible to insect pests from emergence to late grainfill. Early sorghum pests include armyworms and soil insects. These pests are normally present in a grain sorghum crop in low numbers where their damage can be tolerated. However, seasonal conditions can sometimes stimulate the buildup of a large population of one or more of these, and they can cause significant damage.

Seed dressings to combat soil insects are commonly available and may be the most effective control as well as the least disruptive to natural enemies.

Choosing open-headed type sorghum hybrids can deter pests such as aphids and Rutherglen bugs. These insects prefer compact or closed panicle types, on which they are hard to control because of the difficulty of achieving spray penetration.

It is now possible to adopt an integrated pest management (IPM) strategy to control *Helicoverpa* and midge (Figure 1) on sorghum with a nuclear polyhedrosis virus (NPV) that is selective for *Helicoverpa*, and by planting of midge-tolerant hybrids. Such a strategy eliminates any impact on natural enemies that naturally attack both midge and *Helicoverpa*. [1]

Figure 1: *Sorghum midge is a serious pest of sorghum crops.*

Photo: QDAF

7.1 Sorghum pests at a glance

A summary of information about sorghum pests is presented in Table 1.

1 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

Table 1: *Sorghum pests.* [2]

Insect	Threshold	Crop growth stage	Crop damage	Comments	Frequency
Aphids	Do not cause yield loss unless populations are extreme. Dryland crops under moisture stress most severely affected	Just before head emergence, flowering up to harvest	Reduce head emergence, seed set and quality. Honeydew interferes with harvest	Rarely economic to spray. Aphids usually controlled by natural enemies before stickiness occurs. Rain will reduce stickiness. A pre-harvest spray with a knockdown herbicide will usually avoid the harvest problems caused by aphids	Annual
Armyworms	No established threshold. Use defoliation as guide to potential impact. Consider stage of growth and potential damage	Feed on leaves of young plants, through to head emergence and flowering	Feed on leaves in funnels or throats of plants. In rare instances, or outbreaks of Day-feeding Armyworm can cause significant defoliation. Severe leaf area loss at flowering can reduce yields	Feeding during evening and night. Caterpillars hide near ground during day. Day-feeding armyworm active during the day	Rarely
Black field earwigs	Usually in large numbers. Examine soil before sowing for nymphs and adults	Attack germinating seed and roots of young seedling and tap roots of older plants	Destroy roots and cause plants to fall over in wind	Populations regulated by soil moisture, favoured by moist soils and organic matter. Sow treated seed and band spray in situations of high risk. Damage reduced by shallow sowing into moist warm soils using press-wheels	Rarely
Cutworms	At first sign of damage. Usually in large numbers in patches or moving in from edges	Seedling	Cut off leaves and stems at ground level, causing plant death. Most feeding in evening and night. Caterpillars hide in soil during day	Inspect crops late evening or night for presence of large, dark grey-green caterpillars. Spot treatment may be effective. Cutworm build up in weedy fallows and field edges. Weed control can force them onto seedling crops	Rarely
False wireworms	Treat seed or soil if ≥3 larvae/m row	Newly emerged seedling. Can attack dry sown seed. More damage when emergence and growth delayed by dry weather	Feed on dry seed and eat into the stems of young plants just above ground level	Check at junction of loose cultivated soil and undisturbed soil before sowing. Vary from 8–40 mm in length. Often feed on decaying vegetable matter. Use germinating seed baits to assess population pre-sowing. Warm soil and press wheels can reduce damage	Intermittent
Helicoverpa caterpillars	Economic thresholds (ET) can be calculated using the following formula: $ET = (C \times R) \div (V \times N \times 2.4)$, where C is cost of control ($/ha), R is row spacing (cm), V is value of crop ($/t), N is number of heads/m row, 2.4 is damage (g/larva)	Infestations on vegetative plants do not cause economic damage. Eggs are laid on heads just prior to flowering from December to March	Small caterpillars (<10 mm) eat flower spikelets, larger caterpillars eat developing seed reducing yields and allow entry of fungal pathogens. Each larva destroys ~2.4 g of grain	To determine heads per m row, count 10 m of row at 10 sites. Sample larvae by shaking sorghum heads into a bucket. Compact-headed varieties suffer more serious damage than open-headed types. Cultivation of stubble over winter reduces pupae survival. Threshold calculators are available at www.thebeatsheet.com.au/economic-threshold-calculators	Annual

2 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

MORE INFORMATION

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/284576/Insect-and-mite-control-in-field-crops-2013.pdf

http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/insect-mite-crops

http://thebeatsheet.com.au/economic-threshold-calculators/

7.2 *Helicoverpa (Helicoverpa armigera)*

Helicoverpa do little economic damage as foliage feeders. Eggs laid on heads just before flowering produce larvae that cause economic damage. Sorghum is most at risk from *Helicoverpa* from head emergence to early grainfill. Larvae of *Helicoverpa* can be confused with sorghum head caterpillar and yellow peach moth. [3]

Figure 2: Helicoverpa armigera *caterpillar.*

All *Helicoverpa* caterpillars on sorghum are *H. armigera* (Figure 2). [4]

7.2.1 Damage

Helicoverpa can attack sorghum in both the vegetative and reproductive phases. It is only when they attack developing grain that control may be warranted. [5]

- Small larvae (<10 mm long) feed on the pollen sacs in the flower head where they cause little damage.
- Larger *Helicoverpa* larvae feed on developing seed; 80% of damage is done in by the final larval instar.
- Each larva destroys ~2.4 g of grain in its lifetime.

Monitoring

- Monitor weekly from head emergence through to early grain.
- Determine *Helicoverpa* numbers by rotating five head stalks into a bucket.
- Count larvae in the bucket and work out an average per head.
- Determine larval sizes (important for control decisions).
- Repeat sampling at a minimum of six sites throughout the paddock. [6]

3 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

4 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

5 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

6 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

7.2.2 Thresholds

Action levels vary with factors such as grain prices and cost of control. The critical number of insects per head is the number of insects that can eat a greater monetary value of grain than the cost of spraying. Control is recommended when insect numbers are at or above the critical threshold level.

The critical *Helicoverpa* larvae number can be calculated with the following formula:

(C (cost of control) × R (row spacing)) ÷ (V (value of crop in $) × N (no. of heads/m row) × 2.4)

7.2.3 Monitoring and control

Checking for *Helicoverpa* should be done very early in the morning or very late in the evening twice a week. Aim to control larvae before they reach 7 mm in length, because larger larvae cause more damage and are harder to control. Eggs are laid between head emergence and flowering. [7]

The best product to use for control of *Helicoverpa* is a naturally occurring virus that targets this pest (Figure 3). NPV is regarded as a highly successful, alternative control option when used under the right conditions. The use of NPV will reduce selection for resistance and is therefore the preferred control option. Note that NPV often works more slowly than conventional chemistry in terms of killing larvae; however, the larvae do not feed for a few days prior to dying. [8]

- NPV is most effective against small larvae (<7 mm). Avoid targeting larvae >3 mm.
- Crop coverage is critical because this is an ingestion product.
- Spray NPV when ~50% of the sorghum panicles have completed flowering (see label for instructions).
- Spray when larvae are actively feeding, at temperatures between 25°C and 35°C.
- NPV is harmless to wildlife and natural enemies of *Helicoverpa*. [9]

7 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

8 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

9 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

Figure 3: *NPV infected, and killed,* Helicoverpa *larva.*

Photo: QDAF

Helicoverpa armigera is highly resistant to pyrethroids, organophosphates and carbamates. The effectiveness of these products depends on the percentage of resistant *Helicoverpa*, but their use cannot be relied on for control, particularly under high pest pressure.

There are other chemical means of controlling *Helicoverpa*; however, these chemicals severely disrupt natural enemies. For current chemical control options, see Pest Genie or the Australian Pesticides and Veterinary Medicines Authority (APVMA). [10]

MORE INFORMATION

http://www.pestgenie.com.au/

www.apvma.gov.au

7.2.4 Natural enemies

The combined action of natural enemies can have a significant impact on potentially damaging *Helicoverpa* populations. It is therefore desirable to conserve as many natural enemies as possible. Natural enemies of *Helicoverpa* include predators of eggs, larvae and pupae, parasites of eggs, and larvae and caterpillar diseases.

Predatory bugs and beetles that attack *Helicoverpa* eggs and larvae include:

- spined predatory bugs
- glossy shield bugs
- damsel bugs
- big-eyed bugs
- apple dimpling bugs
- assassin bugs
- red and blue beetles
- predatory ladybird beetles
- ants
- spiders
- lacewings

10 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

Parasites include:

- Trichogramma spp.—tiny egg parasite wasps
- *Microplitis* and *Netelia* (wasps)—caterpillar parasites
- Species of tachinid flies—caterpillar parasites

With the exception of *Trichogramma* and *Microplitis*, most parasites do not kill *Helicoverpa* until they reach the pupal stage. Predatory earwigs and wireworm larvae are significant predators of *Helicoverpa* pupae. [11]

7.3 Sorghum midge (*Stenodiplosis sorghicola*)

Sorghum midge is a serious pest of sorghum that may require several insecticide applications during flowering, particularly for late-planted crops (Figure 4). Management is now centred on growing midge resistant hybrids that not only simplify management and decreases cost, but provide greater midge control. [12]

Figure 4: *Severe damage caused by sorghum midge to sorghum head.*

Photo: QDAF

MORE INFORMATION

http://ipmguidelinesforgrains.com.au/pests/sorghum-midge/

http://espace.library.uq.edu.au/view/UQ:106771

http://www.publish.csiro.au/paper/EA9930193.htm

http://groundcover.realviewdigital.com/?iid=83218&startpage=page0000043#folio=42

Sorghum midge rating scheme

In 1993, Department of Agriculture, Fisheries and Forestry Queensland (QDAF), in partnership with Grains Research and Development Corporation (GRDC) and the commercial sorghum breeding companies, developed a protocol for measuring the midge resistance (MR) levels in grain sorghum hybrids and assigning official MR ratings to all the commercially released lines.

The rating number is a measure of: amount of grain lost per visiting female midge per day. It ranges from 1 (nil resistance) through to 8+ ('practical field immunity' under most conditions and maximum commercially available resistance). In practical terms, this means that a 7-rated hybrid, when exposed to the same midge pressures as a 1-rated hybrid, will sustain 7 times less damage.

11 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

12 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

MORE INFORMATION

https://www.grdc.com.au/Research-and-Development/Major-Initiatives/The-Sorghum-Midge-Tested-Scheme

MORE INFORMATION

http://thebeatsheet.com.au/sorghum/helicoverpa-and-midge-management-in-sorghum/

MORE INFORMATION

http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-107-NovDec-2013/Cost-effective-control-of-sorghum-midge

http://www.grdc.com.au/GRDC-FS-SorghumMidgeEconomicThresholds

http://www.ausgrain.com.au/Back%20Issues/175jfgrn08/Niv_Cost.pdf

http://www.ausgrain.com.au/Back%20Issues/185jfgrn09/27_Thresholds.pdf

The testing protocol, carried out by QDAF, involves planting an annual trial in a semi-controlled environment (ideal for sorghum and midge) and subjecting the plants to high midge pressures. The resulting midge damage per head is then assessed for all entries.

For evaluation purposes, the test (pre-commercial) hybrids are grown alongside standard/control lines of known MR ratings. After statistical analysis of the results, official MR ratings are then assigned for each hybrid. This testing regime provides a measure of quality assurance for growers in that hybrids are independently assessed in a precise and consistent manner every time, and the ratings and accompanying logo are issued only to hybrids assessed by the scheme. [13]

7.3.1 Damage

Sorghum midge can severely reduce yields, especially in late-sown crops:

- Midge eggs hatch into transparent white larvae that feed on immature seed.
- Feeding creates a depression in the developing seed and prevents seed kernel development.
- High populations of midge can destroy the crop.
- The progeny of each egg-laying adult can destroy 1.4 g of grain.
- Sorghum midge activity is evident by white pupal cases that stick out of the tips of glumes.

The midge lifecycle varies from 2 to 4 weeks, depending on temperatures. This allows many generations to occur in one season and accounts for the rapid build-up of extremely high midge densities, especially where the flowering period of sorghum is extended by successive plantings. [14]

7.3.2 Monitoring

Count adult midge on flowering heads at mid-morning. Repeat daily. [15]

Weekly trap catch data for *H. punctigera* and *H. armigera* from locations across all states can now be viewed online. The adjustable bar below the map allows selection of a time period (1 wk, 2 wks, 1 mth, etc). https://jamesmaino.shinyapps.io/MothTrapVis/

7.3.3 Thresholds

Thresholds vary with the resistance levels of the hybrids as well as commodity prices and the cost of insecticides. Threshold levels can be calculated using the factor of 1.4 g of grain destroyed per one egg-laying adult. On susceptible hybrids, this level is usually about one adult per head. [16]

The sorghum midge economic threshold calculator

The calculator helps growers decide whether to apply an insecticide by asking the question: is the number of midge high enough to justify insecticide and application expenses, or is the number too low to affect the crop yield?

The tool uses your specific farming conditions to provide tailored advice.

It is available online, along with information on how to collect the pest data used by the calculator, at: http://thebeatsheet.com.au/economic-threshold-calculators/. [17]

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13 GRDC. The sorghum midge tested scheme. GRDC Major Initiative, https://www.grdc.com.au/Research-and-Development/Major-Initiatives/The-Sorghum-Midge-Tested-Scheme

14 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

15 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

16 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

17 GRDC (2013) Cost and benefit of treating sorghum midge. GRDC Sorghum Midge Spray Calculator Fact Sheet, http://www.grdc.com.au/GRDC-FS-SorghumMidgeEconomicThresholds

Alternatively, midge thresholds for a particular crop can be calculated by using the following formula. For more detailed information, seek advice from your agronomist.

Control midge when:

NM/R is greater than (C × W × CB)/(1.4 × V × RD)

where:

NM is number of midge/m row

R is midge rating of hybrid used

C is cost of control ($/ha)

W is row spacing width (cm)

CB is cost benefit ratio

1.4 is weight of sorghum (grams) lost per midge

V is value of crop ($/t)

RD is residual life of chemical used (days)

Example calculation: NM/R = 4/3 =1.33 and (C × W × CB)/(1.4 × V × RD) = (17 × 100 × 2)/(1.4 × 155 × 4) = 3.92

As 1.33 < 3.92, do not spray at this stage. [18]

7.3.4 Control

The most common means of controlling sorghum midge is by planting resistant hybrids. Since 1993, all commercial sorghum hybrids have been assigned official midge resistant (MR) ratings from 1 to 7.

Hybrids with a rating 7, when exposed to the same midge density as the susceptible hybrid (rating 1), sustain 7 times less damage. In 2002, the rating system was extended to a new 'open-ended' rating of 8+. Trials have shown that some 8+ hybrids contain levels of resistance that approach 'practical field immunity'. Note that for 8+ varieties, some are just a little better than 7, whereas others are 'practically immune'.

Today, >99% of grain sorghum in Australia has some level of midge resistance, with most commercial hybrids rating 4–6. The high level of adoption of MR cultivars and the elimination of low-rated MR hybrids means that spraying for midge is now very rare, with <5% of crops treated, in contrast to the mid-1990s when 30–40% of the crops were sprayed. The use of resistant hybrids also means that natural enemies are conserved.

Producers are recommended to use resistant sorghum hybrids to combat sorghum midge, particularly for later plantings when midge pressure is highest. See the current variety ratings.

Insecticides are still available for the control of midge, but these chemicals will severely disrupt natural enemies. For current chemical control options, consult Pest Genie or APVMA. [19]

During head emergence and flowering, crops should be checked daily about 3–4 h after sunrise. Midge are very mobile, so re-infestation of crops is common. Crops should be sprayed when the economic thresholds in Table 2 are reached (based on $17/ha spray cost, grain at $120/t and a benefit : cost ratio of 2 : 1). Because insecticides are only 60–80% effective, a cost : benefit ratio of 2 : 1 is appropriate in most situations.

18 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

19 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

MORE INFORMATION

http://www.pestgenie.com.au/

www.apvma.gov.au

http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/planting-information

Table 2: *Sorghum midge per head warranting control in hybrids with different levels of midge resistance.* [20]

Hybrid midge resistance (tested rating)	Flowering (no. of heads/ha)		
	20,000	40,000	60,000
Susceptible (1)	2.5	1.2	0.8
Low (2)	5.0	2.5	1.7
Moderate (4)	10.0	5.0	3.3
High (6)	15.0	7.5	5.0

7.3.5 Natural enemies

Three small, black wasp parasitoids play a role in the control of sorghum midge populations, but they do not reduce levels of crop damage. They are *Eupelmus* sp., *Tetrastichus* sp. and *Aprostocetus* sp. Their presence in sorghum crops may be recognised by their small, round emergence holes in the spikelet. [21]

7.4 Minor pests

MORE INFORMATION

GRDC Update Paper: Emerging insect threats in northern grain crops

PODCAST

Melina Miles QDAF discusses soil dwelling insect pests and describes germinating seed bait technique for checking populations prior to sowing. GRDC Podcast: 104 Thrips worrying early summer crops

7.4.1 Soil insects

These include false wireworms *Pterohelaeus* spp. (eastern false wireworm, striate false wireworm) and *Gonocephalum* spp. (small false wireworm, southern false wireworm, northern false wireworm); also earwigs, cockroaches, and field crickets (black field crickets or brown field crickets).

Damage

- Larvae feed on decaying vegetable and crop residues in the soil.
- They also feed on newly germinating seed and the growing points of seedlings, which results in patchy stands.
- Damage is most common in early-planted crops where crop residue has become scarce.
- During summer, adults may damage young plants, by surface feeding or cutting of the plant at or near soil level.
- Damage by both larvae and adults may necessitate re-planting.

Risk period

The risk from adults is highest in summer. With larvae, the risk is highest for early-planted (September–October) crops. Damage may occur if early plant growth is slowed by cool, damp weather allowing larvae to remain in the moist root-zone. As soil dries, larvae retreat below the root-zone.

Monitoring and thresholds

Soil insects are often difficult to detect as they hide under trash or in the soil. Immature insects such as false wireworm larvae are usually found at the moist/dry soil interface. [22]

Most soil insects are active at night or very averse to bright sunny conditions so using germinating seed baits [23] to check for insects before the crop goes is recommended.

20 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

21 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

22 QDAF (2011) How to recognise and monitor soil insects, Department of Agriculture, Fisheries and Forestry, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects

23 GRDC Podcast 3 Nov 2015, 104 Thrips worrying early summer crops, https://grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2015/11/104-north

Management

High mortality of false wireworms can be caused by cool wet weather from autumn to spring. False wireworm beetles are more damaging to seedlings where stubble is buried by cultivation than in crops that are directly drilled into the surface retained stubble. This is because the surface-feeding beetles remain feeding on the stubble and not the crop.

- Prepare ground for even and rapid germination.
- Use of press-wheels at planting provides some protection.
- Clean cultivation during summer dries out topsoil and eliminates weeds that provide food for adults.
- Larvae can be controlled by insecticide applications at planting or insecticide-treated seed.
- Control of adults is obtained by baiting with insecticide-treated cracked grain broadcast evenly over the surface at or immediately after planting.
- Where broadcasting is not possible, the bait may be laid in trials spaced ≤2 m apart. For current chemical control options, see Pest Genie or APVMA.

Natural enemies provide little control. [24]

7.4.2 Cutworms (*Agrostis* spp.)

These include brown cutworm (*Agrotis munda*), Bogong moth (*Agrotis infusa)*, black cutworm (*Agrotis ipsilon*) and variable cutworm (*Agrotis prophyricollis*).

The common name of cutworm is derived from the larval habit of severing the stems of young seedlings at or near ground level, causing the collapse of the plant. Cutworm larvae typically shelter in the soil during the day. They curl into a 'C' shape when disturbed (Figure 5).

Figure 5: *Cutworm larvae on the soil surface.*

Photo: J Wessels, QDAF

Damage

- Cutworm larvae can sever stems of young seedlings at or near ground level.
- Sometimes the young plant is partially dragged into the soil where the larvae feed on it.
- Larvae may also climb plants and browse on, or cut off, leaves.
- Crop areas attacked by cutworms tend to be patchy and the destruction of seedlings in one area may cause cutworms to migrate to adjacent fields.

24 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

- Risk period is spring and summer—one generation per crop.
- Weedy fallow prior to sowing can lead to cutworm infestation.

Monitoring and thresholds

- Inspect emerging seedlings twice per week.
- Treat seedlings when there is a rapidly increasing area or proportion of crop damage (>10% seedling loss).
- Treat older plants if >90% of plants are infested or >50% of plants have ≥75% leaf tissue loss.

Control

- Cutworms are attacked by a range of natural enemies such as parasitoids, predators and diseases that also affect *Helicoverpa*.
- Controlling weeds in the field and field edges prior to planting will reduce cutworm populations that may have built up on these weeds. Spraying or cultivation of weeds just before or after crop emergence may force cutworm larvae onto the seedling crop.
- Insecticides are used when damage warrants their use. For current chemical control options, see Pest Genie or APVMA.
- Spot-spraying of identified patches may suffice. For best results, spray late in the afternoon, close to feeding time. [25]

7.4.3 Black field earwig (*Nala lividipes*)

Black field earwigs are a sporadic pest of sorghum, usually in areas with heavy, black soils.

Damage

- Eat newly sown and germinating seed and the roots of crops belowground, resulting in poor establishment.
- Chew the stems of newly emerged seedlings aboveground.

Monitoring and control

- Monitor crops after planting until establishment.
- Use germinating seed baits or digging and sieving to detect adults and nymphs prior to planting.
- Control if >50 earwigs are present in 20 germinating seed baits.
- Grain baits containing insecticide applied at sowing offer best protection.
- Insecticide seed dressings provide some protection.
- In-furrow sprays are not effective in protecting against dense populations.
- Earwigs prefer cultivated soils rather than undisturbed soil (no-till).
- Use press-wheels at sowing.
- For current chemical control options, see Pest Genie or APVMA. [26]

7.4.4 Armyworms

These include northern armyworm (*Leucania separate*), common armyworm (*Leucania convecta*) and day-feeding armyworm (*Spodoptera exempta*).

Armyworm is the caterpillar stage of certain moths and can occur in large numbers, especially after good rain following a dry period (Figure 6). During the day, armyworms shelter in the throats of plants or in the soil and emerge after sunset to

25 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

26 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

feed. The adults of the common and northern armyworms may be confused. Genitalia dissection by a specialist is required to separate the species. The larval stages likely to be encountered in cereals are all similar in appearance.

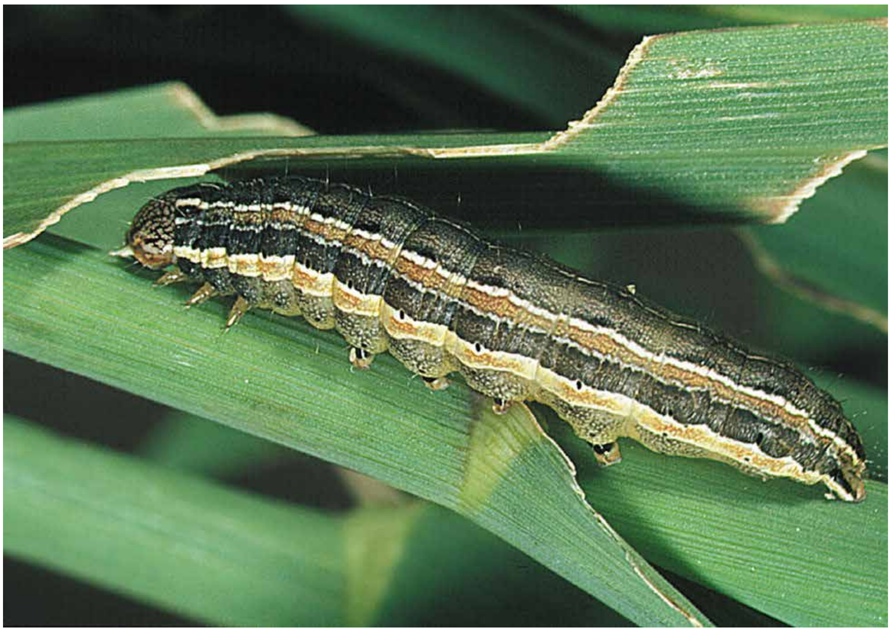


Figure 6: *Armyworm.*

Photo: QDAF

Damage

- Small infestations are usual in vegetative sorghum, causing little damage other than 'shot holes' in the leaves.
- Young plants may be defoliated or killed by heavy infestations, particularly of day-feeding armyworm .
- Older plants can outgrow damage, but seed yield may be reduced.
- Signs of damage include chewed leaf margins and faecal pellets at the base of young plants or in the throats of older plants.
- The northern and common armyworm feed at night and hide in vegetation during the day.
- Day-feeding armyworms feed during the day.

Monitoring

- Visually monitor during the early growth stage and again during head emergence and flowering.
- Egg lays are often associated with heavy rainfall, so check for larvae several weeks after rainfall events.
- Since armyworms (except day-feeding armyworm) hide during the day, look under clods of soil, under vegetation and at the base of plants. Also look for dark green-brown faecal pellets.

Thresholds

Treatment decisions should be made on the extent of defoliation and whether the crop can compensate for damage, the prevalence of natural enemies, the value of the crop and the cost of treatment.

Control

- Many chemicals will control armyworms. Their effectiveness is often dependent on good penetration into the crop to achieve contact with the caterpillars.

- Control may be more difficult in high-yielding thick canopy crops, particularly when larvae are resting under leaf litter at the base of plants.
- Because larvae are most active at night, spraying in the afternoon or evening may produce the best results. For current chemical control options, see Pest Genie or APVMA.

Natural enemies

Armyworm larvae are attacked by a number of parasitoids that may be important in reducing the intensity of outbreaks. When armyworms are in numbers likely to cause damage, parasitoids are unlikely to give timely control.

Predators include those that attack *Helicoverpa*, and green scarab beetles, predatory shield bugs and perhaps common brown earwigs. Viral and fungal diseases are recorded as causing mortality of armyworm. [27]

7.5 Corn aphid *(Rhopalosiphum maidis)*

Aphids frequently infest sorghum heads towards the end of grainfill; however, there is usually minimal economic damage, even when conditions are dry. Under extremely high populations, they may affect yield and quality. [28]

Damage

- Adults and nymphs suck sap and produce honeydew, which causes blockages and breakdowns of harvesters and can delay or extend harvest.
- High numbers can cause plants to turn yellow and appear unthrifty.
- High populations on heads produce sticky grain, which can clog harvesters.
- Water-stressed dryland crops loose yield.

Monitoring

- Estimate the percentage of plants infested and the percentage of leaf area covered by aphids.
- Check for the presence of predators and parasitoids. Record changes in aphid and natural enemy populations over successive checks.

Thresholds

The action level in the vegetative stage is 100% of plants, with 80% of the leaf area covered by aphids. On the heads, it is 75% of heads with 50% of the head covered by aphids.

Control

- Control is rarely warranted as natural enemies tend to control aphids before they start to cause stickiness in heads. Rainfall prior to harvest will reduce stickiness.
- Choosing hybrids with open heads can reduce aphid numbers, as these are generally less infested than tight-headed hybrids. [29]
- A pre-harvest spray with a knockdown herbicide will avoid the harvest problems caused by aphids. In severe cases, chlorpyrifos is a registered option for corn aphids. [30]

27 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

28 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

29 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

30 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

- Chemical control options are cost-effective but all insecticides that control aphids impact on natural enemies. For current chemical control options, see Pest Genie or APVMA. [31]

Natural enemies

A range of parasitoids and predators will help reduce aphid populations. Predators of aphids include:

- ladybird larvae
- damsel bugs
- big-eyed bugs
- larvae of green lacewings
- larvae of hoverflies
- wasp parasitoids such as *Lysiphlebus testaceipes, which* mummify and kill aphids [32]

PODCAST

Melina Miles QDAF discusses Rutherglen bug. GRDC Podcast: 106 Safe seed storage strategy

7.5.1 Rutherglen bug (*Nysius vinitor)* and grey cluster bug (*N. clevelandensis*)

Rutherglen bugs (RGB) can cause damage when present in very high numbers, by sucking sap from the plant leaves, stems and heads, thereby reducing yield and/or quality. [33]

Damage

- Seed heads may be damaged by feeding, resulting in reduced yield and quality.
- Affected seed is red and spotty and hollowed out.
- Grain will be small and shrivelled and does not continue to fill beyond the point it was damaged.
- Damaged seed is subject to fungal and bacterial attack.
- Seedling crops can be damaged by nymphs moving from nearby canola stubbles.

Monitoring

- Monitoring for RGB can be done at the same time as for *Helicoverpa*.
- Monitor by beating sorghum heads into a bucket and counting the number of RGB adults and nymphs.
- Because the impact on seed-set by RGB is greatest during flowering and early seed development, monitoring should start at early flowering.
- Distribution is typically patchy across the field, which means that random sampling, and the more samples taken, the greater the level of confidence in the overall infestation.

Thresholds

Rutherglen bug populations within a head can increase rapidly. Preliminary indications suggest at flowering a threshold of 20–25 bugs/head; increasing to 30–35 bugs/head at the soft-dough stage. By the hard-dough stage through to harvest, no damage occurs. [34]

31 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

32 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

33 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

34 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

MORE INFORMATION

http://thebeatsheet.com.au/sorghum/management-of-rutherglen-bug-in-seedling-crops-sorghum-and-sunflower/

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2008/09/RUTHERGLEN-BUG-SORGHUM-MIDGE-AND-DIAGNOSING-POOR-SEED-SET-IN-GRAIN-SORGHUM

Control

- If the threshold is exceeded, control of RGB should occur from flowering to soft dough. Although large populations often occur close to harvest, there is no impact on yield from RGB activity post physiological maturity. The RGB are feeding on the plant, not on the seed.
- There are no soft chemical options for the control of RGB. Repeated influxes of migrating adults can make repeat applications necessary.
- Control of the adults is generally recommended because of the rapid population build-up as well as the difficulty of controlling nymphs hidden within the sorghum head. Carbaryl and maldison are registered for their control. [35]
- For details on current chemical control options, see Pest Genie or APVMA. [36]

Natural enemies

Egg parasitoids are the most commonly recorded natural enemy of RGB. Their potential contribution to population control will be limited in seasons when there are large influxes of adults. Predation has rarely been recorded, but spiders may play a role. [37]

7.5.2 Sorghum head caterpillar (*Cryptoblabes adoceta)*

This pest in more prevalent in tropical and sub-coastal areas of north-eastern Australia. It may be confused with *Helicoverpa* and yellow peach moth.

Damage

- Larvae feed on developing seed, each larva destroys ~0.5 g of grain.
- They web clusters of seed together.

Monitoring

- Presence of caterpillars is indicated by webbing of seed clusters, webbing of whole heads and presence of small white–pink excreta.
- Count larvae on heads by dislodging them from sorghum heads into a bucket.

Thresholds

- Action levels vary with commodity prices and the cost of insecticides.
- The threshold level can be calculated using the factor of 0.5 g of grain destroyed by the larva.
- The threshold is usually in the range of 5–10 larvae/head.

Control

- Open-headed sorghum varieties are generally less infested that tight-headed varieties and also allow better penetration of insecticides.
- There are currently no registered products against sorghum head caterpillar but chemicals targeting *Helicoverpa* are likely to be effective.
- For chemical control options, consult Pest Genie or APVMA.

Natural enemies

- Parasitic wasps provide some biological control, but are unlikely to control populations above 10/m^2.

35 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

36 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

37 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

- The avoidance of broad-spectrum pesticides prior to flowering (e.g. for aphids or armyworm) will help conserve natural enemies. [38]

7.5.3 Yellow peach moth (*Conogethes punctiferalis)*

This pest may be confused with *Helicoverpa* and sorghum head caterpillar.

Damage

Larvae feed on developing seed. Each larva destroys ~1 g of grain.

Monitoring

Count larvae during milky dough stage and by dislodging them from heads into a bucket.

Thresholds

The level varies with factors such as commodity price and cost of insecticide. The level can be calculated using the factor of 1 g of grain destroyed per larva. The threshold usually works out to be 2–5 larvae/head.

Control

- Open-headed sorghum varieties are generally less infested than tight-headed varieties because they allow better penetration of insecticides.
- Chemical control is cost-effective. For current control options, see Pest Genie or APVMA.

Natural enemies

The avoidance of broad-spectrum pesticides prior to flowering will help conserve natural enemies. Parasitic wasps provide some biological control. [39]

MORE INFORMATION

http://www.grdc.com.au/Resources/Ute-Guides

38 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

39 QDAF (2012) Insect pest management in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/ipm-information-by-crop/insect-pest-management-in-sorghum

Nematode management

Root-lesion nematodes (RLN; *Pratylenchus* spp.) are microscopic, worm-like animals that extract nutrients from plants, causing yield loss. In the northern grains region, the predominant RLN, *P. thornei*, costs the wheat industry A$38 million [1] annually, and including the secondary species, *P. neglectus*, RLN are found in three-quarters of fields tested.

Intolerant crops such as wheat and chickpeas can lose 20–60% [2] in yield when nematode populations are high. Resistance and susceptibility of crops can differ for each RLN species; for example, sorghum is resistant to *P. thornei* but susceptible to *P. neglectus*. A tolerant crop yields well when large populations of RLN are present (the opposite is intolerance). A resistant crop does not allow RLN to reproduce and increase in number (the opposite is susceptibility). [3]

Successful management relies on:

- farm hygiene to keep fields free of RLN
- growing tolerant varieties when RLN are present, to maximise yields
- rotating with resistant crops to keep RLN at low levels [4]

Nematodes reduce yields in intolerant wheat cultivars and reduce the amount of water available for plant growth.

Nematodes also impose early stress that reduces yield potential despite the availability of water and nutrients.

Maintaining a low nematode population improves crop yields. [5]

MORE INFORMATION

vGRDC Tips and Tactics: Root-Lesion Nematodes

MORE INFORMATION

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/How-nematodes-reduce-yield

Root lesion nematodes importance impact and management

8.1 Background

Root-lesion nematodes use a syringe-like 'stylet' to extract nutrients from the roots of plants (Figure 1). Plant roots are damaged as RLN feed and reproduce inside plant roots. *Pratylenchus thornei* and *P. neglectus* are the most common RLN species in Australia. In the northern grains region, *P. thornei* is the predominant species but *P. neglectus* is also present. These nematodes can be found deep in the soil profile (to 90 cm depth) and are found in a broad range of soil types, from heavy clays to sandy soils. Wheat is susceptible to both *P. thornei and P. neglectus*. [6]

New CSIRO research funded by the Grains Research and Development Corporation (GRDC) is examining how nematodes inflict damage by penetrating the outer layer of wheat roots and restricting their ability to transport water.

1 GM Murray, JP Brennan (2009) The current and potential costs from diseases of wheat in Australia. Grains Research and Development Corporation Report. https://www.grdc.com.au/~/media/B4063ED6F63C4A968B3D7601E9E3FA38.pdf

2 KJ Owen, T Clewett, J Thompson (2013) Summer crop decisions and root-lesion nematodes: crop rotations to manage nematodes – key decision points for the latter half of the year, Bellata. GRDC Grains Research Update, July 2013.

3 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

4 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

5 GRDC (2014), How nematodes reduce yield. http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/How-nematodes-reduce-yield

6 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

MORE INFORMATION

Soil Quality Pty Ltd nematode survey results

GRDC Parasitic Plant Nematodes (Northern Region Fact Sheet)

http://www.daff.qld.gov.au/__data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf

Figure 1: *Microscope image of a root-lesion nematode. Notice the syringe-like 'stylet' at the head end, which is used for extracting nutrients from the plant root. This nematode is less than 1 mm long.*

Photo: Sean Kelly, Department of Agriculture and Food, Western Australia

8.2 Symptoms and detection

Root-lesion nematodes are microscopic and cannot be seen with the naked eye in the soil or in plants. The most reliable way to confirm the presence of RLN is to have soil tested in a laboratory. Fee-for-service testing of soil offered by the PreDicta B root disease testing service of the South Australian Research and Development Institute (SARDI) can determine levels of *P. thornei* and *P. neglectus* present. [7]

Similar results can be obtained by soil testing either by manual counting (under microscopes) or by DNA analysis (PreDicta B), with commercial sampling generally at depths of 0–15 or 0–30 cm. [8]

Vertical distribution of *P. thornei* in soil is variable. Some paddocks have relatively uniform populations down to 30 cm or even 60 cm, some will have highest *P. thornei* counts at 0–15 cm depth, whereas other paddocks will have *P. thornei* populations increasing at greater depths, e.g. 30–60 cm. Although detailed knowledge of the distribution may be helpful, the majority of on-farm management decisions will be based on presence or absence of *P. thornei* confirmed by sampling at 0–15 or 0–30 cm depth.

Signs of nematode infection in roots include dark lesions or poor root structure. The damaged roots are inefficient at taking up water and nutrients—particularly nitrogen (N), phosphorus (P) and zinc (Zn)—causing symptoms of nutrient deficiency and wilting in the plant shoots. Intolerant wheat varieties may appear stunted, with yellowing of lower leaves and poor tillering (Figure 2). These symptoms may not be present in other susceptible crops such as barley and chickpea. [9]

7 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

8 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

9 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

MORE INFORMATION

http://www.sardi.sa.gov.au/products__and__services/entomology/diagnostic_services/predicta_b

Figure 2: *Symptoms of root-lesion nematode infection of an intolerant wheat variety include yellowing of lower leaves, decreased tillers and wilting. There are no obvious symptoms in the susceptible chickpea and faba bean plots on either side of the wheat.*

Photo: Kirsty Owen, QDAF

8.2.1 What is seen in the paddock?

Although symptoms of RLN damage in wheat can be dramatic, they can easily be confused with nutritional deficiencies and/or moisture stress.

Damage from RLN is in the form of brown root lesions but these can be difficult to see or can also be caused by other organisms. Root systems are often compromised, with reduced branching, reduced quantities of root hairs and an inability to penetrate deeply into the soil profile. The RLN create an inefficient root system that reduces the ability of the plant to access nutrition and soil water.

Visual damage above ground from RLN is non-specific. Yellowing of lower leaves is often observed, together with reduced tillering and a reduction in crop biomass. Symptoms are more likely to be observed later in the season, particularly when the crop is reliant on moisture stored in the subsoil.

In the early stages of RLN infection, localised patches of poorly performing wheat may be observed. Soil testing of these patches may help to confirm or eliminate RLN as a possible issue. In paddocks where previous wheat production has been more uniform, a random soil-coring approach may be more suitable. Another useful indicator of RLN presence is low yield performance of RLN-intolerant wheat varieties. [10]

8.3 Management

MORE INFORMATION

GRDC Update Paper: High performance crop sequences for Southern Queensland

There are four key strategies for the management of RLN (Figure 3):

1. Test soil for nematodes in a laboratory.
2. Protect paddocks that are free of nematodes by controlling soil and water run-off and cleaning machinery; plant nematode-free paddocks first.
3. Choose tolerant wheat varieties to maximise yields (www.nvtonline.com.au). Tolerant varieties grow and yield well when RLN are present (Figure 4).
4. Rotate with resistant crops to prevent increases in RLN (Table 1, Figure 5). When large populations of RLN are detected, you may need to grow at least two resistant crops consecutively to decrease populations. In addition, ensure that

10 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

MORE INFORMATION

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Latest-nematode-summer-and-winter-crop-rotation-results

fertiliser is applied at the recommended rate so that the yield potential of tolerant varieties is achieved. [11]

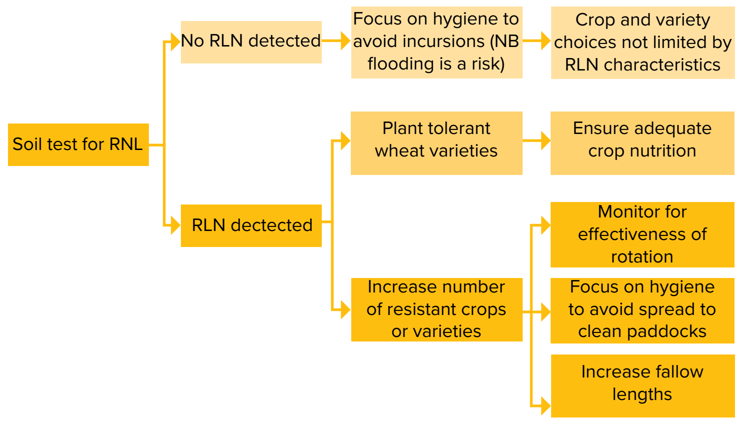


Figure 3: *Root-lesion nematode management flow-chart.*

Other considerations include:

- **Nematicides.** There are no registered nematicides for RLN in broadacre cropping in Australia. Screening of potential candidates is conducted, but RLN are a very difficult target, with populations frequently deep in the soil profile.
- **Nutrition.** Damage from RLN reduces the ability of cereal roots to access nutrients and soil moisture and can induce nutrient deficiencies. Under-fertilising is likely to exacerbate RLN yield impacts; however, over-fertilising is unlikely to compensate for a poor variety choice.
- **Variety choice and crop rotation.** These are currently our most effective management tools for RLN. However the focus is on two different characteristics: tolerance, i.e. ability of the variety to yield under RLN pressure; and resistance, i.e. impact of the variety on RLN build-up. Note that varieties and crops often have varied tolerance and resistance levels to *P. thornei* and *P. neglectus*.
- **Fallow.** Populations of RLN will decrease during a 'clean' fallow, but the process is slow and expensive in lost 'potential' income. Additionally, long fallows may decrease arbuscular mycorrhiza (AM) levels and create more cropping problems than they solve. [12]

Table 1: *Susceptibility and resistance of various crops to root-lesion nematodes.* [13]

RLN species	Susceptible	Intermediate	Resistant
P. thornei	Wheat, chickpea, faba bean, barley, mungbean, navy bean, soybean, cowpea	Canola, mustard, triticale, durum wheat, maize, sunflower	Canary seed, lablab, linseed, oats, sorghum, millet, cotton, pigeon pea
P. neglectus	Wheat, canola, chickpea, mustard, sorghum (grain), sorghum (forage)	Barley, oat, canary seed, durum wheat, maize, navy bean	Linseed, field pea, faba bean, triticale, mungbean, soybean

11 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

12 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

13 KJ Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

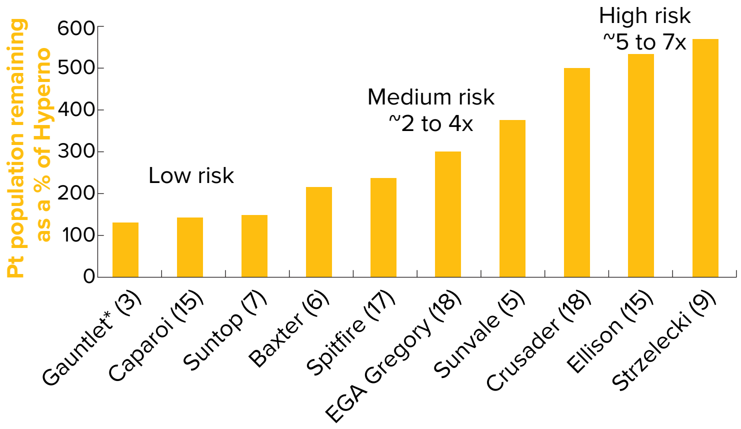


Figure 4: *Impact of crop varieties on RLN multiplication, Brendan Burton, Northern Grower Alliance.* [14]

Figure 5: *Crop rotation to manage root-lesion nematodes depends on the nematode species present in your field. Mungbeans (left) are susceptible to* P. thornei *but resistant to* P. neglectus. *By contrast, sorghum (right) is resistant to* P. thornei *but susceptible to* P. neglectus.

Photo: Kirsty Owen, QDAF

Canola is now thought to have a 'biofumigation' potential to control nematodes, and a field experiment has compared canola with other winter crops or clean-fallow for reducing *P. thornei* population densities and improving growth of *P. thornei*-intolerant wheat (cv. Batavia) in the following year.

Immediately after harvest of the first-year crops, populations of *P. thornei* were lowest following various canola cultivars or clean-fallow and highest following susceptible wheat cultivars (1957–5200 *v.* 31,033–41,294 *P. thornei*/kg dry soil). Unexpectedly, at planting of the second-year wheat crop, nematode populations were at more uniform, lower levels (<5000/kg dry soil), regardless of the previous season's treatment, and remained that way during the growing season, which was quite dry.

Growth and grain yield of the second-year wheat crop were poorest on plots previously planted with canola or left fallow due to poor colonisation with AM fungi, with the exception of canola cv. Karoo, which had high AM fungal colonisation and low wheat yields. There were significant regressions between growth and yield

14 http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Impact-of-crop-varieties-on-RLN-multiplication

MORE INFORMATION

https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Summer-crop-decisions-and-root-lesion-nematodes

http://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-109-Mar-Apr-2014/Variety-choice-and-crop-rotation-key-to-managing-root-lesion-nematodes

http://www.nga.org.au/results-and-publications/download/325/grdc-update-papers-diseases/root-lesion-nematodes-in-winter-cereals/grdc-grower-update-paper-spring-ridge-warialda-burren-junction-warra-condamine-jul-aug-2014.pdf

parameters of the second-year wheat and levels of AM fungi following the pre-crop treatments.

Canola appears to be a good crop for reducing *P. thornei* populations, but the dependence of subsequent crops on AM fungi should be considered, particularly in the northern grains region. [15]

8.3.1 Crop rotation

P. neglectus was found in 32% of paddocks (often in combination with *P. thornei*) in the northern region in a survey of 800 paddocks (Thompson *et al.* 2010). Summer crops that are partially resistant or poor hosts of *P. neglectus* include sunflower, mungbean, soybean and cowpea. When these crops are grown, populations of *P. neglectus* do not increase because the crops do not allow the nematode to reproduce.

In a field experiment, populations of *P. neglectus* increased after growing grain sorghum (Figure 4). Populations increased from 3.1 times after MR32⟮D (4,400 *P. neglectus*/kg soil) to 7.3 times after MRGoldrush⟮D (10,400 *P. neglectus*/kg soil) compared to soil at planting (1,400 *P. neglectus*/kg soil). [16]

Summer crops have an important role in management of RLN. Research shows that when *P. thornei* is present in high numbers, two or more resistant crops in sequence are needed to reduce populations to low enough levels to avoid yield loss in the following intolerant, susceptible wheat crops. [17]

Key points

- One resistant crop in sequence may not be enough to decrease damaging populations of *P. thornei*.
- Management of *P. thornei* by growing several resistant crops works, and populations can be reduced to very low levels. However, ongoing vigilance by testing soil for nematodes is essential when susceptible crops are planted.

8.3.2 Latest summer-crop rotation trial

Two summer-crop rotation trials were conducted by QDAF in adjacent fields in December 2011:

- The first field had low *P. thornei* populations (<125/kg soil or 0.125/g soil). The previous cropping history was five resistant crops since 2004 (cotton, maize and sorghum).
- The second field had moderate *P. thornei* populations (range 2000–3000/kg soil (or 2–3/g soil) at 0–90 cm soil depth). The previous cropping history was wheat, sorghum, wheat (Figure 6).

Several cultivars of mungbeans, soybeans, sunflowers, maize and sorghum were planted in each field in December 2011 in a replicated design with sufficient plots to plant wheat cvv. EGA Wylie⟮D (tolerant) and Strzelecki⟮D (intolerant) in 2013. There was also an unplanted, bare fallow treatment. After harvest of the summer crops, nematode populations were recorded to 120 cm soil depth.

15 KJ Owen, TG Clewett, JP Thompson (2010) Pre-cropping with canola decreased *Pratylenchus thornei* populations, arbuscular mycorrhizal fungi, and yield of wheat. *Crop & Pasture Science* 61, 399–410.

16 http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Summer-crop-decisions-and-root-lesion-nematodes

17 K Owen, T Clewett, J Thompson (2013) Summer crop decisions and root-lesion nematodes: crop rotations to manage nematodes – key decision points for the latter half of the year, Bellata. GRDC Grains Research Update, July 2013.

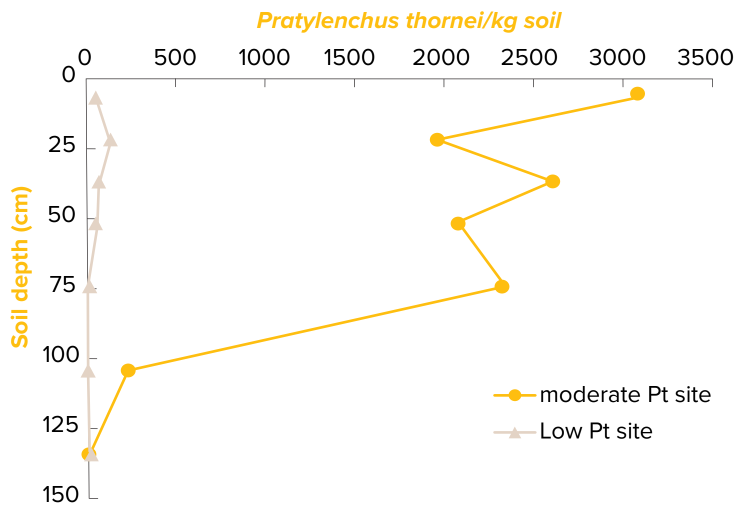


Figure 6: *Starting populations of* Pratylenchus thornei *(Pt) in the summer crop rotation experiments in adjacent fields.*

Moderate P. thornei site

Pratylenchus thornei was found to 90 cm soil depth and populations were greatest at 0–15 cm soil depth (Figure 7).

Populations of *P. thornei* after growing sorghum, sunflowers and maize were similar to populations after bare fallow (range 2900–4500/kg soil at 0–15 cm; Figure 7). There were no significant differences between varieties within each of these crop species (Figure 8).

By contrast, populations of *P. thornei* increased after growing mungbeans or soybeans compared with sunflowers, sorghum, maize or clean fallow (Figure 7). There were also differences between varieties of soybean and mungbean (Figure 8).

Soybean cv. Soya791⁽ᴅ was moderately resistant (4800 *P. thornei*/kg soil at 0–15 cm) and its effect did not differ significantly from the fallow treatment. However, all other soybean varieties were very susceptible. Populations of *P. thornei* increased 4–6.7 times to 12,000–20,600 *P. thornei*/kg soil at 0–15 cm (Figure 8).

Mungbean cv. Emerald⁽ᴅ was moderately resistant (3400 *P. thornei*/kg soil) and its effect did not differ significantly from the fallow treatment. However, all other mungbean varieties tested were susceptible, and *P. thornei* populations increased 2.2–3.8 times to 6700–11,700 *P. thornei*/kg soil at 0–15 cm (Figure 8).

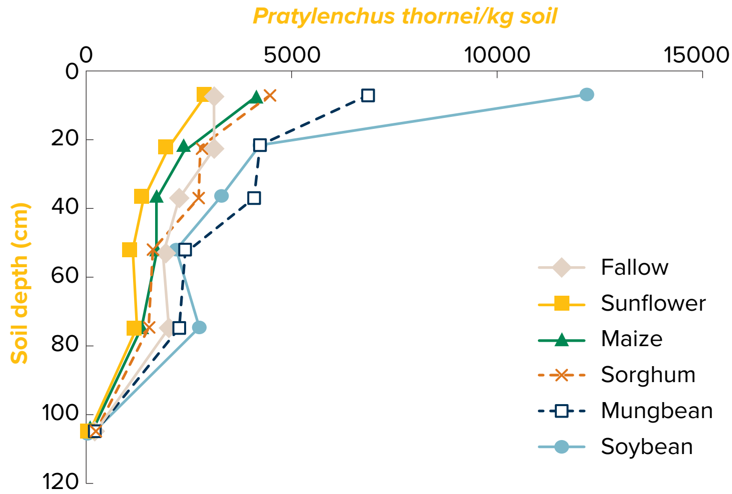


Figure 7: *Populations of* Pratylenchus thornei *increased after growing mungbeans and soybeans. After growing sunflowers, maize and sorghum, populations were similar to the bare fallow (blue line). Means of varieties within each crop are presented for the moderate* P. thornei *site.*

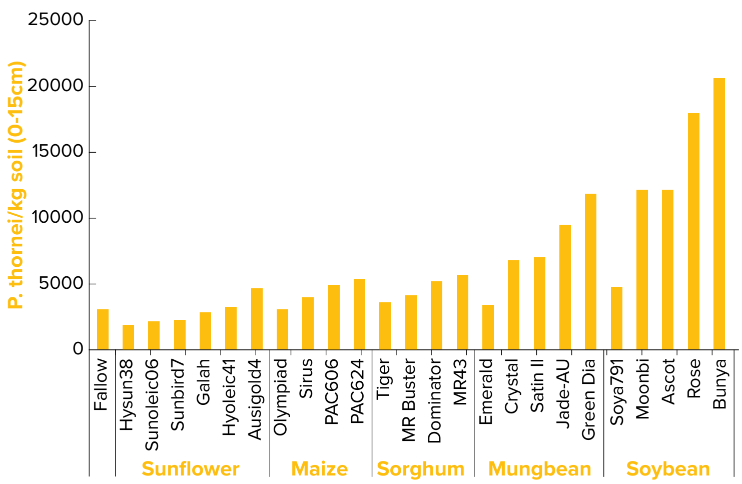


Figure 8: *After harvest of the summer crops,* Pratylenchus thornei *was found in highest populations at 0–15 cm soil depth. Varieties of sunflowers, maize, sorghum, mungbean cv. Emerald⦶ and soybean cv. Soya791⦶ did not differ significantly from the fallow treatment. 'Green Dia' is mungbean cv. Green Diamond⦶.*

Low P. thornei site

Pratylenchus thornei was detected to 60 cm soil depth; below that depth, populations were very low or zero (Figure 9).

There were no significant differences in *P. thornei* populations after the different summer crops or the varieties.

Overall, populations increased five times compared with those before planting the summer crops, but remained below 250/kg soil (Figure 9).

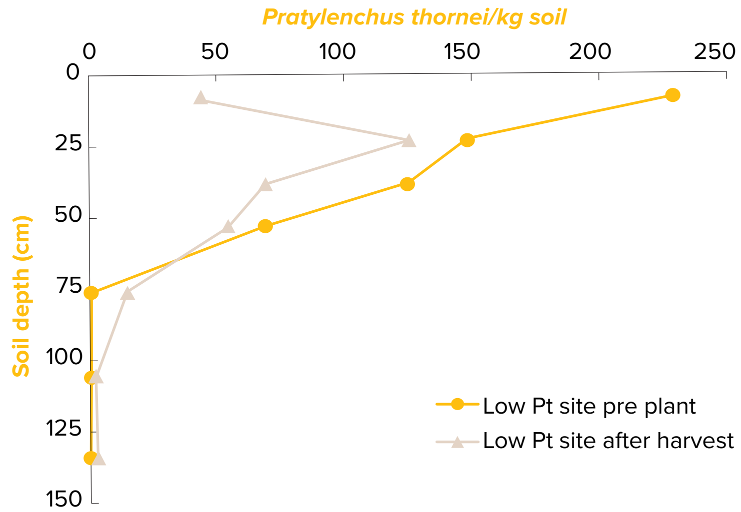


Figure 9: Pratylenchus thornei *(Pt) populations after harvest of the summer crops at the low Pt site. Mean data for all crops are presented; there were no significant differences between crops or varieties.*

Summer crop biomass and yield

There were no differences in biomass or grain yield of the summer crops between the low and moderate *P. thornei* sites. The summer crops used were tolerant to *P. thornei* so they did not suffer yield loss.

Impact on the next wheat crop

At the site that started with moderate *P. thornei* populations, the yield of the intolerant wheat cv. Strzelecki⫽ was reduced by 49% compared with the tolerant wheat cv. EGA Wylie⫽ (1900 kg/ha after Strzelecki⫽ compared with 3700 kg/ha after EGA Wylie⫽). By contrast, at the site that started with low *P. thornei* populations, there was only a 4% difference in yield between cvv. Strzelecki⫽ and EGA Wylie⫽ (3600 and 3700 kg/ha, respectively). The yield of cv. Strzelecki⫽ increased 47%, or 1700 kg/ha, at the low *P. thornei* site compared with the moderate *P. thornei* site (Figure 10).

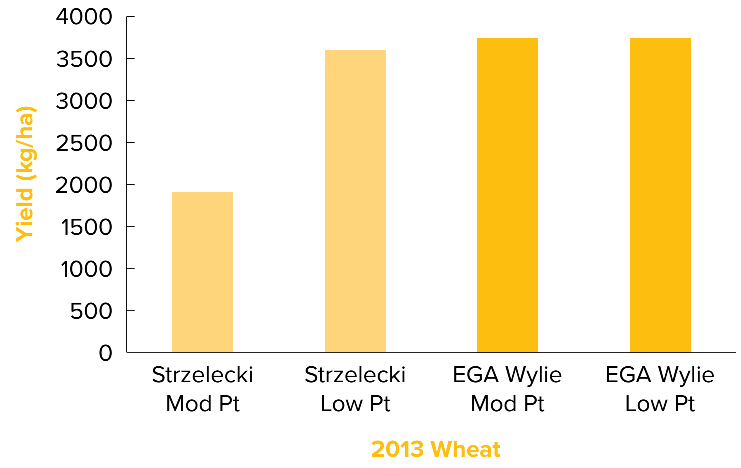


Figure 10: *Yield of the intolerant wheat cv. Strzelecki⦶ was reduced by 47% in the experiment that started with moderate* P. thornei *populations (Mod Pt; 2000–3000/ kg soil before the trial started) compared with the low* P. thornei *site (Low Pt; <125/ kg soil before the trial started). ⦶ All varieties listed are protected under the Plant Breeders Rights Act 1994.*

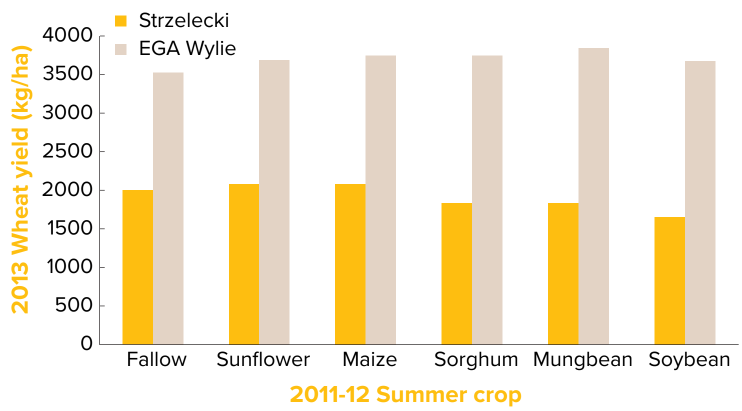


Figure 11: *Yield of the 2013 intolerant wheat cv. Strzelecki⦶ and tolerant cv. EGA Wylie⦶ at the site that started with moderate* P. thornei *populations (2000–3000/kg soil at 0–90 cm soil depth) before planting the summer crops in 2011–12.*

Yield of wheat cv. Strzelecki⦶ was lowest following soybean (1600 kg/ha) and highest following maize and sunflowers (2100 kg/ha) (Figure 11). An unexpected result was that there were no significant differences in yield of cv. Strzelecki⦶ after fallow, sorghum and mungbeans. This result may be partly due to dry conditions during the 2011–12 summer and following winter season, which limited nematode multiplication, particularly after the susceptible mungbean.

Additionally and importantly, the results support that one resistant crop in sequence was not enough to reduce populations of *P. thornei* sufficiently. Nevertheless, there was a strong negative relationship between populations of *P. thornei* after the summer crops and yield of the following intolerant wheat cv. Strzelecki⦶. By contrast, there was no relationship between populations of *P. thornei* and yield of tolerant wheat cv. EGA

Wylie⫯ (Figure 12), which is an expected result because of the high level of tolerance of EGA Wylie⫯ to *P. thornei*.

At the low *P. thornei* site, there was no relationship between yields of the tolerant and intolerant wheat and populations of *P. thornei* after growing the summer crops. Populations were below the damage threshold for wheat cv. Strzelecki⫯.

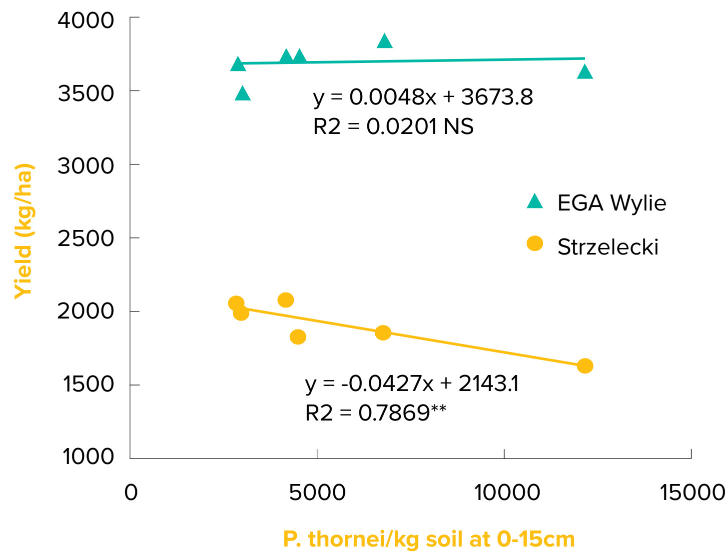


Figure 12: *There was a strong negative relationship between populations of* Pratylenchus thornei *after the 2011–12 summer crops and yield of following wheat cv. Strzelecki⫯ (P = 0.01,n = 6). By contrast, there was no significant relationship between yield of cv. EGA Wylie⫯ and populations of* P. thornei. *Data are from the moderate* P. thornei *site (2000–3000/kg soil at 0–90 cm soil depth before the trial began) and means for five summer crops and a fallow treatment are plotted.*

8.4 Varietal resistance or tolerance

A tolerant crop yields well when large populations of RLN are present (in contrast to an intolerant crop). A resistant crop does not allow RLN to reproduce and increase in number (in contrast to a susceptible crop) (Table 2).

Table 2: *Combinations and examples of tolerance and resistance* [18]

There are four possible combinations of resistance and tolerance:	
Tolerant–resistant	**Tolerant–susceptible**
e.g. sorghum cv. MR43 to *P. thornei and wheat breeding lines released for development*	e.g. wheat cv. EGA Gregory to *P. thornei*
Intolerant–resistant	**Intolerant–susceptible**
No commercial wheat lines in this category	e.g. wheat cv. Strzelecki to *P. thornei*

Tolerance and resistance of wheat varieties to RLN are published each year at www.nvtonline.com.au or in *Wheat varieties for Queensland*.

18 K Owen, T Clewett, J Thompson (2013) Summer crop decisions and root-lesion nematodes: crop rotations to manage nematodes – key decision points for the latter half of the year, Bellata. GRDC Grains Research Update, July 2013.

MORE INFORMATION

Impact of cereal varieties on the build-up of Pratylenchus thornei across three sowing dates – Narrabri 2013: Steven Simpfendorfer, Rick Graham, Guy McMullen p96

Impact of cereal variety and crown rot on the build-up of Pratylenchus neglectus – Bithramere 2013 p99

Impact of wheat variety choice on the build up of Pratylenchus thornei – Wongarbon 2013, Steven Simpfendorfer, Finn Fensbo, Robyn Shapland. p101

Impact of crop varieties on RLN multiplication

Current GRDC-funded research by the NGA and NSW DPI is examining the importance of crop and variety choice. The NGA has run large and complex trials and results are outlined in the GRDC Update Paper.

Growers are advised to recognise that there are consistent varietal differences in *P. thornei* and *P. neglectus* resistance within wheat and chickpea varieties; to avoid crops or varieties that allow the build-up of large populations of RLN in infected paddocks; and to monitor the impact of rotations.

The QDAF and NSW DPI wheat variety guides detail the level of variety tolerance to both species of RLN. Selection of wheat varieties based on these published RLN tolerance rankings is critical to avoid significant yield losses, particularly in paddocks with large populations of *P. thornei*.

GRDC-funded researchers are currently incorporating *P. thornei* resistances found in a wheat line selected from the variety Gatcher⚲ and some wheat landraces from West Asia and North Africa into pre-breeding efforts. Excellent resistance to *P. thornei* and *P. neglectus* has been found in synthetic hexaploid wheats.

Resistances are being incorporated into some of the most tolerant wheat varieties, including EGA Gregory⚲ and EGA Wylie⚲, to produce parents that are adapted to the northern region. [19]

8.4.1 Tolerance

Wheat breeding has provided a number of varieties with moderate or higher levels of tolerance to *P. thornei*, e.g. Sunvale⚲, Baxter⚲, EGA Wylie⚲ and EGA Gregory⚲. These varieties will reduce the level of yield loss due to *P. thornei*.

At a trial site near Yallaroi in 2012, a range of crops and varieties was grown and performance evaluated under relatively 'low' and 'high' starting population densities of *P. thornei* (~2,000 and 19,000 nematodes/kg soil). Figure 14 shows the impact of *P. thornei* on yield of varieties with a range of tolerance levels.

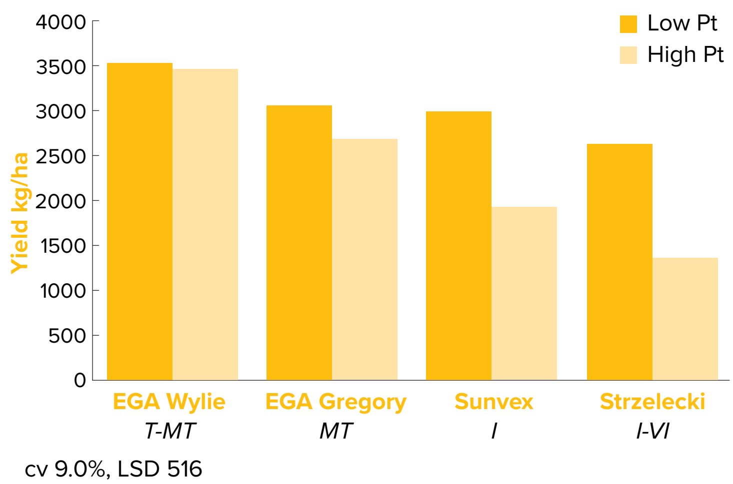


Figure 13: *Comparison of wheat variety yields under 'low' and 'high' starting population densities of* P. thornei *(Pt) near Yallaroi 2012 (Trial RH1213).*

*Indicates significant yield difference within a variety between 'low' and 'high' P. thornei strips at P = 0.05.

Codes below variety names are the QDAF published ratings of P. thornei tolerance: T, tolerant; MT, moderately tolerant; I, intolerant; VI, very intolerant.

NB: What was categorised as the 'low' starting population density of P. thornei was still equal to the current industry threshold. At this level, significant yield losses (up to 20%) may occur in intolerant wheat varieties. Consequently, the measured yield impact between 'low' and 'high' P. thornei in this trial is an underestimate of the full P. thornei affect. [20]

19 J Thompson, J Sheedy, N Robinson, R Reen, T Clewett, J Lin (2012) Pre-breeding wheat for resistance to root-lesion nematodes. GRDC Grains Research Update, Goondiwindi, March 2012.

20 K Owen, J Sheedy, N Seymour (2013) Root lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

The varieties rated as *P. thornei* intolerant (Strzelecki⦇ and Sunvex⦇) suffered significant yield reductions of 35–48 % in this trial when grown in the 'high' *P. thornei* plots. Yield losses of ~1–1.25 t/ha were recorded, with economic losses >$250/ha. The two varieties that were more tolerant (EGA Wylie⦇ and EGA Gregory⦇) did not suffer a significant yield reduction.

Choosing tolerant varieties will limit the yield and economic impact from *P. thornei*; however, some of these varieties still allow high levels of nematode build-up. The second issue to be considered is variety resistance/susceptibility. [21]

8.4.2 Resistance

Resistance is the impact of the variety on RLN multiplication. Eradication of RLN from an individual paddock is highly unlikely, so effective long-term management is based on choosing options that limit RLN multiplication. This involves using crop or varieties that have useful levels of *P. thornei* resistance and avoiding varieties that will cause large 'blow-outs' in *P. thornei* numbers.

Resistance differences between crops

The primary method of managing RLN populations is to focus on increasing the number of resistant crops in the rotation. Knowledge of the species of RLN present is critical, as crops that are resistant to *P. thornei* may be susceptible to *P. neglectus*. Key crops that are generally considered resistant or moderately resistant to *P. thornei* are sorghum, sunflower, maize, canola, canary seed, cotton, field peas and linseed.

Wheat, chickpeas, faba beans, mungbeans and soybeans are generally susceptible, although the level of susceptibility may vary between varieties.

Resistance differences between commercial wheat varieties

Resistance ratings for wheat varieties to RLN have been available for many years; however, the development of high-throughput DNA analysis has enabled an increased amount of testing to compare RLN build-up between varieties under field conditions. These data appear to be a very useful addition to our current knowledge on varietal resistance, with relative variety performance fairly consistent across sites. Figure 15 shows the relative performance of a range of varieties as a percentage of EGA Gregory⦇ in a wide range of trials during 2009–2012.

21 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

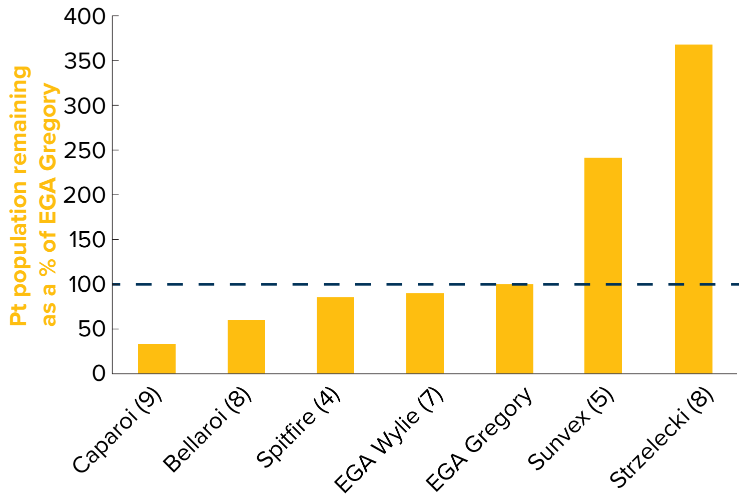


Figure 14: *Comparison of* P. thornei *(Pt) population remaining as a percentage of EGA Gregory⟑, 2009–2012. Values in parentheses are the number of trials in which the variety was compared with EGA Gregory⟑. The red broken line indicates the Pt level remaining after EGA Gregory⟑.*

Bread wheats are generally susceptible to *P. thornei* but there are large differences between varieties in the level of susceptibility. Growers with *P. thornei* infestations must avoid 'sucker' varieties that result in very high levels of *P. thornei* multiplication. Although durum wheats generally restrict *P. thornei* multiplication compared with bread wheats, they are very susceptible to crown rot. [22]

22 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? Northern Grower Alliance/GRDC Update Paper, 16/07/2013.

Diseases

9.1 Sorghum ergot (*Claviceps africana*)

Sorghum ergot is a fungus whose spores compete with pollen at flowering. Ergots are creamy-coloured sclerotes usually smaller than sorghum seed that replace the developing seed.

Sorghum ergot has been found in late-flowering commercial grain crops in northern NSW. It has also occurred in seed production crops in the Macquarie Valley and at Boggabri, and in late-flowering forage sorghum crops in the Moree and Gunnedah districts. It is difficult to estimate the impact of sorghum ergot on yields of commercial grain crops in NSW.

The fungus infects sorghum heads at flowering and is favoured by mild temperatures (15–30°C), high humidity and overcast conditions. Ergot spores compete with pollen in the unfertilised florets, decreasing grain-set and potential yield (Figure 1). [1]

Breeding lines with high resistance to ergot have been funded by GRDC and bred by the Department of Agriculture, Fisheries and Forestry Queensland (QDAF) Sorghum Breeding team, and released under licence to the private breeding companies. If the transfer of resistance to hybrids is successful, the use of ergot-resistant lines will not only significantly reduce the risk from ergot, but also allow the broadening of planting windows. [2]

MORE INFORMATION

http://www.daff.qld.gov.au/plants/field-crops-and-pastures/research/sorghum-research-program

Figure 1: *Honeydew oozing on a grain sorghum head caused by* Claviceps africana *(ergot).*

Photo: QDAF Qld

1 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

2 QDAF (2011) Disease management for sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management

9.1.1 Recommended practices to minimise risk

Agronomic practices can minimise risk of sorghum ergot:

- Sow at recommended times.
- Ensure even flowering (use press-wheels, high-germination seed, accurate seed depth control; good crop nutrition, wide row spacing (90–100 cm), especially with hybrids that tiller heavily, and consider pre-harvest kill-off of tillers using glyphosate herbicide)
- Graze forage sorghum heavily to delay flowering until after grain sorghum has flowered. This reduces inoculum levels and hence the potential for ergot infection of grain sorghum.
- Crops should be inspected for ergot 10–14 days after flowering during cool, wet weather, particularly around the edges.
- Estimate infection levels of ~100 heads (an average level of <0.3% or 1% of infected spikelet per head should be safe, depending on the intended use of the grain).
- Spray-out plants if late tillers are infected.
- Increase fan speed of headers to maximise sclerote removal during harvesting.
- Harvest heavily contaminated areas of the crop separately.
- Consider mixing ergot-contaminated sorghum with clean seed to reduce ergot sclerote levels to <0.3% or 0.1%, depending on the intended use of the grain. [3]

To reduce the risk of ergot in northern NSW, plant crops by early January so that they flower by mid-March (when the weather is hotter and drier than it is later in autumn). Crops with poor pollination risk the same infections as do forage sorghum crops, tillers of late-flowering plants, late-sown grain crops and those affected by cold temperatures during flowering.

Sorghum ergot can cause harvest delays, with the sticky honeydew clogging machinery. At levels >0.3% by weight, ergot is toxic to livestock. If precautions are in place to ensure that ergot levels are <0.3% by weight, the grain is within safe usage levels for many end-users. [4]

If planting outside the recommended window, growers need to aim for an evenly flowering crop to ensure large quantities of highly viable pollen during flowering, because flowers that are fertilised by pollen are resistant to infection by the ergot spores.

In late-planted crops, a quick-maturing, low-tillering hybrid will also help to minimise the ergot risk. Even then, ergot can develop if there is persistent rainfall during the flowering period.

Pre-harvest spraying of grain sorghum crops with a herbicide registered for that purpose (e.g. glyphosate) is commonly used to aid in rapid plant dry-down and harvesting. In ergot-affected crops, it will also assist in stopping the production of honeydew. [5]

9.1.2 The impact of wet summers

Wet summers often encourage growers to consider planting a late-summer grain sorghum crop.

However, crops planted after the end of January in southern Queensland and mid-February in central Queensland run an increased risk of ergot infection, an airborne fungal disease that is favoured by cool wet conditions during flowering.

3 QDAF (2011) Wet summers increase ergot risk in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/wet-summers-increase-ergot-risk-in-sorghum

4 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

5 QDAF (2011) Wet summers increase ergot risk in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/wet-summers-increase-ergot-risk-in-sorghum

In a La Niña year, the chances of these conditions occurring from April onwards, when late-planted crops will flower, are higher than in other years. [6]

9.1.3 How ergot affects the crop

The disease reduces yield through poor seed set and can cause harvesting difficulties from the sticky honeydew on the heads. Honeydew is modified plant sap, so it will be produced from infected heads for as long as the plant is alive. [7] Fungal bodies, called sclerotes, which replace the seed, are toxic to livestock, particularly cows, sows and beef cattle.

There is no known resistance to ergot in Australian grain sorghum hybrids, and fungicide control is not practical because of the high cost of the effective fungicides. Therefore, management relies on good agronomic practices.

9.1.4 Impact on animals

Research by QDAF has clearly shown that milk production in lactating cows and sows can be seriously reduced if there is >0.3% by weight of ergot sclerotes in sorghum grain.

Weight gains in feedlot cattle can be significantly impaired by even lower ergot levels of 0.1%. Limits set on ergot-infected sorghum grain intended for stockfeed reflect these critical levels. [8]

9.1.5 At harvest

At harvest, a high percentage of sclerotes are blown from the header because they are lighter than sorghum grain, so increasing the header fan speed may further reduce the levels of contamination. The worst affected parts of the paddock should be harvested last and kept separate from areas with less ergot. [9]

What to do with ergot-infected crops

Marketing options are limited for grain that is contaminated by ergot above the legislated limits. It can be mixed with clean grain to reduce the levels of contamination. Laying hens, broiler chickens and growing pigs >20 kg are generally more tolerant of ergot than other livestock, so those markets offers an option for ergot-affected grain at or near the 0.3% limit. [10]

MORE INFORMATION

vGRDC Update Paper: Disease control in summer crops and management strategies to minimise financial losses

9.2 Fusarium stalk rot (*Fusarium* spp.)

Fusarium stalk rot in sorghum is caused by a range of *Fusarium* species; however, research by QDAF has identified *Fusarium thapsinum* and *F. andiyazi* as the major species causing disease in Australia (Figure 2).

6 QDAF (2011) Wet summers increase ergot risk in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/wet-summers-increase-ergot-risk-in-sorghum

7 QDAF (2011) Wet summers increase ergot risk in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/wet-summers-increase-ergot-risk-in-sorghum

8 QDAF (2011) Wet summers increase ergot risk in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/wet-summers-increase-ergot-risk-in-sorghum

9 QDAF (2011) Wet summers increase ergot risk in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/wet-summers-increase-ergot-risk-in-sorghum

10 QDAF (2011) Wet summers increase ergot risk in sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/wet-summers-increase-ergot-risk-in-sorghum

MORE INFORMATION

http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/fusarium-stalk-rot

Figure 2: *Fusarium stalk rot causes red internal discoloration of sorghum stalks*

Photo: QDAF, Qld

9.2.1 Symptoms

The most obvious and important of symptoms is crop lodging. However an orange-red discoloration of the pith tissue inside the stalks, often centred around the nodes, also occurs. [11]

Lodging is often the first obvious sign of Fusarium stalk rot in sorghum plants, but the diagnostic symptoms of the disease are usually not evident until the plants are stressed. When a stalk infected by *Fusarium* is split lengthwise, a pink–red discoloration is evident from ground level up the stem.

Stalks can be infected by *Fusarium* but not lodge; this depends on the strength of the stalk, and on the speed at which *Fusarium* invades the stalk. The latter is influenced by the severity of the stress and perhaps by the tolerance of the hybrid. *Fusarium* or other stalk-rotting pathogens may not be the sole cause of crop lodging; physiological (non-biotic) stress factors can often be the cause. [12]

MORE INFORMATION

http://espace.library.uq.edu.au/view/UQ:270992

http://ausgrain.com.au/Back%20Issues/194ndgrn09/Nv-lodging.pdf

http://www.grdc.com.au/uploads/documents/2010ASGCPowerPointPresentationsPDF/Keller_FusariumInSorghum_slides.pdf

http://www.nga.org.au/results-and-publications/download/48/australian-grain-articles/diseases-1/fusarium-stalk-rot-of-sorghum-may-2010.pdf

9.2.2 Conditions favouring development

Fusarium stalk rot is favoured by a period of physiological stress. This may be moisture stress as a result of seasonal conditions or stress caused by the application of a desiccant. Additional research is required to differentiate between the main causes of *Fusarium* spp. and charcoal rot (*Macrophomina phaseolina*).

9.2.3 Management

Any practices that minimise moisture stress on the crop should be encouraged. However, rotation with non-host crops is also recommended. Currently, sorghum species are the only known hosts of *Fusarium thapsinum* and *F. andiyazi.* The use of desiccants is suspected of increasing crop lodging; so, when they are applied to sorghum crops, harvesting should be carried out as soon as practical. [13]

During a La Niña summer, sorghum crops are at increased risk from Fusarium stalk rot. The mild wet weather is conducive to root infection from the soil-borne *Fusarium* species, which in turn can result in increased stalk rot. Climatic stress during late

11 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

12 QDAF (2011) Fusarium stalk rot. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/fusarium-stalk-rot

13 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

grainfill, or after pre-harvest spraying, can lead to rapid development of stalk rot and may result in lodging. [14]

For further information see Charcoal rot 9.3.3 Management

9.2.4 Northern Grower Alliance trials

Trials were conducted by the Northern Grower Alliance (NGA) in collaboration with QDAF pathologists in the 2009–10 (two trials) and 2010–11 (one trial) seasons in northern NSW and southern Queensland to address the questions:

- Can *Fusarium* species (and *Macrophomina phaseolina*) cause yield loss in the absence of lodging?
- Is there a link between spray-out of sorghum with glyphosate and lodging?

The following treatments were used in one or more of the trials:

- four varieties in 2009–10, two varieties in 2010–11
- +/– *Fusarium* inoculum (grown on sterile pearl millet seed or stubble from infected crop) (all trials)
- +/– fungicide seed dressing (2010–11 trial only)
- +/– two fungicide sprays (2009–10 trial only)
- +/– desiccant spray of glyphosate (all trials)

In 2009–10, the roots of 20 young plants from each plot were inspected for the presence of red discoloration (a symptom of *Fusarium* infection), and 30 isolates were obtained from randomly selected plants in uninoculated plots. In all trials, ~7–10 days after glyphosate had been applied to the appropriate plots, 10 plants from each plot were cut off at ground level, the stalks split lengthwise and the numbers of discoloured internodes counted. In the 2010–11 trial, a second rating was made 24 days after the first. All three trials were harvested and the grain yield of every plot was measured.

Major findings of the trials

Inoculum

The roots of plants in all treatments in the 2009–10 trials were discoloured, including plants in treatments that had not been inoculated; either *F. thapsinum* or *F. andiyazi* was isolated from all 30 roots. This result suggests that the *Fusarium* species were already present at high levels in the soil at both sites, despite sorghum having not been grown at one site for 4 years, and in living memory at the other. In the 2009–10 trials, a similar amount of stalk discoloration occurred in the inoculated and non-inoculated plots that had been sprayed with glyphosate. In the 2010–11 trial, the mean stalk-rot severity ratings of the treatments that were not inoculated were consistently lower than those that were inoculated.

Fungicides

Neither the seed dressing treatment (2010–11 trial) nor the fungicide spray treatment (2009–10 trials) significantly reduced the incidence or severity of internal stalk discoloration due to *Fusarium* infection.

Desiccation

In the 2009–10 trials, at harvest there was little stalk discoloration in non-desiccated treatments (average 0–0.6 internodes discoloured, depending on the treatment) but significant discoloration in desiccated plots (average 6.1–9.3 internodes). Similarly, in the 2010–11 trial there was a higher mean number of discoloured nodes in every treatment that had a glyphosate application compared with the same treatment without the glyphosate application, with the differences being statistically significant

14 QDAF (2011) Fusarium stalk rot. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/fusarium-stalk-rot

(average of glyphosate sprayed plots 3.8 internodes, average of unsprayed plots 1.5 internodes).

Variety

Two hybrids (A and B) were common to the three trials. In all trials, hybrid A had significantly more stalk discoloration than hybrid B after the glyphosate sprays. In the 2010–11 trial, when no desiccant was applied there were no statistical differences in final stalk-rot severity between the two varieties. However, in the sprayed treatments, stalk rot developed more rapidly in hybrid B than in hybrid A, and in unsprayed treatments, the reverse was true. These results suggest that there may be differences in the response of hybrids to pre-harvest desiccant sprays.

Yield

Lodging did not occur in any of the three trials. There were no significant differences in yield between treatments in any of the three trials, indicating that Fusarium stalk rot did not cause yield loss in the absence of lodging after the soft finishes experienced in the trials. It is possible that yield losses from Fusarium stalk rot could occur in the absence of lodging during a hard finish.

Strategies for managing Fusarium stalk rot

- Agronomic practices to minimise stress need to be followed. Crops should be sown into paddocks with good soil moisture, and row spacing and plant densities should be optimum for the paddock situation to reduce moisture stress. Weeds need to be managed not only to minimise moisture stress but also to eliminate a possible method of carryover onto grass weeds of the *Fusarium* species that cause stalk rot. Despite the ability of *F. thapsinum* and *F. andiyazi* to survive for up to 3 years in infected stubble, overseas work indicates that nil or minimum tillage practices can significantly reduce the incidence of Fusarium stalk rot compared with conventional tillage practices.
- Rotations with non-host crops will reduce the build-up of the *Fusarium* species that cause stalk rot. Based on current knowledge, sorghum species are the only known hosts of *F. thapsinum* and *F. andiyazi*, the dominant species causing stalk rot in the northern grains region. Although maize has not been recorded as a host of *F. thapsinum* in Australia, it is possible that the pathogen could survive on maize stubble, based on overseas reports. Evidence from the 2011 season indicates that the wheat head blight fungus, *Fusarium graminearum*, can colonise sorghum plants when there are high inoculum levels in the field and prolonged wet weather during flowering. Therefore, care should be taken when using sorghum in rotation with wheat in regions where the climate favours the carryover of high inoculum levels of *F. graminearum*.
- The use of desiccant herbicide to aid in harvesting should be carefully evaluated in paddocks where sorghum stalk-rotting pathogens have been found in the past. The desiccant herbicide must be applied when >95% of the seed is at the 'black layer' stage, because there is some evidence that lodging is more likely to occur the earlier that crops are sprayed. Prompt harvesting after desiccation will minimise the impact of lodging if stalk-rotting pathogens are present. Results from the 2010–11 trial indicate that Fusarium stalk rot can also develop in the absence of desiccation, so harvesting should not be delayed even when crops are not sprayed out.
- Lodging resistance is a major trait that seed companies select for in their development of new hybrids. Selection sites may or may not have a history of *Fusarium* or charcoal rot infection, so resistance to the stalk-rotting pathogens may or may not be a component of lodging resistance. There is evidence that hybrids with good 'staygreen' resistance have a better tolerance to invasion by *Macrophomina phaseolina* than 'non-staygreen' hybrids, but there is no clear evidence that it confers tolerance to stalk invasion by *Fusarium* species. Preliminary work conducted in conjunction with NGA suggests that commercial

MORE INFORMATION

http://www.nga.org.au/results-and-publications/download/48/australian-grain-articles/diseases-1/fusarium-stalk-rot-of-sorghum-may-2010.pdf

http://www.nga.org.au/results-and-publications/download/48/australian-grain-articles/diseases-1/fusarium-stalk-rot-of-sorghum-may-2010.pdf

PODCAST

Arthur Gearon grower at Chinchilla Queensland and GRDC northern panellist discusses the impact of charcoal rot on sorghum yield and management options. GRDC Podcast: 122 The Right Water - the missing ingredient in successful spraying

hybrids differ in their tolerance to the development of Fusarium stalk rot; this area of research needs further investigation. [15]

9.3 Charcoal rot (*Macrophomina phaseolina*)

Charcoal rot in sorghum is caused by the soil borne fungus *Macrophomina phaseolina* and is a major stalk rotting disease in sorghum which can lead to plant lodging. The causal agent, *M. phaseolina* can infect via the roots of sorghum plants at almost any stage of plant growth, but develops more rapidly in plants closer to maturity.

The fungus is widely distributed throughout Australia infecting the root and stems of over 400 plant species (all major summer field crops and many summer and winter weeds). The microsclerotes can survive in the soil and on stubble for >4 years. It is uncertain what soil conditions are necessary to reduce the survival of microsclerotes in Australia but overseas studies indicate wet soil can significantly impede their survival. [16]

9.3.1 Symptoms

The pathogen is easily identifiable when stems are split longitudinally. The characteristic appearance of black microsclerota (resting bodies) in the vascular tissue and inside the rind of the stalk results in a 'peppered' look in conjunction with shredded internal vascular tissue which is grey/charcoal in colour.

9.3.2 Conditions favouring development

Extensive colonisation of stem tissue generally occurs post flowering when plants are placed under a stress, such as unfavourable environmental conditions, particularly hot, dry conditions. This can be further exacerbated by the application of defoliants which also act as a stressor, further promoting growth and invasion of the stem. [17]

9.3.3 Management

Management strategies for *Fusarium* stalk rot and charcoal rot are closely related. There are no effective foliar fungicides for either disease. Management strategies that need to be taken into consideration include the following: [18]

- Soil moisture—planting into adequate soil moisture and ensure row spacing and plant populations are suitable for the field and seasonal situation, to minimise possible post flowering moisture stress.
- Adequate nutrition—application of adequate fertilisers should be exercised to maintain plant health and vigour reducing nutrient related stress. More specifically, excessive N and low levels of K should be avoided.
- Crop rotations—rotating out of susceptible crop hosts can be effective in reducing the build-up of *Fusarium* and/or *M. phaseolina* which may have occurred in mono-cropping systems. Currently, the host range of *F. thapsinum* and *F. andiyazi* is thought to be limited, providing a number of options for rotations. However, alterations and additions to the list are possible as maize is thought to host *F. thapsinum* at low levels and more recently a survey overseas has found infection of *F. thapsinium* on soybean seed. In Australia, surveys and research into possible hosts, including the role of stubble from alternative non-hosts is still ongoing. Rotating out of susceptible crop hosts is more difficult with

15 M Ryley, L Kelly, L Price (2011) Fusarium stalk rot in sorghum types, damage and management. GRDC Update Papers 13 September 2011

16 J White, S Thompson, M Ryley, S Blake, C Douglas (2015) Disease control in summer crops and management strategies to minimise financial losses, GRDC Update Papers 31 July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Disease-control-in-summer-crops-and-management-strategies-to-minimise-financial-losses

17 J White, S Thompson, M Ryley, S Blake, C Douglas (2015) Disease control in summer crops and management strategies to minimise financial losses, GRDC Update Papers 31 July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Disease-control-in-summer-crops-and-management-strategies-to-minimise-financial-losses

18 J White, S Thompson, M Ryley, S Blake, C Douglas (2015) Disease control in summer crops and management strategies to minimise financial losses, GRDC Update Papers 31 July 2015, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Disease-control-in-summer-crops-and-management-strategies-to-minimise-financial-losses

M. phaseolina due to its extensive host list. Overseas research suggests that the build-up of microsclerotes is less in some hosts than in others; in some U.S. trials the number of microsclerotes in the soil after several crops of sorghum was less than the numbers after maize or soybeans. This type of rotational farming systems work has not yet been conducted in Australia.

- Use of lodging resistant, drought tolerant, non-senescent varieties. In the absence of information regarding the genetics for resistance for *M. phaseolina* and *Fusarium*, which are not well understood, the use of cultivars which include some or all of the combined characteristics (drought tolerance, staygreen, standability) may reduce the development of disease, particularly charcoal rot. While evidence has previously shown that staygreen lines have a better tolerance to *M. phaseolina* invasion than senescent lines, there is no conclusive evidence yet to suggest that this holds true for *Fusarium* species. Preliminary results from field trials where cultivars were colonised with both *M. phaseolina* and *Fusarium*, demonstrate that assessment of disease levels based on internal lesion lengths correlated well with assessments for lodging. However, the absence of lodging does not preclude high incidence levels of either disease, which means caution should be taken to avoid build-up of disease unknowingly, particularly in monoculture systems.
- Application and timing of desiccant and harvest. Timing of application of a desiccant must be assessed with a number of factors in mind. Early application of a desiccant can increase stress and lodging potential (if applied when <95% seed are at black layer) as much as a desiccant applied too late, particularly if lodging is already occurring and disease incidence is high. Timely harvest once application of the desiccant has been applied is essential. Preliminary results demonstrate some varietal differences in reaction to application of a desiccant which needs further investigation to determine its role, if any in affecting structural integrity of the stem.

9.4 Rust (*Puccinia purpurea*)

9.4.1 Symptoms

Early symptoms on leaves are small purple–red or tan spots. These enlarge to produce elongated raised pustules that break open to release brown, powdery masses of spores.

Sorghum rust is more serious in late-sown crops or susceptible hybrids in humid areas. If the disease is serious, leaves are destroyed and pinching of the grain results. Select hybrids with resistance for late planting.

Leaf rust is a serious disease in susceptible hybrids in humid coastal areas. The incidence of leaf rust in northern NSW has increased in recent years.

9.4.2 Conditions favouring development

The spores germinate on wet leaves, penetrating the leaf and will then take ~10–14 days for the pustules to appear. The spores are primarily dispersed by wind. Little is known about the fungus but suggestions are that the rust tends to occur in cool wet conditions.

9.4.3 Management

Although rust often appears in autumn at the end of grainfill in northern NSW, it does not usually reduce yields. If severe it can reduce yields and contribute to lodging in susceptible hybrids. [19]

19 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

9.5 Johnson grass mosaic virus

9.5.1 Symptoms

Symptoms of this virus are a mosaic (light and dark-green lines on veins):

- red leaf (severe leaf reddening, followed by formation of red spots or large areas of dead tissue)
- red stripe (red or tan stripes parallel to the veins)

Hybrids developing red leaf or red stripe reaction should not be sown late, as the disease can be serious, causing stunting and death in some plants. The virus is spread from plant to plant by aphids.

Control by planting resistant hybrids. A strain of the virus exists in south and central Queensland that can infect resistant hybrids. [20]

9.6 Head smut (*Sporisorium reilianum*)

9.6.1 Symptoms

Symptoms appear at the booting stage when the head is replaced by a mass of black spores enclosed in a white fungal membrane:

- This membrane ruptures on emergence of the head and releases the spores.
- Partially affected heads are sterile.

Head smut is a soil-borne disease favoured by cool weather. It may also be introduced on the seed. Control by sowing resistant hybrids. Also avoid sowing susceptible hybrids in cool weather. [21]

9.7 Leaf blight (*Exserohilum turcicum*)

9.7.1 Symptoms

Symptoms are large elliptical spots up to 20 mm wide and 100 mm long, initially water-soaked, but drying to straw-coloured spots with red, purple or tan margins, depending on the hybrid.

Spores produced on leaf spots during moist weather are spread by wind. The fungus survives on undecomposed sorghum residues, volunteer sorghum plants and Johnson grass. Severe disease can cause pinched grain and lower yields. The disease may be serious on susceptible hybrids under humid conditions and in coastal areas.

Control by sowing resistant hybrids where the disease may be a problem. [22]

20 QDAF (2011) Disease management for sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management

21 QDAF (2011) Disease management for sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management

22 QDAF (2011) Disease management for sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management

Plant growth regulators and canopy management

Not applicable for this crop.

Crop desiccation/spray out

Desiccation allows crops to be harvested earlier and more efficiently. Herbicide application at this time can also be used as a salvage weed spray.

A pre-harvest spray of knockdown herbicides glyphosate or Reglone® can be applied to sorghum immediately after physiological maturity has been reached. This will hasten dry-down of the grain and should kill or desiccate the crop.

The timing of the pre-harvest sprays is critical. Crops should be sprayed preferably before the end of March when the temperatures are still warm and the crops are green. The aim is to maximise yield through the assimilation of carbohydrate in the seed, but balance this moisture use with the need to store water for the next crop.

When 95–100% of the grains have formed a 'black layer' (i.e. are physiologically mature) (Figure 1), the crop is ready to be desiccated. Sprayed crops should be harvested as soon as they have dried down and the withholding period for the herbicide has been met, as they are more prone to lodging.

Figure 1: *Researchers say the black layer on this sorghum seed is 'close to ideal' for spray-out.*

Recent research by the NSW Department of Primary Industries (NSW DPI) and the Northern Grower Alliance (NGA) has shown that significant reductions in yield and quality occur when crops are sprayed prior to physiological maturity. By contrast, when spraying is delayed beyond physiological maturity, the amount of water stored in the profile is reduced.

Desiccated crops stop using moisture and therefore allow soil moisture storage in the profile to begin. Many growers in northern NSW have found that in wet summers, spraying out an early sorghum crop for harvest has given them a higher return over 14 months, because it also allowed them to grow a successful double crop such as chickpeas. [1]

MORE INFORMATION

http://www.nga.org.au/results-and-publications/browse/20/sorghum-spray-out

http://www.nga.org.au/results-and-publications/download/21/grdc-update-papers-general-/sorghum-spray-out-1/grdc-adviser-update-paper-dalby-august-2008-.pdf

http://www.farmingahead.com.au/News/efarmingnews/9574/spray-out-timing-critical-for-sorghum-crop-success

http://www.farmingahead.com.au/News/efarmingnews/7530/trials-increase-timing-confidence-in-sorghum-spray-out

1 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

11.1 Sorghum spray-out timing

Sorghum spray-out with glyphosate is a common practice for sorghum growers in both NSW and Queensland.

Desiccation can be used to:

1. Manipulate time to harvest and assist in paddock harvest scheduling
2. Maximise potential soil water available for the following crop by reducing late season transpiration losses
3. Increase the effective length of the fallow period to maximise future cropping opportunities

Desiccating the crop too early can result in greater lodging, particularly if harvest is then delayed, and may affect both grain yield and quality. Desiccating too late, however, provides poor returns on the spray operation and may result in lost soil moisture, which will limit future planting options.

Sorghum growers and advisers in Queensland have appeared more comfortable with an optimal timing of sorghum spray-out largely based on grain black-layer (abscission zone) development.

However, industry feedback from northern NSW indicated that growers and advisers were frequently much more conservative in their spray-out timing. A project funded by the Grains Research and Development Corporation (GRDC) was established to help validate the impact of spray-out timing and, consequently, assist growers and advisers in their decision-making.

11.1.1 Trial design

Nine trials were conducted during the 2007–08 and 2008–09. In 2007–08, two small plot trials were established in commercial sorghum paddocks on the Liverpool Plains. Paddocks were targeted where growers indicated that they were at least 4 weeks from commercially planned desiccation. Plots consisted of four rows of 20 m length arranged in a completely randomised block design with four replications.

Both trials evaluated five desiccation timings, applied at approximately weekly intervals (Table 1). Glyphosate (Roundup® CT) was applied at 1.6 L/ha in all applications using a hand-boom.

Table 1: *Timing of desiccation sprays 2007-08 (variety in parentheses).*

Application	Wandobah (Pacific MR43)	Pine Ridge (MR Buster)
Timing 1	27 March 08	27 March 08
Timing 2	3 April 08	3 April 08
Timing 3	10 April 08	10 April 08
Timing 4	18 April 08	18 April 08
Timing 5	29 April 08	30 April 08

In 2008–09, seven trials were established from Goondiwindi, Queensland, to Premer, NSW. Trial commencement was determined differently from 2007–08. In 2007–08, growers and advisers indicated when they believed they were ~4 weeks from commercial spray-out. In 2008–09, the first application timing was made ~14 days after flowering (DAF) on the main heads (Table 2). The trials evaluated five or six desiccation timings again applied at approximately weekly intervals. Glyphosate (Roundup PowerMAX®) was applied at 2.0 L/ha in all applications using a hand-boom.

Table 2: *Timing (days after flowering, DAF) of desiccation sprays 2008–09 (variety in parentheses)*

Application	Goondiwindi (86G56)	Goondiwindi (Pacific MR43)	Premer (MR-Buster)	Spring Ridge (Pacific MR43)	Millie (Pacific MR43)	Spring Ridge (86G56)	Pine Ridge (MR-Buster)
14 DAF	22 Dec. 08	19 Feb. 09	24 Feb. 09	9 March 09	10 March 09	-	23 March 09
21 DAF	29 Dec. 08	26 Feb. 09	3 March 09	16 March 09	17 March 09	23 March 09	30 March 09
28 DAF	5 Jan. 09	4 March 09	10 March 09	23 March 09	24 March 09	30 March 09	8 April 09
35 DAF	12 Jan. 09	12 March 09	17 March 09	30 March 09	31 March 09	8 April 09	17 April 09
42 DAF	19 Jan. 09	19 March 09	24 March 09	6 April 09	7 April 09	–	27 April 09
49 DAF	27 Jan. 09	25 March 09	–	–	15 April 09	26 April 09	–

11.1.2 Assessments

Grain samples were taken at each application to determine grain moisture. Although grain-head moisture of ~25% is a useful guide to spray-out timing and is specified on the various glyphosate labels as the maximum grain moisture under which glyphosate can be used as a pre-harvest aid, it is often difficult to measure.

The formation of the black abscission layer at the base of the seed is a more reliable and easy-to-assess parameter for growers to assess.

Plots were scored visually for leaf brown-out and using a hand-held GreenSeeker® to measure crop reflectance as NDVI (normalised difference vegetation Index) for all Liverpool Plains trials. Digital photos were taken at each of the desiccation timings to indicate grain maturity. Plots were harvested using a small-plot harvester, with grain yield, protein, screenings, hectolitre weights and grain size measured. Soil cores were taken from each plot shortly after harvest, with soil moisture determined gravimetrically.

In 2007, one trial site was ready for desiccation even when the trial commenced. Therefore, there was no impact on yield or grain quality from any timing.

11.1.3 Yield impact

Figure 2 shows the yield of each spray-out timing as a percentage of the final desiccation-timing yield. 'Safe' timings would have an average yield close to 100%.

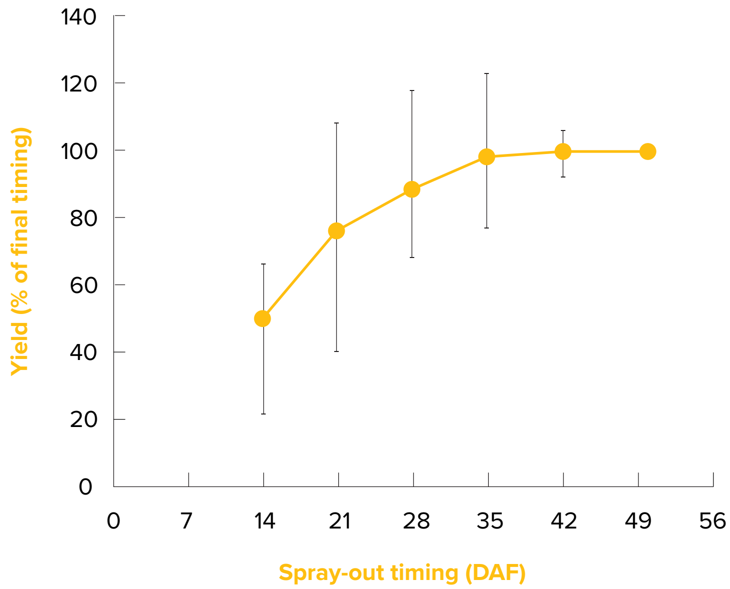


Figure 2: *Sorghum yield (%) compared with final spray-out timing in 2008 (mean of seven trials). Range bar shows maximum and minimum percentage yields, and individual points show average yield.*

11.1.4 Key messages—yield

- Spray-out at 14 DAF resulted in dramatic yield losses in all trials, with a 50% mean loss.
- Spray-out at 21 DAF was also unacceptable, with mean losses >20%.
- Spray-out at 28 DAF resulted in significant yield losses in three of the seven trials, with a yield reduction of ~10%.
- Spray-out at 35 DAF resulted in only one significant yield reduction (in a trial with larger numbers of late-maturing heads), with an average yield ~2% lower than the final desiccation timing.

11.1.5 Grain quality and spray-out timing

Spray-out at 14 DAF resulted in increased grain screenings at all sites. When applied at 21 DAF, spray-out significantly increased screenings at four of six sites. There was no significant impact on screenings from application at 28 DAF or later.

There were large decreases in test weight with the 14 DAF timing. Test weight was unaffected when desiccation occurred at 28 DAF or later.

11.1.6 Soil-water impact

Soil water was measured at each site by taking cores from each plot shortly after harvest. Soil-water contents were compared with those of the final desiccation timing at each site. The greatest water savings were from early application timings but these were associated with unacceptable yield losses. There was some inconsistency in soil-moisture benefit, especially with 86G56. With spray-out timing at 35 DAF or later, the average soil moisture benefit was <10 mm, with 24 mm the largest benefit measured.

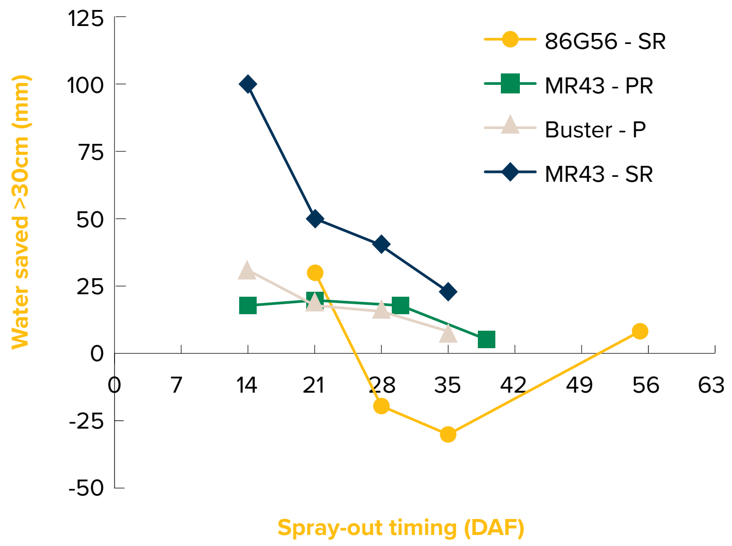


Figure 3: *Soil moisture saved below 30 cm from sites on the Liverpool Plains in 2008, relative to the final desiccation timing.*

Most of the water that was remaining in the profile though was deeper in the profile (below 30 cm). This soil water is significantly more valuable to the next crop in the sequence, because it is used later in the season and results in higher Water Use Efficiency at this time. Timing spray-out correctly may save some water in the profile (Figure 3) but it also commences the fallow period sooner, stopping unproductive water use from weeds and regrowth sorghum.

11.1.7 Tools to schedule spray-out timing

Spray-out timing can safely commence after grain physiological maturity. In sorghum, grain moisture of ~25% often coincides with this stage, but is hard to measure. Data (not presented) from these trials would support that an average grain moisture of 25% is suitable to schedule desiccation, and this supports the 25% moisture cut-off that appears on various glyphosate product labels.

In 2008, the rule-of-thumb recommended by seed companies of roughly timing spray-out at 35 DAF was evaluated. This proved useful, but is likely to be influenced by operator assessment of maturity, tiller or head synchronicity, environmental conditions and, possibly, unexpected differences in variety maturity.

The 35 DAF approach appears a useful starting point to 'mark the calendar', and from there commence field inspection.

Black-layer (abscission layer) formation in field was shown to be the best tool to schedule spray-out timing safely. Using this tool ensures that growers can determine their own risk approach and modify by variety and paddock as necessary. Assessment in a uniform, solid-plant crop is rarely a problem but is more challenging when there are multiple tiller maturities and increased paddock variability.

The results from these trials suggest that the most practical approach is to identify heads of the latest maturity considered 'economic to take to harvest'. Inspect grain about two-thirds of the way down the head and ensure that black-layer formation has occurred. Although there will still be some grains below this point that are less mature, timing at this stage will ensure negligible yield or grain quality impact but will maximise the opportunity for soil-moisture retention and consequently minimise the recropping period. By waiting for every grain in late-maturing heads to reach black-layer stage, the approach will be too conservative.

MORE INFORMATION

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/03/Sorghum-sprayout-timing

Harvest

Harvesting must be done efficiently and rapidly while the crop is at its peak (Figure 1). The aim of the harvest operation is to deliver the grain in prime condition to its storage.

Timeliness of harvest is a crucial factor in ensuring maximum profit from the crop. The harvesting task requires planning, because all equipment must be set up correctly and operated efficiently. [1]

The crop requires a warm, summer growing period of 4–5 months. As a guide, medium to medium-quick varieties will flower in 60–65 days when planted in October, and 50–55 days when planted in late December.

If drying facilities are available, harvesting can commence at 25% grain moisture, followed by drying to 13–14% moisture. Grain moisture should be 13.5% delivered into storage. For long-term storage, aim for moisture content of 12%. Heads harvested at various stages of maturity can complicate harvesting and storage. [2]

Figure 1: *Sorghum harvest under way.*

The availability of good on-farm storage can speed up harvest and allow attention to the post-harvest marketing of grain. Both aeration and drying facilities may also assist in progressing harvest. It is most important that storage facilities are clean and free from grain insect pests.

Issues of trafficability should also be addressed, particularly on the heavier clay soils. Serious soil compaction can occur when soils are too wet. This can result in long-term soil damage reducing the performance of following crops. [3]

1 NSW DPI (2005) Grain sorghum. Agfact P3.3.5. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre/summer-crops/sorghum/sorghum/grain-sorghum

2 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

3 N Moore, L Serafin, L Jenkins (2014) Grain sorghum. Summer crop production guide 2014, pp. 5–16, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/303485/Summer-crop-production-guide-2014.pdf

12.1 Header settings

Drum speed should be 750–900 rpm for conventional header and 550–650 rpm for rotary header:

- new threshing bars, use slower drum speed
- old threshing bars, use standard speed
- use sorghum extension fingers (Figure 2)

Figure 2: *Sorghum harvest.*

12.2 Ergot in the crop?

If ergot is present at harvest, prepare for delays due to clogging of machinery by honeydew on the heads (Figure 3). Be prepared to sacrifice some lighter grain in order to send as much ergot as possible out the back of the header—ergots are lighter than grain. Ergots are toxic to livestock; honeydew is not. Queensland and NSW grain receival depots allow for 0.3% ergot content by weight.

To estimate levels of ergot contamination a grain sample, spread half a cupful (~100 g) of grain on to a light-coloured background and separate the different colours and shapes. After removing sound grains, >20 ergots may constitute a problem. [4]

4 QDAF (2011) Sorghum—nutrition, irrigation and harvest issues. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/nutrition,-irrigation-and-harvest

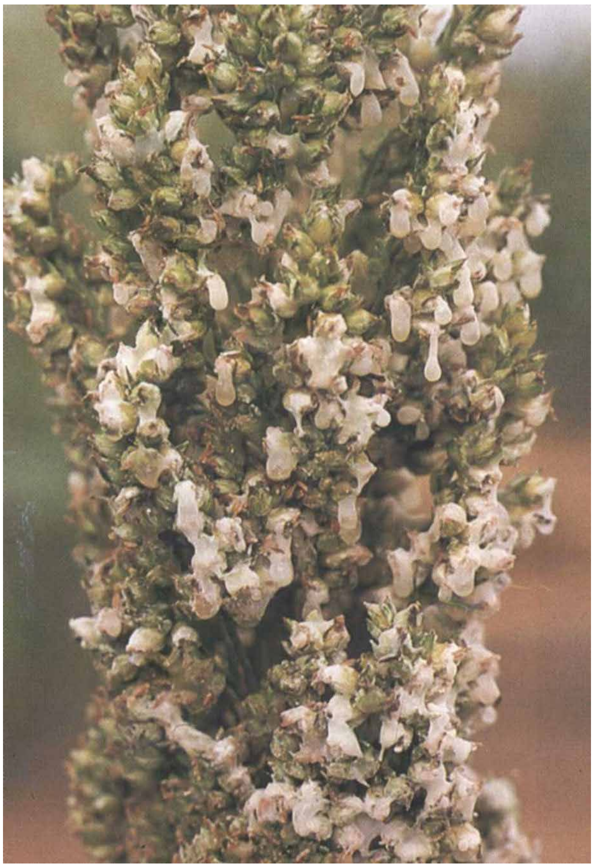


Figure 3: *Sorghum ergot—honeydew on the sorghum heads.*

The following laboratories may accept grain for ergot contamination estimation (costs may vary per sample):

SGS–Agritech Laboratory Services
214 McDougall Street
Toowoomba, Qld
Ph: +61 7 4633 0599
Fax: +61 7 4633 0711

Queensland Seed Testing Laboratory
c/- University of Queensland, Gatton
Ph: +61 7 5460 1487
Fax: +61 7 5460 1486

Seed Testing Laboratories of Australia Pty Ltd
Mansfield Qld
Ph: +61 7 3849 2744
Fax: +61 7 3849 2704

MORE INFORMATION

http://www.grdc.com.au/uploads/documents/2010ASGCSummaryPapersPDF/Griffiths_SorghumSilage_summary.pdf

http://www.grdc.com.au/Media-Centre/GRDC-Podcasts/Northern-Weekly-Update/2014/01/024

http://www.graintrade.org.au/sites/default/files/file/Commodity%20Standards/2013_2014/Section%2002%20-%20Sorghum%20Standards%20201314%20Final.pdf

PODCAST

Phil Burrill QDAF discusses storage of high moisture recently harvested sorghum. GRDC Podcast: 082 Managing sorghum moisture levels

PODCAST

Phil Burrill QDAF talks about getting things right in storages. GRDC Podcast: 119 Crown rot & Takeall warning

PODCAST

Phil Burrill QDAF discusses storage strategy. GRDC Podcast: 106 Safe seed storage strategy

MORE INFORMATION

GRDC Update Paper: Part I Achieving great aeration results and Part II Silo recirculation as an aid to fumigation

Storage

For more information, see the GRDC GrowNotes WHEAT (Northern region), Section 13: Storage.

Environmental issues

14.1 Waterlogging and flooding issues

Grain sorghum is a very water-efficient crop and is more tolerant of heat and moisture stress than is maize. Sorghum is capable of very high Water Use Efficiency, but under cooler environments with good water supply, maize will produce more grain per mm of crop potential evapotranspiration. Sorghum crop water use index ranges between 10 and 25 kg/mm, depending on the level and timing of stress and management. With careful management and today's hybrids, 25 kg/mm is possible. [1]

14.1.1 Irrigation rules of thumb

For maximum yields, the available water in the active root-zone should not drop below 50% storage capacity. At peak use, sorghum will use ~80–95 mm of water in a 1-day period.

Under flood, furrow or border-check irrigation, 12-h irrigation shifts will be ideal. If watering time is prolonged and waterlogged conditions result for >24 h at each irrigation, yield losses of up to 50% have been recorded compared with non-waterlogged areas. The rule-of-thumb is 0.2 t/ha.day of waterlogging lost. [2]

14.1.2 Stage of development

Researchers have investigated the effect of waterlogging on sorghum and sunflower in relation to stage of development (sunflowers: 6-leaf, buds-visible, anthesis; sorghum: 5-leaf, initiation, anthesis) and duration of waterlogging (3, 6 and 9 days) under glasshouse conditions.

Additionally, the potential adaptation of the two crops was observed by waterlogging some plants at all three growth stages.

Waterlogging of sorghum plants suppressed normal tillering but had little effect on dry weight of the main stem. Late tillering was stimulated by waterlogging. Reductions in leaf area occurred at all stages of development in response to waterlogging, with these effects being more marked at initiation. Similarly, yield was most reduced by the initiation waterlogging, largely a result of reduced seed number.

In neither species was there a clear relationship between duration of waterlogging and subsequent reduction in growth and yield. With respect to yield, stage of development seemed to be of greater importance than the duration of waterlogging. The growth and yield of multiple-waterlogged sunflowers was less affected by the anthesis treatment than that in plants experiencing a single waterlogging, suggesting that some form of adaptation was induced. By contrast, no such response was seen in sorghum. [3]

MORE INFORMATION

http://link.springer.com/article/10.1007%2FBF02206901

http://www.regional.org.au/au/asa/1982/contributed/irrigation-water-use/p-11.htm

http://www.moreprofitperdrop.com.au/wp-content/uploads/2013/10/WATERpak-4_2-Irrigated-Sorghum-best-practice.pdf

http://www.ruralweekly.com.au/news/sorghum-survives-inundation/1989908/

http://www.landmanager.org.au/reference/furrow-irrigation-grain-sorghum-tropical-environment-i-influence-period-inundation-and-nit

http://www.nga.org.au/results-and-publications/download/21/grdc-update-papers-general-/sorghum-spray-out-1/grdc-adviser-update-paper-dalby-august-2008-.pdf

MORE INFORMATION

GRDC Tips and Tactics: Denitrification

1 T Philip, G Harris. Irrigated sorghum—best practice. WATERpak—a guide for irrigation management in cotton and grain farming systems. pp. 298–304. Cotton CRC, guide http://www.moreprofitperdrop.com.au/wp-content/uploads/2013/10/WATERpak-4_2-Irrigated-Sorghum-best-practice.pdf

2 T Philip, G Harris. Irrigated sorghum—best practice. WATERpak—a guide for irrigation management in cotton and grain farming systems. pp. 298–304. Cotton CRC, http://www.moreprofitperdrop.com.au/wp-content/uploads/2013/10/WATERpak-4_2-Irrigated-Sorghum-best-practice.pdf

3 P Orchard, RS Jessop (1984) The response of sorghum and sunflower to short-term sunflower. Plant and Soil 81, 199–132, http://link.springer.com/article/10.1007%2FBF02206901

14.1.3 Denitrification

Denitrification is a process where bacteria convert plant-available soil nitrate (NO_3-) into nitrogen (N) gases that are lost from the soil. In normal, aerated soils, bacteria break down organic matter in the presence of oxygen to produce carbon dioxide (CO_2), water and energy. But in very wet or waterlogged soils, oxygen is rapidly depleted, so bacteria use nitrate instead of oxygen for respiration.

Soil doesn't have to be under water to have low oxygen availability. This can occur in any soil where internal drainage is restricted; for example, soil with a high clay content that drains slowly, or sandy soil over an impervious layer that impedes drainage. It can be influenced by factors such as the amount of rain, duration of rain, how wet the soil profile was, and capacity for the soil to drain internally. [4]

Key points

- Loss of soil nitrate via denitrification is usually minimal, unless soils are waterlogged.
- Denitrification, a naturally occurring process, happens when bacteria convert soil nitrate into nitrogen (N) gases that are lost from the soil. It occurs in soils nearing saturation because oxygen becomes increasingly limited.
- Bacteria need a supply of soil nitrate and readily available organic matter for denitrification to proceed. Denitrification rates are faster at hotter temperatures and in alkaline, rather than acidic, soils.
- Soil nitrate comes from mineralisation of soil organic matter, decomposition of crop residues (especially nitrogen-fixing legumes), and addition of N fertiliser.
- The source of the nitrate determines when denitrification losses may occur. For instance, in N-fertilised summer crops such as sorghum, losses can be large if heavy rains waterlog the soil during hot conditions soon after planting.
- The best way to tell how much nitrate remains in the soil pro le after an extended wet period is to have it soil cored and tested for nitrate. Denitrification is extremely variable, so growers need to test wetter areas separately from drier ones.
- Limiting future denitrification losses is difficult. However, growers can reduce the potential for denitrification by using split applications of N fertiliser, enhanced-efficiency fertilisers, growing short-season 'cover crops', improving paddock drainage, or planting in raised planting beds. [5]

MORE INFORMATION

GRDC Tips and Tactics: Managing frost risk - Northern Southern and Western Regions

14.2 Frost

Sorghum is a subtropical grass, so is susceptible to cold weather during its growth. Frosts (ground temperature <0°C) at any time will cause damage. Occasional frosts have occurred in late October on the eastern sectors of the northern grainbelt, killing plant tillers and delaying their development. Entire crop mortality is very rare.

Frosts also have a detrimental impact at the end of the season (June–August) for any crops still attempting to fill grain, typically if they have been planted very late or if they have be left to regrow. Overall, industry losses incurred as a result of frost are negligible.

For information on the effect of temperature on seed set, see GrowNotes Sorghum 3. Planting.

For information on long-fallow disorder, see GrowNotes Sorghum 1. Planning and paddock preparation.

MORE INFORMATION

https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS109

https://www.grdc.com.au/uploads/documents/2010ASGCEditedPapersPDF/Prasad_HighTemperatureTolerance_edited_paper.pdf

4 GRDC (2014) Denitrification, GRDC Fact Sheet, http://www.grdc.com.au/GRDC-FS-N-Denitrification

5 GRDC (2014) Denitrification, GRDC Fact Sheet, http://www.grdc.com.au/GRDC-FS-N-Denitrification

Marketing

The final step in generating farm income is converting the tonnes produced into dollars at the farm gate. This section provides best in class marketing guidelines for managing price variability to protect income and cash flow.

Figure 1 shows a grain selling flow chart that summarises:

- decisions to be made
- drivers behind the decisions
- guiding principles for each decision point.

The grower will run through a decision-making process each season, because growing and harvesting conditions, and prices for grains, change all the time. For example, over the five years to and including 2015, Brisbane sorghum values have varied A$90–190/t, a variability of 30–60% (Figure 2). For a property producing 500 tonnes of sorghum this means $45,000–$95,000 difference in income, depending on the timing of sales.

The reference column refers to the section of the GrowNote where you will find the details to help in making decisions. [1]

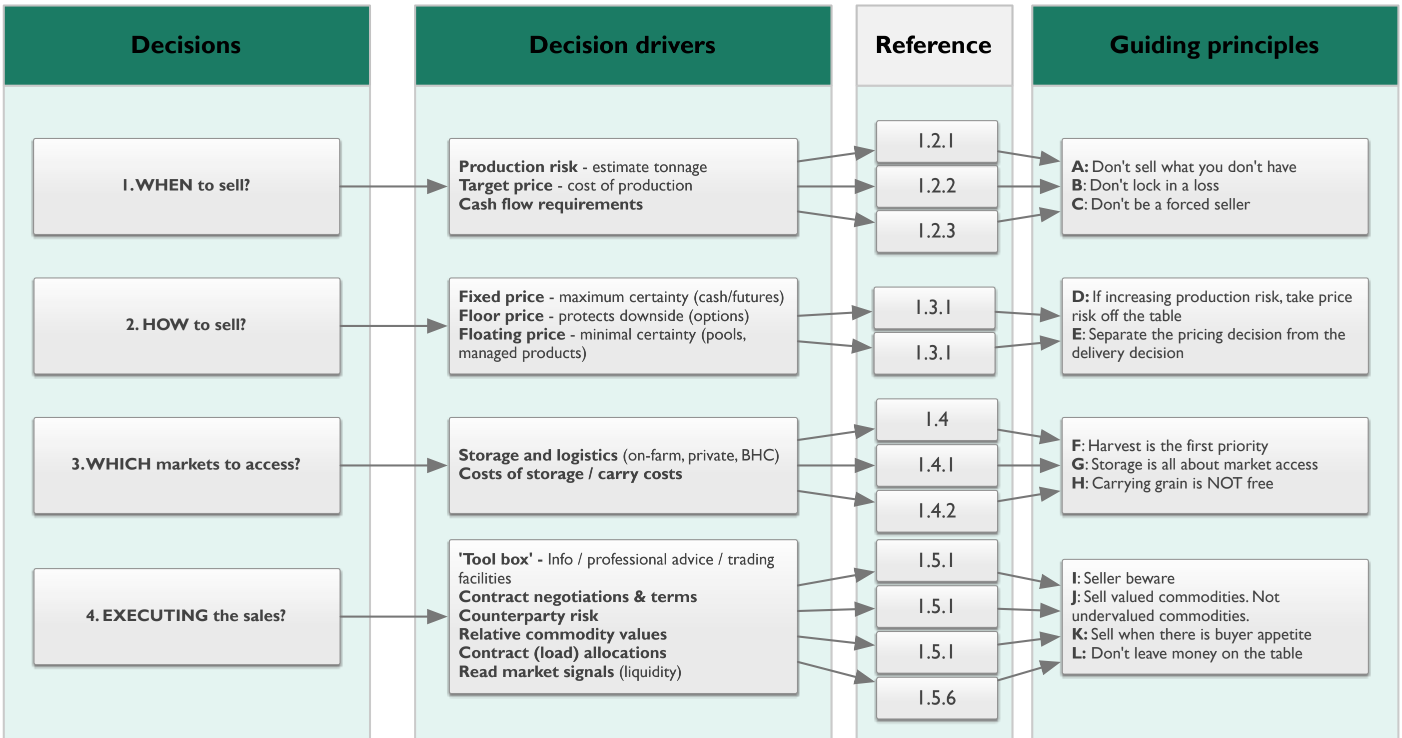


Figure 1: *Grain selling flowchart.*

1 Profarmer Australia (2016), Marketing Field Peas, GRDC Northern Field Pea GrowNote

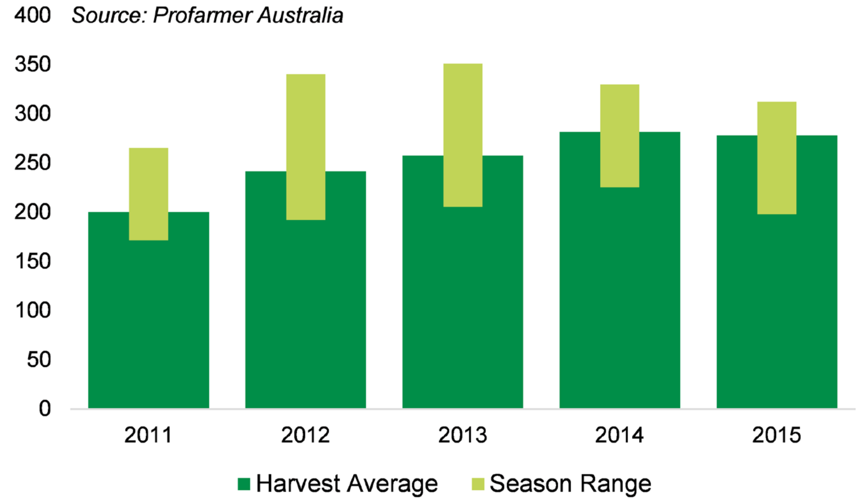


Figure 2: *Seasonal variance of Brisbane sorghum values.*

Source: Profarmer Australia

15.1 Selling principles

The aim of a selling program is to achieve a profitable average price (the target price) across the entire business. This requires managing several unknowns to establish a target price and then work towards achieving the target price.

Unknowns include the amount of grain available to sell (production variability), the final cost of producing the grain, and the future prices that may result. Australian farm-gate prices are subject to volatility caused by a range of global factors that are beyond our control and are difficult to predict.

The skills growers have developed to manage production unknowns can also be used to manage pricing unknowns. This guide will help growers manage and overcome price uncertainty. [2]

15.1.1 Be prepared

Being prepared by having a selling plan is essential for managing uncertainty. The steps involved are forming a selling strategy, and forming a plan for effectively executing sales. The selling strategy consists of when and how to sell.

When to sell

Knowing when to sell requires an understanding of the farm's internal business factors, including:

- production risk
- a target price based on the cost of production and the desired profit margin
- business cashflow requirements

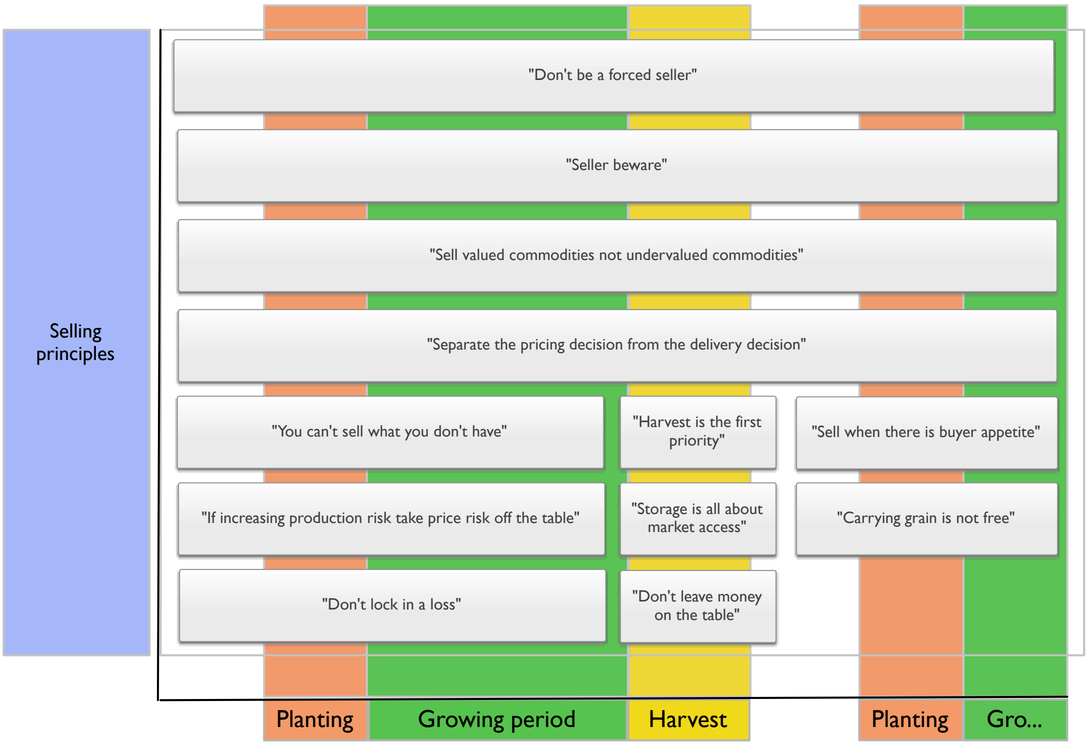
How to sell

Working out how to sell your grain is more dependent on external market factors, including:

- the time of year—determines the pricing method
- market access—determines where to sell
- relative value—determines what to sell

2 Profarmer Australia (2016), Marketing Field Peas, GRDC Northern Field Pea GrowNote

The following diagram (Figure 3) lists the key principles to employ when considering sales during the growing season. Exactly when each principle comes into play is indicated in the discussion of marketing planning and timing in the rest of section 15. [3]



Note to figure: The illustration demonstrates the key selling principles throughout the production cycle of a crop.

Profarmer AUSTRALIA

Figure 3: *Timeline of grower commodity selling principles.*

Source: Profarmer Australia

15.1.2 Establish the business risk profile

Establishing your business risk profile helps you determine when to sell: it allows you to develop target price ranges for each commodity, and provides confidence to sell when the opportunity arises. Typical business circumstances and how to quantify the risks during the production cycle are described below (Figure 4).

3 Profarmer Australia (2016), Marketing Field Peas, GRDC Northern Field Pea GrowNote

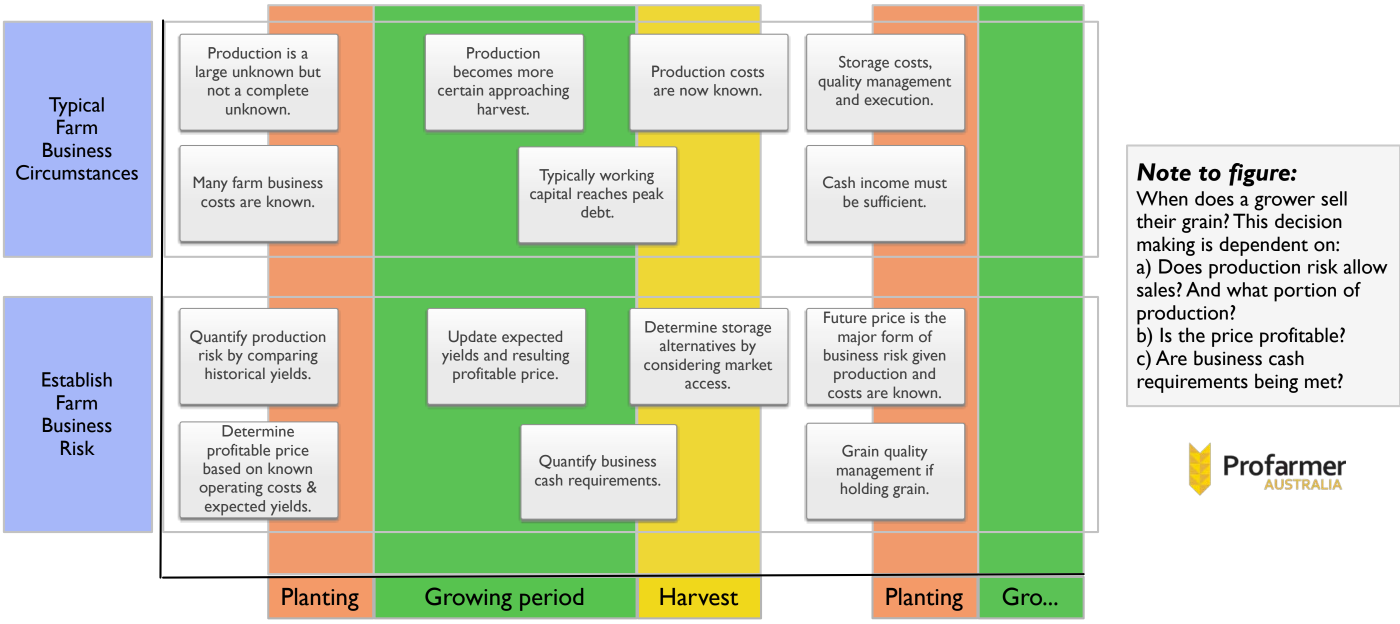


Figure 4: *Typical farm business circumstances and risk.*

Source: Profarmer Australia

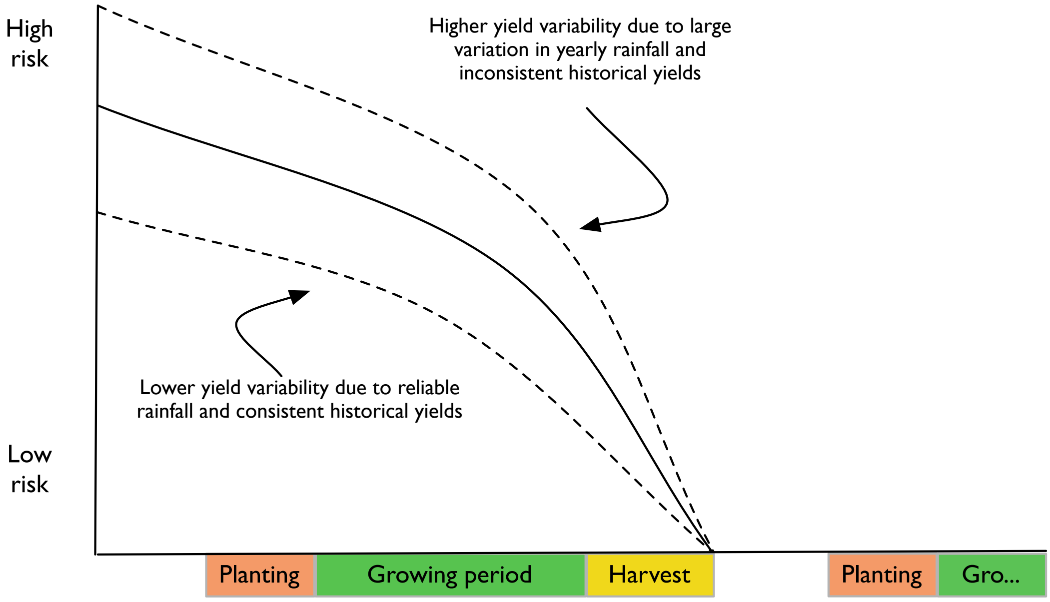
Production risk profile of the farm

Production risk is the level of certainty around producing a crop and is influenced by location (climate, season and soil type), crop type, crop management, and the time of the year.

Principle: You can't sell what you don't have.

Therefore, don't increase business risk by over committing production. Establish a production risk profile (see Figure 5) by:

1. Collating historical average yields for each crop type and a below-average and above-average range.
2. Assessing the likelihood of achieving the average, based on recent seasonal conditions and the seasonal outlook.
3. Revising production outlooks as the season progresses.



Note to figure: The quantity of crop grown is a large unknown early in the year however not a complete unknown. 'You can't sell what you don't have' but it is important to compare historical yields to get a true indication of production risk. This risk reduces as the season progresses and yield becomes more certain. Businesses will face varying production risk levels at any given point in time with consideration to rainfall, yield potential, soil type, commodity etc.

Profarmer AUSTRALIA

Figure 5: *Typical risk profile of a farm operation.*

Source: Profarmer Australia

Establishing a target price

A profitable commodity target price is the cost of production per tonne plus a desired profit margin. It is essential to know the cost of production per tonne for the farm business, which means knowing all farming costs, both variable and fixed.

Principle: Don't lock in a loss.

If committing production ahead of harvest, ensure the price will be profitable. The steps needed to calculate an estimated profitable price is based on the total cost of production and a range of yield scenarios, as provided below (Figure 6).

Estimating cost of production - Wheat	
Planted Area	1,200 ha
Estimate Yield	2.85 t/ha
Estimated Production	3,420 t
Fixed costs	
Insurance and General Expenses	$100,000
Finance	$80,000
Depreciation/Capital Replacement	$70,000
Drawings	$60,000
Other	$30,000
Variable costs	
Seed and sowing	$48,000
Fertiliser and application	$156,000
Herbicide and application	$78,000
Insect/fungicide and application	$36,000
Harvest costs	$48,000
Crop insurance	$18,000
Total fixed and variable costs	$724,000
Per Tonne Equivalent (Total costs + Estimated production)	$212 /t
Per tonne costs	
Levies	$3 /t
Cartage	$12 /t
Receival fee	$11 /t
Freight to Port	$22 /t
Total per tonne costs	$48 /t
Cost of production Port track equiv	$259.20
Target profit (ie 20%)	$52.00
Target price (port equiv)	**$311.20**

Step 1: Estimate your production potential. The more uncertain your production is, the more conservative the yield estimate should be. As yield falls, your cost of production per tonne will rise.

Step 2: Attribute your fixed farm business costs. In this instance if 1,200 ha reflects 1/3 of the farm enterprise, we have attributed 1/3 fixed costs. There are a number of methods for doing this (see M Krause "Farming your Business") but the most important thing is that in the end all costs are accounted for.

Step 3: Calculate all the variable costs attributed to producing that crop. This can also be expressed as $ per ha x planted area.

Step 4: Add together fixed and variable costs and divide by estimated production

Step 5: Add on the "per tonne" costs like levies and freight.

Step 6: Add the "per tonne" costs to the fixed and variable per tonne costs calculated at step 4.

Step 7: Add a desired profit margin to arrive at the port equivalent target profitable price.

Figure 6: *An example of how to estimate the costs of production.*

Source: Profarmer Australia

GRDC's manual Farming the Business also provides a cost-of-production template and tips on grain selling *v.* grain marketing.

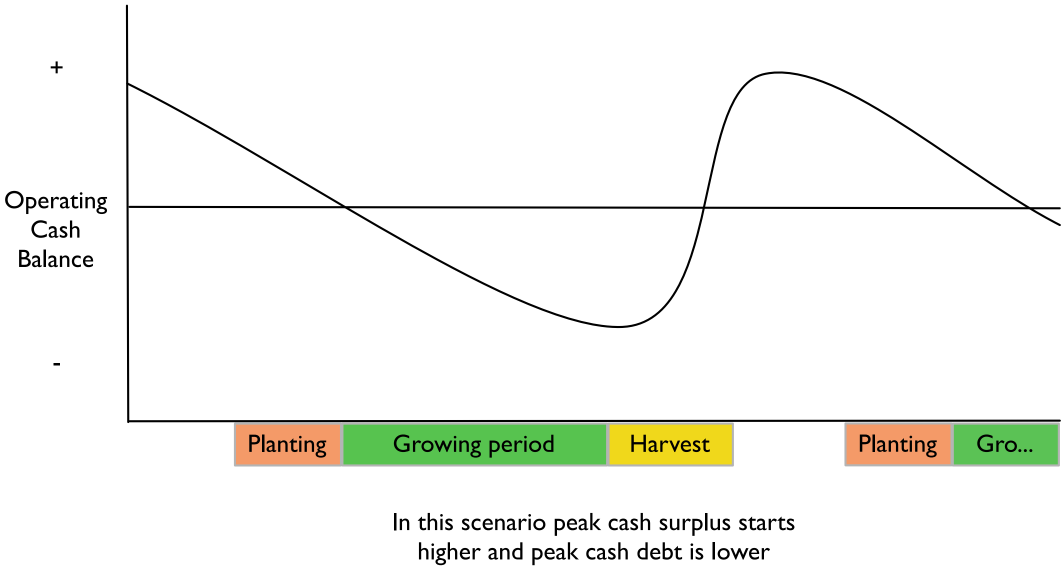
Income requirements

Understanding farm business cash-flow requirements and peak cash debt enables growers to time grain sales so that cash is available when required. This prevents having to sell grain below the target price to satisfy a need for cash.

Principle: Don't be a forced seller.

Be ahead of cash requirements to avoid selling in unfavourable markets.

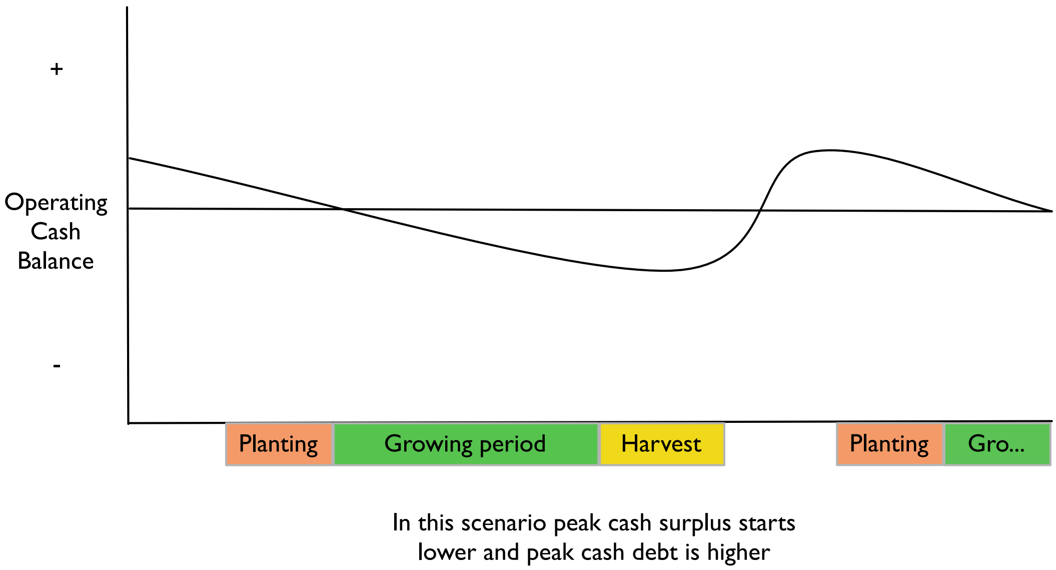
Typical cash flow to grow a crop are illustrated below (Figures 7 and 8). Costs are incurred up front and during the growing season, with peak working capital debt incurred at or before harvest. Patterns will vary depending on circumstance and enterprise mix. Figure 8 demonstrates how managing sales can change the farm's cash balance.



Note to figure:
The chart illustrates the operating cash flow of a typical farm assuming a heavy reliance on cash sales at harvest. Costs are incurred during the season to grow the crop, resulting in peak operating debt levels at or near harvest. Hence at harvest there is often a cash injection required for the business. An effective marketing plan will ensure a grower is 'not a forced seller' in order to generate cash flow.

Figure 7: *A typical operating cash balance when relying on cash sales at harvest.*

Source: Profarmer Australia



Note to figure:
By spreading sales throughout the year a grower may not be as reliant on executing sales at harvest time in order to generate required cash flow for the business. This provides a greater ability to capture pricing opportunities in contrast to executing sales in order to fulfil cash requirements.

Figure 8: *Typical operating cash balance when crop sales are spread over the year.*

Source: Profarmer Australia

The 'when to sell' steps above result in an estimated production tonnage and the risk associated with producing that tonnage, a target price range for each commodity, and the time of year when cash is most needed. [4]

4 Profarmer Australia (2016), Marketing Field Peas, GRDC Northern Field Pea GrowNote

15.1.3 Managing your price

The first part of the selling strategy answers the question about when to sell and establishes comfort around selling a portion of the harvest.

The second part of the strategy, managing your price, addresses how to sell your crop.

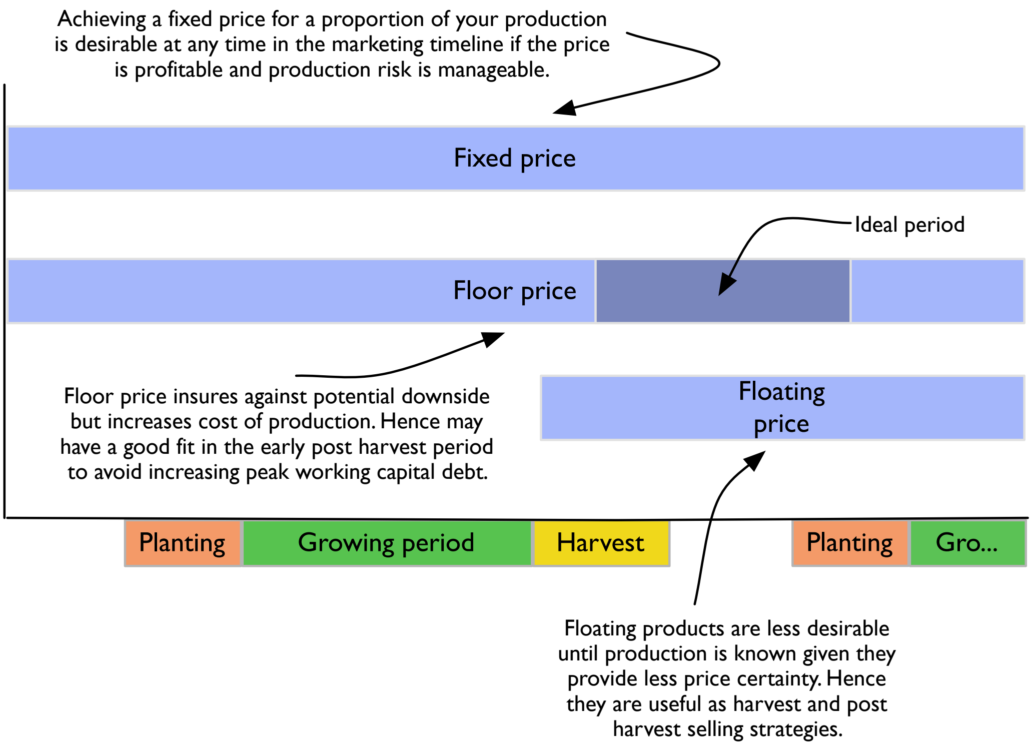
Methods of price management

Pricing products provide varying levels of price risk coverage, but not all products are available for all crops (Table 1).

Table 1: *Pricing methods and how they are used for different crops.*

	Description	Wheat	Barley	Canola	Oats	Lupins	Field Peas	Chick Peas
Fixed price products	Provides the most price certainty	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash	Cash	Cash	Cash
Floor price products	Limits price downside but provides exposure to future price upside	Options on futures, floor price pools	Options on futures	Options on futures	none	none	none	none
Floating price products	Subject to both price upside and downside	Pools	Pools	Pools	Pools	Pools	Pools	Pools

Figure 9 summarises how the different methods of price management are suited to the majority of farm businesses.



Note to figure:
Different price strategies are more applicable through varying periods of the growing season. If selling in the forward market growers are selling something not yet grown hence the inherent production risk of the business increases. This means growers should achieve price certainty if committing tonnage ahead of harvest. Hence fixed or floor products are favourable. Comparatively a floating price strategy may be effective in the harvest and post harvest period.

Profarmer AUSTRALIA

Figure 9: *Price strategy timeline, summarising the suitability for most farm businesses of different methods of price management for different phases of production.*

Source: Profarmer Australia

Principle: If increasing production risk, take price risk off the table.

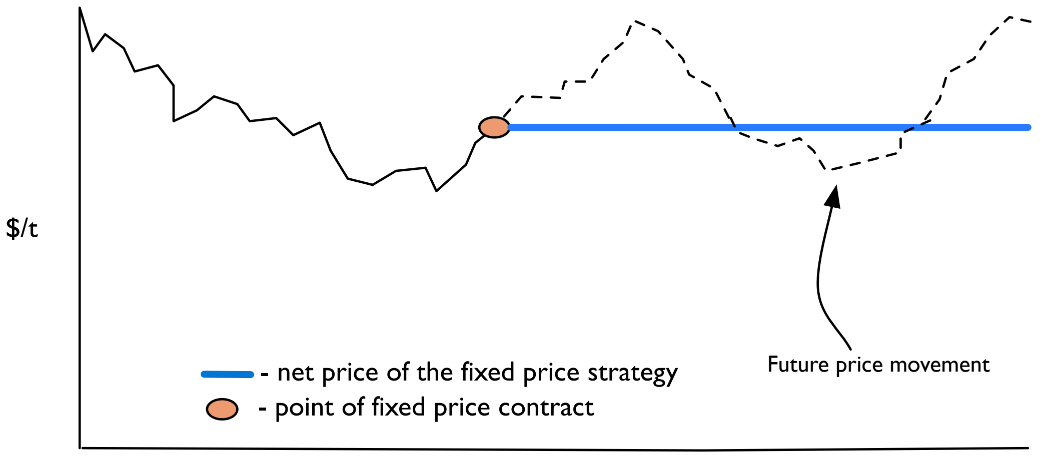
When committing to unknown production, price certainty should be achieved to avoid increasing overall business risk.

Principle: Separate the pricing decision from the delivery decision.

Most commodities can be sold at any time with delivery timeframes being negotiable, hence price management is not determined by delivery.

1. *Fixed price*

A fixed price is achieved via cash sales and/or selling a futures position (swaps) (Figure 10). It provides some certainty around expected revenue from a sale as the price is largely a known factor, except when there is a floating component in the price, e.g. a multi-grade cash contract with floating spreads or a floating-basis component on futures positions.



Note to figure:
Fixed price product locks in price and provides certainty over what revenue will be generated regardless of future price movement.

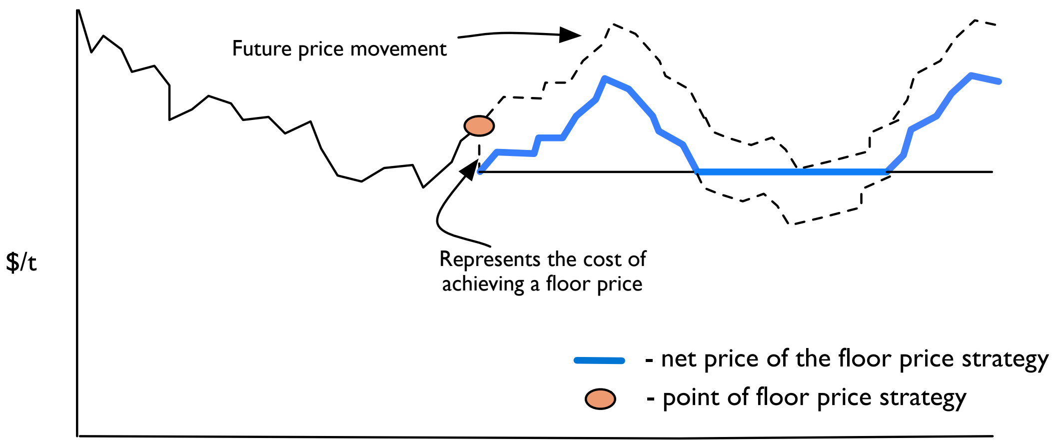
Profarmer AUSTRALIA

Figure 10: *Fixed price strategy.*

Source: Profarmer Australia

2. *Floor price*

Floor price strategies (Figure 11) can be achieved by utilising options on a relevant futures exchange (if one exists), or via a managed-sales program (i.e. a pool with a defined floor price strategy) offered by a third party. This pricing method protects against potential future price decrease while capturing any price increase. The disadvantage is that this kind of price 'insurance' has a cost, which adds to the farm's cost of production.



Note to figure:
A floor price strategy insures against potential future downside in price while allowing price gains in the event of future price rallies.

Profarmer AUSTRALIA

Figure 11: *Floor price strategy.*

Source: Profarmer Australia

3. *Floating price*

Many of the pools or managed-sales programs are a floating price, where the net price received will move up and down with the future movement in price (Figure 12). Floating price products provide the least price certainty and are best suited for use at or after harvest rather than before harvest.

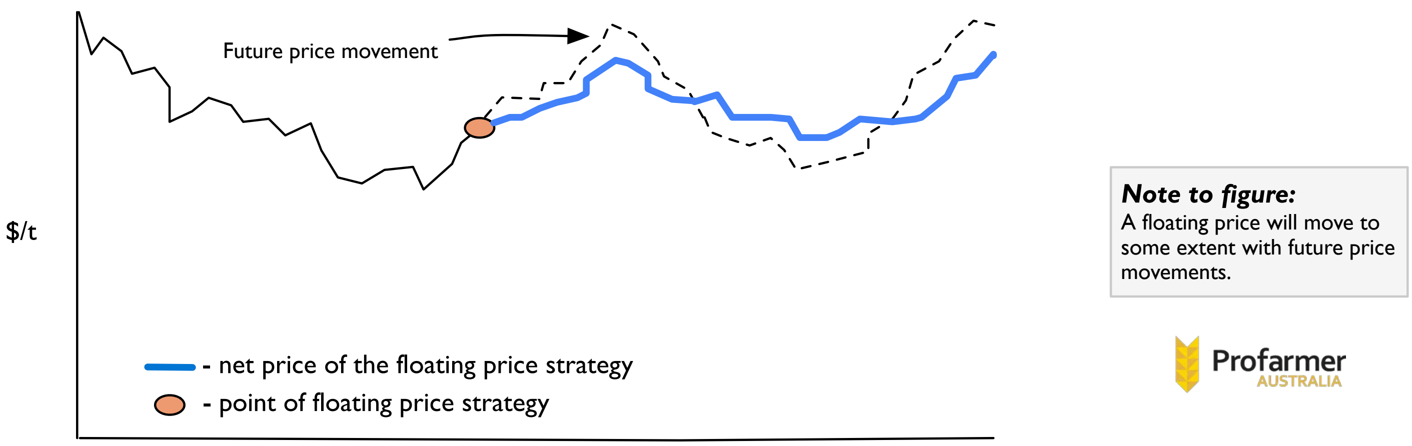


Figure 12: *Floating price strategy.*

Source: Profarmer Australia

Having considered the variables of production for the crop to be sold, and how these fit against the different pricing mechanisms, the farmer may revise their selling strategy, taking the risks associated with each mechanism into account.

Fixed price strategies include physical cash sales or futures products, and provide the most price certainty, but production risk must be considered.

Floor price strategies include options or floor price pools. They provide a minimum price with upside potential and rely less on production certainty, but cost more.

Floating price strategies provide minimal price certainty, and so are best used after harvest. [5]

15.1.4 Ensuring access to markets

Once the questions of when and how to sell are sorted out, planning moves to the storage and delivery of commodities to ensure timely access to markets and execution of sales. Planning where to store the commodity is an important component of ensuring the type of access to the market that is likely to yield the highest return (Figure 13).

5 Profarmer Australia (2016), Marketing Field Peas, GRDC Northern Field Pea GrowNote

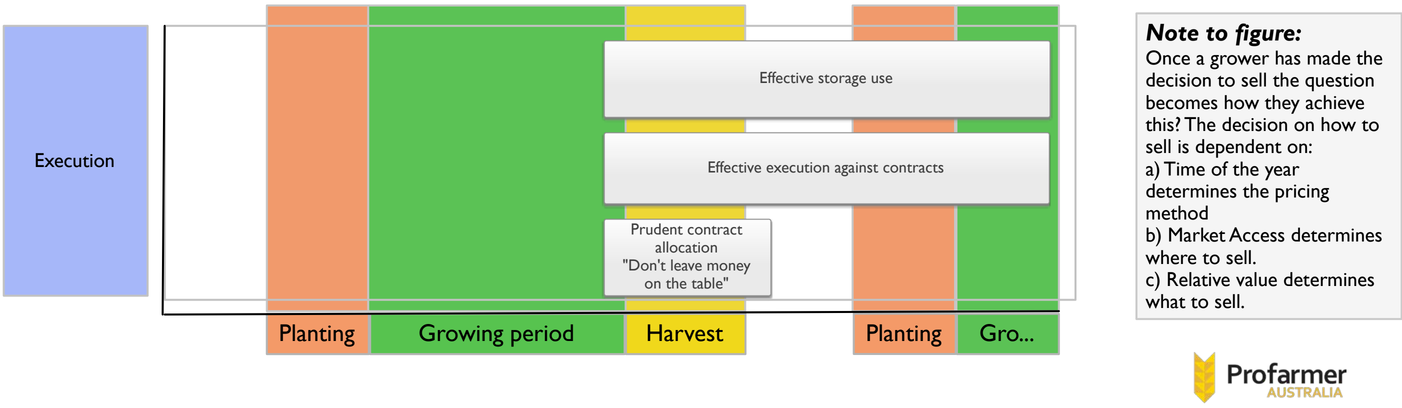


Figure 13: *Storage decisions are influenced by selling decisions and the timing of all farming activities.*

Source: Profarmer Australia

Storage and logistics

The return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access so as to maximise returns as well as harvest logistics.

Storage alternatives include variations of bulk handling, private off-farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity (Figure 14).

Principle: Harvest is the first priority.

During harvest, getting the crop into the bin is the most critical aspect of business success; hence storage, sale and delivery of grain should be planned well ahead of harvest to allow the grower to focus on the harvest itself.

Bulk export commodities requiring significant quality management are best suited to the bulk handling system. Commodities destined for the domestic end user market, (e.g. feedlot, processor, or container packer), may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on the farm requires prudent quality management to ensure that the grain is delivered to the agreed specifications. If not well planned and carried out, it can expose the business to high risk. Penalties for out-of-specification grain arriving at a buyer's weighbridge can be expensive, as the buyer has no obligation to accept it. This means the grower may have to incur the cost of taking the load elsewhere, and may also have to find a new buyer.

On-farm storage also requires that delivery is managed to ensure that the buyer receives the commodities on time and with appropriate weighbridge and sampling tickets.

Principle: Storage is all about market access.

Storage decisions depend on quality management and expected markets.

For more information on on-farm storage alternatives and economics refer to Section 13: Grain Storage.

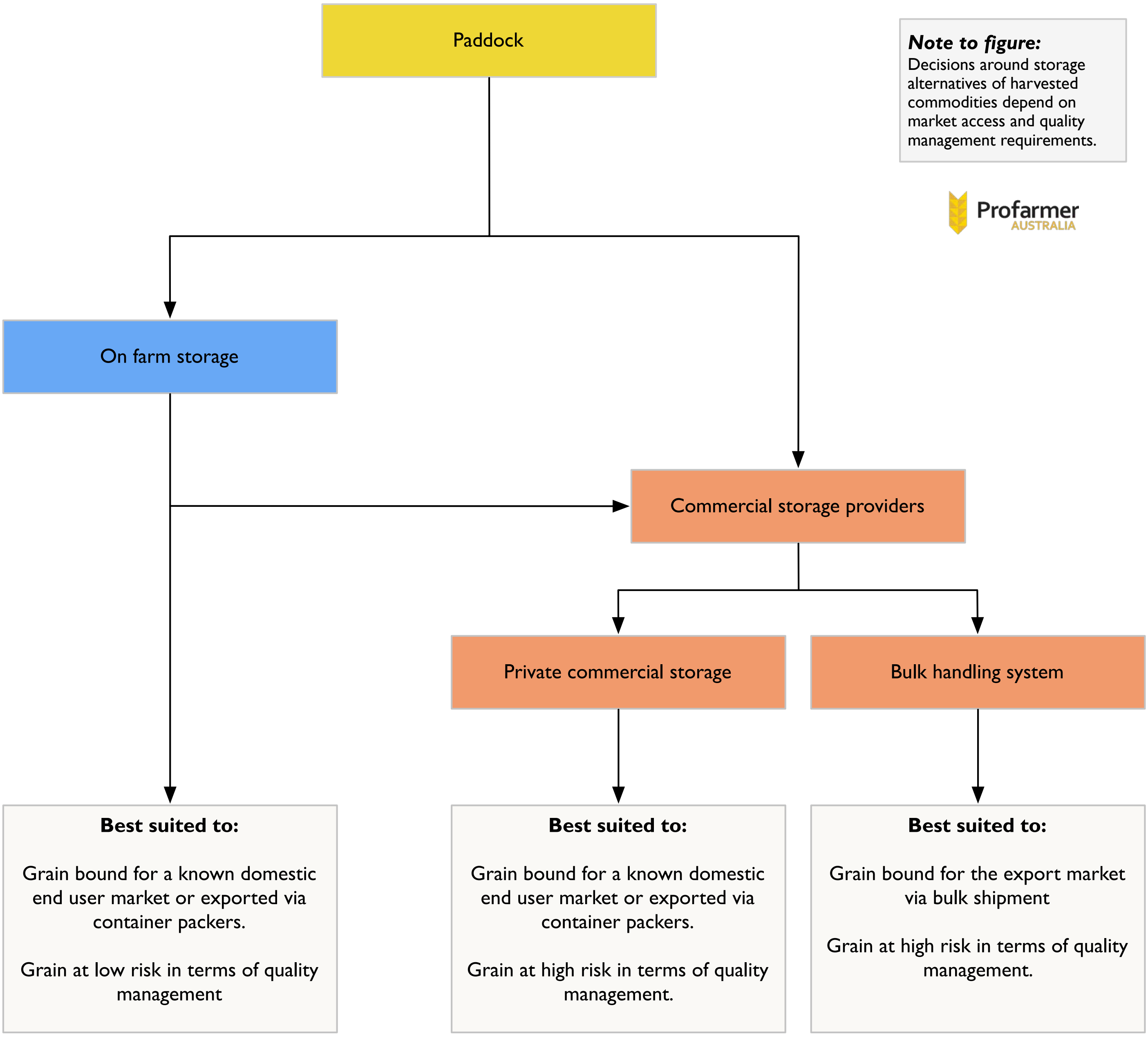


Figure 14: *Grain storage decision-making.*

Source: Profarmer Australia

Cost of holding grain

Storing grain to access sales opportunities post-harvest invokes a cost to 'carry', or hold, the grain (Figure 15). Price targets for carried grain need to account for the cost of carrying it. Carrying costs are typically \$3–4/t per month and consist of:

- monthly storage fee charged by a commercial provider (typically ~\$1.50–2.00/t)
- monthly interest associated with having wealth tied up in grain rather than available as cash or for paying off debt (~\$1.50–\$2.00/t, depending on the price of the commodity and interest rates).

The price of carried grain therefore needs to be \$3–4/t per month higher than the price offered at harvest.

The cost of carrying also applies to grain stored on the farm, as there is the cost of the capital invested in the farm storage plus the interest component. A reasonable assumption is a cost of $3–4/t per month for on-farm storage.

Principle: Carrying grain is not free.

The cost of carrying grain needs to be accounted for if holding it for sale after harvest is part of the selling strategy.

If selling a cash contract with deferred delivery, a carrying charge can be negotiated into the contract. For example, a March sale of canola for March–June delivery on the buyers call at a price of $300/t + $3/t carrying per month, would generate revenue of $309/t delivered in June.

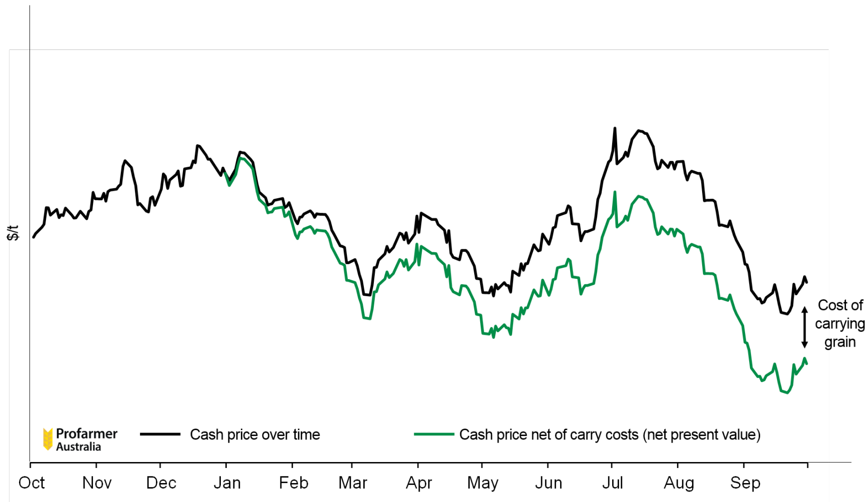


Figure 15: *Cash values v. cash values adjusted for the cost of carrying.*

Source: Profarmer Australia

Optimising farm-gate returns involves planning the appropriate storage strategy for each commodity so as to improve market access and ensure that carrying costs are covered in the price received. [6]

15.1.5 Converting tonnes into cash

This section provides guidelines for converting the selling and storage strategy into cash by effective execution of sales.

Set up the toolbox

Selling opportunities can be captured when they arise by assembling the necessary tools in advance. The toolbox for converting tonnes of grain into cash includes the following.

1. Timely information—this is critical for awareness of selling opportunities and includes:
   - market information provided by independent parties
   - effective price discovery including indicative bids, firm bids and trade prices
   - other market information pertinent to the particular commodity.
2. Professional services—grain-selling professional services and cost structures vary considerably. An effective grain-selling professional will put their clients' best interests first by not having conflicts of interest and by investing time in the relationship. A better return on investment for the farm business is achieved through higher farm-gate prices, which are obtained by accessing timely information, and being able to exploit the seller's greater market knowledge and greater market access.

6 Profarmer Australia (2016), Marketing Field Peas, GRDC Northern Field Pea GrowNote

MORE INFORMATION

Access to buyers, brokers, agents, products and banks through Grain Trade Australia

Commodity futures brokers

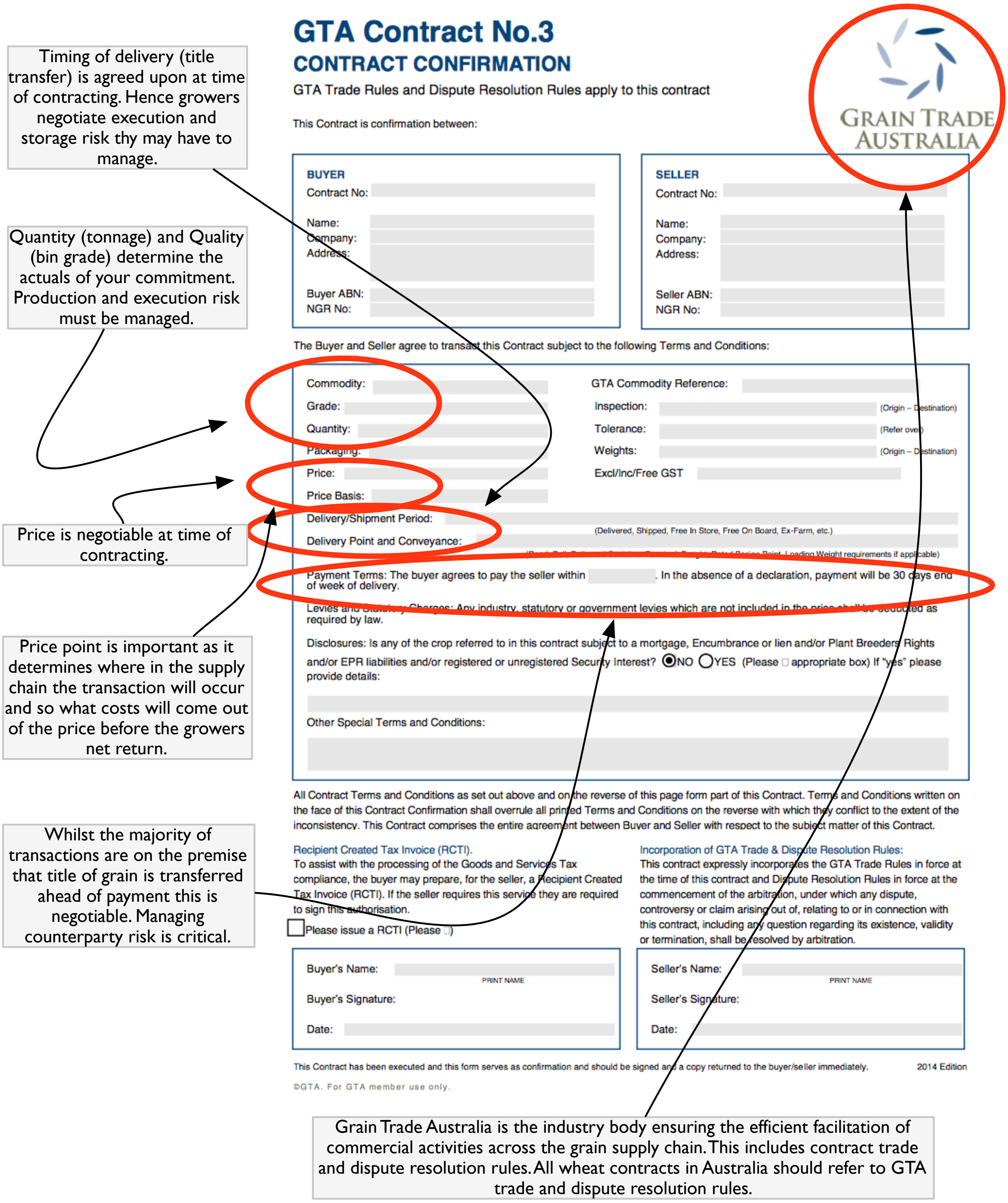
ASX's Find a futures broker

3. Futures account and a bank-swap facility—these accounts provide access to global futures markets. Hedging futures markets is not for everyone; however, strategies which utilise exchanges such as the Chicago Board of Trade (CBOT) can add significant value.

How to sell for cash

Like any market transaction, a cash–grain transaction occurs when a bid by the buyer is matched by an offer from the seller. Cash contracts are made up of the following components, with each component requiring a level of risk management (Figure 16):

- Price—future price is largely unpredictable, so devising a selling plan to put current prices into the context of the farm business is critical to managing price risk.
- Quantity and quality—when entering a cash contract, you are committing to deliver the nominated amount of grain at the quality specified, so production and quality risks must be managed.
- Delivery terms—the timing of the title transfer from the grower to the buyer is agreed at time of contracting. If this requires delivery direct to end users, it relies on prudent execution management to ensure delivery within the contracted period.
- Payment terms—in Australia, the traditional method of contracting requires title on the grain to be transferred ahead of payment, so counterparty risk must be managed.



GTA Contract No.3

CONTRACT CONFIRMATION

GTA Trade Rules and Dispute Resolution Rules apply to this contract

This Contract is confirmation between:

BUYER
Contract No:
Name:
Company:
Address:
Buyer ABN:
NGR No:

SELLER
Contract No:
Name:
Company:
Address:
Seller ABN:
NGR No:

The Buyer and Seller agree to transact this Contract subject to the following Terms and Conditions:

Commodity:
Grade:
Quantity:
Packaging:
Price:
Price Basis:
Delivery/Shipment Period:
Delivery Point and Conveyance:

GTA Commodity Reference:
Inspection: (Origin – Destination)
Tolerance: (Refer over)
Weights: (Origin – Destination)
Excl/Inc/Free GST

(Delivered, Shipped, Free In Store, Free On Board, Ex-Farm, etc.)

Payment Terms: The buyer agrees to pay the seller within . In the absence of a declaration, payment will be 30 days end of week of delivery.

Levies and Statutory Charges: Any industry, statutory or government levies which are not included in the price shall be deducted as required by law.

Disclosures: Is any of the crop referred to in this contract subject to a mortgage, Encumbrance or lien and/or Plant Breeders Rights and/or EPR liabilities and/or registered or unregistered Security Interest? NO YES (Please appropriate box) If "yes" please provide details:

Other Special Terms and Conditions:

All Contract Terms and Conditions as set out above and on the reverse of this page form part of this Contract. Terms and Conditions written on the face of this Contract Confirmation shall overrule all printed Terms and Conditions on the reverse with which they conflict to the extent of the inconsistency. This Contract comprises the entire agreement between Buyer and Seller with respect to the subject matter of this Contract.

Recipient Created Tax Invoice (RCTI).
To assist with the processing of the Goods and Services Tax compliance, the buyer may prepare, for the seller, a Recipient Created Tax Invoice (RCTI). If the seller requires this service they are required to sign this authorisation.
Please issue a RCTI (Please)

Incorporation of GTA Trade & Dispute Resolution Rules:
This contract expressly incorporates the GTA Trade Rules in force at the time of this contract and Dispute Resolution Rules in force at the commencement of the arbitration, under which any dispute, controversy or claim arising out of, relating to or in connection with this contract, including any question regarding its existence, validity or termination, shall be resolved by arbitration.

Buyer's Name: PRINT NAME
Buyer's Signature:
Date:

Seller's Name: PRINT NAME
Seller's Signature:
Date:

This Contract has been executed and this form serves as confirmation and should be signed and a copy returned to the buyer/seller immediately. 2014 Edition

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Figure 16: *Typical terms of a cash contract.*

Source: Grain Trade Australia

The price point within a cash contract will depend on where the transfer of grain title will occur along the supply chain. Figure 17 depicts the terminology used to describe these points and the associated costs to come out of each price before growers receive their net return.

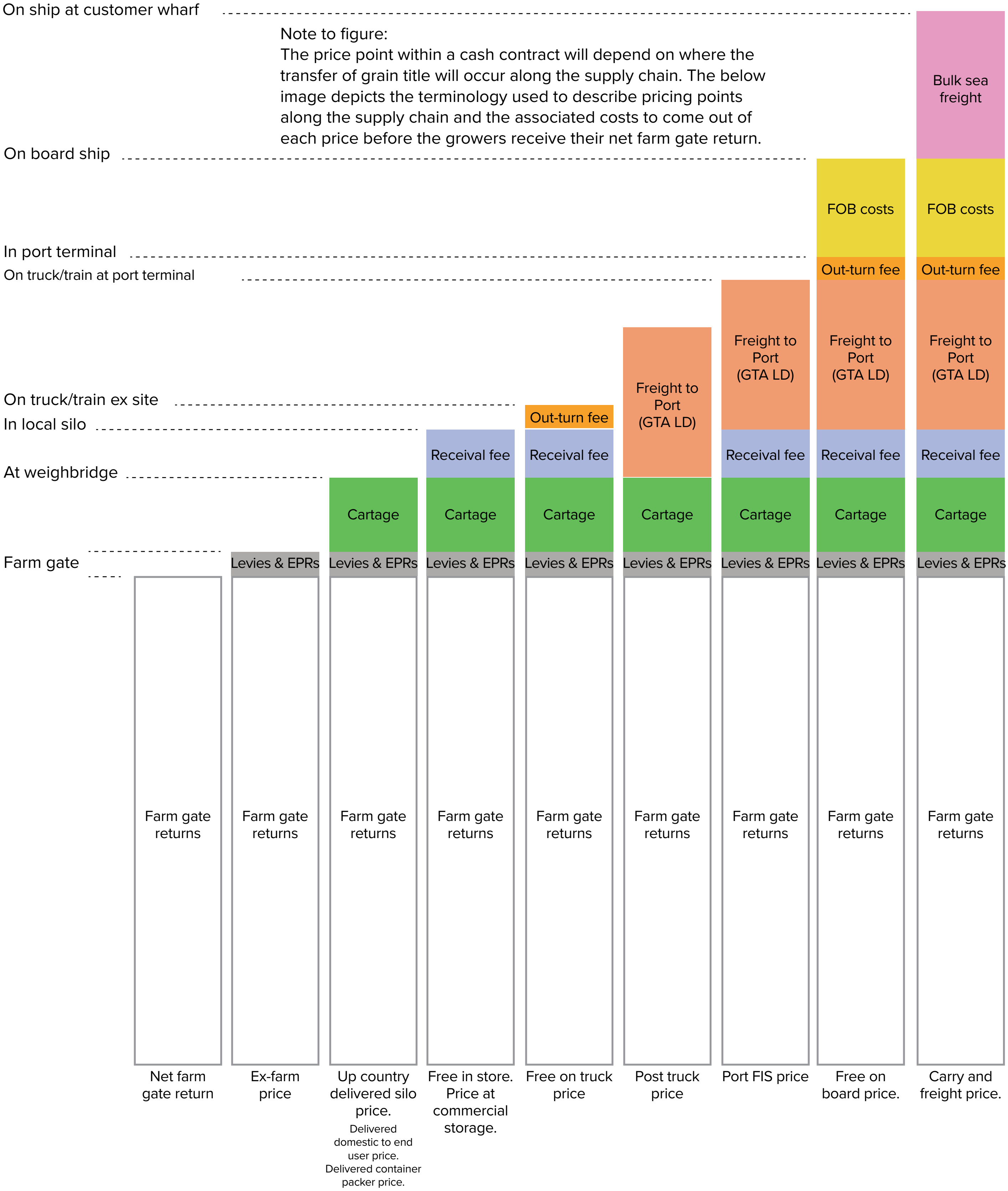


Figure 17: *Cost and pricing points throughout the supply chains.*

Source: Profarmer Australia

MORE INFORMATION

http://www.graintrade.org.au/contracts

http://www.graintrade.org.au/commodity_standards

http://www.graintransact.com.au

http://www.grainflow.com.au

http://emeraldgrain.com/grower-logins/

https://www.cleargrain.com.au/terms-and-conditions

https://www.cleargrain.com.au/get-started

MORE INFORMATION

GTA managing counterparty risk 14/7/2014

Clear Grain Exchange title transfer model

GrainGrowers guide to managing contract risk

Counterparty risk: A producer perspective, Leo Delahunty

Cash sales generally occur through three methods:

- Negotiation via personal contact—traditionally prices are posted as a public indicative bid. The bid is then accepted or negotiated by a grower with the merchant or via an intermediary. This method is the most common and is available for all commodities.
- Accepting a public firm bid—cash prices in the form of public firm bids are posted during harvest and for warehoused grain by merchants on a site basis. Growers can sell their parcel of grain immediately by accepting the price on offer via an online facility and then transfer the grain online to the buyer. The availability of this option depends on location and commodity.
- Placing an anonymous firm offer—growers can place a firm offer price on a parcel of grain anonymously and expose it to the entire market of buyers, who then bid on it anonymously using the Clear Grain Exchange, which is an independent online exchange. If the offer and bid match, the particulars of the transaction are sent to a secure settlement facility, although the title on the grain does not transfer from the grower until they receive funds from the buyer. The availability of this option depends on location and commodity. Anonymous firm offers can also be placed to buyers by an intermediary acting on behalf of the grower. If the grain sells, the buyer and seller are disclosed to each counterparty.

Counterparty risk

Most sales involve transferring the title on the grain prior to being paid. The risk of a counterparty defaulting when selling grain is very real and must be managed. Conducting business in a commercial and professional manner minimises this risk.

Principle: Seller beware.

There is not much point selling for an extra $5/t if you don't get paid.

Counterparty risk management includes:

- Dealing only with known and trusted counterparties.
- Conducting a credit check (banks will do this) before dealing with a buyer they are unsure of.
- Selling only a small amount of grain to unknown counterparties.
- Considering credit insurance or a letter of credit from the buyer.
- Never delivering a second load of grain if payment has not been received for the first.
- Not parting with the title before payment, or requesting and receiving a cash deposit of part of the value ahead of delivery. Payment terms are negotiated at time of contracting. Alternatively, the Clear Grain Exchange provides secure settlement whereby the grower maintains title on the grain until they receive payment, and then title and payment are settled simultaneously.

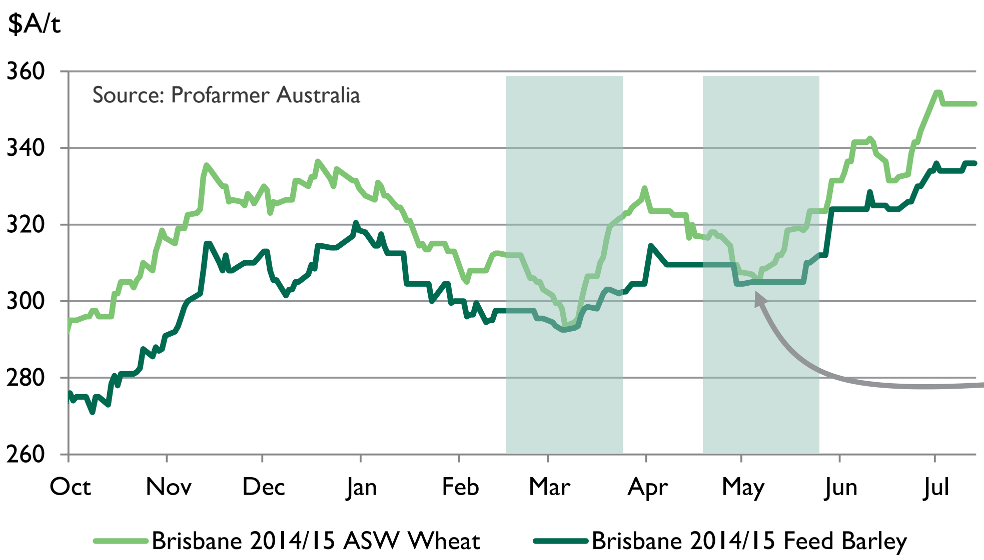
Above all, act commercially to ensure the time invested in implementing a selling strategy is not wasted by poor management of counterparty risk.

Relative values

Grain sales revenue is optimised when selling decisions are made in the context of the whole farming business. The aim is to sell each commodity when it is priced well, and to hold commodities that are not well priced at any given time. That is, give preference to the commodities with the highest relative value. This achieves price protection for the overall revenue of the farm business and enables more flexibility to a grower's selling program while achieving the business goal of reducing overall risk.

Principle: Sell valued commodities, not undervalued commodities.

If one commodity is priced strongly relative to another, focus sales there. Don't sell the cheaper commodity for a discount. For example, a farmer with wheat and barley to sell will sell the one that is getting good prices relative to the other, and hold the other for the meantime (see Figure 18).



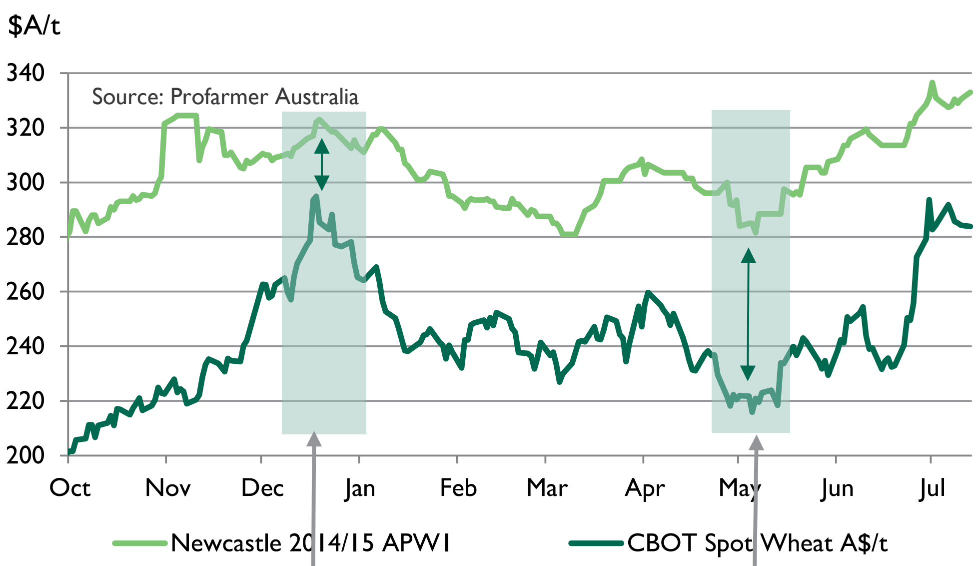
Note to figure:
Price relativities between commodities is one method of assessing which grain types 'hold the greatest value' in the current market.

Example:
Feed barley prices were performing strongly relative to ASW wheat values (normally ~15% discount) hence selling feed barley was more favourable than ASW wheat during this period.

Figure 18: *Brisbane ASW wheat v. feed barley are compared, and the barley held until it is favourable to sell it.*

Source: Profarmer Australia

If the decision has been made to sell wheat, CBOT wheat may be the better choice if the futures market is showing better value than the cash market (Figure 19).



Note to figure:
Once the decision to take price protection has been made, choosing which pricing method to use is determined by which selling methods 'hold the greatest value' in the current market.

Example:
Sales via CBOT wheat were preferred over cash.

Example:
Cash sales were preferred over CBOT wheat.

Figure 19: *By comparing prices for Newcastle APWI vs CBOT wheat, the grower can see which market to sell into.*

Source: Profarmer Australia

Contract allocation

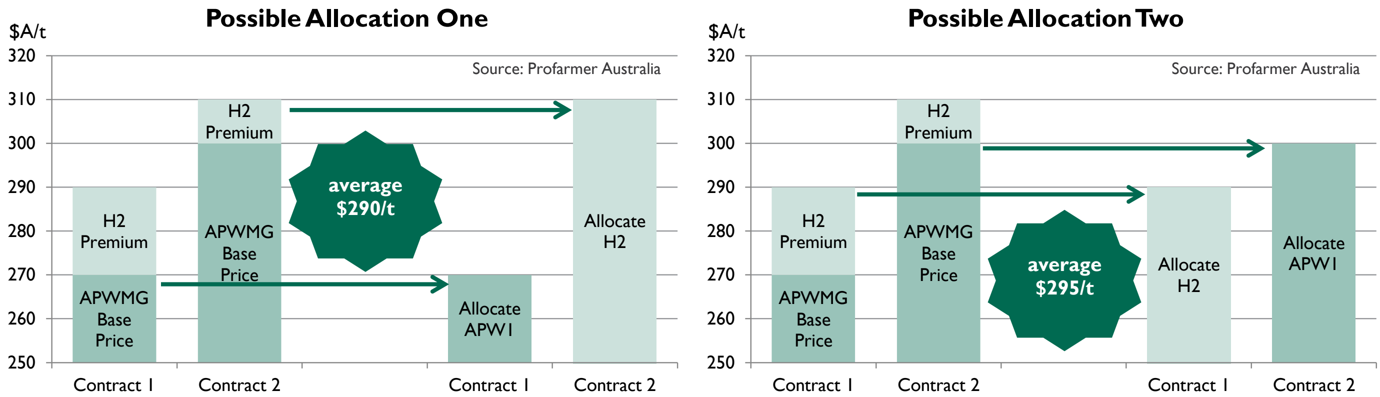
Contract allocation means choosing which contracts to allocate your grain against come delivery time. Different contracts will have different characteristics (e.g. price, premiums-discounts, oil bonuses), and optimising your allocation reflects directly on your bottom line.

Principle: Don't leave money on the table.

Contract allocation decisions don't take long, and can be worth thousands of dollars to your bottom line.

To achieve the best average price for their crop growers should:

- allocate lower grades of grain to contracts with the lowest discounts.
- allocate higher grades of grain to contracts with the highest premiums (Figure 20).



Note to figure:
In these two examples the only difference between acheiving an average price of $290/t and $295/t is which contracts each parcel was allocated to. Over 400/t that equates to $2,000 which could be lost just in how parcels are allocated to contracts.

Figure 20: *How the crop is allocated across contracts can have an impact of earnings from the crop. Although this example uses wheat, the same principle applies for sorghum.*

Source: Profarmer Australia

Read market signals

The appetite of buyers to buy a particular commodity will differ over time depending on market circumstances. Ideally growers should aim to sell their commodity when buyer appetite is strong, and stand aside from the market when buyers are not very interested.

Principle: Sell when there is buyer appetite.

When buyers are chasing grain, growers have more market power to demand the price they want.

Buyer appetite can be monitored by:

- The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate that buyer appetite is strong. However, if one buyer is offering $5/t above the next best bid, it may mean that cash prices are susceptible to falling $5/t as soon as that buyer satisfies their appetite.
- Monitoring actual trades against public indicative bids. When trades are occurring above indicative public bids it may indicate strong appetite from merchants and the ability for growers to offer their grain at price premiums to public bids.

The selling strategy is converted to maximum business revenue by:

- ensuring timely access to information, advice and trading facilities.
- using different cash-market mechanisms when appropriate.
- minimising counterparty risk by conducting effective due diligence.
- understanding relative value and selling commodities when they are priced well.
- thoughtful contract allocation.
- reading market signals to extract value from the market or to prevent selling at a discount. [7]

15.2 Northern sorghum: market dynamics and execution

15.2.1 Price determinants for northern sorghum

In a normal year Australia produces 1.5–2.2 Mt of sorghum. Australia is a small producer of sorghum relative to global production, accounting for 2–3% of the global crop. Over 99% of sorghum grain produced in Australia is grown in Queensland and northern NSW.

Although it is only a small player in terms of production, Australia is an important contributor to global sorghum trade, accounting for 12–14% of global sorghum exports. On average, Australia exports approximately 50% of the sorghum production in each year, while the remainder of the crop will find buyers in the domestic feed or ethanol markets. Ethanol consumes approximately 150 kt of sorghum in Queensland each year.

The major sorghum-exporting nations are USA, Argentina and Australia; these three countries account for 90–95% of global sorghum trade. The major importing nations are China, Japan and Mexico, which account for 75–90% of world sorghum imports.

The proportion of the Australian crop that is exported is great enough that a major determinant of Australian sorghum values is the price at which international trade is transacting. This is influenced by:

- global supply *v.* demand
- the quality of the global crop
- the timing of Australian exports

Traditionally Australia's main export markets have been Japan and New Zealand, where Australian sorghum is used for animal feed. Combined these two nations would account for ~90% of Australian sorghum exports.

However, in 2013 China showed a strong appetite for Australian sorghum, and over three years volumes to China grew to over 90% of Australian sorghum exports (Figure 21). The increase in demand from China was a combination of demand for alcohol and demand for stockfeed. The alcohol market is serviced primarily by container, whereas the stockfeed market is serviced via a combination of bulk and container exports.

Since then changes to Chinese import regulations for feed grain has resulted in a reduction in Chinese demand for Australian sorghum. The dynamics of this market continue to evolve.

7 Profarmer Australia (2016), Marketing Field Peas, GRDC Northern Field Pea GrowNote

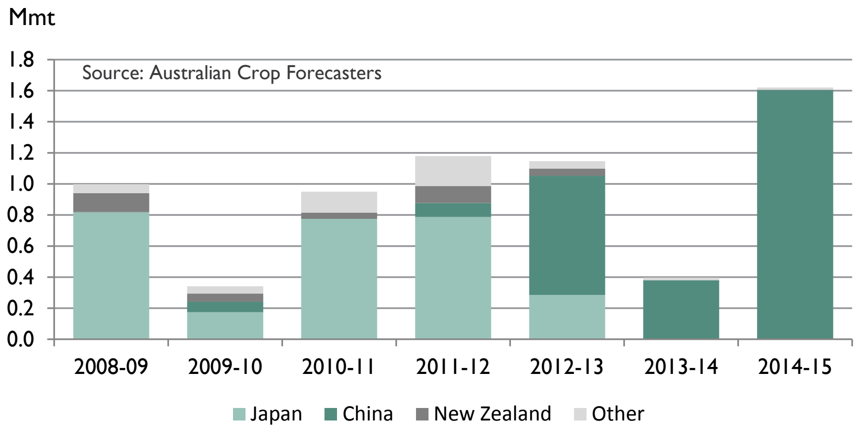


Figure 21: *Fluctuations in Australian sorghum export markets and quantities from 2008 to 2015.*

Source: Australian Crop Forecasters

As sorghum is an important input to animal-feed rations in domestic and export markets, sorghum prices are also influenced by relative values to other feed grains such as wheat, barley and corn (Figure 22). [8]

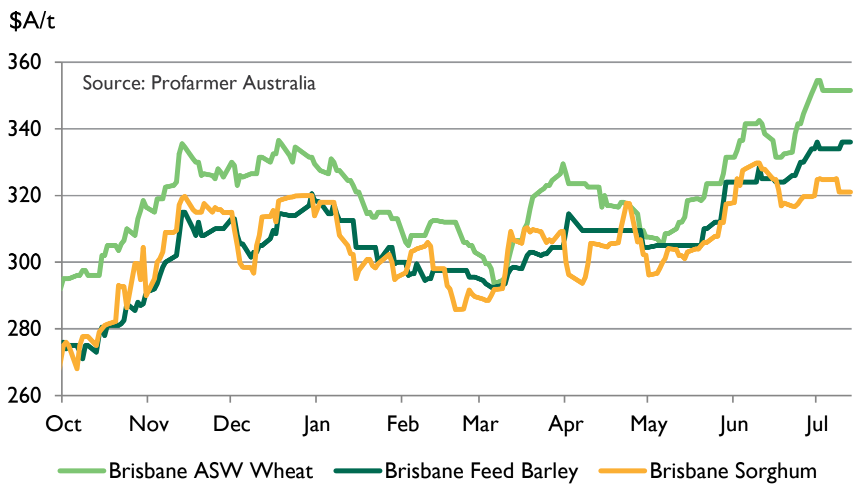


Figure 22: *Relative prices for Brisbane feed grains, 2014–15.*

Source: Profarmer Australia

15.2.2 Ensuring market access for northern sorghum

Australian sorghum generally ends up in one of four major markets:

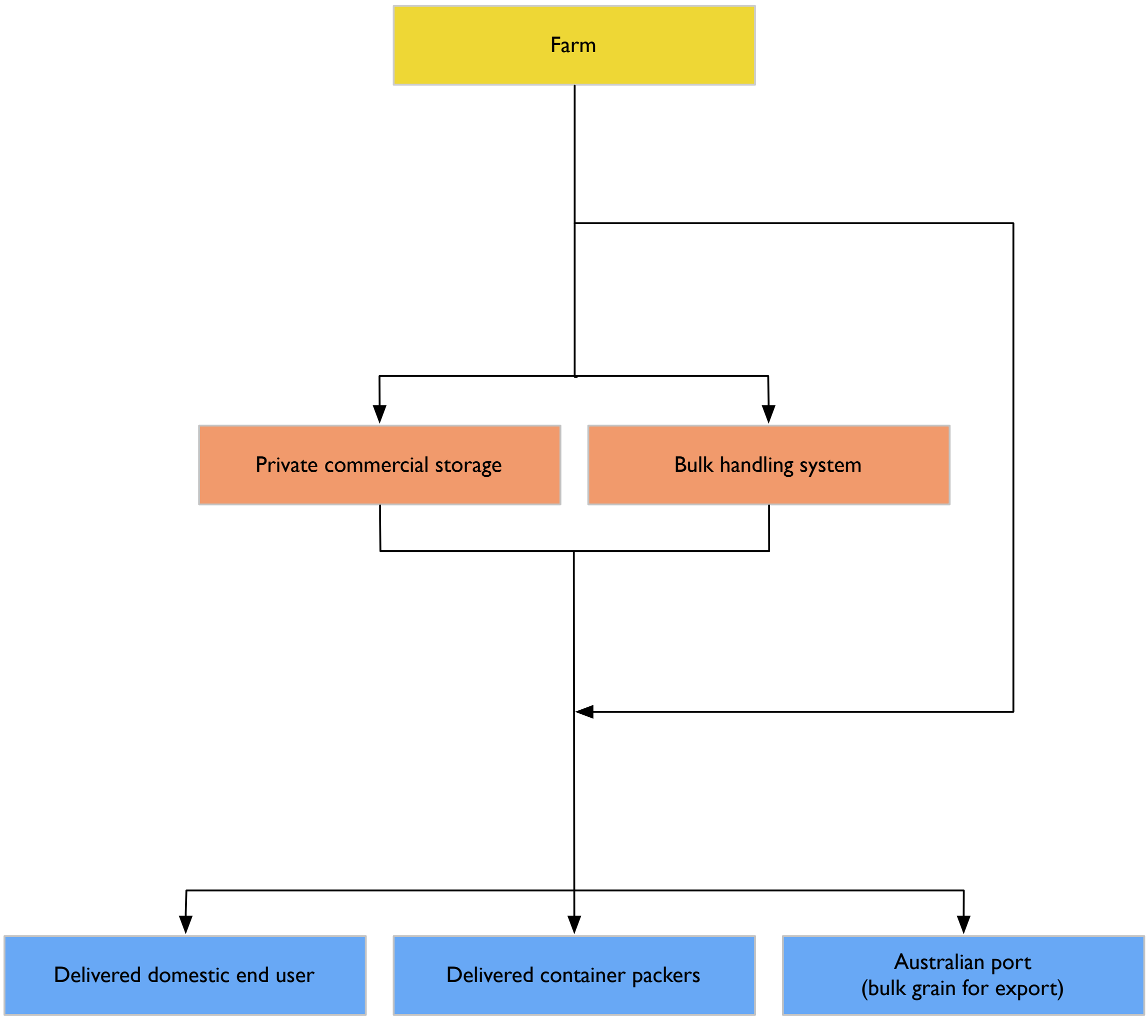
1. Domestic market for use as stockfeed
2. Domestic market for use as biofuel
3. Export market for use as stockfeed
4. Export market for human consumption and alcohol.

Of the sorghum that is destined for export markets, over 90% is executed via bulk export vessels rather than container exports. Hence the bulk handling system is an effective means for sorghum destined for the export market.

8 Profarmer Australia (2016), Marketing Field Peas, GRDC Northern Field Pea GrowNote

For off-spec sorghum, sorghum destined for domestic consumption or container-packing markets, on-farm storage may be cheaper than off-farm storage.

For sorghum that is destined for export markets, understanding whether they are likely to ship via bulk export or in containers can help to inform storage decisions and ensure market access (Figure 23). Although the bulk-handling system can be cheaper for product destined for bulk export, storage on the farm and delivery direct to the end user is likely to be cheaper and also more flexible in the domestic and container export markets. [9]



Note to figure:
Storage decisions should be determined by assessing market access. The large majority of northern canola is exported in bulk. Hence the bulk handling system should provide efficiencies to market. NSW also services a relatively large domestic market and private commercial and on-farm storage should provide a reasonable method to access these markets.

Profarmer AUSTRALIA

Figure 23: *Australian supply chain flow.*

Source: Profarmer Australia

15.2.3 Converting tonnes into cash for northern sorghum

Growers of sorghum have a number of avenues to convert tonnes into cash.

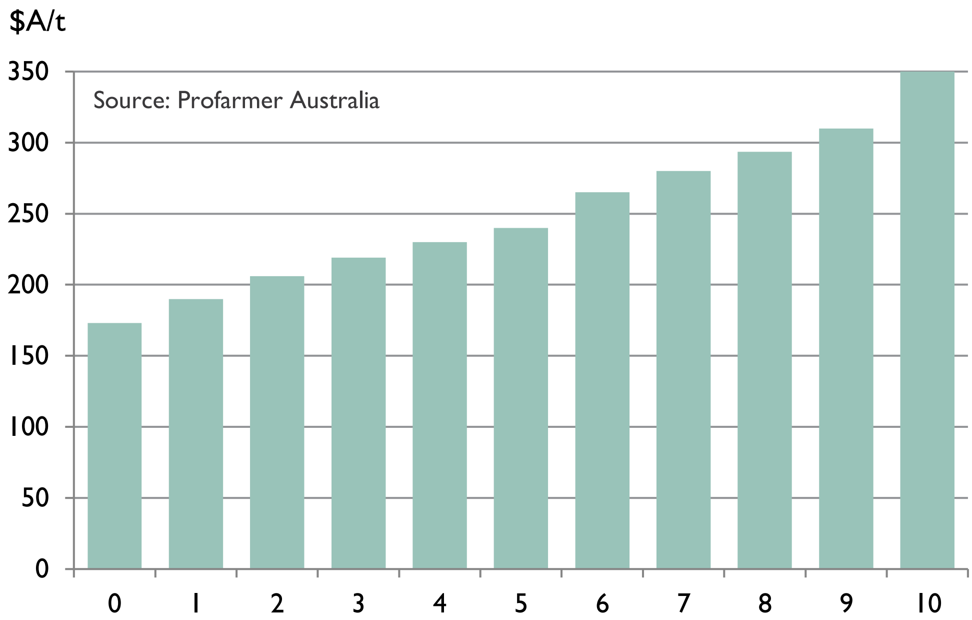
In the forward market, forward multigrade contracts for fixed tonnages are available. An important consideration of any forward contract is the quality of grain that is deliverable against the contract. There are a number of receival grades for sorghum, from SOR1 down to SORX, so it is important to consider which grade you may end up delivering and whether this will meet the terms of your contract.

9 Profarmer Australia (2016), Marketing Field Peas, GRDC Northern Field Pea GrowNote

Only SOR1 is acceptable for the human-consumption and alcohol markets, unless otherwise specifically negotiated with the buyer.

Delivery periods on forward contracts are also an important consideration. Premiums may be offered for prompt delivery; however, the seller needs to ensure they will be able to meet a commitment to deliver.

It can be important to separate the delivery decision from the pricing decision when making sales of sorghum. This means that, at times, it may be advantageous to secure a price in the current market for delivery at a later, but pre-defined, time. This may be achieved through contracts that contain delivery dates in the future, or through the use of forward multigrade contracts with various delivery periods. Rather than waiting until being ready to deliver the grain to the customer, using a contract with delivery at a point in the future allows the seller to lock in the price in advance of delivery, rather than remaining exposed to the risk of prices falling up to the delivery date. Decile charts can help the farmer determine where to set their price (Figure 24). [10]



Note to figure:
Decile charts such as the one to the left provide us an indication of how current values are performing relative to historical values. For example, a decile of 8 or above indicates current values are in the top 20% of historical price observations.

Figure 24: *Brisbane sorghum deciles. Deciles provide an indication of price performance relative to historical values. Decile 1 indicates values in the bottom 10% of historical observations, and a decile 9 indicates the top 10%.*

Source: Profarmer Australia

MORE INFORMATION

Sorghum marketing guide

Grain Trade Australia, sorghum trading standards

10 Profarmer Australia (2016), Marketing Field Peas, GRDC Northern Field Pea GrowNote

MORE INFORMATION

http://www.graintrade.org.au/

Figure 25: *Ripe grain on the eve of harvest.*

Photo: Jill Alexander, AppliedAg

15.3 Marketing options for ergot-contaminated grain

MORE INFORMATION

http://www.hsrseeds.com.au/pdf/news/HSR_MR_007_WhiteSorghum.pdf

http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/planting-information

http://www.apri.com.au/1B-114_Final_Research_Report_101019.pdf

Although there is a 0.3% sclerote contamination limit for sorghum intended for livestock, some end users will not accept ergot-contaminated grain. Grower pigs, chickens and laying hens are most tolerant of the alkaloids in sclerotes, and so are a potential market for sorghum that contains 0.3% sclerotes.

While this 0.3% limit remains for all other uses, stockfeed intended for feedlot cattle has been further limited to 0.1% sclerotes by weight since 2004.

Deliveries of sorghum with sclerote levels >0.3% will be rejected by grain merchants, and >0.1% will be rejected by cattle feedlotters. Most commonly, a sorghum sample containing 0.3% sclerote will contain ~1 mg alkaloid/kg (1 ppm), but because the alkaloid concentration can vary, it will be advisable to minimise ergot wherever possible. Some end-users will not accept ergot-contaminated grain at all.

Sorghum with levels higher than the stockfeed limit can be mixed with clean grain to reduce the sclerote levels. Fortunately, the incidence of ergot contamination of bulk grain has been extremely low over the past few years. If large amounts of sorghum become ergot-contaminated in future, then alkaloid estimation should be undertaken in order to plan for end-uses.

Several effective analytical tests have been developed for this purpose. These tests are provided by the Department of Agriculture, Fisheries and Forestry, Queensland (QDAF), but additional laboratories will eventually be able to provide this service. [11]

11 QDAF (2010) The biology, management and toxicity of sorghum. Department of Agriculture, Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/sorghum/disease-management/biology-management-and-toxicity-of-sorghum-ergot

15.4 Weather-damaged or mouldy grains

There is a legislated limit of 0.02 mg/kg for aflatoxin B1 in grain sold for stockfeed in Queensland. Testing over many years has indicated that that sorghum is unlikely to contain this limit without a history of high-moisture storage. Aflatoxins are not a significant risk in weathered sorghum. No other mycotoxins are legislated against in sorghum in Australia.

Marketing and use of mould-affected grain often presents a dilemma for growers and livestock producers, and usually rests on how much the grain should be discounted.

The key questions that need to be answered are whether the nutritional content has been affected and whether fungal toxins (mycotoxins) are present in high enough concentrations to adversely affect livestock.

15.4.1 Two groups of toxins

Growers need to be aware of two main groups of toxins in sorghum, which are controlled under Queensland stock food regulations. The first group is ergot alkaloids, produced by sorghum ergot growing prior to harvest, and the second is aflatoxins, which are mainly produced if sorghum is stored with high moisture content. Other types of mould associated with 'weathering' generally produce only slight affects on the feeding value of the grain.

Figure 26: *Immature sclerotes of* Claviceps africana.

15.4.2 Variable levels of toxin

Sclerotes of *Claviceps africana* (Figure 2) contain toxic chemicals, in particular the ergot alkaloid dihydroergosine. Feeding trials have established that sorghum contaminated with sclerotes can affect milk production in cows and sows, and weight gain in cattle. There is large variation in the levels of alkaloids (and toxicity) between ergot-contaminated grain samples, a result of differences in the maturity of the sclerotes and perhaps other factors such as weather and variety.

If ergot is present at harvest, delays can occur from clogging of machinery by honeydew on the heads; however, ergots are toxic to livestock, whereas honeydew is not.

15.4.3 Weathered grain

Weathering refers to any deterioration in the appearance of grain caused by climatic influences on a crop. This results in:

- shrunken and pinched grain, following drought or from soil fertility constraints
- discoloured grain, often covered with black, gray, pink or orange fungal growth (mould), after extensive warm, humid periods during grain maturation (Figure 4)

- premature germination of the grain, caused by wet or humid weather conditions at harvest, resulting in sprung, shot or sprouted grain

Figure 27: *Grain mould on sorghum.*

15.4.4 Mouldy grain

Various fungi are associated with weathered grain, mostly requiring moisture contents of >20% to grow, so they are rarely a problem after harvest. The most important of these is *Alternaria alternata*.

These moulds can produce mycotoxins, but even in very badly affected grain, these toxins rarely reach concentrations that can adversely affect livestock. Pigs and poultry are far more likely to be affected than are cattle and other ruminants. There have been instances of false oestrus in young pigs from zearalenone from *Fusarium* species, and of slightly impaired feed conversion in pigs, and altered feathering in chickens, from very badly weathered sorghum in central Queensland, possibly from *Alternaria* mycotoxins. Dilution of damaged grain or not feeding it to young livestock will minimise this risk.

Mould growth in storage, particularly of *Aspergillus* species, will occur when grain is stored having a high moisture content or suffers water damage during storage. Lightweight material and weed seeds increase the risk because they block aeration channels in the grain. If grain is stored with high moisture contents (14–20%), resultant heating promotes the growth of *Aspergillus* fungi. These produce aflatoxins, which can cause severe liver damage and reduce growth rates in pigs and other livestock. There have been several instances of this occurring in Queensland grain-growing areas.

15.4.5 Nutritional changes

Nutritional changes can result from weathering of grain, and this varies depending on the cause. Grain that is shrunken and pinched from drought or impaired soil fertility will have reduced starch content and increased fibre. Protein and lysine are usually higher, but less available for pigs and poultry. Such grain will be lightweight and have reduced value as feed. Grain that is in the early stages of sprouting (shot or sprung) can have a slightly increased digestibility for pigs.

Mould growth in sorghum can also reduce its value for pigs and poultry feed mixes (there is little effect on ruminants). In severe instances, reduction of the nutritional value of grain occurs by the removal of fat and starch and the hydrolysis of protein. The amount of fibre in mouldy grain will increase relative to the decline in starch, protein components and lipids and, in some instances, lead to reductions in digestible and metabolisable energy. However, in the most cases, nutritional changes in weathered grain due to mould growth are slight. Badly damaged grain often exhibits 'off' aromas and flavours, which pigs may find unpalatable; caution is warranted when feeding young pigs where maximum feed intakes are sought.

PODCAST

Daniel Rodriguez University of Queensland discusses a new project looking at tactical sorghum and maize agronomy in the northern region, focusing on matching genotypes, climates and management. GRDC Podcast: 041 Boundary weed control and tactical agronomy

Current and past research

Project Summaries www.grdc.com.au/ProjectSummaries

As part of a continuous investment cycle each year the Grains Research and Development Corporation (GRDC) invests in several hundred research, development and extension and capacity building projects. To raise awareness of these investments the GRDC has made available summaries of these projects.

These project summaries have been compiled by GRDC's research partners with the aim of raising awareness of the research activities each project investment.

The GRDC's project summaries portfolio is dynamic: presenting information on current projects, projects that have concluded and new projects which have commenced. It is updated on a regular basis.

The search function allows project summaries to be searched by keywords, project title, project number, theme or by GRDC region (ie Northern, Southern or Western Region).

Where a project has been completed and a final report has been submitted and approved a link to a summary of the project's final report appears at the top of the page.

The link to Project Summaries is www.grdc.com.au/ProjectSummaries

Final Report Summaries http://finalreports.grdc.com.au/final_reports

In the interests of raising awareness of GRDC's investments among growers, advisers and other stakeholders, the GRDC has available final reports summaries of projects.

These reports are written by GRDC research partners and are intended to communicate a useful summary as well as present findings of the research activities from each project investment.

The GRDC's project portfolio is dynamic with projects concluding on a regular basis.

In the final report summaries there is a search function that allows the summaries to be searched by keywords, project title, project number, theme or GRDC Regions. The advanced options also enables a report to be searched by recently added, most popular, map or just browse by agro-ecological zones

The link to the Final Report Summaries is http://finalreports.grdc.com.au/final_reports

Online Farm Trials http://www.farmtrials.com.au/

The Online Farm Trials project brings national grains research data and information directly to the grower, agronomist, researcher and grain industry community through innovative online technology. Online Farm Trials is designed to provide growers with the information they need to improve the productivity and sustainability of their farming enterprises.

Using specifically developed research applications, users are able to search the Online Farm Trials database to find a wide range of individual trial reports, project summary reports and other relevant trial research documents produced and supplied by Online Farm Trials contributors.

The Online Farm Trials website collaborates closely with grower groups, regional farming networks, research organisations and industry to bring a wide range of crop research datasets and literature into a fully accessible and open online digital repository.

Individual trial reports can also be accessed in the trial project information via the Trial Explorer.

The link to the Online Farm Trials is Online trials - http://www.farmtrials.com.au/

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