GRDC GROWNOTES

Western Region

Know more. Grow more.

Wheat

Western Region

August 2015

wheat development stages • water use efficiency • disease • pests • nutrition • integrated weed management • pre-season • pre-sowing • sowing • early season • mid season • late season • harvest • grain storage • marketing

GRDC Grains Research & Development Corporation
Your GRDC working with you

Start here for answers to your immediate wheat crop management issues

What variety should I grow?

Is dry seeding a profitable option?

How do I determine the optimum sowing rate?

How do I manage non-wetting soils?

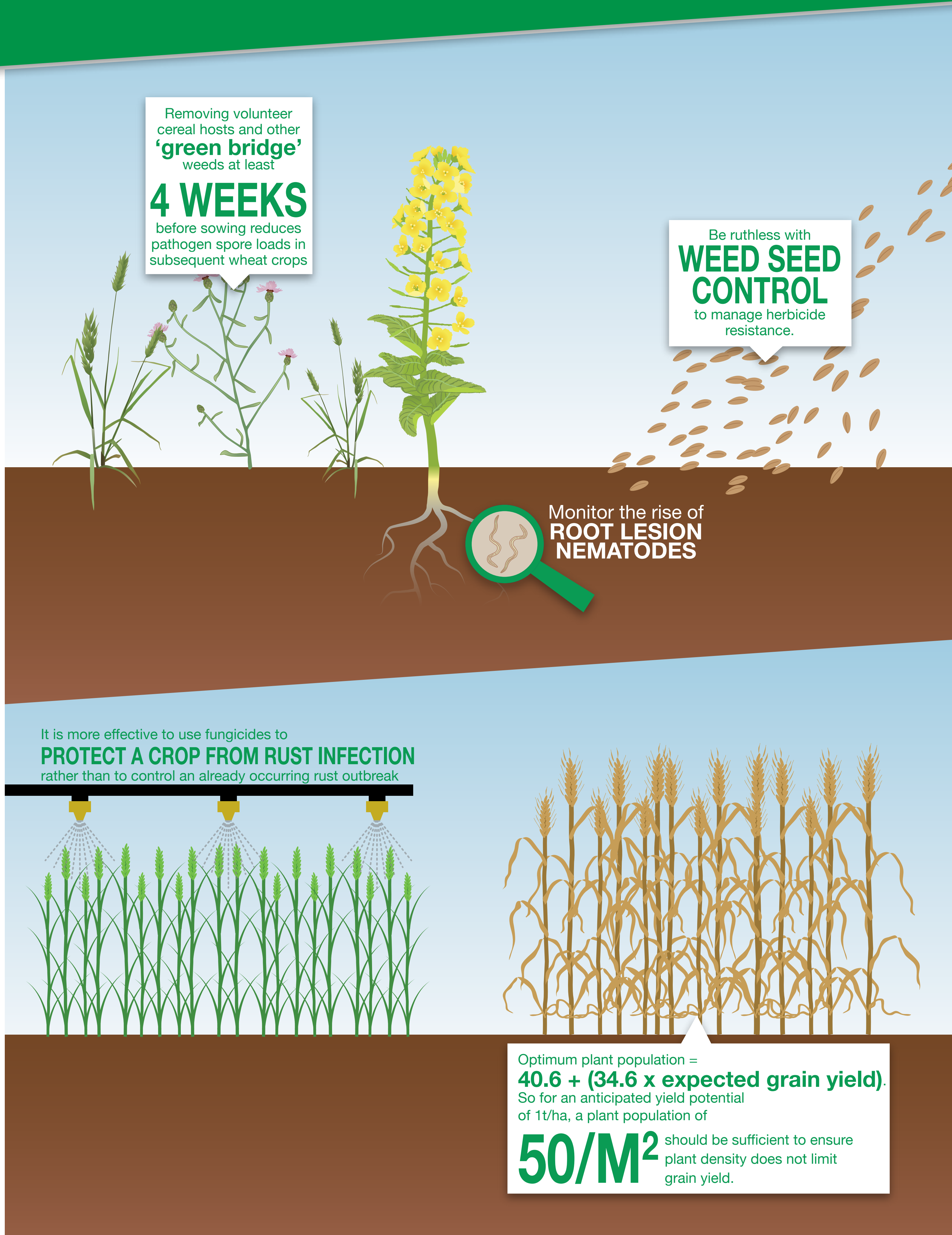
What pre-emergent herbicide control options do I have?

How do I implement harvest weed seed control?

GRDC Grains Research & Development Corporation
Your GRDC working with you

Know more. Grow more.

Keys to successful wheat production



ISBN 978-1-921779-86-2

Cover photo

Harvesting at Dowerin. Photo credit: Evan Collis.

Disclaimer

This publication has been prepared in good faith on the basis of information available at the date of publication without any independent verification. The Grains Research and Development Corporation does not guarantee or warrant the accuracy, reliability, completeness or currency of the information in this publication nor its usefulness in achieving any purpose.

Readers are responsible for assessing the relevance and accuracy of the content of this publication. The Grains Research and Development Corporation will not be liable for any loss, damage, cost or expense incurred or arising by reason of any person using or relying on the information in this publication.

Products may be identified by proprietary or trade names to help readers identify particular types of products but this is not, and is not intended to be, an endorsement or recommendation of any product or manufacturer referred to. Other products may perform as well or better than those specifically referred to.

GRDC
Grains Research & Development Corporation

Chairman's message

GrowNotes are interactive, digital documents that provide a user-friendly one stop shop of best management practice, further information and contacts for each of the western region grain commodities. Whether you are in the paddock or back at the office GrowNotes can be downloaded to your tablet, computer or smart phone to provide information and answers at your fingertips.

The GrowNotes bring together grains research and field trial results, Crop Update and journal papers, relevant GRDC fact sheets, GRDC publications, You Tube video and multimedia materials, links to specific pages and documents on external websites and resources such as National Variety Trials, herbicide, pesticide and fungicide registration charts and the latest variety guide for each grain commodity.

While GrowNotes has pulled together a vast amount of knowledge, it's a breeze to navigate through the information or use in-built search features to quickly find what you need.

GrowNotes - Wheat is the first in the western region GrowNotes series, with additional GrowNotes on barley, canola, oats, lupins and pulses planned.

GrowNotes - Wheat represents decades of GRDC-funded wheat RD&E carried out by the Department of Agriculture and Food, WA, the University of Western Australia, Curtin and Murdoch universities, CSIRO, Western Australian trial operators and other GRDC research partners from across Australia. Pulling this first version together has been an enormous achievement. Special thanks is extended to the Department staff and commercial agronomists who supported the GRDC writing team in sourcing and reviewing content.

A wide range of information has been integrated into an easy-to-read style complemented with clear graphics and tables. Close to 500 embedded web and video links take the reader to more detailed information about a particular topic. Hyperlinked references at the end of each section provide the primary source of information referred to in the document.

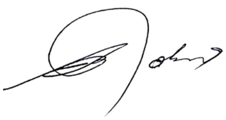
Specific contacts for each section are also provided as a source of further information.

GrowNotes is not a resource to be used once and put on the shelf. The structure is designed to support grain management decisions as they are being made through the season, with each document divided into pre-season, in-season and harvest and post-harvest sections. As a grower I envisage referring to GrowNotes time and again as issues and opportunities arise and as the season unfolds.

What really sets GrowNotes apart is that it will be regularly updated by GRDC. As new research results and best practice guidance becomes available they'll be incorporated. This will give you the confidence that whatever your information needs GrowNotes will provide the latest thinking from experts in the field.

If you can't find the information you are looking for or you have other ideas on how we can improve GrowNotes, please let us know. We are serious about making this resource the most important in your e-library. You will find a feedback link on every page.

The western region Wheat GrowNote can be accessed at www.grdc.com.au/grownotes.



Peter Roberts
GRDC Western Panel Chairman

Foreword

It is my pleasure to welcome you to the GRDC GrowNotes, one of the exciting new GRDC information products providing you with improved access to GRDC research results and support for the decision you need to make about the crops you grow. The GRDC-funded research products referenced throughout this publication are real examples of your levy at work!

The GRDC has been investing in grains RD&E for more than 20 years. During this time, together with our partners, we have generated a mass of information from research outputs and findings, most of which remains relevant today.

Typically, this research has been communicated to industry through GRDC Grower Updates, GRDC Adviser Updates, Ground Cover, fact sheets, media releases, communication campaigns and the GRDC website. While these remain important communication channels, new information technologies such as digital publishing and mobile device applications provide an opportunity to communicate the results of GRDC-funded research more effectively.

The Regional Grower Services business group was established within GRDC to actively listen, service and deliver results to growers. Through Regional Grower Services we have heard your feedback loud and clear. Our Regional Cropping Solutions networks in the Western Region have told us that growers now need more specific information, tailored to their environment and in a format they can access when they need it most. Having this all in one location so they don't have to go trawling through the internet is another key need.

So what's special about GRDC GrowNotes? Put simply, it's about listening and responding to growers needs for R&D information. One of the biggest issues faced in the Information Age is the overwhelming volume of content available. Knowing what's relevant, current and credible is another challenging task. GrowNotes is about saving you time in coming to grips with the latest, GRDC-validated guidance on best management by having it all consolidated in the one place and in a format that allows access online or offline, in the field or back at home.

You'll see a feedback button at the top of every page. I encourage you to use this to provide us with any comments or feedback so we can continue to improve and extend GrowNotes to make it even more useful to you. Our aim is to make GrowNotes the reference to which you, as a grower or agronomist, can confidently turn to view the very latest research and its guidance for cropping in Western Australia.

GrowNotes – Wheat is our first for Western Australia. Stay tuned as other crop modules are progressively rolled out.

I hope you find the GRDC GrowNotes useful.

Stuart Kearns

Stuart Kearns
GRDC Executive Manager Regional Grower Services

Contents

A Introduction

1 Wheat developmental stages

2 Water use efficiency

3 Disease

4 Pests

7 Pre-season

8 Pre-sowing

9 Sowing

10 Early season

11 Mid season

12 Late season

SECTION A

Introduction

More information

DAFWA: Growing wheat in WA

DAFWA: WA wheat industry

GRDC: Area sown to different varieties in WA graph

GIWA Crop Report February 2015, production zones

Wheat production accounts for 70 per cent of Western Australian cereal production with about seven million tonnes generated annually in a rain-fed system across four million hectares of land.

WA generates about 50 per cent of Australia's total annual wheat production.

More than 80 per cent of WA wheat is exported - predominantly to Asia and the Middle East - generating $2 billion in annual export earnings for the State (Figure 1).

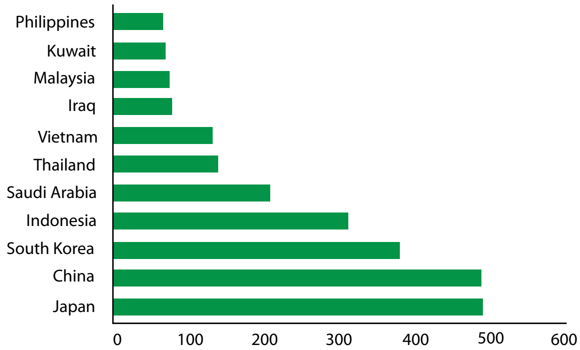


Figure 1: Relative value (A$ million) of major Western Australian cereal markets (wheat, barley and oats) in 2011-12.

Source: Department of Agriculture and Food, WA.

Indonesia is Australia's largest wheat export market accounting for an average 2.3 million tonnes each year. WA is the world's major supplier of wheat for Japanese white salted udon noodles – a one million tonne market. Other significant export markets for WA wheat include Saudi Arabia, which was reopened to Australian wheat imports in 2010.

The area sown to wheat in WA over the past 20 years has remained relatively stable at about four million hectares but over this same period production has more than trebled from two million tonnes to seven million tonnes – a productivity growth rate higher than the world average.

Plant breeding advances combined with wheat agronomy RD&E have led to significant increases in wheat yields per hectare over the past 100 years (Figure 2). In fact, if WA growers were using the same wheat varieties and technology today as they were 50 years ago, the State's average wheat yield would be about half that today's average - about 0.75t/ha (Figure 2).

Note to Figure 2:

New wheat genetics and agronomic packages have resulted in a steady increase in WA wheat yields over time. The significant increase in yields after 1980 was the result of lupins being added to the rotation along with the release of new grass selective herbicides and semi-dwarf wheat varieties.

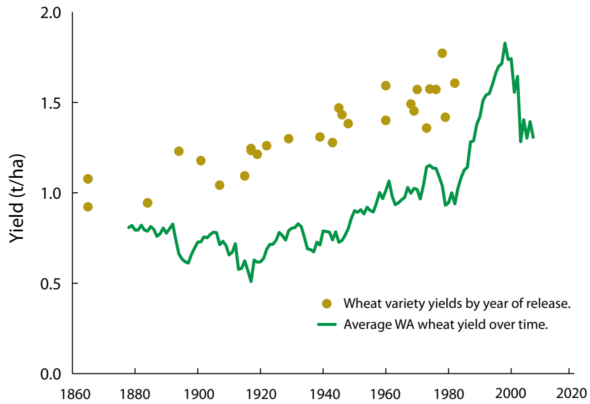


Figure 2: Change in Western Australian wheat yields over time (1880-2010) and the yield of new wheat varieties in the year they were released. Source: Re-drawn from Angus (2011). Variety yield data from Perry and D'Antuono (1989).

However, variable seasonal rainfall means wheat yields vary widely from season to season. For example, the last two seasons, 2013 and 2014, have seen record wheat yields (8-10Mt) for many WA wheat producers but previous years such as 2010 saw the State's wheat yield plummet to just 4.6Mt (Table 1).

Such seasonal variability combined with a high Australian dollar (wheat is sold in US dollars) has placed increasing pressure on wheat profitability. Despite this, a recent study of WA wheat producers found almost two thirds of WA farms can be classed as 'growing' or 'strong' due to their use of technology to create economies of scale and their managerial and social characteristics (Kingwell et al 2013).

Table 1: Western Australian wheat production figures for 2010, 2013 and 2014 by agricultural zone.

Agricultural zone	Annual wheat yield (Mt)		
	2010-11	2012-13	2013-14
Kwinana	1.70	5.10	4.03
Albany	0.75	1.87	1.78
Esperance	0.86	1.37	0.86
Geraldton	1.28	1.87	1.47
Total	**4.59**	**10.21**	**8.13**

Source: Grains Industry Association of Western Australi a, crop reports.

More information

Download regular crop update reports from the Grains Industry Association of Western Australia:
http://www.giwa.org.au

References

Angus, J (2011) The remarkable improvements in Australian mixed farming. Presentation to the Hector and Andrew Stewart Memorial Lecture, The University of Western Australia. 18 March 2011. Sourced from:
http://www.uwa.edu.au/__data/assets/pdf_file/0006/1519566/John-Angus-Presentation.pdf

Kingwell, R Anderton, L Islam, N Xayavong, V Feldman, D and Speijers, J (2013) A decadal assessment of farm performance: any learnings? In Proceedings of the 2013 Agribusiness Crop Updates, Perth, WA.

Perry M and D'Antuono M (1989) Yield improvement and associated characteristics of some Australian spring wheat cultivars introduced between 1860 and 1982. Aust J Agric Res 40: 457-472.

SECTION 1

Wheat developmental stages

Key messages

- Managing to wheat developmental stage is essential for optimal returns from nitrogen, fungicide and herbicide inputs.
- The most commonly used wheat development scale used in Australia is the Zadoks cereal growth stage key.
- The principal growth stages used in relation to disease control and nitrogen management are those from the start of stem elongation through to early flowering (GS30 – GS61).
- The wheat head emerges from underground during early stem elongation GS30-31, making this a critical time for removal of grazing stock.
- Sixty per cent of crop nitrogen use occurs during stem elongation (GS30-39).

Successful crop management requires an ability to identify wheat growth stages and how they interact with nutrition, disease, application of chemicals and environmental stressors.

Figure 1 outlines the developmental stages of a wheat plant and the phases during which potential and actual yield are set.

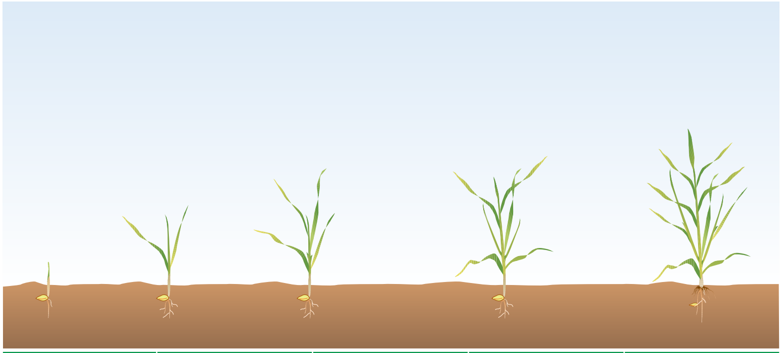
The Zadoks cereal growth stage key depicted in Figure 1 is divided into 10 distinct development phases covering 100 individual growth stages.

Each primary growth stage is divided into 10 secondary growth stages, which indicate the number of plant parts on the main stem or secondary stage of development, extending the scale from 00–99 (Table 1).

*Information in this chapter has been taken from Chapter 3 of The Wheat Book (Anderson and Garlinge, 2000) and the GRDC (2005) publication 'Cereal Growth Stages – the link to crop management'.

Note to Figure 1:

Stem elongation phase: The start of stem elongation is particularly important for decisions on fungicide and nitrogen inputs, since it marks the emergence of the first of the important yield contributing leaves and the point at which nitrogen uptake in the plant increases strongly.



Zadoks Growth Stage	GS 00-09	GS10-19	GS20-29	GS30-39	GS40-49
Development phase	Germination	Seedling growth	Tillering	Stem elongation	Booting

Zadoks Growth Stage	GS 50-59	GS60-69	GS70-79	GS80-89	GS90-99
Development phase	Ear emergence	Flowering	Milk development (grain fill period)	Dough development (grain fill period)	Ripening

Figure 1: Developmental phases of a wheat plant from germination through to maturity and the Zadoks scale associated with each phase.

More information

For details on how to identify the critical growth stage GS30 in the field refer to page 10.24 of these GrowNotes.

A capacity to identify key wheat development stages, particularly those associated with early stem elongation through to flowering, is critical for successful crop management. Photo credit (left): Paul Jones, (right): Paul Matthews.

Key Points

- The Zadoks Growth Stage key does not run chronologically from GS00 to 99, for example when the crop reaches 3 fully unfolded leaves (GS13) it begins to tiller (GS20), before it has completed 4, 5, 6 fully unfolded leaves (GS14, 15, 16).
- It is easier to assess main stem and number of tillers than it is the number of leaves (due to leaf senescence) during tillering. The plant growth stage is determined by main stem and number of tillers per plant e.g. GS22 is main stem plus 2 tillers up to GS29 main stem plus 9 or more tillers.
- In Australian cereal crops plants rarely reach GS29 before the main stem starts to stem elongate (GS30).
- As a consequence of growth stages overlapping it is possible to describe a plant with several growth stages at the same point in time. For example a cereal plant at GS32 (2nd node on the main stem) with 3 tillers and 7 leaves on the main stem would be at GS32, 23, 17, yet practically would be regarded as GS32, since this describes the most advanced stage of development.
- Note: after stem elongation (GS30) the growth stage describes the stage of the main stem, it is not an average of all the tillers. This is particularly important with fungicide timing e.g. GS39 is full flag leaf on the main stem, meaning that not all flag leaves in the crop will be fully emerged.

Note to Table 1:

Each point on the Zadoks scale has two digits, the first indicating the growth stage and the second the number of plant parts or secondary stages of development. For example, GS15 means growth stage 1 with 5 leaves on the main stem. GS24 means growth stage 2 with 4 tillers. Several of the growth stages occur together, so a plant may have more than one decimal code applied at the same time. For example, a plant may be producing leaves and tillering at the same time and so could have a code of GS15, 22, meaning it has five leaves on the main stem and two tillers.

Table 1: Zadoks' decimal growth scale for cereals.

Germination	
00	Dry seed
01	Start of imbibition
03	Imbibition complete
05	Radicle emerged from seed
07	Coleoptile emerged
09	Leaf just at coleoptile tip
Seedling Growth	
10	First leaf through coleoptile
11	First leaf unfolded
12	2 leaves unfolded
14	4 leaves unfolded
16	6 leaves unfolded
18	8 leaves unfolded
Tillering	
20	Main shoot only
21	Main shoot & 1 tiller
22	Main shoot & 2 tillers
24	Main shoot & 4 tillers
26	Main shoot & 6 tillers
28	Main shoot & 8 tillers
Stem Elongation	
30	Stem starts to elongate, head at 1cm
31	1st node detectable
32	2nd node detectable
34	4th node detectable
36	6th node detectable
37	Flag leaf just visible
39	Flag leaf/collar just visible
Booting	
41	Flag leaf sheath extending
43	Boot just visibly swollen
45	Boot swollen
47	Flag leaf sheath opening
49	First awns visible
Head Emergence	
50	1st spikelet of head just visible
53	1/4 of head emerged
55	1/2 of head emerged
57	3/4 of head emerged
59	Emergence of head complete
Anthesis (Flowering)	
61	Beginning of anthesis
65	Anthesis 50%
69	Anthesis compete
Milk Development	
71	Seed watery ripe
73	Early milk
75	Medium milk
77	Late milk
Dough Development	
83	Early dough
85	Soft dough
87	Hard dough
Ripening	
91	Seed hard (difficult to divide by thumbnail)
92	Seed hard (can no longer be dented by thumbnail)
93	Seed loosening in daytime
94	Overripe, straw dead & collapsing
95	Seed dormant
96	Viable seed giving 50% germination
97	Seed not dormant
98	Seed dormancy induced

More information

DAFWA: Date of flowering table, p22-23.

DAFWA: Flower Power flowering predictor.

1.1 Key growth stages

1.1.1 Germination (GS00-09)

It is during germination and establishment that the crop is most vulnerable to pests and to management practices connected to depth of sowing, fertiliser toxicity and poor soil-seed contact.

The goal is to achieve a vigorous, highly competitive crop via uniform germination and rapid seedling emergence and establishment.

Sowing depth plays a large role in seedling establishment and vigour. Fertiliser, herbicide (trifluralin) and some fungicide seed dressings can also impact on seedling vigour. Pests such as mice and several insect species can lower germination and establishment rates significantly.

For more information on the impact of sowing depth on wheat germination and establishment refer to Section 9 of this GrowNote.

1.1.2 Vegetative growth (GS10-GS31)

During the vegetative growth stage the goal is to set up the wheat crop to support maximum grain production. Root and leaf area along with tiller number underpin the capacity of the crop to access soil nutrients and water and convert sunlight into biomass via photosynthesis.

WA wheat varieties commonly form between 8 and 14 leaves on the main stem. However, because continual leaf death and tiller production make leaf counting difficult, it is seldom possible to determine leaf number past GS16 (the six-leaf stage).

The rate at which leaves appear is controlled by daily temperature. Wheat crops sown in June will usually generate a leaf about every 10 days.

Leaf growth in wheat occurs between 0°C and 38°C but is optimum at 29°C. As temperature drops below this optimum leaf growth slows. The optimum temperature for leaf growth is associated with faster tillering, which is why early-sown crops develop biomass more quickly.

Individual leaves have a limited life span and as leaves at the base of a stem die, new leaves form and unfold higher up the plant.

The leaf area per unit of ground area (leaf area index or LAI) determines crop water use. The higher the LAI the more water is used during the vegetative growth stage. Excessive early season nitrogen can result in a large LAI during early vegetative growth, which in turn can result in insufficient soil moisture for flowering and grain fill ('haying off').

1.1.3 Root growth

There is a strong connection between the number of leaves, tillers and nodal roots on a wheat plant. In southern Australia root growth rates are about 1-1.5cm/day, with the wheat root system capable of reaching at least 150cm by flowering and even deeper by grain maturity.

The pattern of root elongation and branching means a considerable length of root can develop on each plant, with a typical value for WA cereals of about 4km/m^2.

The total amount of dry matter in the roots is substantial. In terms of returning organic matter to the soil, the root dry matter can equal the contribution of stubble remaining after harvest (2.8t/ha in the example in Table 2).

Depth of soil moisture usually determines the final rooting depth in wheat but several factors can prevent roots from developing in the subsoil including lack of moisture, chemical constraints such as salinity, acidity or high aluminium and physical constraints such as soil density or compaction.

For more information on subsoil constraints refer to Section 7 of this GrowNote.

Table 2: Root and shoot dry matter (g/m^2) in a wheat crop grown at Merredin, Western Australia.

Dry matter (g/m^2)	34 days	62 days	104 days (flowering)
Roots	22	75	280
Shoots	12	69	509
Root to Shoot ratio	2:1	1:1	0.5:1
Root % total dry matter	65	52	35

Source: Anderson and Garlinge (2000), page 44.

1.1.4 Tillering (GS20-26)

Tillers are lateral branches or shoots that emerge from buds in the axil of the leaves at the base of the main stem. Primary tillers are produced from the leaves of the main stem and can form their own secondary tillers.

Not all of the tillers produce an ear (head). Non-productive tillers can provide nutrient and carbohydrate reserves for grain-bearing tillers.

In dryland wheat production systems about 100 heads/m^2 are required for each tonne of grain per hectare. Typically, only 70- 75 per cent of tillers go on to produce a head, so for a target yield of 3t/ha, about 400 tillers/m^2 would be needed by the end of tillering (usually around stem elongation).

Tiller production is very sensitive to environmental and nutritional stress and tiller development can slow or stop in response to poor nitrogen supply or water stress. Tillers are produced until about the start of stem elongation, when numbers reach a maximum. Tiller numbers then decline until flowering and remain more or less constant until harvest.

Tillers cannot survive alone until they have about three leaves and have started to produce their own nodal roots. Usually only the first 2-3 tillers reach this stage before tillering and leaf production stops.

1.1.5 Reproductive growth (GS14-69)

Final grain yield is largely a function of grain number, which in turn is set by floret production and survival.

Florets are produced on spikelets, which collectively make up the wheat ear (head). Ear or head number is set by tiller number, which in turn is a function of wheat variety and environmental conditions, particularly nitrogen.

Floret number per spikelet rises and then falls so that by flowering usually about two to five florets per spikelet remain. The exact reason for this floret death is uncertain but it could be the result of competition between the stem and the ear for carbohydrate reserves.

In a typical wheat crop only 30-40 per cent of florets go on to set grain.

Water stress and high temperatures two to three weeks before flowering (GS61-69) can seriously reduce floret production and survival.

Pollen formation is also highly vulnerable to water deficit and excessive temperatures.

Frost damage can occur at all stages of crop development but is particularly damaging to floret production and survival between flag leaf emergence and 10 days after flowering.

Floret survival is greatest when there is an adequate supply of water and nutrients, optimum temperature and high solar radiation.

1.1.6 Terminal spikelet

The terminal spikelet signals the end of the wheat head development phase. The total number of spikelets produced per ear varies between 18 and 22. After the terminal spikelet is initiated, rapid head growth begins and the stem elongates.

1.1.7 'Head at 1cm' (GS30)

The developing head is not visible until it is at least 1cm above the ground. Once the terminal spikelet is formed, rapid stem growth brings the well-developed head from below ground to above ground.

Grazing stock must be removed from the crop before 'head at 1cm' (GS30) or stock will remove heads and cause extensive yield loss.

For details on how to identify GS30 in the field refer to page 10.24 of this GrowNote.

1.1.8 Stem elongation (GS31–GS36)

Stem growth is the result of the elongation of the internodes.

The wheat crown (base of stem) consists of eight to 14 nodes stacked closely above one another, separated by internodes less than 1mm long. The growth of the first five or six internodes pushes the head higher and elongates the stem. Lower internodes remain compressed at the base, with the number depending on sowing rate and variety. When the internodes elongate the individual nodes become detectable.

Stem elongation represents a period of rapid dry matter production and high nitrogen demand.

About 60 per cent of total crop nitrogen uptake occurs during stem elongation.

1.1.9 Flag leaf extension (GS39)

The flag leaf is located just below the head and is the last leaf to develop. The flag leaf plays an important role in producing carbohydrates for grain fill, particularly in higher rainfall areas. Protecting the flag leaf from fungal disease is an important management requirement in medium-high rainfall areas.

The emergence of the tips of the awns (awn peep) is an indicator that the flag leaf is fully extended (GS39).

For more information on protecting the flag leaf from fungal disease refer to Section 11 of this GrowNote.

1.1.10 Flowering and grain-fill

Flowering (GS61-69) is a short phase lasting only a few minutes in an individual floret, a couple of hours in a head and about three to four days across a crop. The vast majority of florets self-pollinate with the empty anthers appearing on the outside of the head following fertilisation.

Grain enlargement begins after floret fertilisation and continues for 10 to 14 days.

Grain fill follows the period of grain enlargement and lasts for 15 to 35 days. During this stage grain weight increases at a constant rate as carbohydrate and protein are deposited into the grain. The grain moves from what is known as milk stage through to dough stage. The exact stage is determined by the amount of solids in the grain ‘milk’ or the stiffness of the grain ‘dough’.

Once filled, the wheat grain is 70 per cent carbohydrate, with 97 per cent of this carbohydrate as starch. The protein content is between nine and 12 per cent, depending on final grain weight (which can range from 2.5-4.5mg).

1.1.11 Estimating grain yield

There are four components to wheat grain yield:

- number of ears (heads) per square metre
- number of spikelets per ear
- number of grains per spikelet
- weight per grain.

Ear and spikelet numbers are set well before flowering, grain numbers at around flowering and grain weight between flowering and maturity (Figure 1).

Grain weight is the least variable of the yield components because it is largely determined by the genetic potential of the variety.

Grain yield is therefore most closely related to the number of grains produced by the crop.

1.1.12 Yield compensation

Wheat yield can respond to seasonal conditions almost to maturity due to the capacity of the wheat plant to increase or decrease some or all of its yield components.

For example, low tiller number caused by stress during tiller formation can be compensated for by a larger number of spikelets per head and more grains per spikelet. Similarly, an excessive number of ears/m^2 might result in smaller ears or lower grain weight.

References

Anderson, W and Garlinge, J (2000) The Wheat Book: Principles and Practice. Western Australian Department of Agriculture, Perth, WA.

GRDC (2005) Cereal Growth Stages – the link to crop management. Grains Research and Development Corporation, Canberra.

White, J and Edwards, J (2007) Wheat Growth and Development. New South Wales Department of Primary Industries, NSW.

Estimating grain yield*

The yield of a wheat crop can be estimated by:
Grain yield (kg/ha) = ears/m^2 x grains/spikelet x weight/grain (g) x 10

Ears per square metre
Count the ears in a square metre of crop or count the number of ears in a one metre row length and multiply by 5.6 (there are 5.62 metres of row in one square metre for a 7-inch or 17.8cm row spacing).
For 12-inch or 30cm row spacing multiply by 3.3.

Spikelets per ear
Count the number of spikelets on an average ear; for most crops it will be between 16-20.

Grains per spikelet
Count the grains in spikelets at the top, middle and bottom of the ear. More and heavier grains are usually set in the central spikelets. The number should be between two and four.

Grain weight
Grain weight depends on growing conditions and variety but will usually be between 0.0025 and 0.045 grams per grain (2.5-4.5mg). To determine grain weight, count and weigh 1000 grain and divide by 1000 to get weight per grain. If it is not possible to weigh grain, a good average figure to use is 0.0356g/grain (3.56mg/grain), which is equivalent to 28 grains per gram.

Grain yield
Using the components above the grain yield can be calculated as:
Yield = 100 (ears/m^2) x (18 spikelets x 2 grains/spikelet x 0.03g/grain)
= 100 x 1.08
= 108g/m^2 or 1.08t/ha

This leads to the very simple rule of thumb that 100 ears per square metre will generate about one tonne per hectare of grain.

*Taken directly from Anderson and Garlinge (2000) The Wheat Book, Chapter 3 page 50.

SECTION 2

Water use efficiency

More information

For a comprehensive coverage of water use efficiency and crop production in Australia read: www.grdc.com.au/GRDC-Booklet-WUE and www.grdc.com.au/GRDC-Booklet-PlantAvailableWater

Read the GRDC factsheet on water use efficiency: www.grdc.com.au/GRDC-FS-WaterUseEfficiencySouthWest

To assess whether a crop has yielded to its potential use the MyCrop yield constraint calculator: www.agric.wa.gov.au/grains-research-development/wheat-yield-constraint-calculator

Key messages

- Water use efficiency (WUE) is the efficiency with which the crop converts water to grain.
- Management practices that result in more soil water channelling through the plant rather than being lost to soil evaporation, drainage or run-off will lift the WUE of a crop.
- Time of sowing is a significant driver of WUE because crops sown on time are more likely to flower within their optimum flowering window.
- Soil constraints such as compaction, non-wetting soils, soil acidity and sodicity can lower WUE significantly.
- Summer weed control can increase the water available to crops in a below average season and in doing so lift WUE significantly.

In simple terms the water use efficiency (WUE) of wheat production is the grain yield of a crop divided by the water used by that crop. It is the efficiency with which the crop converts water to grain.

The amount of water available to a crop is usually defined as the amount transpired through crop leaves during photosynthesis plus the evaporation of moisture from bare soil. In reality, the evaporation component also integrates any crop water lost to run-off and drainage, as these losses are very difficult to quantify.

Transpiration represents a productive use of water (because it results in crop growth) while water lost via soil evaporation, run-off and drainage represent unproductive water losses.

Management options that channel proportionally more water through the transpiration route than the soil evaporation route will result in increased yield and therefore higher water use efficiency. This is the principle behind early-sown crops, which tend to cover the ground and develop deeper roots more quickly than later sown crops and in doing so reduce soil water evaporation (and potentially drainage), leaving more water for crop production.

In southern Western Australia, water use efficiencies of wheat have been shown to vary from 8 to 22kg/mm/ha (Hall et al 2014) with 22kg/mm/ha being towards the upper potential limit for WUE of WA wheat crops. This wide variation in WUE is the result of seasonal, agronomic and soil constraint factors which, when combined, affect the amount of water taken up by a crop and the efficiency with which it is converted to yield.

2.1.1 WUE and potential yield

Annual rainfall and WUE underpin potential wheat yield in dryland agricultural systems.

While annual rainfall cannot be controlled, the efficiency with which seasonal rainfall is converted to grain can be manipulated using pre-crop and in-crop management practices.

2.1.2 Summer weeds

For example, summer weed control can significantly increase the amount of water available to crops in some years (Table 2) and be a major driver of WUE, particularly in parts of the WA wheatbelt that increasingly rely on out-of-season rainfall to grow winter crops.

Ensuring good summer weed control conserves valuable summer rainfall for crop growth early in the season and grain fill during spring.

Combining summer weed control with stubble retention and minimum tillage also increases water infiltration and reduces water runoff.

More information

For more information on summer weed control and its impact on WUE read: www.grdc.com.au/GCS103-ControlSummerWeedsToReapYieldBenefits

2.1.3 Soil constraints

Soil amelioration practices such as liming, incorporation of gypsum, deep ripping and claying can lift WUE significantly on affected soils.

Applying 5t/ha of gypsum on responsive soils lifted WUE by more than 50 per cent along the WA south coast from 11 to 17kg/ha/mm (Table 2).

For more information on the yield responses possible from deep ripping, claying and liming see Section 7 of this GrowNote.

Note to Table 2:

In the Ravensthorpe research detailed in Table 1 all responsive soils had dispersible clay (indicative of sodicity) making water pool on the surface of paddocks. Sub-surface and surface sodicity is prevalent across the south coast of WA and often results in poor drainage, surface sealing and transient waterlogging, which in turn results in poor germination and early growth. Low plant available water from sodicity further reduces crop WUE.

Table 1: Soil moisture difference in the top 40cm between WA plots sprayed and unsprayed for summer weeds.

Location	Soil type	Soil moisture difference (mm) (0-40cm)
Bodallin	Sandy earth	+15
Merredin	Calcareous loam	+25
Southern Cross	Shallow sandy loam	+60
Southern Cross	Gravelly loam	+10
Kellerberrin	Alkaline shallow duplex	+46
Bencubbin	Calcareous loamy earth	+11
Beacon	Shallow loam duplex	+9
Doodlakine	Sandy duplex	+9
Narambeen	Deep loamy duplex	+41

Source: GRDC Regional Cropping Solutions Network – Kwinana East zone. *Plots sprayed between Dec 2012 and Feb 2013.

Table 2: Impact of gypsum application on wheat yield and WUE on gypsum-responsive soils at Ravensthorpe, WA (2010).

Gypsum (t/ha)	Wheat yield (t/ha)	WUE kg/ha/mm	Yield potential (%)
0	1.5	11	56
2.5	1.8	13	66
5	2.2	16	80
10	2.3	17	84
Potential yield			2.7t/ha
Top 10% of paddock			>2.6t/ha

Source: Department of Agriculture and Food, WA.

2.1.4 Time of sowing

Time of sowing is arguably the most important management practice influencing water use efficiency and yield of wheat.

Sowing time influences flowering time, which in turn has a large impact on yield through its interaction with water frost, high temperature and disease.

Many studies show that yields drop significantly for each day that a wheat variety flowers outside its optimum flowering window (Table 3).

Note to Table 3:

Delayed sowing beyond the optimum time reduced grain yields of wheat by an average of 6.6 per cent
per week.

Table 3: Mean yield loss of wheat when sowing is delayed past an optimum date, grouped according to the maximum yield recorded in the trial.

Yield category (t/ha)	Number of trials	Mean max yield (t/ha)	Yield loss per week*	
			%	kg/ha
<1.5	3	1.1	5.9	61 (51)
1.5-2.0	5	1.7	8.2	139 (98)
2.0-3.0	15	2.3	7.8	178 (109)
3.0-4.0	8	3.3	8.7	285 (129)
4.0-5.0	9	4.3	4.5	197 (77)
>5.0**	9	6.2	4.0	239 (118)
Average			6.6	239 (118)

*Figures in brackets are +/- standard deviation. **Some trials irrigated in this yield category. Source: Extracted from Sadras and McDonald (2012). Data were derived from NSW, Victoria, SA and WA, trials carried out mostly between 1972 and 2008.

More information

For more information on the soil constraints to WUE in WA wheat systems read: www.agric.wa.gov.au/sites/gateway/files/Agronomy%20jigsaw%20bulletin%204850.pdf

For more information on the use of gypsum to overcome sodic soils read: www.grdc.com.au/GCS103-GypsumImprovesYieldsOnResponsiveSoil

For more information on sowing time and water use efficiency read: www.grdc.com.au/GCS103-EarlySowingLowersProductionRisk

Read the GRDC Fact Sheet: www.grdc.com.au/GRDC-FS-TimeOfSowing

Note to Table 4:

Nitrogen can be used to manipulate canopy development and in turn water use and biomass production. Crops with sufficient early season nitrogen are more vigorous, cover the ground more quickly and have deeper roots than nitrogen-deficient crops.

Interestingly, time of sowing generally has only a small effect on total crop water use but can have a marked impact on water use efficiency – with the highest water use efficiencies consistently achieved when the crop is sown at the optimum time.

Late sowing (relative to maturity rating) reduces water use efficiency through its impact on crop establishment and early vigour because seedlings are establishing in colder soil. Late sown crops also lose more water through soil evaporation and there is a higher likelihood of heat stress around flowering and during grain growth.

2.1.5 Matching nitrogen to yield potential

Nitrogen supply is a major driver of wheat yield and water use efficiency. Applying nitrogen at strategic times throughout the season to match crop demand and soil moisture supply can increase yield and water use efficiency above that of a single application at sowing (Table 4).

Table 4: Grain yield response and water use efficiency of 100kg/ha nitrogen applied either at sowing or at various growth stages throughout the season.

Nitrogen treatment	Grain yield (t/ha)	Water use efficiency
Nil	2.25	7.1
Sowing	2.86	9.1
3.5 leaf	3.00	9.5
1st node	3.02	9.6
3.5 leaf + 1st node	3.17	10.1
3.5 leaf + awn peep	3.05	9.7
1st node + awn peep	2.96	9.4
Sowing + 3.5 leaf + awn peep	2.95	9.4
$LSD_{0.05}$	0.14	

Source: Extracted from Sadras and McDonald (2012) Based on Hooper (2010).

2.1.6 French and Shultz

Water use efficiency estimates are based on the work of French and Shultz (1984).

French and Shultz (1984) investigated the wheat yield variability at 61 field sites in South Australia over 12 years (1964-75). The main variety used in the trials was Halberd. French and Shultz measured rainfall and evaporation, soil water at sowing and harvest and crop growth and yield.

The selected sites had minimal risk of runoff or deep drainage, which enabled French and Schultz to estimate crop water use by measuring the change in soil water content between sowing and crop maturity plus the rainfall over the same period.

When the wheat yields at the 61 sites were plotted against measured values of water use, the data points were widely scattered and there was no clear correlation between water use and grain yield (Figure 1).

To interpret the scattered data, French and Shultz drew a line through the highest grain yields at different levels of water use (Figure 1). This line represented the linear relationship between the highest (potential) yields possible at particular levels of water use.

More information

For more information on matching inputs to yield potential and overcoming soil constraints to lift water use efficiency read: www.grdc.com.au/GCS103-MatchNitrogenToSoilType and www.grdc.com.au/GCS103-SecuringYieldsOnTheEdge

For information on canopy management and water use efficiency read: www.grdc.com.au/CanopyManagementGuide

Note to Figure 1:

An alternative (but less accurate) approach to the French and Shultz model for calculating WUE on-farm is to simply divide crop yield by growing season rainfall. This 'rain use efficiency' index generally has a value of about 10kg/ha/mm in the central and eastern wheatbelt of WA and can be used as a target or benchmark against which the cropping system can be measured.

The data points spread below the potential yield line were assumed to be sites where yield was limited by factors other than water such as soil constraints, disease, nutrition, pests and extremes of temperature.

The potential yield line intercepted the X-axis at 110mm of water use (see Figure 1). This was assumed to mean that, on average, in South Australia in the 1960-70s up to 110mm of water (stored soil moisture and rainfall) was lost through soil evaporation – and was therefore not used for grain production.

Water in excess of this 110mm contributed to the water-limited yield potential to the extent of 20kg/ha/mm (the slope of the potential yield line in Figure 1). The 20kg/ha/mm value was considered the potential water use efficiency possible for wheat varieties in South Australia during the 1960s-70s – provided all other constraints (e.g. disease, nutrition, frost) were non-limiting. More modern Australian wheat varieties have been bred to use water more efficiently and have potential WUE values closer to 25kg/ha/mm.

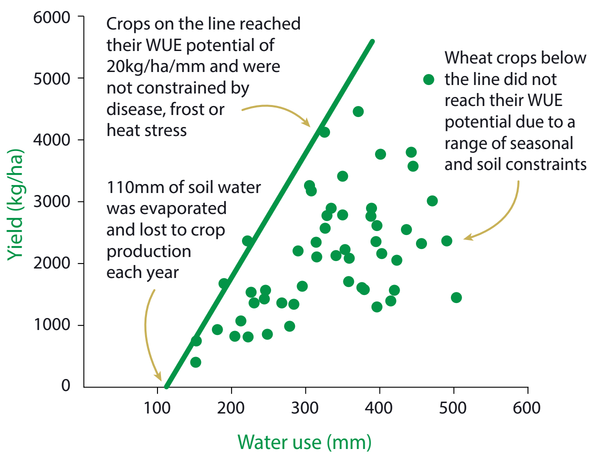


Figure 1: Yield and water use data of wheat crops grown in South Australia between 1964-75. The data were used to generate the now widely used French-Shultz water use efficiency equation for wheat. Source: Extracted from Anderson and Garlinge (2000) from the original paper of French and Shultz (1984).

The water loss (evaporation/transpiration) and water use efficiency (WUE) values were used to develop the now famous French and Shultz equation:

Yield potential = (crop water use – 110mm) x 20

French and Shultz used April-October rainfall as a surrogate for total crop water use (water available to the crop). However, this did not account for summer rainfall stored at depth – an increasingly important source of crop water in southern Australian wheat systems. By not accounting for stored soil water, WUE values calculated using French and Shultz are overestimated because the calculation assumes that the crop has generated its grain yield from less water than it might actually have had access to.

A common mistake when using the French and Shultz equation to develop potential yield or water use efficiency estimates is to assume that the 110mm of soil evaporation is a constant when, in reality, soil evaporation can vary considerably with management, rainfall and soil type. In fact, published values of soil evaporation under crops range from 20-60 per cent of total water use (Tennant, 2000).

French and Schultz demonstrated that the evaporation component in their equation was highly variable; ranging from 30-70mm in northern New South Wales and Queensland crops that used predominantly stored soil water through to 170mm on hard-setting South Australian soils with poor infiltration, surface ponding and surface runoff.

In Western Australia water evaporation losses can range from 40-90mm on mallee soils along the south coast through to 130mm on the deep sands common at Wongan Hills.

WUE and potential yield estimates will be inaccurate if the evaporation component of the French and Shultz equation is not adjusted to suit the agronomic and climatic characteristics of the wheat system being assessed.

2.1.7 Modified French and Shultz

To address these issues Oliver et al (2009) modified the French and Shultz equation in several important ways to adapt it to rainfall patterns and soils of the WA wheatbelt.

First, they modified the growing season rainfall (GSR) of the 'crop water use' component to be rainfall from the start of May through to the end of October (instead of April-October as used by French and Shultz).

Second, they included one-third of out-of-season (OSR) (January-April) rainfall in the 'crop water use' component. This accounted for the fact that about 30 per cent of rainfall falling between January-April is still available in the soil by seeding.

Third, they introduced a cap on the 'crop water use' component so that it could not exceed the plant available water capacity (PAWC) of the soil. This meant that the 'crop water use' component could not be overestimated in higher rainfall years on soils with relatively low capacity to hold water.

Finally, they included a sliding scale for the soil evaporation component that was more suited to WA conditions with soil evaporation set at 130mm when GSR was greater than 180mm and 90mm when GSR was less than 180mm. This helped ensure that water use efficiency was not underestimated in low-rainfall years.

Hall et al (2014) compared the WUE values of 174 south coast WA wheat trials calculated using the French and Shultz (1984) equation with those calculated using the modified Oliver et al (2009) equation and another modified French and Shultz equation of Kirkegaard and Hunt (2009).

They found that while each of the methods delivered a different absolute WUE value, the relative WUE rankings of the wheat trials was similar.

The modified Oliver et al (2009) equation resulted in less variation between actual and potential yield values – most likely due to the cap placed on 'crop water use' relative to soil PAWC.

For a full coverage of the modified French and Shultz equation developed by Kirkegaard and Hunt (2009) read the *Water Use Efficiency Benchmarking Guide*.

Note to Table 5:

Within the mallee and sandplain, considerable variation in WUE was found between certain districts, with values ranging from 6 to 24kg/mm/ha. This analysis will enable lower performing areas to be targeted for further research and development. Although the three WUE calculations resulted in different absolute WUE values each of the methods ranked the sites similarly in terms of WUE.

Table 5: Water use efficiency of wheat crops across the south-coast of Western Australia calculated using modified French and Shultz equations and the original French and Shultz (1984) WUE equation.

Region	Area	Site years	*WUE_{FS} (kg/mm/ha)	*WUE_{H} (kg/mm/ha)	*WUE_{O} (kg/mm/ha)
Mallee	Beaumont	9	17	10	15
	Cascade	13	22	9	14
	Grass Patch	8	23	11	17
	Jerramungup	12	14	8	12
	Mt Ridley	4	18	11	16
	Mt Madden	26	19	8	13
	Ravensthorpe	2	12	7	11
	Salmon Gums	18	22	10	15
	Scaddan	12	24	13	20
	West River	1	10	3	6
	Wittenoom Hills	11	22	11	16
Mallee total/average		**116 (total)**	**20 (average)**	**10 (average)**	**15 (average)**
Sandplain	Coomalbidgup	8	16	10	15
	Dalyup	7	11	7	10
	Gibson	7	15	10	13
	Hopetoun	2	19	11	18
	Mt Howick	8	17	11	16
	Jerdacuttup	11	14	8	11
	Munglinup	11	12	8	11
	South Stirling Range	4	17	11	17
Sandplain total/average		**58 (total)**	**15 (average)**	**9 (average)**	**13 (average)**

WUE_{FS} - original French and Shultz (1984) WUE equation. WUE_{H} - modified French and Shultz equation developed by Kirkegaard and Hunt (2009). WUE_{O} - modified French and Shultz equation developed by Oliver et al (2009).

In the modified French and Shultz equation developed by Oliver et al (2009):

Crop yield = (May-Oct rainfall + 0.3(Jan-April rainfall)) – soil evaporation

For soil evaporation the following qualifications are used:

If GSR >180mm then soil evaporation = 130mm

If GSR <180mm then soil evaporation = 90mm

If GSR+OSR > PAWC then GSR+OSR = PAWC.

Source: Oliver et al (2009)

References

Anderson W and Garlinge, J (2000) The Wheat Book: Principles and Practice Published by Western Australian Deptartment of Agriculture.

French, R.J. and Schultz, J.E. 1984. Water use efficiency of wheat in a Mediterranean-type environment. I. The relationship between yield, water use and climate. Australian Journal of Agricultural Research 35, 743-764.

Hall, D Galloway, P Lemon, J Curtis, B van Burgel, A Kong, K and Metz, M (2014) The Agronomy Jigsaw: Finding the pieces that maximize water use efficiency. Bulletin 4850. Department of Agriculture and Food, WA.

Hooper P (2010) Strategic applications of nitrogen fertiliser to increase the yield and nitrogen use efficiency of wheat. MSc Thesis. The University of Adelaide.

Oliver Y, Wong M, Robertson MJ, Andrews J (2014) Response of crop yield to soil acidity and lime: Diagnosing acid constraints and case studies. Forms output 2 and 3 of GRDC project: Realising yield potential through farming systems research, development and extension – Western Region - Extension". CSIRO, Australia.

Oliver Y.M., Robertson M.J., Stone P.J., Whitbread A. (2009) Improving estimates of water-limited yield of wheat by accounting for soil type and within-season rainfall. Crop and Pasture Science 60, 1137–1146.

Sadras, V and McDonald, G (2012) Water use efficiency of grain crops in Australia: principles, benchmarks and management. Grains Research and Development Corporation, South Australian Research and Development Institute and University of Adelaide. GRDC Project Code: DAS00089

Tennant, D (2000) Chapter 4 in Anderson and Garling (2000) The Wheat Book: Principles and Practice Published by Western Australian Department of Agriculture.

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

DAW00219 - Characterising and exploiting genetic diversity in wheat and barley for tolerance to water deficit during germination and crop establishment
(S: 01/07/2011 F: 30/06/2015)

DAS00089 - Improving crop and farm water use efficiency in Australia
(S:01/07/2008 F: 30/6/2013)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC water use efficiency projects can be found at: www.grdc.com.au

SECTION 3

Disease

3.1 Rust

More information

DAFWA: Disease update, p15.

GRDC: Disease update, p11-13.

DAFWA: Crop diseases, Pestfax.

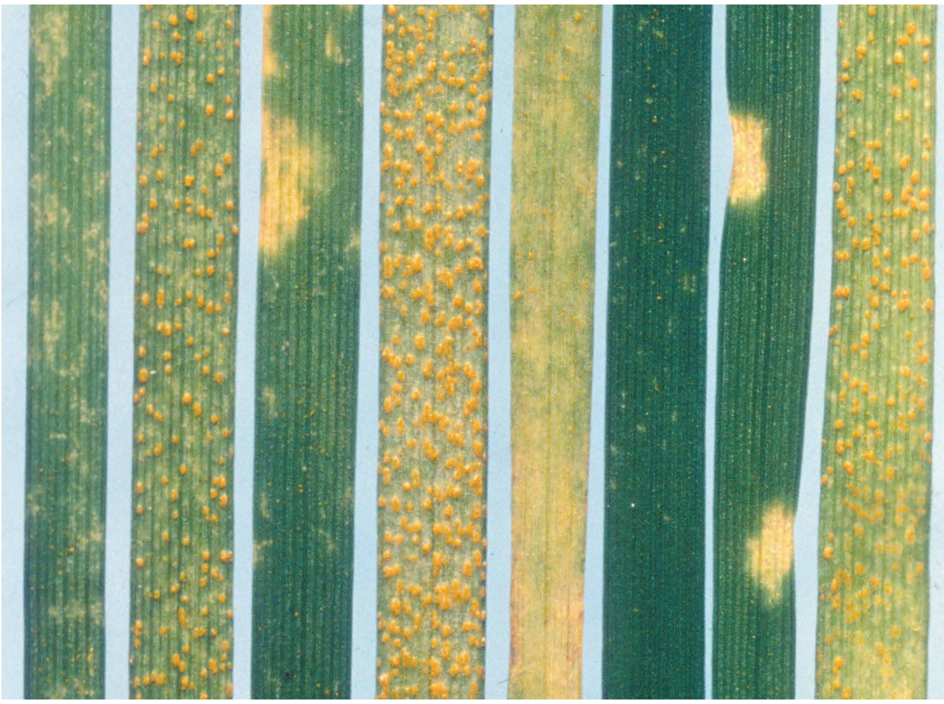
DAFWA: Wheat disease ratings.

DAFWA: Control of green bridge for disease management.

GRDC: Stop disease and pest cycles in their tracks with crop checks this harvest.

Key messages

- Leaf, stem and stripe rust can only survive on living plants. Removing volunteer cereal hosts and other 'green bridge' at least four weeks before sowing reduces pathogen spore loads in subsequent wheat crops.
- Where possible avoid very susceptible or susceptible wheat varieties; growing varieties with some level of rust resistance is the key to controlling rust outbreaks.
- Knowing the seedling and adult rust resistance characteristics of wheat varieties underpins effective fungicide management.
- It is more effective to use fungicides to protect a crop from rust infection rather than to control an already occurring rust outbreak. Crop monitoring is essential for timely fungicide application.
- The rust fungi constantly mutate and some of these mutations are capable of overcoming wheat rust resistance. The more rust there is in the environment the higher the possibility that mutations with new virulence will develop.



Widespread epidemics of cereal rusts are only a sporadic problem for Western Australian wheat producers however smaller outbreaks of leaf, stem or stripe rust are more common and can cause severe losses in susceptible varieties (Table 1).

Photo credit: Brad Collis.

Table 1: Potential yield loss from leaf and stripe rusts in wheat varieties of varying rust resistance ratings.

Resistance rating	Definition	Potential yield loss (%)	
		Leaf rust	Stripe rust
Very susceptible (VS)	High disease build-up early in season; can promote epidemic development	40	80
Susceptible (S)	High disease build-up	30	60
Moderately susceptible (MS)	Develops disease less quickly, which reduces risk of yield loss	20	40
Moderately susceptible-moderately resistant (MS-MR)	Some partial resistance; losses depend on disease pressure	15	30
Moderately resistant (MR)	High partial resistance; yield losses generally low	5	15
Resistant (R)	Highly effective resistance; no or very low yield loss	<5	5
Highly resistant (HR)	Complete resistance	0	0

Table 2: Characteristics of stem, leaf and stripe rust diseases of wheat.

Characteristics	Stem rust	Leaf rust	Stripe rust
Colour*	Reddish brown	Orange brown	Yellow
Shape of pustules	Oval to elongated with tattered edges	Circular to oval	Small circular in yellow stripes running along leaf.
Location on plant	Both sides of leaf, leaf sheaths, stems and external head.	Mostly on upper surface of leaf.	Mostly on upper surface of leaf in characteristic stripes along leaf veins. Also on leaf sheaths, awns and inside glumes.
Optimal conditions	Warm, humid (18-30°C)	Moist with temperature between 10-20°C.	Cool, moist conditions (8-15°C)
Potential yield loss	Usually 10-50% (but can be up to 90%)	Up to 30%	60%

Videos

Watch a video on the importance of controlling the green bridge: www.grdc.com.au/GCTV5-GreenBridge

More information

To diagnose stripe, stem or leaf rust in-crop use the MyCrop tool: https://agric.wa.gov.au/n/2152

For more information on wheat rust disease refer to: www.grdc.com.au/GRDC-BPG-WheatRust

Read the GRDC factsheet on removing the green bridge: www.grdc.com.au/GRDC-FS-GreenBridge and visit https://agric.wa.gov.au/n/2406

3.1.1 Managing rust

Rust management is all about managing inoculum load and requires a farm, district and regional level approach:

- Remove the green bridge (volunteer cereals) by mid-March;
- Grow varieties with adequate resistance to stem, stripe and leaf rusts;
- Apply fungicides to seed or fertilisers for early season rust suppression in high-risk areas; and
- Monitor crops for rust and if needed apply registered foliar fungicides for disease control.

3.1.2 Controlling the green bridge

The rust fungus cannot survive without a living host. Removing the green bridge – especially volunteer cereals, reduces the amount of pathogen that survives over summer and therefore the amount of rust present at the start of the growing season.

The green bridge must be totally removed at least four weeks before sowing to minimise the risk of carrying rust into new season crops.

If high levels of rust are present in a green bridge when crops are sown, even crops with moderate levels of rust resistance can potentially be severely affected because the rust will infect crops during the very susceptible establishment phase, before adult plant resistance traits have had a chance to develop (Figure 1).

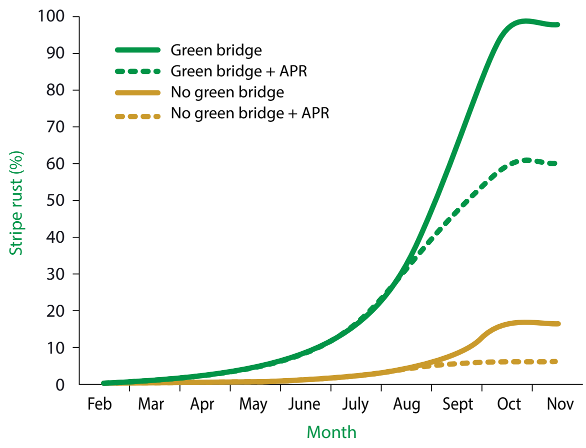


Figure 1: Illustration of the effects of a green bridge and adult plant resistance (APR) on the development of stripe rust in wheat compared with a drier summer.

3.1.3 Grow resistant varieties

Growing wheat varieties with some level of rust resistance is the best way to minimise rust outbreaks in-crop. Strategic use of fungicide with partially resistant varieties will also minimise yield losses and lower pathogen loads in-crop (Figure 2).

Note to Figure 2

The susceptible variety (S-VS) suffered extreme yield loss (87%) under very high stripe rust disease pressure in a long season environment. Varieties with partial resistance to stripe rust (MS/MR) also suffered high yield losses (up to 50%) under high disease pressure with no fungicide control. Partial fungicide protection combined with partial resistance reduced yield losses to about 30%, depending on variety. Only the fully resistant variety was able to maintain yield potential with no fungicide control.

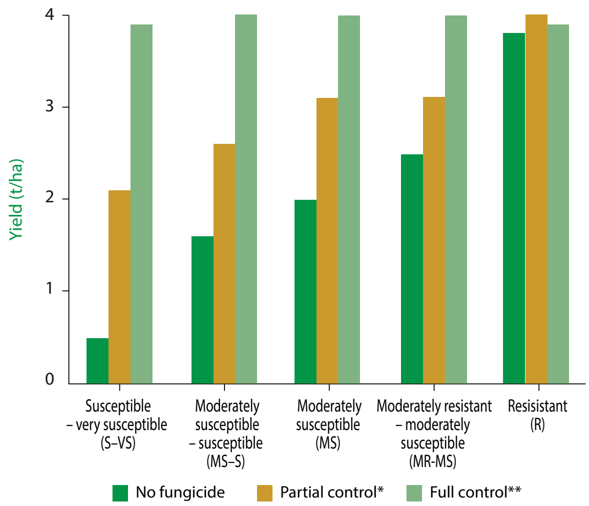


Figure 2: Impact of fungicide management for stripe rust on the yield of wheat varieties differing in stripe rust resistance. Source: Jayasena et al (2009)

*Partial fungicide control consisted of a single application of Tebuconazole @ 290 mL/ha at ear emergence

**Full control consisted of a single application of Tebuconazole @ 290 mL/ha applied at early stem elongation, flag leaf emergence, ear emergence and late flowering

Stripe rust severity ranged from 4 to 96% in untreated plots.

Rust disease will develop more slowly in wheat varieties with increasing levels of resistance. A slower-developing epidemic offers more time to make spray decisions and the fungicide applied is likely to be more effective in controlling the disease. Resistant varieties also generate fewer rust spores on volunteers over the summer-autumn period.

However it is important to be as proactive as possible, because the three wheat rusts have different latent periods (the time between rust infection and expression).

More information

Consult the latest WA wheat variety guide to determine current rust-resistance ratings of varieties.
www.grdc.com.au/WAWheatVarietyGuide

Information on the mix of seedling and APR rust resistance genes in current wheat varieties can be found in: http://sydney.edu.au/agriculture/documents/pbi/cereal_rust_report_2012_vol_10_1.pdf

For more information on adult plant resistance read the GRDC Fact Sheet: http://grdc.com.au/grdc-fs-AdultPlantResistance

Growing susceptible varieties not only increases rust pathogen loads in-crop but also creates a susceptible 'green bridge' in years with summer rain. This build-up of the pathogen in susceptible varieties allows greater opportunity for mutation to generate new strains capable of overcoming cereal rust resistance.

3.1.4 Rust resistance genes

Two forms of resistance operate in rust resistant wheat varieties. The first, seedling resistance (also known as all-stage resistance) operates throughout the life of the plant and is controlled by major resistance genes that are strain-specific.

The second, adult plant resistance (APR) develops as the plant matures and works by slowing down the rate of epidemic development.

3.1.5 Seedling resistance

Seedling resistance is usually controlled by a single major gene and is highly effective but because it is strain specific it is only effective against particular strains of rust.

Mutations within the rust pathogen can overcome single-gene seedling resistance. When a resistance gene is overcome or 'broken down' the level of varietal resistance will depend on the other rust resistance genes present in that variety.

For example, stripe rust resistance in Mace⁽ᴾ⁾ is controlled by the single seedling resistance gene *Yr17,* which is currently effective in WA but not in the eastern states. It is very likely that *Yr17* will be overcome in WA either through rust mutation or through introduction of the *Yr17* virulent pathotype from the eastern states.

Considering the extensive cultivation of Mace⁽ᴾ⁾ in WA, such an incursion or mutation could result in a stripe rust epidemic. By contrast, varieties like Fang⁽ᴾ⁾, which is mainly dependent on Yr17 for stripe rust resistance also has the added protection of the adult plant resistance gene *Yr18*.

3.1.6 Adult plant resistance

In wheat varieties containing adult plant resistance for rust, the resistance switches on sometime between tillering and heading, depending on the environment, crop nutrition, specific genes involved and the variety.

Adult plant resistance is considered 'partial resistance' and can be derived from several genes. It has generally proved more durable than single major gene resistance (seedling resistance).

Varieties with adult plant resistance but no seedling resistance are vulnerable to early season rust outbreaks and may require seed or foliar fungicide at earlier growth stages before the adult plant resistance becomes active.

When most of a wheat production area is sown to varieties with effective adult plant resistance, rust is not seen until after flag leaf emergence and little damage occurs.

However, if the epidemic starts before flag leaf emergence damage to varieties with adult plant resistance can be more than 20 per cent.

3.1.7 Monitoring for new rust strains

The rust pathogen is constantly changing, either through exotic incursions of completely new rust strains or through mutations within local strains.

The introduction of stripe rust into WA in 2003 and to eastern Australia in 2004 resulted in significant changes in variety responses to rust and resulted in considerable increases in management costs for wheat varieties that had become susceptible to the disease.

In the four years between 2007-2011 ten new cereal rust strains were identified in Australia, which resulted in the loss of five rust resistance genes in Australian cereal varieties. There are currently 700 known unique strains of rust in Australia.

Rust pathogens can be spread thousands of kilometres by wind, clothing or machinery.

Introduction of new strains of rust from outside WA can introduce new virulence and dramatically alter the responses of varieties. For example, a new wheat leaf rust strain, originating in eastern Australia, with virulence for Lr13 was detected in WA in 2013 and this has altered wheat disease ratings for some prominent WA wheat varieties.

Biosecurity measures are particularly important for curbing the spread of rust pathogens which can be easily moved via clothing, machinery and wind.

More information

Watch a video about adult plant resistance for rust and fungicide timing: www.grdc.com.au/GCTV9-APR

Watch a video on the importance of growing resistant varieties for rust management and the determining the resistant genes of wheat varieties: www.grdc.com.au/GCTV1-CerealRust

Mace⏀ and stem rust

Mace⏀ has become a dominant variety in WA making up more than 50 per cent of the area sown in 2013.

Mace⏀ contains two major rust resistance genes, *Sr15* and *Sr38*, and an adult plant resistance gene called *Sr2*.

The two major genes have each broken down separately but not in the same variety. *Sr38* in the previously popular variety Camm⏀ broke down years ago but fortunately the rust strain that overcame *Sr38* does not attack *Sr15*.

Similarly, the *Sr15* gene in Wyalkatchem⏀ is still effective against the *Sr38*-attacking strain of stem rust. However if either rust strain mutates so that it can attack both *Sr38* and *Sr15* then Mace⏀ would be left with only *Sr2,* which is widely accepted not to be sufficient stem rust protection on its own. For example, in a major rust outbreak in 2003 spraying the wheat variety Kukri⏀ (which has only *Sr2*) twice with fungicide did not control stem rust.

Newer wheat varieties that have performed well in WA include Corack⏀, Scout⏀, Envoy⏀ and the later maturing Estoc⏀. Corack⏀ shares some rust genes with Mace⏀ but has an extra stem rust gene *Sr30*, which would likely give some protection if *Sr15* were overcome by a new rust pathotype. Scout⏀, Envoy⏀ and Estoc⏀ are also likely to maintain some resistance, however it is very difficult to predict how a rust mutation will impact varieties until the event occurs.

If rust outbreaks are detected in wheat varieties with rust resistance it is important to send samples for testing to the Australian Cereal Rust Survey as the outbreak may indicate a new virulent rust strain has developed.

Rust samples should be sent in paper envelopes (not plastic bags), marked with your name and contact details, date, location and variety. Leaves and stems with active pustules are required.

Post as soon as possible to:

Australian Cereal Rust Survey
Private Bag 4011
Narellan, NSW 2567.

Sampling instructions, posting details and further information on the new pathotypes can be found on the Australian Cereal Rust Control Program website www.rustbust.com.au

Some fungicide seed dressings can reduce coleoptile length and cause 'silly seedling syndrome' where leaves grow under the soil surface but do not emerge. Coleoptile shortening can also occur with dinitroaniline herbicides (trifluralin, pendimethalin and oryzalin). Take care when using coleoptile-shortening seed dressings together with these herbicides, particularly in sandy soils where it is difficult to obtain good depth control of herbicide incorporation and seed placement.

Leaf rust. Photo credit: GRDC.

Wheat stem rust. Photo credit: Brad Collis.

Stripe rust. Photo credit: GRDC.

3.1.8 Rust fungicide management

Seed dressings and in-furrow control

Registered seed dressing and in-furrow fungicides can suppress leaf or stripe rust on wheat seedlings for four to six weeks, depending on the product and rate. They are particularly important for early-sown and long-season crops and in some cases can replace the need for a foliar spray before flag leaf emergence.

More information

Download the current registered seed dressings and in-furrow fungicides for wheat: https://www.agric.wa.gov.au/barley/seed-dressing-and-furrow-fungicides-cereals-wa

More information

DAFWA: New leaf rust pathotype (2013).

DAFWA: Leaf rust.

DAFWA: Leaf rust.

DAFWA: Stripe rust.

Leaf rust

Seed dressings containing fluquinconazole or triticonazole and in-furrow fungicide triadimefon are registered for the suppression of wheat leaf rust. Wheat plants treated with at-sowing fungicides might still display minor levels of infection, but infection will be significantly lower than untreated crops and treating leaf rust early will make the disease easier to manage in spring if follow-up spraying is required.

Stripe rust

Flutriafol or triadimenol seed dressings suppress stripe rust in seedling crops while longer-term control can be achieved with fluquinconazole seed dressings (depending on application rate) and flutriafol in-furrow fungicides.

Stem rust

No seed dressing or in-furrow fungicides are currently registered for control of wheat stem rust.

3.1.9 Foliar fungicides

Fungicides protect rather than enhance yield potential, they stop disease development and protect green leaf area but do not repair already damaged leaves. Therefore, the earlier fungicide is applied following rust detection the more effective the disease control.

The critical growth stages for foliar fungicide application in wheat lie between the start of stem elongation through to flag leaf emergence (GS30–39). The goal is to slow or stop disease development and consequently conserve green leaf and stem area for grain fill (Figure 3).

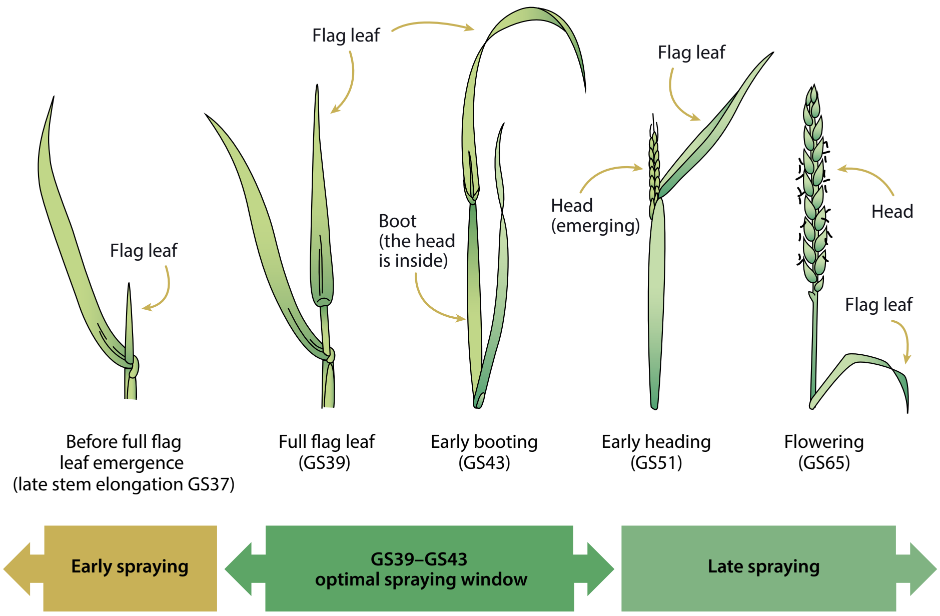


Figure 3: Fungicide spray timing in relation to wheat developmental stages.

Foliar fungicides - leaf and stripe rust

Apply fungicide as soon as possible after the first detection of stripe or leaf rust for the most efficient fungicide control, particularly in more susceptible varieties (Table 3). Potential yield loss from leaf and stripe rust will vary with wheat rust resistance rating (Table 4).

Note to Table 3

Use the recommended higher fungicide rates to achieve longer protection in seasons of high rust risk.

Weigh fungicide costs against expected yield potential.

Stripe rust can infect heads and increase screenings. Apply fungicide at or before heading and ensure optimal rust control on leaves to reduce risk of head infection.

Spraying after crop flowering is normally not economic for stripe or leaf rusts.

Table 3: Foliar fungicide timing for leaf and stripe rusts according to growth stage at which outbreak first detected and resistance rating of wheat variety.

	Crop stage at first sign of stripe rust or leaf rust infection			
Resistance rating	**Pre flag leaf***	**Full flag to late booting**	**Mid to late heading**	**Mid to late flowering**
Very susceptible (VS)	stripe or leaf**	stripe or leaf**	stripe or leaf	n/a
Susceptible (S)	stripe or leaf**	stripe or leaf**	stripe or leaf	n/a
Moderately susceptible (MS)	stripe or leaf	stripe or leaf	stripe or leaf	n/a
Moderately resistant - moderately susceptible (MR-MS)	stripe or leaf	stripe	n/a	n/a
Moderately resistant (MR)	stripe	n/a	n/a	n/a

Source: Department of Agriculture and Food, WA

* Foliar spray required pre-flag leaf if seed dressing or in-furrow fungicide not used.

** The recommended higher label rate was more profitable on more susceptible varieties.

n/a Spraying at these stages or for these resistance ratings generally not applicable.

Table 4: Potential yield loss from leaf and stripe rusts in wheat varieties of varying rust resistance ratings.

Resistance rating	Definition	Potential yield loss (%)	
		Leaf rust	**Stripe rust**
Very susceptible (VS)	High disease build-up early in season; can promote epidemic development	40	80
Susceptible (S)	High disease build-up	30	60
Moderately susceptible (MS)	Develops disease less quickly, which reduces risk of yield loss	20	40
Moderately resistant - moderately susceptible (MR-MS)	Some partial resistance; losses depend on disease pressure	15	30
Moderately resistant	High partial resistance; yield losses generally low	5	15
Resistant (R)	Highly effective resistance; no or very low yield loss	<5	5
Highly resistant (HR)	Complete resistance	0	0

Source: Department of Agriculture and Food, WA.

Table 5: Yield response from one or two fungicide sprays in wheat crops with stem rust at various growth stages and intensity.

Wheat growth stage: stem rust detected	Fungicide applied	Tiller with stem rust (%)*	Yield potential (t/ha)	Yield response – one spray (t/ha)	Yield response –two sprays (t/ha)
Flag emergence	Booting	Trace (<1)	3.0-3.5	0.9	1.5
Early head emergence	Mid-head emergence	5	2.5-3.0	0.2	0.2
Early grain fill	Late milk-early dough	90	1.5-2.0	0.5	n/a

* Proportion of 100 randomly collected wheat stems with any sign of stem rust infection.

More information

To determine the economics of fungicide control of rust disease view: https://agric.wa.gov.au/n/3611

For more information on stem rust control visit: https://agric.wa.gov.au/n/395

3.1.10 Foliar fungicides - stem rust

As there are no registered seed dressings or in-furrow fungicides for stem rust, reducing early epidemic development of the disease, particularly in VS/MS varieties, is critical. Control is more effective if the fungicide is applied early in the development of the disease (Table 5). Experimental trials have shown that fungicide applied when stem rust is well established are less effective and may not produce yield responses.

Stem rust impacts both yield and grain quality, and timely fungicide applications are required to manage the disease. Economic responses to fungicide have been achieved for stem rust in susceptible wheat varieties from pre-head emergence through to grain filling. The yield response of less susceptible varieties to later sprays will be lower (Table 6).

Crops infected with stem rust before flowering are considered at high risk with yield losses of 50 per cent or more possible. If infection starts or re-starts after flowering losses of about 25 per cent are possible. In these cases multiple fungicide applications may be required to first protect the stem and flag sheath and later to protect the peduncle and head.

Susceptible and moderately susceptible crops should be sprayed as soon as possible following rust detection with an appropriate fungicide at the recommended higher label rate. For crops with intermediate resistance continue to monitor following rust detection but spray if infection exceeds an average of five per cent of 100 randomly collected stems (Table 6). If stem rust is detected after head emergence short-term control can be achieved with standard application rates provided infection is not severe. However, the recommended higher label rates have been found to be more profitable (Table 6).

Note to Table 6

If stem rust is detected after grains are at the dough stage, apply fungicide if the crop has at least four more weeks of grain filling to go before hard dough stage. Consider withholding periods when choosing an appropriate fungicide.

More information

Report any occurrences of rust in crops or re-growth to the Department of Agriculture and Food, WA by emailing to PestFax@agric.wa.gov.au or completing an online report at: www.agric.wa.gov.au/diseases/pestfax-map

View seasonal cereal rust reports developed by the Australian Cereal Rust Control Program at: www.rustbust.com.au

Table 6: Foliar fungicide timing for stem rust in relation to stage and level of infection and wheat resistance rating.

Crop growth stage	Stems infected (%)*	Resistance rating	
		VS, S, MS-S	MR-MS
Before flowering	First sign of infection	Spray	Monitor
	>5	Spray	Spray
After flowering	<10	Spray	Monitor
	>10	Spray	Spray
Before mid grain fill	<10	Spray	
Mid to late grain filling	>10	Consider spray#	

Source: Department of Agriculture and Food, WA.

* Infection = any level of rust on 100 randomly selected stems.

Response may be limited to fungicide applied in this situation.

Monitoring for rust

Crops need to be monitored to detect rust early, as timing is critical for the effective control of rust diseases with fungicides. Rust epidemics can be explosive and once out of control can be difficult to contain.

The aim of rust monitoring is to detect infection as early as possible. Inspect the most susceptible and earliest sown crops carefully over a wide area of the paddock. Examine leaves at the top and bottom of the canopy for scattered light infections. In green bridge areas also look for heavily infected ‘hot spots’.

Wheat varieties prone to early infection should be inspected at seven to 10 day intervals from early stem elongation (GS31) or from early flag leaf emergence (GS39) if seeding fungicide treatments registered to control rust diseases have been used.

Susceptible and moderately susceptible crops should be sprayed as soon as possible following rust detection with an appropriate. fungicide at a high rate. Photo credit: GRDC

Table 7: Summary of fungicide management principles for wheat varieties with varying rust resistance ratings.

Wheat resistance rating	Seed dressing	In-furrow	Foliar	Notes
Moderately susceptible-very susceptible (MS-VS)	✓	✓	✓	Continual monitoring required: rust epidemics can be explosive in susceptible varieties. Keep abreast of district and regional rust activity. Budget for a seedling protection and up to three foliar sprays to achieve yield potential in highly susceptible varieties. Fungicide spray must be applied either before or soon after rust detection. Protect against stem rust until early grain fill. Stripe or leaf rust after ear emergence may not need a fungicide spray, depending on the seasonal outlook.
Moderately resistant -moderately susceptible (MR-MS)	✓	✓	?	Foliar sprays must be considered if disease begins early (before second node) and chemical protection not applied at sowing. Follow-up spraying to protect flag leaf may be valuable in seasons of high rust pressure. Fungicides not usually economic after heading for stripe rust and leaf rust. Spraying for stem rust after heading may be economic if disease pressure high.
Resistant to moderately resistant (R-MR)	×	×	?	No fungicide management required, but important to monitor for any rust virulence mutations.

Follow-up spraying to protect the flag leaf may be economic in seasons of high rust pressure. Photo credit: Kellie Penfold.

Note to Table 7

Be aware of foliar fungicide product registrations, limits on number of times a particular mode of action can be used on a crop per season and withholding periods for grazing and harvesting.

Foliar fungicide registration charts for cereals are available at: https://agric.wa.gov.au/n/1756

3.2 Leaf spot diseases

Key messages

- *Septoria nodorum* blotch and yellow spot, known as leaf spot diseases, occur throughout the wheatbelt and frequently occur together. They have the capacity to significantly reduce yield and grain quality. *Septoria tritici* blotch has become less common throughout the WA wheatbelt and losses from this disease are currently rare.
- Yellow spot and septoria are best managed through an integrated approach incorporating crop rotation, resistant varieties, nutrition and fungicides.
- In wheat on wheat situations where disease symptoms are seen early, on a susceptible variety, it may be economic to apply fungicide at early stem elongation (GS31, first node) particularly in medium to high rainfall areas.
- In the future there will be more seed dressings and new in-furrow fungicides registered to provide early suppression or protection from leaf spot diseases.

Wheat crops in Western Australia can be affected by three leaf spot diseases yellow spot, *septoria nodorum* blotch and *septoria tritici* blotch.

While each of the diseases is caused by a different fungal pathogen, the disease symptoms and biology are similar.

Symptoms appear as irregular or oval-shaped spots that are initially small and usually yellow, which then enlarge to form brown dead centres with yellow edges. Often a badly affected leaf will die back from the tip as lesions combine, reducing the photosynthetic area and causing early leaf death (Table 8).

Distinguishing the various leaf spot diseases from each other is difficult even to a trained eye and they can often be confused with physiological or nutritional symptoms.

Yield loss from leaf spot diseases varies greatly from season to season, location and with rainfall. Leaf spot diseases are necrotrophic, which means they kill their host and then feed on dead material.

The diseases are also stubble-borne and can be a particular problem in continuous wheat crops where stubble is retained.

Leaf spot fungi can survive on wheat stubble very well for up to six months but survival declines after 18 months, making crop rotation an effective management tool.

More information

To diagnose each of the leaf spot diseases use the MyCrop diagnostic tool: https://www.agric.wa.gov.au/mycrop

For more information on wheat leaf symptoms read: www.grdc.com.au/GRDC-BPG-WheatBarleyLeafSymptoms

For more information on genetic research in to yellow spot resistance visit: https://www.agric.wa.gov.au/grains-research-development/germplasm-enhancement-yellow-spot-resistance-wheat

More information

DAFWA: Yellow spot.

DAFWA: Yellow spot and septoria nodorum blotch.

DAFWA: Registered foliar fungicides.

DAFWA: Early fungicide applications for yellow spot and septoria nodorum blotch.

Wheat yield impact can be as high as 20-30 per cent but will depend on varietal disease resistance and the presence and severity of the disease throughout the life of the crop. When the diseases are severe they can also cause reductions in grain quality such as increased screenings and lower hectolitre weights.

Yellow spot is usually more prevalent in crops in the northern than the southern WA wheatbelt, which is likely due to the different timing of yellow spot spore maturation on stubble at different locations in the wheatbelt.

Spore release from fruiting bodies on the stubble is controlled by temperature and rainfall.

The wetter, cooler conditions in the southern wheatbelt favour the release of spores before wheat crops are sown or have emerged. However rainfall and temperature conditions in northern and central wheatbelt areas favour spore development and release from May through to September, which coincides with the wheat-growing season.

Table 8: Characteristics and management of wheat leaf spot diseases.

Septoria nodorum **blotch**	**Yellow spot**
Primary infection from wheat stubble.	Primary infection from wheat stubble.
Infection requires heavy and frequent rain with warm weather (20-25°C) that results in leaves remaining wet for more than six hours.	Infection requires at least six hours of leaf wetness with temperatures of 15-28°C and periods of dew.
Air-borne spores can spread kilometres.	Air-borne spores heavier than *septoria nodorum* blotch and spread only metres.
Secondary infection results from splash dispersed spores spreading the disease through the crop. Disease can spread from leaves to heads in a wet spring, this is known as glume blotch.	Secondary infection (leaf to leaf) occurs via air borne spores and is favoured by leaf wetness (dew, fog or rain), high relative humidity and temperatures above 10°C.
Integrated disease management options	
Crop rotation	
Avoid very susceptible or susceptible wheat varieties.	
Ensure crop has adequate nutrition; particularly nitrogen and potassium.	
No seed treatments or in-furrow fungicides are registered for control of yellow spot or *septoria nodorum* blotch.	
A fluquinconazole based seed dressing is now registered for suppression of *septoria nodorum* blotch.	
Apply foliar fungicides when evidence of disease moving up the canopy.	

3.2.1 Fungicide strategies for leaf spot diseases

While no seed treatments or in-furrow fungicides are currently (2014) registered for control of yellow spot or *septoria nodorum* blotch, product developments are in the pipeline. A fluquinconazole based seed dressing is now registered for suppression of *septoria nodorum* blotch.

Department of Agriculture and Food, WA research has established that an economic response to foliar fungicide is more likely when:

- the wheat crop has good yield potential;
- there is evidence of increasing leaf spot intensity down the canopy;

More information

For a list of registered foliar fungicides for leaf spot diseases refer to: www.agric.wa.gov.au/barley/registered-foliar-fungicides-cereals-western-australia-wa

For information on cereal fungicides read: www.grdc.com.au/GRDC-FS-CerealFungicides

For more information on yellow spot read: www.grdc.com.au/GRDC-FS-YellowSpotWest

More information

DAFWA: Smut and bunt diseases.

DAFWA: BYDV and CYDV

DAFWA: Stem rust.

- disease covers at least 10 per cent of leaf area on the second top leaf at the time of spray; and
- there are good prospects of finishing rains; about 100mm in the two months after flag leaf emergence. This is more likely in early sown crops because the early flag leaf emergence exposes the leaf to more disease and in high rainfall areas or years of above average seasonal rainfall.

3.2.2 Wheat in rotation

When wheat is grown in rotation, the optimal timing for fungicide application is at or around flag leaf emergence (GS39) as this will protect the upper leaves that contribute most to yield.

Presence of other foliar diseases will boost returns from fungicide application.

Use the higher recommended fungicide rates for longer duration of protection when seasonal conditions that favour infection are likely to persist, such long season environments or when susceptible varieties are grown.

3.2.3 Wheat on wheat

For susceptible wheat varieties grown under high and early season disease pressure, it can be economic to apply fungicide at or before early stem elongation (GS31, first node) particularly in medium to high rainfall areas.

A second spray may also be required at or after flag leaf emergence (GS39) if there is evidence of disease moving up the canopy, the crop is of good yield potential and there are good prospects of 100mm rainfall in the two months after flag leaf emergence.

Department of Agriculture and Food, WA research showed fungicide application at first node (GS31) gave the most reliable control of yellow spot and *stagonospora nodorum* and lifted yield by an average of about 11 per cent above untreated crops (Table 9).

A double spray at first node (GS31) and again at flag leaf emergence (GS39) gave the highest average yield and profit response in the eight trials across the WA wheatbelt (Table 9).

Fungicide applied at seedling (GS15) or tillering stage (GS25) reduced early infection but often gave a shorter duration of disease protection and was less likely to be as profitable as application at the first node stage (Table 9).

Late onset of leaf spot disease, particularly *septoria nodorum* blotch, can warrant a spray before flowering (e.g. 50 per cent of heads emerged: GS55) particularly in long season environments.

Note to Table 9

A second spray at flag leaf emergence is generally considered profitable when there are good prospects of about 100mm rain in the two months after flag leaf emergence. Consult historical records or climate tools such as CliMate to determine likelihood of receiving 100mm. http://www.australianclimate.net.au

Table 9: Impact of fungicide for yellow spot and stagonospora nodorum at various wheat growth stages on wheat yield and profit.*

Fungicide treatment	Yield increase (t/ha)**	Profit increase ($/ha)**
Single spray GS15 or GS25	0.2	57
Single spray GS31	0.3	75
Single spray GS41	0.3	57
Double spray GS15/GS25 and GS39	0.3	56
Double spray GS31 and GS39	0.5	109

Source: Department of Agriculture and Food, WA.

* Results are summary of eight trials across the WA wheatbelt between 2010-2011.

** Results are averages of eight trials. Profit depended on fungicide product and rate used. Wheat price used 2011 = $270/t and 2010 = $313/t. Cost of fungicide application = $8/ha. Fungicides used: Prosaro® at 300mL/ha = $19.80, Tilt® at 500mL/ha = $9.

3.2.4 Glume blotch

Severe, late season *septoria nodorum* blotch can spread from the leaves to infect wheat heads during grain fill to cause glume blotch. In these late-season *septoria nodorum* infections fungicide needs to be applied before crop heading is complete to reduce risk of head infection. Spraying after heading is sub-optimal and spraying after crop flowering has finished is generally not economic.

Glume blotch results in dark patches on the glumes and can result in shrivelled grain and even complete loss of seed. Care needs to be taken to distinguish glume blotch from other causes of glume darkening, including pseudo black chaff, loose smut, frost and copper deficiency.

Send suspected glume blotch samples to AGWEST Plant Labs for diagnosis: https://www.agric.wa.gov.au/plant-biosecurity/agwest-plant-laboratories

Distinguishing the various leaf spot diseases from each other is difficult even to a trained eye and they can often be confused with physiological or nutritional symptoms. Pictured above is Septoria nodorum, which can spread from leaves to heads in severe late-season infections. Photo credit: GRDC.

Small tan-brown spots with yellow margins that become more elongated with age indicate the presence of yellow leaf spot. Photo credit: Hugh Wallwork.

3.2.5 Leaf spot disease and nutrition

Research by the Department of Agriculture and Food, WA has shown that wheat crops deficient in nitrogen and/or potassium are more vulnerable to leaf spot infections.

Nitrogen and fungicide can have an additive effect in reducing leaf spot diseases until ear emergence, resulting in significant yield increases in susceptible varieties (Figure 4). Nitrogen increases wheat vigour and tiller number to lift yield and possibly enable more effective fungicide application, particularly on susceptible wheat varieties.

Addition of potassium, when limiting, does not control disease but enables plants to meet their yield potential. In a 2013 trial at Eneabba, adding 30, 60 and 120kg/ ha of muriate of potash significantly reduced levels of *septoria nodorum* blotch on Mace leaves and heads and increased grain yield by about 30 per cent above the nil potassium treatment.

Note to Figure 4

Both varieties suffered significantly more disease in the minimum nitrogen treatment than the medium and maximum nitrogen treatments.

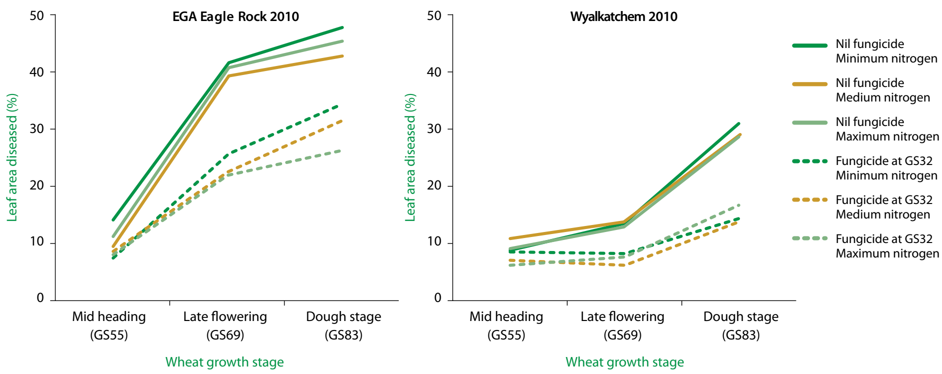


Figure 4: Average percentage leaf area diseased on top three leaves at GS69, EGA Eagle Rock and Wyalkatchem under three nitrogen regimes on wheat stubble at Eradu in 2010 at GS55, GS69 and GS83.

More information

For further information on integrated management strategies for leaf spot control see: https://agric.wa.gov.au/n/2196

Figure 5: Nitrogen and potassium deficiency can exacerbate leaf disease impact in wheat. Photo credit: Kellie Penfold.

3.2.6 References

Beard, C (2013) Potassium deficiency can make wheat more vulnerable to septorium nodorum blotch and yellow spot. Proceedings 2013 Perth Agribusiness Crop Updates, Perth, Western Australia. https://agric.wa.gov.au/n/2694

Beard, C and Smith, A (2012) Wheat leaf diseases – latest research on yellow spot and septorium nodorum blotch. Proceedings 2012 Perth Agribusiness Crop Updates, Perth, Western Australia.https://www.agric.wa.gov.au/sites/gateway/files/Beard%20Interaction%20of%20Nitrogen%20and%20Fungicide%20applications%20for%20%20Managing%20Yellow%20Spot%20in%20Wheat.pdf

Galloway, J Payne, P and Salam, M (2013) Environment affects maturation of yellow spot on wheat stubble. Proceedings 2013 Perth Agribusiness Crop Updates, Perth, Western Australia. http://www.giwa.org.au/_literature_128624/Galloway,_Jean_-_Environment_affects_maturation_of_yellow_spot_on_wheat_stubble

Salam, K Thomas, G Beard, C Loughman, R MacLeod, W and Salam, M (2013) A meta-analysis of 30 years of DAFWA field trials on fungicide management of yellow spot - septoria nodorum blotch disease complex of wheat in Western Australia. Proceedings 2013 Perth Agribusiness Crop Updates, Perth, Western Australia. http://www.giwa.org.au/2013-crop-updates

3.3 Smut diseases

Key messages

- Smut diseases have one of two distinct life cycles: internally seed-borne or externally seed-borne. It is important to know the type of smut and its life cycle to determine effective control options.
- Smut diseases commonly occur at low levels but without fungicide seed dressings they can increase rapidly to cause significant yield loss.
- There are no registered in-furrow fungicides for smut diseases.
- Smuts can only be controlled by specific seed dressings applied at the correct label rate.
- It is critical that every seed is covered with seed dressing for effective control.

Wheat smut diseases are caused by fungi which parasitise the host plant and produce masses of soot-like spores in the leaves, grains or ears and reducing grain yield and quality (Table 10).

Many grain receival points have low or zero tolerance of smut contaminated grain.

Smut diseases have one of two distinct life cycles: internally seed-borne or externally seed-borne. It is important to know the type of smut and its life cycle in order to determine effective control options.

3.3.1 Karnal bunt of wheat

Karnal bunt of wheat (*Tilletia indica*) does not occur in Australia but is found in many other wheat producing countries. Contaminated grain has a characteristically strong fishy odour. Spores are dispersed from bunted heads at harvest to contaminate healthy grains, soil or machinery.

This disease has a minor effect on grain yield but significantly affects grain quality because of its distinctive fishy odour and discolouration.

An outbreak of this disease would have major impacts on Australian wheat export markets.

Karnal bunt is externally see-borne and could enter Australia as spores contaminating grain, machinery or clothing.

Minimising the possibility of Karnal bunt spores entering Australia is very important to the Australian grains industry. Suspect samples should be reported immediately to the Department of Agriculture and Food, WA on the Exotic Plant Pest Hotline on 1800 084 881.

More information

For more information on diagnosing and treating smut diseases in wheat: https://agric.wa.gov.au/n/326

A current list of seed dressings for wheat smut diseases can be found at: https://agric.wa.gov.au/n/1794

Karnal bunt does not occur in Australia but an outbreak would have major impacts on Australian wheat markets. Grain contaminated with Karnal bunt has a characteristically strong fishy odour. Photo credit: GRDC.

Table 10: Smut diseases that infect wheat.

Disease	Location	Management	Notes
Covered smut (common bunt)	Seed and soil-borne.	Seed dressing. Some variety resistance is available. Use only clean seed and thoroughly clean contaminated machinery. Rotate contaminated paddocks out of wheat and into barley, oats and broadleaf crops for at least one year. Destroy any wheat regrowth In the break crop year.	Extremely difficult to detect infield; low levels can remain undetected in harvested grain. Seed can be tested at AGWEST Plant Labs https://www.agric.wa.gov.au/n/1766 Zero tolerance for common bunt in wheat delivered to Cooperative Bulk Handling Ltd (CBH). Barley, oats and broad leaf crops are not affected by common smut. To diagnose covered smut in the field use MyCrop: https://agric.wa.gov.au/n/2129
Flag smut	Seed and soil-borne.	Correct seed dressing – especially for susceptible varieties. Resistant varieties.	Barley, oats and broad leaf crops are not affected by flag smut. To diagnose covered smut in the field use MyCrop: https://agric.wa.gov.au/n/2136
Loose smut	Internally seed-borne. Carried as a small colony of fungus inside the seed embryo rather than as spores on the seed coat.	No resistant varieties yet. Seed dressings reduce incidence - correct application of seed dressings is critical to ensuring adequate control. In-furrow and foliar fungicide applications are not effective.	Infected seed shows no symptoms and appears normal. Machinery and soil do not transmit loose smut. Prevalent in areas receiving more than 450mm average annual rainfall. Frequent rain showers and high humidity at flowering favour infection. To diagnose covered smut in the field use MyCrop: https://agric.wa.gov.au/n/2140

3.4 Root disease - rhizoctonia

More information

DAFWA: Root diseases.

Soil Quality: Rhizoctonia Western Australia.

Soil Quality: Take-all.

GRDC Update Paper: Geoff Thomas, White Grain Disorder in Wheat in Western Australia.

DAFWA: Disease resistance for varieties, p16-17.

Curtin Uni: Genetic disease resistance wheat

GRDC Update Paper: Rhizoctonia and Crown Rot status of Western Australian paddocks can be managed with crop rotation.

DAFWA: Falling number and sprouting tolerance.

Key messages

- Crops following cereals are at highest risk from rhizoctonia bare patch disease.
- A canola break crop or a chemical fallow can reduce rhizoctonia inoculum in the soil.
- Poor nutrition, compacted soils and herbicide residues slow root growth and exacerbate rhizoctonia damage.
- In heavily infested paddocks early sowing and cultivation to about 10 centimetres using knife-points breaks up the rhizoctonia hyphae, encourages early root growth and reduces rhizoctonia impact.
- Fungicide seed dressings can suppress but not eliminate rhizoctonia and need to be used in conjunction with cultivation and adequate nutrition to minimise rhizoctonia damage.

The rhizoctonia fungus, *Rhizoctonia solani* AG8, has a wide range of hosts but it is the cereals and grasses that drive up soil inoculum levels. Controlling the autumn 'green bridge' and implementing a canola break crop or chemical fallow can curb the build-up of inoculum before sowing.

Adequate nutrition during crop emergence gives the crop a better chance of 'getting ahead' of the disease because fast growing roots will push past the infected topsoil before rhizoctonia can infect the root tip.

Yield losses as high as 50 per cent can occur in badly diseased cereal paddocks where inoculum levels are high and seasonal conditions are conducive for the disease. However, in general, losses of 5-20 per cent are more common.

The increasing incidence of rhizoctonia across southern Australia is associated with the widespread adoption of minimum tillage because the lack of cultivation slows organic matter breakdown, which provides a habitat for the disease.

All rainfall regions are prone to rhizoctonia. Rhizoctonia impact is often higher following prolonged dry spells over summer and autumn because the dry conditions reduce the population of beneficial organisms capable of suppressing rhizoctonia.

Table 11: Diagnosing and managing rhizoctonia bare patch in wheat.

Monitor	Diagnose	Manage
PredictaB® maps: http://www.sardi.sa.gov.au/diagnostic_services/predicta_b/disease_distribution	Correct identification of rhizoctonia is essential as its symptoms can be very similar to root lesion nematodes. https://agric.wa.gov.au/n/2143	Managing rhizoctonia effectively requires an integrated approach: www.grdc.com.au/GRDC-FS-RhizoctoniaSW https://agric.wa.gov.au/n/2143
	To diagnose rhizoctonia in-crop use the Department of Agriculture and Food, WA's MyCrop web tool: https://agric.wa.gov.au/n/2143	Check current registered fungicides for rhizoctonia: https://agric.wa.gov.au/n/1794

Rhizoctonia root rot has been an ongoing problem in the low to medium rainfall areas, especially on sandy soils and in some areas of the high rainfall zone. Yield losses up to 25% have been observed in experiments in the western region. Inoculum levels in the medium rainfall zone of the western region have been increasing in the last few years.

Rhizoctonia solani AG8 fungus grows on crop residues and soil organic matter and is adapted to dry conditions and lower fertility soils.

The fungus causes crop damage by pruning newly emerged roots. This can occur from emergence to crop maturity. The infection results in water and nutrient stress to the plant. When severe, infection is seen as patches of poor crop growth (bare patches).

Damage to crown roots can result in wheat grain losses of 8-19%.

Field trials, including a multi-year trial, in Western Australia showed the effective control of Rhizoctonia disease in cereal crops requires both the reduction of pathogen inoculum and the control of infection processes through sound management practices spread over more than one cropping season.

3.4.1 Key points

Effective control of Rhizoctonia disease requires both the reduction of the pathogen inoculum and the control of the infection process.

Levels of Rhizoctonia inoculum will be highest following cereals and lowest after canola and mustard.

Experiments in western and south eastern Australia have shown that canola provides an effective break following cereal crops.

Other grass-free (<2%) non-cereal rotations including peas, vetch, chickpeas, sown medic, etc, provide a useful reduction in Rhizoctonia inoculum; lupins may be a less effective break crop.

Rainfall events post-harvest cause a significant reduction in the inoculum and multiple rainfall events over summer and autumn can reduce inoculum levels to low risk.

At sowing, disturbance below the seed using narrow points promotes rapid root growth away from the Rhizoctonia in the surface layers.

Factors that reduce the rate of root growth (e.g. cold soils, poor nutrition, compacted soils, herbicide residues) will result in increased Rhizoctonia root damage.

Biological disease suppression has been identified in a range of soils and can provide effective long-term control of disease.

In crops that establish quickly, plants are often not affected by Rhizoctonia until mid-winter when cold temperatures encourage crown root infection, resulting in reduced tillers and uneven growth.

3.4.2 Management options

Early weed control (within 3 weeks of germination) in the summer fallow will reduce inoculum levels and complement the moisture and nitrogen conservation benefits of summer weed control.

Crop rotation with a grass-free, non-cereal crop is one of the best available management strategies to reduce Rhizoctonia disease impact. The beneficial effect of rotation on reducing Rhizoctonia inoculum generally lasts for one season.

Fungicide treatments need to be used as part of an integrated management strategy/ package.

Nitrogen deficient crops are more susceptible to Rhizoctonia damage. Application of adequate N fertiliser at sowing is necessary to ensure early seedling vigour. At tillering, applications of nitrogen (and micronutrients) to deficient crops affected by Rhizoctonia can reduce yield loss in poor growth patches by up to 50%.

Soil openers in the seeding systems can have a significant influence on disease severity. Disturbance of at least 10 cm below seeding depth reduces Rhizoctonia disease impact. Knife points have less disease incidence than single disc seeders. Tillage can cause redistribution of inoculum to deeper levels.

PreDicta™ B is a unique DNA-based service which identifies soilborne diseases, such as Rhizoctonia.

3.4.3 New fungicide options

In 2013, new fungicide options for rhizoctonia became available for application on seed, including Vibrance® and EverGol Prime®. GRDC-funded field trials in Western Australia showed these new seed treatments increased wheat and barley yield by about five per cent compared to untreated seed.

Promising fungicide banding treatment options for rhizoctonia have also performed well in GRDC-funded trials across southern Australia. If approved, these new fungicides could be available to growers after 2015.

GRDC-funded wheat and barley trials in WA and South Australia have shown that liquid banding with one of the new fungicides, increased yields by up to 0.87 tonnes per hectare in a paddock with very high levels of rhizoctonia in the soil before sowing.

Videos

Watch a video explaining the outcomes of the recent GRDC-funded liquid banding research: www.grdc.com.au/GCTV9-BandingFungicide

Difference in root growth in wheat plants treated with fungicicde (left) and without to control Rhizoctonia.

Photo credit: Emma Leonard.

Rhizoctonia root rot can cause wheat yield losses as high as 50 per cent. New banding fungicide treatments are showing promise for treating the fungal disease.

Photo credit: GRDC.

3.4.4 References

Huberli, D., Connor, M., Miyan, S., MacLeod, W., Bogacki, P. and McKay, A. (2013). Integrated disease management options to control rhizoctonia bare-patch in cereals. Proceedings 2013 WA Crop Updates http://www.giwa.org.au/_literature_125849/Huberli,_Daniel_et_al_-_Integrated_disease_management_options_to_control

Huberli D., Connor M., Miyan S., MacLeod W., Bogacki P., Desbiolles J., Correll R., Gupta V., Battaglia R., McKee K., May L., Forsyth L., Roget D. and McKay, A. (2014) Liquid banding of fungicide increases yields of cereals in paddocks with rhizoctonia bare-patch Proceedings 2014 North Mallee Farm Improvement Group Crop Updates http://researchrepository.murdoch.edu.au/21390/1/liquid_banding_of_fungicide.pdf

3.5 Root disease - crown rot

More information

GIWA: Reduce losses from crown rot through variety choice and inter-row sowing.

Key messages

- Most wheat varieties grown in Western Australia are either susceptible or very susceptible to crown rot.
- There are no registered seed or post-emergent chemical treatments to control crown rot.
- Crown rot is most common in continuous cereal crops or after long-term grass pastures.
- The crown rot fungus can persist in infected cereal residues for up to two years and also be carried into wheat crops via infected grass weeds.
- Rotating cereals with non-susceptible crops such as pulses, oilseed, lupin or grass-free pasture and maintaining good grass weed control lowers crown rot inoculum.
- Inter-row sowing using GPS guidance in no-till systems has been shown to halve the number of plants infected with crown rot, resulting in a five to 10 per cent yield increase.

More information

For more information on cultivation and crown rot read: www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS111/Cultivation-can-exacerbate-crown-rot

Crown rot is a fungal disease that blocks water movement from root to stem causing grain to shrivel or fail to form. The disease is often not detected until after heading when white heads, prematurely ripened, are seen scattered throughout a crop (not in distinct patches as with take-all).

Significant yield losses can occur when high disease levels coincide with moisture stress during grain fill – crown rot causes greater yield losses in seasons with a wet start followed by a dry finish.

The PredictaB® diagnosis service can be used to monitor crown rot levels and guide crop rotation and wheat management decisions.

Table 12: Diagnosing and managing crown rot in wheat.

Diagnosis	Symptoms	Management
Use PredictaB® to monitor soil inoculum levels and guide wheat management decisions: http://www.sardi.sa.gov.au/diagnostic_services/predicta_b/why_test/crown_rot	To diagnose crown rot in-crop use the Department of Agriculture and Food, WA's MyCrop web tool: https://agric.wa.gov.au/n/2131	High nitrogen environments create large crops that can collapse with a large crown rot outbreak. A grass-free break from cereals is the best way to lower crown rot inoculum levels. There are no registered seed or post emergent chemical treatments to control crown rot. More information on managing crown rot: www.grdc.com.au/GRDC-FS-CrownRotCerealsSW New GRDC-funded research by the Department of Agriculture and Food, WA is evaluating the crown rot resistance of new and upcoming wheat varieties: https://agric.wa.gov.au/n/3774

More information

DAFWA: Yield loss to crown rot.

DAFWA: Diagnosing crown rot in cereals.

GRDC Update Paper: Reduce losses from crown rot through variety choice and inter row sowing.

GRDC Update Paper: Daniel Huberli, Rhizoctonia solani AG8: New breakthroughs in control and management.

GRDC Update Paper: Roger Lawes, Rhizoctonia and Crown Rot status of Western Australian paddocks can be managed with crop rotation.

infocus

3.5.1 Understanding the disease underpins effective management

Assess crown rot risk in paddocks by checking crops for browning at the base of infected tillers or by taking soil and stubble samples for analysis. Don't rely solely on whiteheads as an indicator (Figure 6).

Figure 6: Plants affected by crown rot have whiteheads and awns that tend to stick out compared to the normal green heads of the unaffected plants close by. But don't rely solely on whiteheads as an indicator of crown rot. Other factors (mice, insect damage, frost) can cause whiteheads. However, a whitehead caused by crown rot will always have a characteristic browning at the base of the infected tiller. Whiteheads are not expressed in seasons with a 'soft' finish, so inoculum levels can build-up unnoticed. (Image: SARDI)

About crown rot

Crown rot is caused primarily by the fungus *Fusarium pseudograminearum* with another species *F. culmorum* also being important in some other regions;

This fungal disease is hosted by all cereals and many grass weeds;

The crown rot fungus can survive for multiple years as mycelium inside infected plant residues and infection can occur when plants come in close contact with these residues;

High cereal intensity and stubble retention in cropping programs are factors which increase crown rot levels;

The impact of the disease is worse in a dry finish.

Major yield losses occur when disease levels are high and there is moisture and/or evaporative stress during grain fill. In these circumstances yield loss can be up to 90% in durum and 50% in bread wheat with increases in screenings also occurring.

The disease

Survival

All winter cereals and many grass weeds host the crown rot fungi, which survive inside infected plant residues. As infected residues decompose, inoculum levels reduce. Therefore, where decomposition rates are slow such as in dry seasons, crown rot inoculum can survive multiple years.

Infection

When infected plant residues come in contact with growing cereal plants, crown rot infection can occur (Figure 7). Even minute pieces of residue can cause infection and a paddock with little visible stubble may still have a crown rot risk. Infection is favoured by moderate soil moisture at any time during the season. Infection occurs through the coleoptile, sub-crown internode, crown and/or outer leaf sheaths at the tiller bases. The fungus spreads up the stem during the season, with most inoculum being found near the base of the plant.

Figure 7: Infection occurs when cereal plants come in contact with infected cereal or grass weed residues. (Image SARDI)

Stem browning

A brown stem base is the most reliable indicator of crown rot and this symptom becomes more pronounced from mid to late grain filling through to harvest (Figures 8 and 9). In wetter or milder years, checking plants around tree lines can be a better indicator. To see the honey/dark brown colour more easily the leaf sheaths should be pulled back. This symptom may not appear on all stems of an infected plant and is difficult to see in oats.

Figure 8: White tillers (on left) uninfected by crown rot with tillers (on right) showing characteristic basal browning associated with crown rot infection. (Image NSW DPI)

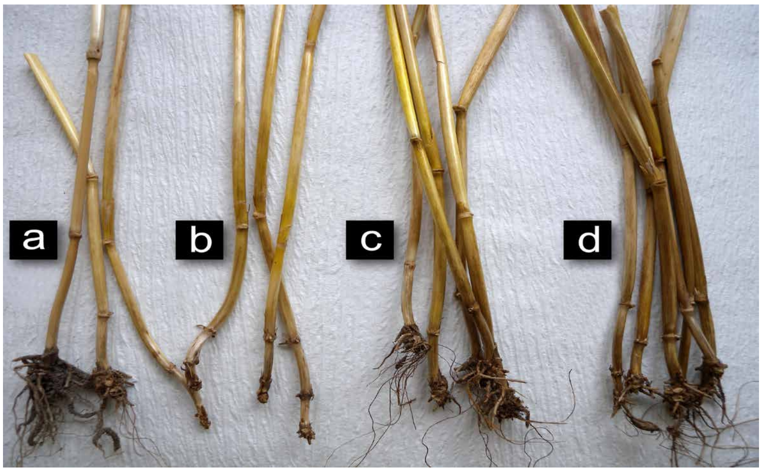


Figure 9: Brown stem bases are a sure sign of crown rot in wheat. (Image: DAFWA)

Whiteheads

Whiteheads caused by crown rot are usually scattered through the crop and do not appear in distinct patches as seen with the root disease take-all. The expression of whiteheads is favoured by moisture stress during grain filling and there is a direct relationship with yield loss. Whiteheads may first appear in wheel tracks, old weed patches or around trees where crop-available soil moisture is more limited (Figure 10). However, whiteheads may not appear on all stems of an infected plant. Barley generally does not produce whiteheads because it matures earlier than wheat, which helps it escape late season moisture-stress. Oats rarely exhibit this symptom. In seasons with good spring rain, white heads may not occur, even in infected crops.

Figure 10: Whiteheads are more prevalent with moisture stress. Checking around tree lines can be a better indicator in wetter or milder years. (Image NSW DPI)

3.5.2 Assessing the disease risk

Soil sampling for future risk

PreDicta™ B is a DNA-based soil test which detects levels of a range of cereal pathogens, including the main *Fusarium* species which cause crown rot:

- It is commercially available to growers from accredited agronomists through the South Australian Research and Development Institute (SARDI: http://pir.sa.gov.au/).
- It is a good technique for identifying the level of risk for crown rot and other soil-borne pathogens prior to sowing. However, this requires a dedicated sampling strategy and is not a simple add on to a soil nutrition test.
- Soil cores should be targeted at the previous winter cereal rows, if evident, and any stubble fragments should be retained.
- Short pieces of stubble (1-2 from each PreDicta™ B soil sampling location) from previous winter cereal crops and/or grass weed residues should be added to the soil sample to enhance detection of the inoculum that causes crown rot.
- Accredited agronomists can consult SARDI for the latest recommended sampling strategy for your region.

Plant disease diagnosis

- A commercial plant disease diagnosis service is available through AGWEST Plant Laboratories (DAFWA) for crown rot and other pathogens (see Useful Resources).

Stem browning assessment

Check cereal crops for crown rot between grain filling to harvest. Collect plant samples from within the paddock by walking in a large 'W' pattern, collecting 5 plants at 10 different locations (Figure 6). Examine each plant for basal browning, record what percentage shows the symptom and then put in place appropriate measures for next year.

As a general rule, the risk for a cereal in the next season will be:

- LOW – less than 10% of plants infected;
- MEDIUM – 11 to 24% of plants infected; and
- HIGH – more than 25% of plants are infected.

3.5.3 Reducing yield loss

If crown rot has caused yield loss, or is suspected, there are a number of ways in which the risk can be minimised in the coming season. However, actual yield loss will be determined by seasonal conditions. For example, a paddock may have a high inoculum load, but the cereal crop may only suffer small yield losses if there is good spring rainfall with mild temperatures.

Paddock selection

- Cereals – avoid paddocks with a high crown rot risk.
- Determine paddock risk (see section on 'Assessing the disease risk' for details) by visually assessing crown rot levels in a prior cereal crop or have soil/stubble samples analysed by PreDicta™ B.

Paddock history can also provide clues. Histories likely to result in high crown rot risk include:

- high infection levels in a winter cereal crop in the last three years;
- high frequency of winter cereals in the rotation;
- stubble retention with no tillage;
- low rainfall during the last fallow or break crop from cereals where dry conditions have made residue decomposition slow;
- poor grass weed control;
- stubble cultivated close to sowing; and
- paddocks with low stored soil moisture at sowing or soil types with a lower water holding capacity.

Cereal type

While all winter cereals host crown rot, yield loss due to infection varies with cereal type and between different varieties. Yield loss varies between crops and the approximate order of increasing loss is oats, barley, bread wheat, triticale and durum wheat.

Barley is very susceptible to crown rot infection and will build-up inoculum but tends to suffer reduced yield loss through its earlier maturity relative to wheat. Late planted barley can still suffer significant yield loss especially when early stress occurs within the growing season.

Variety resistance

Variety resistance and tolerance to crown rot exists but are not the sole solution.

Resistance: the plant's ability to limit the development of the crown rot fungus within living tissue.

Tolerance: the plant's ability to maintain yield in the presence of crown rot infection.

Barley and bread wheats – varying levels of susceptibility.

Relative yield loss between varieties

- Cereal varieties differ in their tolerance to crown rot. This can have a significant impact on the relative yield of varieties in the presence of this disease.
- Some newer wheat varieties have a measurable improvement in their tolerance to crown rot. Limited data suggest Emu Rock⟮PBR⟯ is likely to yield better in the presence of high levels of crown rot infection, appearing to suffer less yield impact compared to Mace⟮PBR⟯. However, variety choice is NOT a solution to crown

rot with even the best bread wheat or barley variety still suffering up to 40% yield loss from crown rot under high infection levels and a dry/hot seasonal finish. All current durum varieties are very susceptible to crown rot and should be avoided in medium and high risk situations.

- Variety Guides and the National Variety Trials website, www.nvtonline.com.au provide crown rot ratings which are largely based on the evaluation of resistance. The latest information on the relative yield of varieties in the presence of crown rot can be found on the GRDC website.

Interaction between crown rot and root lesion nematode

- Root lesion nematodes (RLNs), which feed inside root systems, appear to exacerbate yield loss from crown rot infection even in a season not overly conducive to the expression of crown rot.
- Reduced resistance/tolerance to the different species of RLN within bread wheat varieties may also exacerbate yield loss from crown rot.

Stubble management

- Inoculum will be more concentrated below ground and in the bottom 7 cm of the stem (Figure 12).
- Stubble management practices such as cultivation, spreading and slashing through cultivation can increase the rate of stubble decomposition but can also spread the infected residues across the paddock.
- Where there is no stubble moisture or adequate time to accelerate stubble breakdown, then these practices can increase infection rates in the next winter cereal crop.
- Grazing stubble can also spread inoculum.

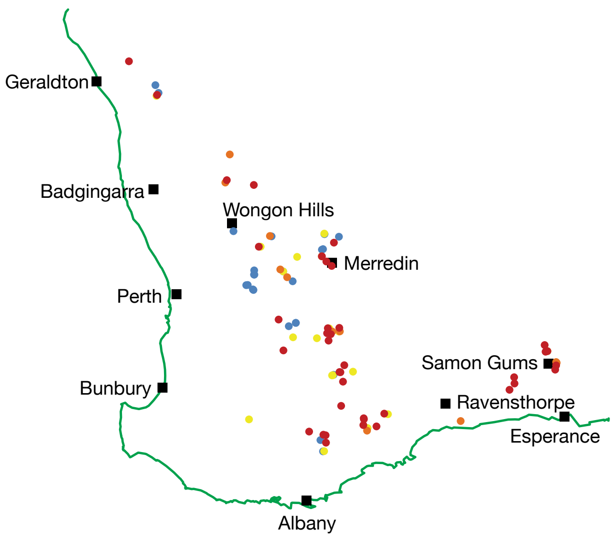


Figure 11: Crown rot incidence in Western Australia based on two-year stubble survey (2013/14). Infected stubble: blue circles = nil (0-2%); yellow circles = low (3-10%); orange circles = medium (11-24%); red circles = high (>25%).

Time of sowing

- There is little impact of time of sowing on the incidence of crown rot infection, however disease severity as measured by basal browning and yield loss increases with later sowing.
- Planting date should be determined by the presence of adequate soil moisture and the type of variety sown to also manage frost risk.
- Sowing a variety early in its sowing window will help minimise the detrimental effects of any crown rot infection by bringing the grain filling period forward into slightly reduced evaporative stress conditions. However, this should be balanced against any risk of frost damage in your area.

Inter-row seeding

- Infection rates can be reduced by sowing between intact rows of previous standing cereal stubble.
- In the western region inter-row sowing using accurate ± 2 cm differential GPS autosteer has shown to decrease the number of infected plants by about 50% – resulting in a 5 to 10% yield advantage in the presence of crown rot.

Crop nutrition

- Bulky crops are more likely to experience moisture stress during grain filling which makes them more vulnerable to yield losses from crown rot.
- Match nitrogen rates and timing to stored soil moisture and targeted potential yield – this will avoid excessive early crop growth which can diminish soil water reserves prior to the critical grain filling period.
- Pay attention to zinc nutrition – the expression of whiteheads in crown rot infected tillers can be more severe in zinc-deficient crops. Applying zinc above recommended rates will not provide further protection from crown rot.

3.5.4 Changing crown rot levels

Reducing inoculum is vital to managing crown rot. Rotation remains the most important component in the integrated management of crown rot.

Rotations

- All winter cereals increase crown rot inoculum – durum wheat and barley increase the levels most.
- Breaks from winter cereals decrease crown rot inoculum and will be most effective if free of grass weeds and volunteer cereals.
- Inoculum declines after break crops such as canola and lupins.
- Good rainfall increases the effectiveness of the break, because microbial decomposition of the cereal residues harbouring the pathogen is greater in moist conditions.
- For break crops, early canopy closure and warm, damp conditions under the canopy will result in the fastest decomposition of crown-rot-infected residues and reduction of inoculum levels.

Cultivation

Incorporating infected plant residues into the soil by cultivation can increase the rate of decomposition.

However, decay may take multiple years as it is also influenced by biological activity, soil moisture and nutrient availability.

Unfortunately cultivation spreads infected residues, which may increase plant infection rates – counteracting any benefits from increased residue breakdown. The main infection sites are below ground. Hence cultivation can provide greater distribution of infected residue throughout this zone which can then contact and infect plants.

Prior to cultivating specifically for crown rot management, consider the implications for nutrient loss, erosion and degradation of soil structure.

Baling and burning

Baling and removing straw or hay are not instant solutions for crown rot. This is because much of the crown rot inoculum is below the level at which the hay is cut (Figure 12). For the same reason, stubble burning is not a quick-fix for high crown rot levels because burning does not remove inoculum from below ground.

Prior to baling or burning specifically for crown rot management, consider the implications for nutrient loss, erosion and degradation of soil structure.

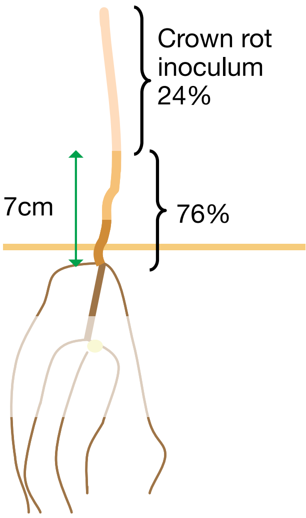


Figure 12: Crown rot distribution in infected cereal stubble

3.5.5 If a cereal must be sown but there is a risk of yield loss from crown rot:

- Select a cereal type which will have the lowest yield loss. Barley is the first choice, followed by bread wheat and triticale. Avoid durum;
- Check wheat variety guide for bread wheats with improved tolerance;
- Match nitrogen application to stored soil moisture and potential yield;
- Limit nitrogen application prior to and at sowing to avoid excessive early crop growth;
- Ensure zinc nutrition is adequate;

- Sow on the inter-row, if this option is available and the soil is not non-wetting;
- Avoid sowing late in the planting window;
- Fungicide(s) used as seed dressings and registered for suppression of crown rot are unlikely to provide consistent or significant yield improvements on their own. They may contribute to an advantage when used in conjunction with other management options;
- Note that by growing a cereal, inoculum levels will increase for subsequent crops.

3.6 Root disease - take-all

Key messages

- A run of good seasons has inoculum levels of the fungal disease take-all at their highest (2014) in more than a decade across southern Australia.
- Take-all survives over summer on residues of cereals and grasses.
- Wheat paddocks most at risk of yield losses are those with a history of high frequency cereals and/or grassy pastures.
- In furrow fungicide applications, non-cereal break crops, grass-free pastures and short chemical fallows to remove grasses will control take-all.
- In low to medium rainfall districts (less than 450mm) grasses must be controlled by late June and by end of July in high rainfall districts.

Take-all is most prevalent in the wetter western and southern areas of the Western Australian wheatbelt.

Take-all restricts water and nutrient flow up the root system, which under periods of moisture stress causes infected plants to die prematurely.

In severe cases, yield losses can exceed 60 per cent.

If there is a soft finish to the season, yield losses will not be as great, but the fungus will keep developing until the crop matures, thus posing an even greater risk to subsequent cereals.

Levels in some paddocks are now (2014) high enough to cause large wheat losses in good seasons combined with a tight finish.

Take-all does not do well in drought conditions and generally takes two to four good seasons and intensive cereals or grassy pastures for inoculum to reach high-risk levels (Table 13).

Table 13: Diagnosing and managing take-all in wheat.

Monitor	Diagnose	Manage
Use Predicta B to monitor take-all inoculum levels and guide wheat management decisions: www.sardi.sa.gov.au/diagnostic_services/predicta_b/why_test/take-all PredictaB take-all map: www.sardi.sa.gov.au/diagnostic_services/predicta_b/disease_distribution	To diagnose take-all in-crop use the Department of Agriculture and Food, WA's MyCrop web tool: https://www.agric.wa.gov.au/n/2153	The most effective way to reduce take-all is to use a non-cereal break crop, grass-free pasture or chemical fallow to remove grasses in the year before wheat: www.soilquality.org.au/factsheets/take-all-disease There are no post emergent fungicide treatments to control take-all check current registered seed dressings at: https://www.agric.wa.gov.au/n/1794

3.7 Root disease - pythium

Key messages

- All major grain crops and pastures grown across Australia can host and be infected by pythium. Wheat and barley are significantly less susceptible than pulses and canola.
- Pythium is ubiquitous in Australian cropping soils, but is more prevalent in regions with an annual rainfall above 350mm.
- Using a pythium-selective seed dressing can reduce soil-borne pythium inoculum and root infection by about 25 per cent.
- There are no post emergent treatments registered for suppression of pythium root rot.
- Disease incidence is greater after long-term legume pastures and repetitive wheat-canola rotations.

Pythium is often distributed relatively evenly in soils. This means that in the absence of a protective treatment all plants are affected by pythium to a similar extent and unless severe infection can go undetected.

Consequently, diagnosis of pythium root rot based on above-ground symptoms is difficult and when the disease is moderate to severe, it is often misdiagnosed as rhizoctonia damage. The effects of pythium root rot are therefore often underestimated (Table 14).

Table 14: Table 14. Diagnosing and managing pythium root rot in wheat.

Monitor	Diagnose	Manage
PredictaB® pythium map: www.sardi.sa.gov.au/diagnostic_services/predicta_b/disease_distribution A PredictaB® test under evaluation for Pythium clade f detected three of the seven root pathogenic Pythium species isolated from cropping trials (2002-2010) including the dominant species Pythium irregular: www.sardi.sa.gov.au/diagnostic_services/predicta_b	Pythium is frequently misdiagnosed as rhizoctonia. To diagnose pythium in-crop use the Department of Agriculture and Food, WA's MyCrop tool: https://www.agric.wa.gov.au/n/2142	Good weed control and the use of diverse rotations and fungicide seed dressings can help manage pythium: www.grdc.com.au/GRDC-FS-PythiumRootRot Check currently registered fungicides for pythium at: https://www.agric.wa.gov.au/n/1794

More information

For more information on cereal root and crown diseases: www.grdc.com.au/GRDC-BPG-CerealRootCrownDiseases

Resources

GRDC Ground Cover supplement: http://www.grdc.com.au/GCS111

MacLeod B, Vanstone V, Khangura R and Beard C (2008) Root disease under intensive cereal production systems. Bulletin 4732, Department of Agriculture and Food, Western Australia.

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

AMC00016 – Development of yield response curves for cereal foliar and root and crown pathogens (S: 01/4/2014 F: 30/06/2018)

DAS00137 – National improved molecular diagnostics for disease management (S: 30/06/2013 F: 30/06/2018)

DAW00207 - National modelling, risk forecasting and epidemiology of crop diseases (S: 07/01/2010 F: 30/06/2013)

DAW00245 – Yield loss response curves for host resistance to leaf, crown and root diseases (S: 30/06/2014 F: 30/06/2019)

DEP00002 – Push Notifications to enable proactive management of pests, weeds and diseases (S: 01/07/2014 F: 30/06/2019)

Rust:

ANU00022 – New strategies for disease resistance to wheat stripe rust: Providing novel resistance to wheat rust disease via RNAi interference (S: 01/07/2013 F: 30/06/2019)

CSP00161 – Triple Rust Resistance Project – ACRCP (S: 30/06/2012 F: 30/06/2017)

FAR00002 - Improved fungicide use for cereal rust control (S: 07/01/2012 F: 6/30/17)

US00063 - Australian Cereal Rust Control Program - Durable genes (S: 1/07/2012 F: 30/06/2017)

US00064 – Australian Cereal Rust Control Program – National breeding support (S: 01/07/2012, F: 30/06/2017)

US00067 – Australian Cereal Rust Control Program – Towards 2019 and a century of monitoring cereal rust pathogens in Australia (S: 01/07/2012 F: 30/06/2017)

UA00141 – Advancement of new stem genes for stem and leaf rust resistance from uncultivated relatives of wheat (continuation) (S: 1/07/2012 F: 30/06/2017)

Leaf spot diseases:

DAW00206 – Germplasm enhancement for yellow spot resistance in wheat (S: 1/07/2010 F: 30/06/2015)

DAW00247 – Improved genetic solutions for management (S: 01/06/2015 F: 30/06/2020)

DAW00229 - Improving grower surveillance, management, epidemiology knowledge and tools to manage crop disease (S: 30/06/2013 F: 30/06/2018)

CUR00019 - Fungicide evaluation of new generation actives in cereals and pulse crops (S: 30/06/2012 F: 30/06/2015)

Root Diseases - Rhizoctonia:

UWA00152 – Managing soil-borne diseases with a focus on Rhizoctonia (Part A) (S: 01/07/2011 F: 30/06/2014)

UWA00154 – Strategies to provide resistance to the economically important fungal pathogen, Rhizoctonia solani (S: 01/06/2012 to 30/06/2016)

CSP00135 – A molecular approach to unravel the dynamics of disease suppressive microbial communities (S: 30/06/2010 F: 01/02/2014)

DAS00141 – Managing crop disease – Improving cereal (wheat and barley) root disease resistance (S: 01/07/2013 F: 30/06/2015)

DAS00122 - Fungicide control of Rhizoctonia Part C (S: 07/01/2011 F: 30/06/2014)

DAS00123 – Fungicide control of Rhizoctonia Part B (S: 01/07/2011 F: 30/06/2014)

DAS00125 – Fungicide control of Rhizoctonia Part A (S: 101/07/2011 F: 30/06/2016)

DAV00128 – National Nematode epidemiology and management program (S: 30/06/2013 F: 30/06/2018)

DAQ00171 – Genetic options for nematode control (S: 30/05/2011 F: 30/05/2016)

Crown Rot:

US00054 – Crown rot germplasm enhancement for wheat (S: 1/07/2010 F: 30/06/2015)

DAS00136 – New fungicide technologies for crown rot management (S: 30/06/2013: F: 30/06/2016)

CRA00003 - Pre-breeding cultivar screening for field tolerance to Crown Rot (S: 01/06/2012, F: 30/06/2015)

CSP00154 - Functional analysis of the genome of the major crown rot pathogen (S: 30/06/2012, F: 25/11/2015)

USQ00013 - Managing crop diseases - Improving crown rot resistance in durum (S: 01/06/2013, F: 30/06/2018)

CIM00018 - Identification and utilization of novel sources of resistance to crown rot and the root lesion nematodes in adapted spring and durum wheat
(S: 01/07/2013 F: 30/06/2018)

Root Disease – Pythium:

CSP00172 - Increasing agricultural productivity through roots and rhizospheres: Putting the small grass Brachpodium to work (S: 30/06/2013 F: 30/06/2014)

DAS00141 - Managing crop disease - Improving cereal (wheat and barley) root disease resistance supplement (S: 01/07/2013 F: 30/06/2015)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC disease projects can be found at: www.grdc.com.au

SECTION 4

Pests

Key messages

- Insects are not normally a major problem in winter cereals however several pests can cause serious damage to wheat in some seasons in Western Australia.
- Widespread use of 'insurance' insecticide sprays is resulting in a growing incidence of insecticide resistance among Australian pest populations.
- Parasitic wasps, ladybeetles, lacewings and hoverflies can provide useful biological control of some crop pests and monitoring of both pest and beneficial populations can reduce the need to apply pesticides.

Insects are not normally a major problem in winter cereals however several pests can cause serious damage in some seasons to wheat in Western Australia.

The significance of particular pests to wheat growth and yield varies from season to season and with farming system.

Increased use of broad-spectrum insecticides, widespread adoption of stubble retention and minimum tillage, increased plantings of vulnerable crops such as canola and drier conditions exacerbated by climate change have all converged to alter the type of pests in WA cropping systems.

For a comprehensive coverage of pests in WA cropping systems download the MyPestGuide app: https://agric.wa.gov.au/n/3588. The app has information on 200 crop and grain storage pests, beneficial and biological control agents and biosecurity pest threats specific to Western Australia. A key feature of the app is that it enables users to send pest reports and photos direct to entomologists at the Department of Agriculture and Food, WA for diagnosis and management recommendations.

More information

For more information on integrated pest management read: http://www.grdc.com.au/Resources/Bookshop/2009/12/Integrated-Pest-Management-Fact-Sheet-National

To monitor and report cropping pest outbreaks throughout the season subscribe to the Department of Agriculture and Food, WA PestFax service: https://agric.wa.gov.au/n/1588

'Insurance' insecticide sprays can be an unnecessary cost and speed up the development of resistance in pest populations.

Integrated pest management

- Prophylactic or 'insurance' sprays can be an unnecessary cost and speed the development of resistance in pest populations.
- Consider carefully the need for insecticides. There may be beneficial insects present that will help control pests if crops are left unsprayed.
- IPM uses cultural, chemical, genetic and biological tactics to prevent pests from reaching damaging levels in crops.
- Only apply insecticides after monitoring and correctly identifying pest species.
- If insecticides are used, minimise chemical impact on beneficial insects by considering a selective spray and limited number of applications.
- Rotate chemical classes with different modes of action to minimise resistance problems.
- Use the recommended label rates and ensure good coverage.
- Base the choice of control strategies on economic thresholds.

More information

DAFWA: Cockchafer damage

DAFWA: Aphids

DAFWA: Russian wheat aphid.

4.1 Aphids

Wheat growth stage affected: tillering and flowering to maturity.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2157

Occasional pests of wheat crops, adult and nymph aphids suck sap. Large populations limit grain yield and size, especially with winter and spring infestations. Cereal aphids also spread barley yellow dwarf virus (BYDV) which reduces cereal yield.

The spread of BYDV by aphids is only economically damaging if aphids transmit the virus early, within the first 8-10 weeks following emergence. Such early BYDV infection usually only occurs in high rainfall areas especially where early season grass and cereal weeds have been present.

Cereal aphid numbers can build up on volunteer cereals and grass weeds (the green bridge) before sowing and then migrate from these to infest new season crops.

The two main cereal aphid species are corn aphid and oat aphid. Infestations of both aphids can cause more damage than either species alone.

Cereal aphid damage in wheat has no obvious signs or symptoms.

Spraying for cereal aphid feeding damage is considered worthwhile if 50 per cent of tillers have at least 15 aphids and crops are expected to yield 3t/ha or more. Damaging populations can develop in three out of five years.

Crops sprayed before stem elongation (GS30) may need respraying between booting and heading (GS50 or later) if aphid numbers build up again. However, it is best to wait until threshold aphid levels are present before spraying as in many years aphid numbers will not reach damaging levels.

Parasitic wasps, ladybeetles, lacewings and hoverflies can provide useful biological control, mainly by preventing secondary outbreaks.

Check crops from late tillering onwards for feeding damage by corn aphids in the furled growing tips, and for oat aphids on stems, ears and the backs of leaves.

More information

For more information of aphid damage in cereals refer to: https://agric.wa.gov.au/n/113 and www.grdc.com.au/GRDC-BPG-CropAphids

For more information on beneficial insect pests and how to identify them refer to: www.agric.wa.gov.au/n/2922 and www.grdc.com.au/GRDC-BPG-BeneficialInsectsSouthWest

Naturally occurring fungal infection of aphids and the impact of beneficial insects such as parasitic wasps, hoverflies, lacewings and ladybird beetles (pictured) will influence eventual aphid population levels. It is best to wait until threshold levels of aphids are present before spraying as in many years aphids will not reach damaging levels. Routine and unnecessary application of synthetic pyrethroids will also accelerate the build-up of resistance in aphids and other non-target pests such as mites. Photo credit: GRDC.

Redlegged earth mite populations with resistance to synthetic pyrethroids and tolerance of omethoate have been recorded in Western Australia. To maintain the useful life of insecticides it is important to spray mites only if absolutely necessary. Using insecticide seed treatments for crops and new pastures with moderate pest pressure directly targets plant feeding pests and enables smaller quantities of insectide to be used.

Photo credit: GRDC.

More information

DAFWA: Insect threshold levels.

4.2 Redlegged earth mite

Wheat growth stage affected: Before seeding and seedling.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2177

Redlegged earth mites normally do not affect grasses or cereals severely. Large numbers of redlegged earth mite are commonly found in annual pastures at the break of the season and can cause heavy and sustained loss of subterranean clover and annual medic throughout the season. The mites also attack lupin, canola, field pea and serradella.

Mites rupture cells on the surface of leaves and feed on exuding sap; affected leaves look silvered, but do not have holes as with lucerne flea attack. Mite damage to seedlings is more severe if plant growth is slowed from cold, waterlogging or low seedling density. Severe damage can kill seedlings.

Spraying for redlegged earth mites should be done only if absolutely necessary, as mite populations with resistance to synthetic pyrethroids and tolerance of omethoate have been recorded in WA.

Using insecticide seed treatments for crops and new pastures with moderate pest pressure directly targets plant-feeding pests and enables smaller amounts of pesticide to be used.

See Section 10 of this GrowNote for more information on insecticide resistance in redlegged earth mite populations.

Adult mites are about the size of a pinhead (up to 1mm). They have velvety black bodies and eight bright orange-red legs. The mites are often gregarious and are found clumped together in large numbers.

Mites hatch from over-summering eggs in autumn when there is adequate moisture and low temperatures. Eggs produced through the season are thin-walled and hatch immediately and several generations can develop over winter and spring. As pastures begin to senesce, the mites produce thick-walled eggs, which resist drying out over summer and carry the mite through to the next season.

4.3 Blue oat mite

Wheat growth stage affected: seedling.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2174

Purplish-blue body with red-orange legs and a red dot on back of body.

Only found if cold temperature requirement for hatching has been met; frequently found with redlegged earth mite.

Can cause extensive leaf bleaching (not the white trails as with Bryobria mite – see below).

4.4 Bryobria mite

Wheat growth stage affected: seedling.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2702

Bryobria mites are easily confused with redlegged earth mite and are difficult to identify without the use of a hand lens. However, redlegged earth mites are not usually present in early autumn when Bryobria are common as they have a cold temperature requirement before hatching.

Bryobria mites mainly affect canola and lupin but can cause seedling damage in wheat.

The rates of insecticides commonly used to control redlegged earth mite and lucerne flea are not effective against bryobia mites.

4.5 Balaustium mite

Wheat growth stage affected: seedling.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2175

Balaustium mites are similar in appearance to the redlegged earth mite with a greyish-red body and red legs. If viewed under a magnifying glass or microscope short stout hairs can be seen covering the body. The adult balaustium mite grows to almost twice the size of redlegged earth mites.

Balaustium mites require rainfall before their over-summering eggs can hatch. Newly hatched nymphs have six legs and are an orange colour. Development from egg to adult takes about 5-6 weeks. Several generations can occur each year.

Mites feed on the leaves of plants by probing into the surface cells with their mouthparts and sucking out sap. Crops sown into paddocks that were in pasture with high levels of broad leaf weeds the previous year (especially capeweed) will be most at risk from Balaustium mite damage.

In most situations crops will not require spraying and balaustium will cause little or no damage.

Early control of summer weeds in paddocks that are to be cropped will prevent the build up of mite populations.

4.6 Webworm

Wheat growth stage affected: before seeding, seedling.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2173

Seldom seen above ground, webworm lives in web-lined tunnels during spring and summer. Caterpillars hatch from eggs among grass in autumn and feed throughout the winter. The insects then proceed through a pupal stage and emerge as adult moths (10mm long), which can be seen flying in large numbers on autumn nights. By day the moths hide in dry grass, the colour of which they closely resemble.

Caterpillars of the webworm sever leaves and whole plants and large areas of emerging wheat or barley crops can be destroyed by the continual chewing damage of a heavy webworm infestation. Severed leaves are pulled into the pest's tunnels.

Eggs are not laid in large numbers and do not survive well in bare paddocks or in stubble.

Grassy weeds and pastures favour survival. Cultivations that result in weed-free paddocks for three weeks reduce survival of larval stages while reduced tillage enables greater survival.

Spray if 25 per cent of plants are seriously damaged at or just after emergence.

4.7 Lucerne flea

Wheat growth stage affected: seedling.

MyCrop tool: https://agric.wa.gov.au/n/2164

Small jumping bugs that appear early in the season and chew young wheat leaves, especially on heavier textured soils.

Seedling death occurs in heavy lucerne flea infestations and the pest can cause serious damage to pasture, legumes and cereals. Green leaf tissue is eaten, leaving the surface of the leaf with a whitish film. From a distance, severely affected areas appear bleached.

Heavy soils and moisture favour the lucerne flea; it cannot live in very sandy situations.

Systemic or contact insecticides control lucerne flea in crops and pastures. However, synthetic pyrethroid sprays are ineffective against the pest.

A predatory mite, the bdellodes mite, is present over most of the WA wheatbelt occupied by lucerne flea and exerts a useful level of control.

4.8 Cutworm

Wheat growth stage affected: before seeding, seedling.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2161

Cutworm is not a regular pest but large crop areas can be affected.

Pests chew through leaves or stems as they feed on or near the ground. Most damage occurs during autumn. Larvae hide in the soil during the day, often at the base of lopped plants on the edge of the damaged patch.

Two large caterpillars per 0.5-metre cereal row can cause extensive damage.

Cutworm are easily controlled with registered rates of synthetic pyrethroid chemicals.

Occasionally, autumn attack by armyworm in cereals resembles cutworm damage. This is significant, because armyworm is more difficult to kill with insecticides than cutworm.

Weather and food supply are the most important factors in determining cutworm abundance.

Biological control by fungal diseases can be very successful, while wasp and fly parasites can also actively prevent more frequent and serious outbreaks.

4.9 Armyworm

Wheat growth stage affected: harvest.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2159

Armyworm caterpillars are plump and smooth (hairless) and are characterised by three parallel white stripes on the collar just behind their large head. A useful visible sign of armyworm caterpillars is to look for their green to straw-coloured droppings which are about the size of a match head, and can be found on the ground between the cereal rows.

Damage to weeds, especially preferred ryegrass, is also a sign of their presence.

Wheat crops are less frequently attacked than barley and usually only minor damage occurs in wheat.

Assessing the number of armyworm in a cereal crop can be difficult, as their location varies with weather conditions and feeding preference. Sometimes they are found sheltering on the ground and under leaf litter while on other days they will be high up on plants and easily picked up using sweep nets.

Armyworm caterpillars are most damaging close to harvest when grubs chew through wheat grain head stems causing the heads to fall to the ground. The economic trigger for spraying in wheat is 10 grubs per square metre.

4.10 Desiantha weevil

Wheat stage most affected: before seeding, seedling.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2162

Desiantha weevil is a sporadic pest of cereal seedlings in south coast WA. Late-sowings are at particular risk. The weevil favours sand over gravel and sandy duplex soils.

The larval stage of the weevil can completely destroy hundreds of hectares of young crop. Larvae chew the swollen seed, or bore into the underground stem of seedlings causing them to become stunted or wither and die. The pest can also bore into tillers at tillering causing them to die.

Desiantha weevil larvae are white and legless, with orange-brown heads and up to 6mm long. Larvae remain under the soil and are difficult to find.

The only in-crop treatment is to reseed with insecticide-coated seed.

4.11 African black beetle

Wheat growth stage affected: seedling.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2156

A pest of cereals and perennial grasses, adult and larval African black beetles can cause economic damage to wheat and barley crops during autumn and winter on the south coast of WA especially in crops growing close to or following kikuyu pastures.

The adult beetles are shiny black (brown when newly emerged), cylindrical and up to 12mm long. The soil dwelling larval stage occurs mostly in late spring, summer and early autumn and is a C-shaped curl grub up to 25mm long with a brown head and three pairs of legs. African black beetle grubs look very similar to the more common pasture cockchafer larvae.

Beetles are more likely to be seen walking on the soil surface at night. A density of 2- 6 beetles per square metre can cause problems especially in newly sown ryegrass pasture.

There are no chemicals registered specifically to control African black beetle in pasture or cereal crops in WA, but pasture seed treated with imidacloprid for redlegged earth mites has shown some efficacy against the pest.

Increasing crop seedling rate and avoiding the use of drill rows can help manage the pest.

African black beetles should not be confused with the black-headed pasture cockchafer listed on some chemical labels, as this is not a known pest in WA.

4.12 Snails and slugs

Wheat growth stage affected: seedling and harvest.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/2172

Snail damage to WA crops has been increasing since the mid-2000s. Three snail species damage broadacre crops in WA:

- The small pointed snail has a conical shell with brown bands of varying width. It is usually less than 10mm in length and diameter. It occurs on all soil types in the high rainfall area.
- The white Italian snail is up to 30mm across, white with broken brown bands.
- The vineyard snail is up to 20mm across with almost continuous brown bands. The vineyard and white Italian snails prefer alkaline sandy soils.

The black-keeled slug and the reticulated slug are the two slug species common in broadacre WA crops. Slugs are usually found on heavy soils and wet areas in the high rainfall area.

For detailed information on snail and slug control in wheat crops see Section 8 of this GrowNote.

4.13 Stored grain pests

Wheat growth stage affected: seedling and harvest.

MyCrop diagnostic tool link: https://agric.wa.gov.au/n/1167

The most common insect pests of stored cereal grains in Australia are:

- Weevils: (*Sitophilus* spp.) Rice weevil is the most common weevil in wheat in Australia.
- Lesser grain borer: (*Rhyzopertha dominica*)

More information

For more information of aphid damage in cereals refer to: https://agric.wa.gov.au/n/113

For more information on beneficial insect pests and how to identify them refer to: https://agric.wa.gov.au/n/2922

For more information on emerging insect pests across southern Australia read: www.grdc.com.au/GCS102

For information on insecticide spraying read: www.grdc.com.au/GRDC-FS-FoliarApplications

To receive a copy of the current pesticide spray option for Western Australia email: PestFax@agric.wa.gov.au

NIPI (National Invertebrate Pest Initiative) www.nipi.com.au

- Rust-red flour beetle: (*Tribolium* spp.)
- Saw-toothed grain beetle: (*Oryzaephilus* spp.)
- Flat grain beetle: (*Cryptolestes* spp.)
- Indian meal moth: (*Plodia interpunctella*)
- Angoumois grain moth: (*Sitotroga cerealella*)

For detailed coverage of stored grain pests see Section 14 of this GrowNote.


Freshly harvested grain usually has a temperature of about 30°C, which is ideal for storage pest breeding. Rust-red flour beetles (top) stop breeding at 20°C while the lesser grain borer (bottom) stops breeding at 18°C. Photo credit: GRDC.

Exotic pests

If unusual or unknown insect pests are found in crops it is important to make note and report details to the Pest and Disease Information Service (PaDIS) free hotline on 1800 084 881 or email info@agric.gov.wa.au.

Information that will help PaDIS identify the pest, plant or animal species includes:

Where the pest was seen. A GPS location is ideal, but otherwise details on where you saw it will help.

A photo or details of the suspected pest and any damage it might have already caused.

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

DAW00230 – PestFax Map II National (S: 190/06/2013 F: 30/06/2016)

UWA00134 – Developing and promoting IPM in Australian grains (S: 01/11/2012 F: 03/01/2013)

UWA00145 – Innovative approaches to resistance to necrotrophic pathogens and sap-sucking insect pests (S: 08/01/2010 F: 30/06/2015)

UWA00158 – Detection and epidemiology of winter/spring aphids and redlegged earth mites (S: 01/11/2012 F: 30/09/2015)

UWA00165 – Options for improved insecticide and fungicide use and canopy penetration in cereals and canola (S: 01/11/2013 F: 30/06/2016)

Red-legged earth mite:

CSE00054 - Pest management in grains - research, coordination and industry engagement (S: 01/01/2011 F: 30/12/2014)

UM00048 - National coordination of invertebrate pest research and insecticide resistance management (S: 01/07/2013 F: 30/06/2018)

UM00049 - Management of insecticide resistance in RLEM and screening new MoA chemistry (S: 30/06/2013 F: 30/06/2016)

Slugs and snails

DAS00134 - Improved management of snails and slugs (S: 30/06/2013 F: 30/06/2016)

UM00047 - Novel, highly targeted, low environmental impact control of pest slugs and snails (S: 01/03/2013 F: 31/10/2015)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC pest projects can be found at: www.grdc.com.au

SECTION 5

Nutrition

Key messages

- Nutrients must be added to Western Australia cropping soils because of their low natural fertility
- The profiles of many WA cropping soils consist of a thin layer of sand or loam above a thicker clay layer. Water, nutrients, and pH of the top layer need careful management to maintain optimum growth conditions.
- The phosphorus content of topsoil needs to be maintained at optimum levels.
- Crop nitrogen requirement depends on expected yield and protein. The amount of fertiliser nitrogen needs to supplement mineralisation from the soil and application timing needs to match the stage of greatest crop nitrogen demand.
- Micronutrient deficiencies are becoming more widespread because of greater removal by higher yielding crops and need to be corrected with fertilisers containing micronutrients.Western Australian soils

Most Western Australian cropping soils are ancient and were formed from granitic parent rock. Weathering over geological time has leached minerals and clay from the topsoils leaving them sandy and chemically infertile. Low buffering capacity makes the soils prone to nutrient leaching and rapid acidification. Many WA soil profiles are duplex, consisting of a thin sandy or loamy topsoil overlaying a thicker clay layer. The sandy topsoils have weak structure and are prone to compaction and a low water and nutrient holding capacity. The clay subsoil can store large amounts of water but its poor structure and small pore size distribution makes it difficult for crop roots to access.

The positive aspect of low fertility soils is that crop nutrient supply and timing is almost entirely in the hands of the farmer. This is increasingly the situation for all cropping soils, not just in WA, as nutrients are depleted by crops.

5.1 Inorganic soil components

Sand, silt and clay, along with structured (crystalline) and non-structured (amorphous) oxides of iron and aluminium make up the mineral or inorganic components of WA cropping soils. The iron oxides absorb ('fix') much of the phosphorus, molybdenum, copper and zinc added as fertiliser, thereby reducing their availability to plants. Applying nutrients in bands reduces their exposure to these oxides and increases their availability to crops.

The major clay in WA soils is kaolinite, which is made up of an aluminium oxide joined to a silicon oxide. In its pure form kaolinite is white however most kaolinite in WA soils is stained yellow, brown or red due to the presence of iron oxides.

Kaolin clays do not expand and contract significantly during wetting and drying and as a result they become impenetrable to crop roots, which tend to concentrate in the channels left by previous plants, especially perennials. Root channels significantly improve nutrient and moisture availability.

5.2 Organic soil components

Organic matter makes up 2-10 per cent of the soil mass and has a critical role in the physical, chemical and biological function of agricultural soils. Organic matter contributes to nutrient turnover and cation exchange capacity, soil structure, moisture retention and availability and soil buffering.

Soil organic matter is difficult to measure directly, so laboratories tend to measure and report soil organic carbon (SOC), which makes up about 58 per cent of soil organic matter.

Globally SOC is generally between 0.3 and 6.0 per cent in dryland agricultural topsoils, with the largest amounts in cool, moist environments with clay-rich soil, and the lowest in warm, dry environments with sandy soils. The SOC content in WA cropping soils typically range between 0.5 to 1.3 per cent in surface (0-10cm) soils – or the equivalent of 8-20 tonnes of carbon per hectare (t C/ha) assuming a bulk density of 1.0 g/cm^3. These amounts are roughly what could be expected from the temperature, rainfall and soil texture in the WA cropping region.

There is a fairly fixed ratio of carbon, nitrogen, phosphorus and sulfur in soil organic matter. Each tonne of carbon is associated with about 80 kg of nitrogen, 20 kg of phosphorus and 14 kg of sulfur. When soil organic matter is broken down, these amounts of nutrients are potentially available to crops.

Managed optimally, WA continuous cropping systems that mostly produce wheat are likely either to just maintain or lose soil organic carbon.

5.3 Soils and nutrients

The surface of clays and organic matter contain negatively charged sites that attract and adsorb nutrient elements with positive charges (cations). Once adsorbed, these minerals are not easily lost even when the soil is leached by water. In this way they provide a nutrient reserve available to plant roots. The minerals adsorbed onto the clay and organic matter can be replaced or exchanged by other cations. The capacity of soil to exchange cations is called its cation exchange capacity (CEC).

The CEC of soils varies according to the proportion and type of clay, the soil pH and the amount of organic matter. Much of the CEC of the sandy soils in WA depends on their organic matter content.

The most commonly occurring clay in WA soils, kaolinite, has a CEC of about 10meq/100g. Milliequivalents (meq) are a measure of the atomic weight and number of positive or negative charges on a nutrient element. Organic matter has a high CEC ranging from 250 to 400meq/100g. The addition of organic matter will temporarily increase the CEC of a soil and continued applications must be made to maintain or increase the level.

Cations in the soil compete with one another for a spot on the CEC and some cations are attracted and held more strongly than others. In decreasing holding strength, the order with which ions are held by the soil particles is aluminium, hydrogen, calcium, magnesium, potassium, nitrate, and sodium.

Soils with a low CEC are more likely to develop deficiencies of potassium, magnesium and other cations while high CEC soils are less susceptible to leaching of these cations.

Figure 1 illustrates how CEC can change with soil depth. The sum of the cations provides an estimate of the CEC of each soil layer. The CEC of the surface 10cm is relatively high (4.6 meq/100 g) because of a high organic content. At10 – 30cm depth, the organic content of the sand is low and so is the CEC. The CEC of the subsoil layers are governed by clay content. The dominant clay in this soil is kaolinite so CEC values are lower than those of some other clay minerals.

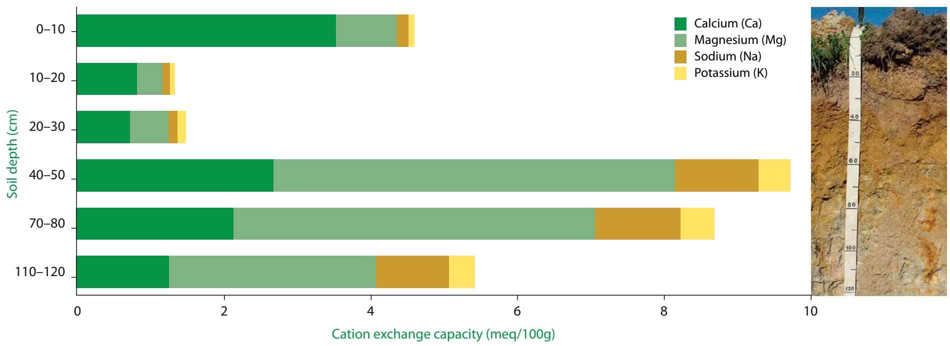


Figure 1: Cation exchange capacity (CEC) of a duplex soil with sand above clay at 40cm. Note that CEC is high at the surface due to the organic matter and in the clay below 40cm. Source: Jeremy Lemon, Department of Agriculture and Food, WA.

5.4 Soil tests – critical values

Tests of the top 10cm of soil are the best means of estimating the status of potassium, phosphorus and sulfur. Nitrogen status is better estimated with models, deep soil nitrate tests and plant tests, as discussed later. Micronutrient status is best measured from plant tests.

The critical value of a soil test is the value required to achieve 90 per cent of crop yield potential. The range around the critical value represents the reliability of the test

More information

For more information on the characteristics and constraints of the major WA soils visit: https://agric.wa.gov.au/n/638

For a comprehensive analysis of soil organic matter and carbon in Australian agricultural soils see: www.grdc.com.au/GRDC-Guide-ManagingSoilOrganicMatter

More information

GRDC Update Paper: Geoff Anderson, Enhancing the sustainability of the Western Australia cropping system by using soil and plant testing combined with nutrient balance calculations.

– with the narrower the range the more reliable the data (Table 1). If a soil test value is less than the lower critical value limit, wheat yield is likely to respond to a nutrient application (Figure 2). Soil test critical values do not predict optimum fertiliser rates.

To determine how much fertiliser to apply, soil test results need to be considered in combination with information about potential yield, soil type and nutrient removal in previous seasons.

Table 1: Critical soil test values at two soil-testing depths for phosphorus, potassium and sulfur according to WA soil types.

Soil sampling depth (cm)	Nutrient*	Soil type	Critical value (mg/kg)	Critical range (mg/kg)
0-10	Phosphorus	Grey sands	10	10-16
		Other soils	23	22-24
	Potassium	All	41	39-45
		Yellow sands	44	34-57
		Loams	49	45-52
		Duplexes	41	37-44
	Sulfur	All	4.5	3.5-5.9
0-30	Phosphorus	All	11	10-11
	Potassium	All	N/A	N/A
	Sulfur	All	4.6	4.0-5.3

Source: Department of Agriculture and Food, WA.

*Micronutrient status is more reliably measured using plant tissue rather than soil testing (see micronutrient section below).

Nitrogen soil tests are a poor indicator of nitrogen requirements and need to be used in conjunction with potential yield outlooks (see nitrogen section below).

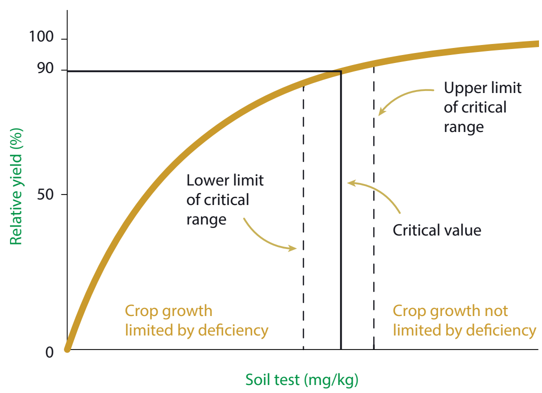


Figure 2: *A generalised soil test–crop response relationship defining the relationship between soil test value and per cent grain yield expected. A critical value and critical range are defined from this relationship. The relative yield is the unfertilised yield divided by maximum yield, expressed as a percentage. Normally 90 per cent of maximum yield is used to define the critical value but critical values and ranges at 80 per cent and 95 per cent of maximum yield can also be produced. Source: Department of Agriculture and Food, WA and Murdoch University.*

5.5 Nutrient movement

Nutrients arrive at the wheat root by the processes of mass flow, root interception and diffusion. Mass flow occurs when soluble and mobile nutrients are swept along in the flow of water moving from the soil towards the wheat root in the transpiration stream.

The nutrients that are mostly taken up in mass flow are nitrate, calcium, magnesium and sulfate, and these soluble nutrients are the most susceptible to leaching. About 80 per cent of nitrate-N reaches wheat roots in this way. Splitting nitrogen applications can reduce leaching risk and maintain high concentrations of nitrate-nitrogen in the soil solution during periods of rapid crop growth. Other nutrients taken up mainly by mass flow are calcium, magnesium and sulfate.

Less soluble nutrients move to plant roots along a concentration gradient by a process called diffusion. Nutrients move from an area of high concentration (the bulk soil solution) towards an area of lower concentration (the root surface). About 90 per cent of phosphorus and 80 per cent of potassium taken up by wheat is via diffusion. Banding potassium and phosphorus fertilisers ensures high nutrient concentrations in the active root zone.

Root interception is responsible for less nutrient uptake, for example, just 1-2 per cent of the uptake of nitrogen, phosphorus and potassium is due to interception by roots as they grow through the soil. Immobile nutrients like zinc are taken up when intercepted by roots or arbuscular mycorrhizal fungi (AMF). The activity of AMF is reduced by canola break crops and high levels of phosphorus fertiliser. Additional zinc fertiliser may be needed for wheat after canola or when fertilised with high levels of phosphorus.

More information

DAFWA: Diagnosing nitrogen deficiency in wheat.

DAFWA: Wheat response to nitrogen 2014 trial.

DAFWA: Diagnosing nitrogen deficiency.

5.6 Nitrogen

Key messages

- Nitrogen supply should be matched to crop requirements which may vary as the season progresses. Growers should consider tactical application of nitrogen fertiliser in response to expected requirement, seasonal conditions and prices.
- Crop nitrogen requirements are related to yield, which in turn is driven by rainfall, crop density, root disease, weeds and the status of other nutrients.
- Most nitrogen in the soil profile is in an organic form that must be mineralised before becoming available for crop uptake. The goal of nitrogen management is to supplement mineralised soil nitrogen with fertiliser nitrogen to match crop requirement.
- Tools such as Yield Prophet®, NuLogic and N-Broadacre (based on Select Your Nitrogen) estimate nitrogen supply from the various pools and can be used to calculate nitrogen fertiliser requirement as the season progresses.

Wheat plants need more nitrogen than any other mineral nutrient. It is recycled within the plants, first mainly for photosynthetic enzymes and later for grain protein. Plants require small amounts of nitrogen early in crop growth to trigger the development of tiller buds. The number of tillers for a particular variety provide a good indication of crop nitrogen status. For example in a normal crop the first tiller emerges from the base of leaf-1 at the same time that leaf-3 emerges on the main stem. Absence of this tiller is a symptom of nitrogen deficiency if other inputs are adequate. Nitrogen demand then jumps significantly during stem elongation - a period of rapid leaf area expansion and crop growth (Figure 3). Nitrogen taken up during stem elongation is helping to build crop yield by increasing head and grain numbers and also providing nitrogen reserves for grain protein.

Wheat nitrogen demand jumps significantly during stem elongation - a period of rapid leaf expansion and growth.

Photo credit: Paul Jones.

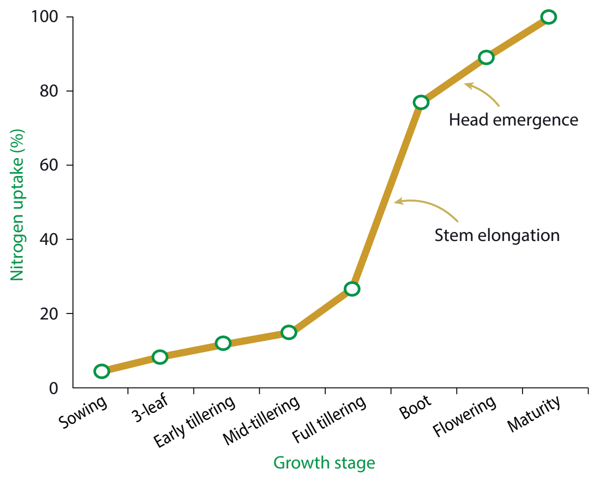


Figure 3: Relationship between growth stage and accumulated uptake of nitrogen by a wheat crop, expressed as a percentage of the total uptake. Source: Re-drawn from Fettell, 2006.

5.6.1 Nitrogen supply, protein and yield

There is a direct relationship between nitrogen supply (from all sources), grain yield and grain protein content (Figure 4). Soil nitrogen status and potential yield dictate a paddock's nitrogen supply zone (deficient, moderate or excessive).

Note to Figure 4

Figure 4 can be used to assess the success of a wheat nitrogen strategy. Grain protein levels above 10-11 per cent usually indicate excess nitrogen has been applied because yield and protein payments do not commonly offset the extra cost of the nitrogen. Conversely if grain protein levels are consistently below 10-11 per cent then it is likely the nitrogen strategy is forgoing yield potential and needs to be adjusted upwards.

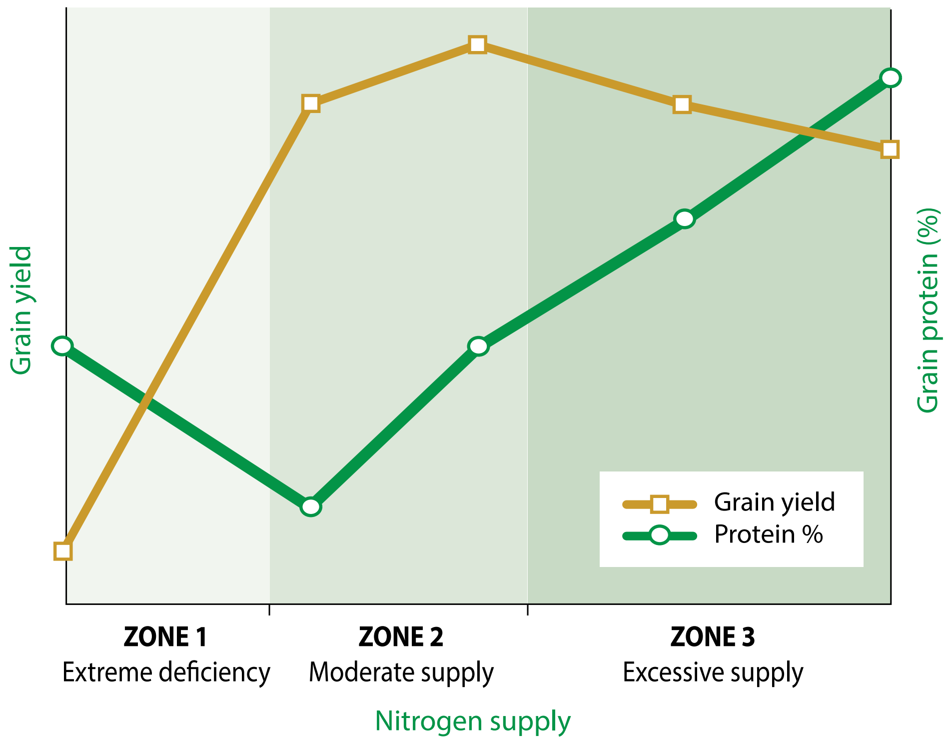


Figure 4: The generalised relationship between nitrogen supply, crop grain yield and grain protein content. Derived from a field experiment at Salmon Gums in 2004.

Source: Jeremy Lemon Department of Agriculture and Food, WA.

Zone 1: Extreme nitrogen deficiency

When nitrogen supply is deficient, adding nitrogen will increase yields markedly (Zone 1 and Figure 1). However, it is likely protein levels will remain unchanged or even decline slightly with additional nitrogen. Crop yield is only half or less of potential and cereal protein levels will be as low as 7-8 per cent.

Zone 2: Moderate nitrogen supply

As nitrogen supply increases to moderate levels (Zone 2) both crop yield and grain protein increase with additional nitrogen fertiliser. Crop yields are 60-80 per cent of potential but grain protein is still below 10 per cent. In general, returns on applied nitrogen are maximised at grain protein levels between 10-11 per cent. Fertiliser strategies to produce grain protein levels above this range are rarely profitable even when taking into account grain segregation bonuses.

Zone 3: Excessive nitrogen supply

Nitrogen supply in excess of crop yield potential (Zone3) can cause yield decline, high screenings and low test weight even while grain protein continues to increase. For example, grain protein levels of 14 per cent can result in a drop in grain yield of about 10 per cent. In general, the efficiency of nitrogen conversion to grain decreases as nitrogen supply increases.

5.6.2 Monitoring a nitrogen strategy

Figure 4 can be used to assess the success of a wheat nitrogen strategy. Grain protein levels above 10-11 per cent usually indicate excess nitrogen has been applied because yield and protein payments do not commonly offset the extra cost of the nitrogen. Conversely if grain protein levels are consistently below 10-11 per cent, provided other inputs and management is satisfactory, then it is likely the nitrogen strategy is forgoing yield potential and needs to be adjusted upwards.

5.6.3 Nitrogen pools

Wheat crops access nitrogen from three major soil pools.

- Stable organic nitrogen (SON).The SON pool is by far the largest source of soil nitrogen. As microbes break down organic matter, they release (mineralise) nitrogen in the form of ammonium (NH_4^+) and nitrate (NO_3^-). Mineralisation occurs most rapidly when the soil is moist and warm. Cultivation increases mineralisation and incorporation of residues that contain a high ratio of carbon to nitrogen (C:N) decreases mineralisation or causes nitrogen immobilisation, which is the opposite of mineralisation. During a normal season about two per cent of the SON pool becomes available to crops, and with significant rain in summer and autumn, mineralisation can be as high as three per cent. SON is estimated by measuring organic carbon percentage (OC%) in the profile. A continuously cropped loamy soil with an OC% of one per cent can supply as much as 48kg/ha of nitrogen (the equivalent of 1t/ha of grain yield) from the SON pool.
- Residue organic nitrogen (RON). The RON pool is significant following grain legumes such as lupin, field pea, chickpea and faba bean and following legume

pastures. This source of nitrogen is mineralised rapidly to ammonium and then nitrate before and during the growing season. RON is mostly depleted within two or three years of the legume phase (Table 2).

- Fertiliser nitrogen. This is required when the SON and RON sources are insufficient to supply crop requirement. Fertiliser nitrogen comes in the forms of urea, ammonium and nitrate. Urea rapidly changes to ammonium, which in turn changes to nitrate and both reactions are more rapid when the soil is warm and moist. Residual mineral nitrogen is sometimes available from mineralisation or fertiliser applied in previous years, particularly from low-yielding crops. Residual mineral nitrogen is measured by soil testing down the profile, for example to 60 cm. In years following leaching rain it is important to soil test to depth to get a good indication of this pool. The deeper the nitrogen uptake from the soil the lower is its efficiency for yield but the greater is its contribution to grain protein.

Note to Table 2

The residue organic nitrogen delivered from a legume crop is usually depleted within three years.

*Table 2: Approximate quantity of legume nitrogen available to a wheat crop in the years following the legume ro tation.**

	Legume nitrogen supplied to wheat in the years after legume rotation (kgN/ha)				
Legume crop/pasture yield	Year 1	Year 2	Year 3	Year 4	Total
1t/ha legume crop	16	7	4	2	29
2t/ha legume crop	30	15	7	4	56
4t/ha pasture (80% legume content)	23	11	5	3	42

Source: Richard Quinlan PlanFarm. *Soil type: loamy sand. Legume crop harvest index: medium.

5.6.4 Forms of nitrogen taken up by wheat

Wheat takes up nitrogen as ammonium and nitrate. Ammonium (NH_4^+) is an intermediate product in the mineralisation of organic matter to nitrate (NO_3^-) and is immobile in the soil due to its positive electric charge. It is usually found in the topsoil and at lower concentrations than nitrate.

Nitrate's negative charge gives it the ability to move in solution to the roots and to leach into the subsoil and sometimes below the root zone after heavy rain. Both ammonium and nitrate can be taken up by the roots. When small amounts are taken up by the crop they are quickly converted to amino acids and then proteins. When a large amount of nitrate is taken up by a vegetative crop it remains as nitrate in the plant for several weeks. The nitrate content of young plants is a good indication of the short-term supply of nitrogen. Nitrate is not normally found in the crop after stem elongation

Applying urea makes the topsoil alkaline in the short term. Plant uptake of ammonium formed from the urea reverses this reaction when roots excrete a hydrogen ion (proton H^+) in exchange for the ammonium. The process of nitrification, converting ammonium to nitrate, also acidifies the topsoil. Crop uptake of nitrate makes the soil more alkaline because roots exchange a hydroxyl ion (OH^-) for nitrate. So, production of nitrate has the effect of making the topsoil more acid and, if the nitrate is then leached, the subsoil becomes more alkaline when nitrate is taken up by roots. The upshot of these reactions is that nitrogen supplied to crops, whether from fertiliser or legume nitrogen fixation leads to topsoil acidification, which should be neutralised by liming.

5.6.5 Calculating nitrogen requirement

Due to many processes involved in delivering nitrogen to the wheat crop, models are used to gain estimates of crop nitrogen requirement, soil nitrogen supply and therefore the fertiliser nitrogen required to reach yield potential. Examples of models for calculating crop nitrogen requirement are:

- Yield Prophet®is based on the APSIM model, which estimates yield potential and fertiliser nitrogen requirement. Yield Prophet® is available through agronomists or directly through the Yield Prophet website. The model is very powerful but requires significant effort to calibrate to soil type.
- Select Your Nitrogen (SYN). Developed by the Department of Agriculture and Food, WA this model provides the user with a thorough understanding of the processes involved in the supply of nitrogen to the crop.
- N-Broadacre developed by Planfarm with COGGO funding, is a user-friendly iPad App (available through the iTunes app store) based on the nitrogen supply and demand processes within SYN.
- NuLogic is a nitrogen model developed by CSBP and based on many of the same inputs used in SYN.
- iPaddockYield is an iPhone and iPad app (available through the iTunes app store) designed by a WA grain grower that estimates wheat yield throughout the season and provides a basic nitrogen requirement to match these yield estimates.

Another method of estimating crop nitrogen requirement is to lay down nitrogen strips in the crop at the start of the season and at the start of stem elongation, observe the crop response to the various strips visually or using infrared (green-seeker) technology. If there is significant response to these nitrogen strips then the yields are likely to respond to topdressed nitrogen. Summit Fertilisers and some private agronomists in WA are using this system to provide nitrogen requirement recommendations.

Table 3: Types of nitrogen fertiliser and their attributes.

Fertiliser	Nitrogen content	Attributes
Urea	46%	Normally the most cost-effective fertiliser.
		Can damage wheat seedlings if drilled with the seed at rates >20kg/ha applied at 17cm spacing.
		Volatilisation losses up to 40% when topdressed on alkaline soils with no follow-up rain.
		Less soil acidifying than ammonium-based fertilisers; prone to leaching soon after application.
		Converted chemically to ammonium and then by microbes to nitrate which is prone to leaching.
Ammonium fertiliser	Various	Weakly held on cation exchange sites so not readily leached.
		Ammonium sulfate is the most acidifying fertiliser.
		Less prone to volatilisation than urea when topdressed.
		Converted by microbes to nitrate, which is prone to leaching.

Nitrate fertilisers	Various	Prone to leaching. Converted to nitrogen and nitrous oxide gases by soil microbes under waterlogged and warm conditions by denitrification. Nitrate derived from other fertilisers, legumes and soil mineralisation is also lost by denitrification. Not volatilised.
Urea ammonium nitrate (UAN, Flexi N)	42% (volume basis) or 32% (weight basis)	About 10% taken up by leaves; remainder has to wash off and into the soil to be absorbed. Can be applied with other spraying operations. When banded below the crop, trial work suggests it can be up to 10% more efficient than top dressed nitrogen due to less weed access to the fertiliser and less tied up by microbes breaking down stubble.

5.6.6 Matching nitrogen to yield potential

Crop yield potential is the major driver of nitrogen requirement. Yield forecasting is therefore crucial to optimising nitrogen rates in wheat crops and most of the models above incorporate various methods of estimating yield potential. Wheat crops require about 40-45kg/ha of nitrogen for each tonne of grain produced. Nitrogen losses due to poor root growth, nitrate leaching or volatilisation into the atmosphere need to be accounted for and added to this figure. These losses are considered in the common estimate that half the soil and fertiliser nitrogen is taken up by the crop. Light soils, especially in higher rainfall areas, are likely to have lower nitrogen use efficiencies than medium and fine textured soils.

Figure 5 illustrates the nitrogen required from all sources (soil, legume residues and fertiliser) to achieve a grain yield at a range of protein levels. An increasing amount of nitrogen is required to achieve higher protein as yield increases. The goal is to determine the value of the extra yield and protein relative to the fertiliser costs of achieving it.

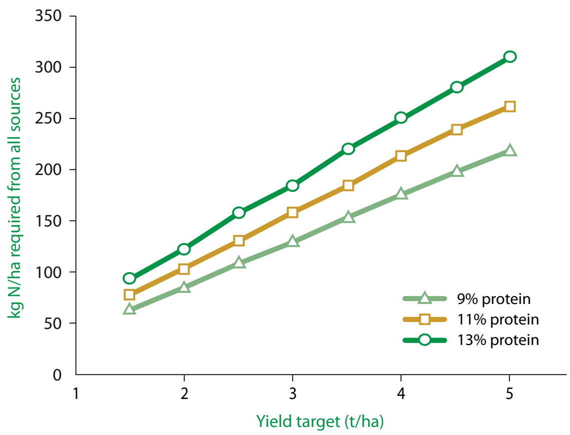


Figure 5: The amount of nitrogen required from all sources (soil, legume residues and fertiliser) to achieve a grain yield at a range of protein levels (derived from the Nitrogen Calculator).

Source: Jeremy Lemon, Department of Agriculture and Food, WA.

Nitrogen timing

As a general rule, nitrogen supplied early in the crop's development will add to yield through increased tillers and tiller bud numbers. Later applications of nitrogen can increase tiller survival, longevity of green leaf area (where the season permits) and grain number per head. Where the season ends more abruptly, later nitrogen applications will cause increases in grain protein. Excess nitrogen applied early is more likely to reduce yield than excess nitrogen applied late.

5.6.7 Delayed nitrogen

In a perfect season with no leaching and a known yield potential, nitrogen applied at seeding will result in high returns on fertiliser investment. However since these conditions rarely, if ever, exist delaying nitrogen application to meet the seasonal conditions is the best approach because it:

- Enables a better assessment of crop yield potential before nitrogen is applied and therefore reduces the risk of over fertilising.
- Reduces the amount of leaching by ensuring a more developed wheat root system for better uptake of nitrogen from the subsoil.

5.6.8 Split nitrogen

Split nitrogen application represents the best of both worlds because it allows sufficient nitrogen to be applied at sowing or tillering to set up yield potential and then for seasonal conditions to be monitored so that additional nitrogen can be matched to expected yield and target protein.

5.6.9 Monitoring plant nitrogen

Tissue testing throughout the season can indicate if nitrogen supply is keeping up with crop demand but will not indicate how much is required. Critical nitrogen concentration of whole shoots required for 90% grain yield decreases with stage of wheat development: four to five per centat tillering (GS20) and three per cent at booting (GS40) (Table 4).

Note to Table 4

Total nitrogen provides an indication of the nitrogen regime for the life of the plant to date. Nitrate nitrogen represents the 'fuel tank' and provides an indication of whether the crop is going to run out of nitrogen in the near future.

Table 4: Wheat tissue test thresholds for total (%) and nitrate (ppm) nitrogen through the season.

Timing	Plant dry weight (g)	Deficient	Marginal	Sufficient
		Total nitrogen (%)		
Mid-tillering (GS25)	0.2-0.4	<3.7	3.7-4.2	>4.2
First node (GS31)	0.6-0.8	<3.0	3.0-3.5	>3.5
Flag leaf emergence (GS39)	0.8-1.5	<2.0	2.0-2.8	>2.8
		Nitrate nitrogen (ppm)		
Mid-tillering (GS25)	0.2-0.4	<2000	2000-3000	>3000
First node (GS31)	0.6-0.8	<1200	1200-1500	>1500
Flag leaf emergence (GS39)	0.8-1.5	<200	200-500	500

Source: Richard Quinlan, Planfarm.

5.6.10 Best-bet nitrogen strategy

- Match wheat nitrogen requirements as the season unfolds. Even in low rainfall areas, potential yields can vary between less than 0.5t/ha and more than 4t/ha. Implementing a best-bet strategy to account for this yield variation limits fertiliser costs in poor seasons and forgone yield in good seasons.
- A best-bet nitrogen strategy pivots on sowing the crop with enough nitrogen for a low or average yield. If the season continues to be dry there is enough nitrogen applied at sowing for the expected yield.If the season continues as poor there is enough nitrogen applied at sowing for the expected yield.
- During late tillering, if an average or better season is developing, apply more nitrogen at first node to match the new water-limited yield potential.
- From stem elongation to ear emergence, further assess the season. If it seems average or drier, apply no more nitrogen. If it is wetter than average, apply more nitrogen but still observe the requirements of moist soil and a reasonable prospect of follow-up rain.
- Unfortunately if the season then dries up there will be too much nitrogen and the crop may be more valuable as hay than as grain. It is unlikely that a season that starts poorly will turn into an above-average season after tillering.

5.6.11 Nitrogen use efficiency

Nitrogen use efficiency is a measure of how well nitrogen is retrieved from the soil profile and converted into grain. Wheat management practices that increase nitrogen use efficiency include:

- Sowing early or into dry soil to ensure that the root system keeps up with the nitrogen being leached down the profile by the wetting front.
- Ensuring that root disease is minimised with break crops, or, with continuous cereals, by applying fungicide to the seed.
- Ensuring that yield is not limited by deficiencies of other nutrients and correcting acidity by liming to optimise root growth and root ability to chase nitrogen down the profile. Be careful to first reduce the risk of take-all with a break crop since this disease is stimulated by liming.
- Correcting soil compaction to increase the speed of root growth down the profile. Deep ripping can result in a doubling of root growth in the subsoil and this can allow roots to keep up with nitrogen leaching especially on deep sandy textured soils.
- Being aware that chemicals such as chlorsulfuron, triasulfuron and trifluralin can prune crop roots and reduce nitrogen use efficiency.
- Banding nitrogen below or beside the rows rather than top dressing can enable the crop to access nitrogen more efficiently because weeds have poorer access to banded nitrogen and it is less likely to be tied up by microbes breaking down stubble.

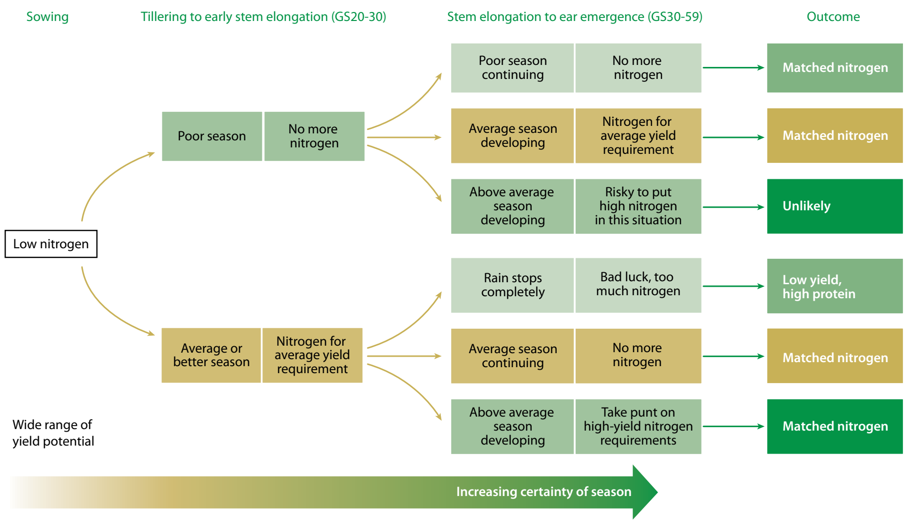


Figure 6: Decision tree for in-season nitrogen applications according to the progress of the season and crop developmental stage.

Source: Jeremy Lemon, Department of Agriculture and Food, WA.

More information

For more information of nitrogen use efficiency: www.grdc.com.au/Media-Centre/Ground-Cover/GC110/Measuring-nitrogen-is-the-first-step-to-lifting-efficiency

For more information on plant available nitrogen read: www.grdc.com.au/GRDC-FS-PlantAvailableNitrogen

Contact

Jeremy Lemon
Department of Agriculture and Food, WA
P: (08) 9892 8413
E: jeremy.lemon@agric.wa.gov.au

More information

DAFWA: Diagnosing phosphorus deficiency in wheat.

Soil Quality: Phosphorus.

GRDC Ground Cover Supplement, Issue 108, Jan-Feb 2014, p6-7

5.7 Phosphorus

Key messages

- After decades of consistent phosphorus application, more than 80 per cent of WA cropping soils now contain more than the critical level of phosphorus.
- Soil phosphorus tests need to be interpreted in association with the soil's capacity to absorb or fix phosphorus, which is estimated by the phosphorus-buffering index or PBI.
- The higher the PBI the more difficult it is for the plant to access phosphorus and the higher the phosphorus concentration required to optimise yield.
- Phosphorus does not move readily in soils except very light sandy soils in high rainfall areas.
- Wheat crops take up only 5 – 30 per cent of phosphorus fertiliser in the year of application.
- Soil phosphorus test critical ranges for wheat are 10-16mg P/kg for grey sands and 22-24mg P/kg for other soils for 0-10cm. However a single critical value of 11mgP/kg is suitable for wheat on all soil types when testing 0 to 30cm.

Many native WA agricultural soils are among the most acutely phosphorus deficient in the world, and profitable crop production has only been possible through significant applications of phosphorus fertilisers.

However the continual use of phosphorus fertiliser means acute deficiency in broadacre crops is now rare, with the exception of Darling Range gravels.

Results from more than 100,000 soil tests indicate that most WA growers are operating at or above the soil phosphorus levels required for near-maximum crop production - with 85 per cent of tests returning soil P test values higher than the critical Colwell-P value (14-23mgP/ kg).

The study showed that WA grain growers are, on average, applying almost twice the amount of phosphorus required and could save $10 to $14 per hectare without losing productivity or reducing soil phosphorus levels. This has led to further research examining the economic and agronomic benefits of diverting phosphorus fertiliser dollars into liming for soil acidity amelioration.

However, some WA soils will be responsive to fertiliser phosphorus even when the soil test phosphorus levels show that phosphorus is adequate. This is particularly true for water-repellent soils where the soil surface does not wet up evenly and the phosphorus on dry patches remains unavailable to the crop.

More information

For more information see the phosphorus model: https://www.agric.wa.gov.au/crop-phosphorus-model

It can also occur where soil pH is low (less than 4.5 in $CaCl_2$), which dramatically increases the soil's ability to fix phosphorus and also where root disease damages roots making them less able to fully explore the soil for nutrients.

Preliminary results suggest that when pH is below
5 ($CaCl_2$), soil phosphorus is about 20 per cent less available than when soil pH is above 6. In acidic soils aluminium is released into the soil solution causing root pruning, which decreases the volume of soil that can be explored by the roots and the opportunity to incercept soil P (which is highly immobile in soil).

The Crop Phosphorus Model developed by the Department of Agriculture and Food, WA enables users to quantify the yield and economic response of broadacre crops to applications of phosphorus fertiliser in WA.

5.7.1 Soil phosphorus

Soil phosphorus is present either as un-dissolved phosphorus in old fertiliser granules, phosphorus that is sorbed onto soil constituents or phosphorus that is bound up in organic matter (Figure 7).

Phosphorus fertiliser is mostly applied in a water-soluble form that can be readily taken up by plants. However in this water-soluble form phosphorus is not stable and rapidly reacts in the soil (principally with iron, aluminium and calcium) to form insoluble, more stable compounds. Consequently there is strong competition for water-soluble phosphorus between the soil and plant roots, with only 5-30 per cent of the phosphorus applied taken up by the crop in the year of application.

Phosphorus is relatively immobile in soils and phosphorus applied to the 0 to10cm layer of most WA soils tends to remain in that layer, especially in no-till systems. However grey sands have low phosphorus sorption capacity and phosphorus in these soils can leach from the 0 to 10cm soil layer and accumulate in layers below 10cm.

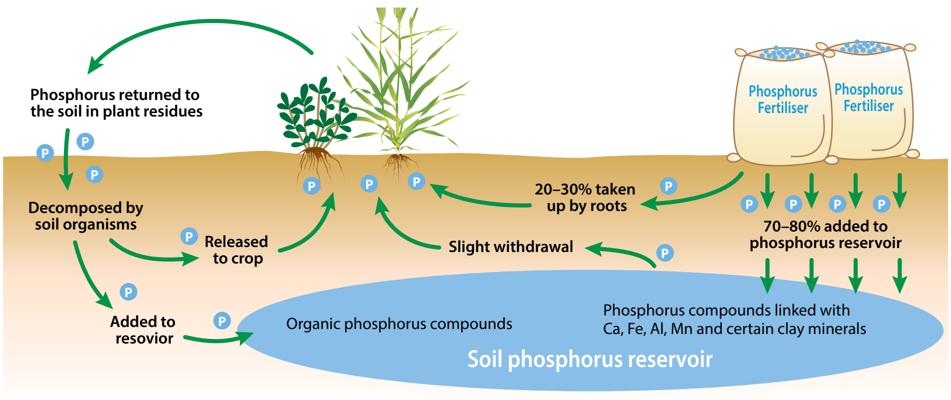


Figure 7: The phosphorus cycle in a typical cropping system is particularly complex, where movement through the soil is minimal and availability to crops is severely limited.

Source: Re-drawn from http://soilquality.org.au/factsheets/phosphorus

5.7.2 Soil tests

Determining a soil's ability to fix phosphorus underpins phosphorus fertiliser decisions. A high fixing soil will require significantly more phosphorus-fertiliser than a low-fixing soil (Figure 8).

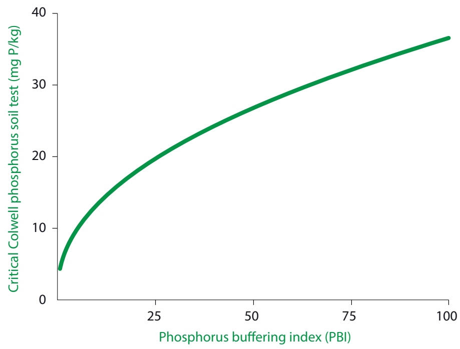


Figure 8: Relationship between phosphorus required to meet 90% wheat yield potential (Critical Colwell P) and the phosphorus fixing capacity of a soil (phosphorus buffering index).

Source: Richard Quinlan, Planfarm.

Commercial tests have been developed to determine the phosphorus fixing capacity of soils. Results from these tests are used in conjunction with other soil and crop traits to optimise fertiliser phosphorus applications:

- Phosphorus Retention Index (PRI) is a direct measure of phosphorus-sorption and involves mixing a quantity of soil in solution with a single amount of phosphorus for a set period of time. The amount of phosphorus remaining in solution measures the soil's ability to fix phosphorus.
- Phosphorus Buffering Index (PBI) is similar to PRI except that a range of phosphorus rates are mixed with the soil, and the index is adjusted for pH. This is becoming the Australian standard for measuring soil phosphorus-sorption.
- Reactive Iron Test measures the amount of iron extracted from soil by ammonium oxalate. This indirect measure of a soil's ability to fix phosphorus is only accurate when soil is adjusted for pH.

Additionally a new test has been developed to overcome some of the problems caused by variation in phosphorus fixation. Diffuse Gradient Technology Phosphorus (DGT-P) is currently being tested for use with Australian soils, and mimics the action of the plant roots in accessing available phosphorus.

References

Wong, M Weaver, D and Bell, R (2013) Use soil test to inform change from phosphorus build-up to maintenance for more profits. Proceedings 2013 Crop Updates, Perth.

Contact

Dr Craig Scanlan
Department of Agriculture and Food, WA
P: (08) 9368 3333
E: craig.scanlan@agric.wa.gov.au

5.8 Potassium

Key messages

- Sandy soils in high rainfall areas are prone to potassium deficiency, which can cause shriveled grain and exacerbate frost and leaf disease impacts.
- Most clay and clay-loam WA soils contain sufficient potassium for wheat production however potassium deficiency is starting to show up in some duplex and loam soils.
- Subsoil potassium can represent a significant potassium store in some soils.
- The economically optimum rate for potassium fertiliser will differ between paddocks and relative to yield potential, soil potassium test value and the fertiliser being used.
- Stubble contains three times as much potassium as grain – making it important to account for potassium export when calculating nutrient budgets.
- Potassium deficiency diagnosed in-crop cannot usually be corrected until the following season. Early season potassium deficiency can be more detrimental to yield than late season deficiency.
- Deficiency occurs first in older leaves and can be mistaken for leaf diseases such as yellow spot and Septoria nodorum.

Most heavy soils in WA contain adequate amounts of naturally occurring potassium for optimum crop and pasture growth. Sandy soils in higher rainfall areas are prone to potassium deficiency, as both native and fertiliser applied potassium is held poorly (low CEC) and is subject to leaching. In most sandy soils potassium concentration is highest in the surface layer where the organic matter (and CEC) is higher.

Soil types of the west midlands and southern sandy soils are commonly potassium deficient.

Until the early 1990s duplex soils rarely showed responses to potassium, however responses to the application of potassium on these soils are now well documented in the central and southern wheatbelt. Potassium deficiency has also been identified on York Gum red loam soil surrounding Moora.

Soil acidity, soil compaction and waterlogging modify root growth and lower the capacity of wheat to extract subsoil potassium. As a result, there is a poor relationship between soil test potassium values and crop yield response in wheat across all soil types. The critical range for potassium across all soil types is 39-45mg K/kg to achieve a relative yield of 90 per cent for wheat. Loams have a higher critical range of 45-52mg K/kg.

More information

DAFWA: Diagnosing potassium deficiency in wheat.

DAFWA: Potassium deficiency.

Soil Quality: Potassium.

GRDC Ground Cover Supplement, Issue 108, Jan-Feb 2014, p13

Videos

Watch a video on the use of variable rate technology to apply potassium and save on fertiliser costs: www.abc.net.au/landline/content/2010/s3357291.htm

Responses to potassium on duplex soils are more difficult to predict due to possible potassium at depth. In paddocks with high yield potential profitable responses have been measured where the soil test was up to 45mgK/kg.

Topdressing test potassium strips in soils above 30mgK/kg can help determine economic responses.

Windrow burning and canola swathing can concentrate potassium - causing large spatial variations in potassium content across paddocks. It is therefore important to use soil potassium tests in conjunction with tissue testing and visual symptoms to determine application rates for paddocks.

However, tissue testing only determines potassium deficiency not requirement and is only useful for determining potassium requirements for following seasons.

Potassium lost through product removal should be replaced once paddocks reach a responsive situation (Table 5).

Note to Table 5

High-yielding sections of paddocks will remove considerably more potassium than low-yielding sections.

Table 5: Potassium removal per tonne of produce.

Crop	Annual K removal (kg)
Wheat	4
Barley	5
Oats	5
Canola	5
Lupins	10
Oaten hay	25

The economically optimum rate of potassium fertiliser will differ between paddocks and depend on the yield potential, soil potassium test value and fertiliser being used. Soil tests for potassium can be used in conjunction with the potassium model developed by the Department of Agriculture and Food, WA to determine the predicted gross margin from applying muriate of potash (Figure 9).

Note to Figure 8

Figure 8 shows that for a wheat crop with a potential yield of two tonnes per hectare there is only a positive economic response to potassium when the soil test value is 20mg/kg K with gross margins declining at soil test values of 40mg/kg K and above.

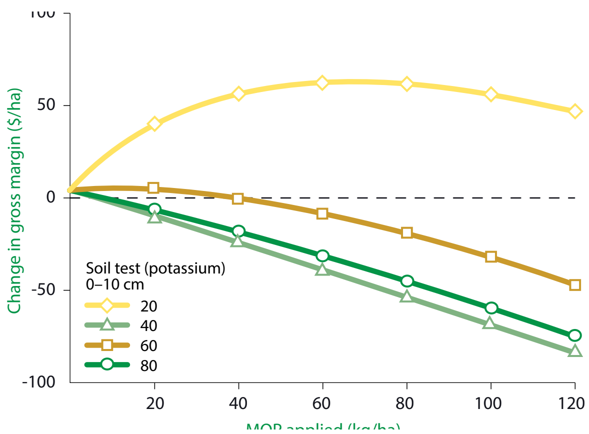


Figure 9: Economic response to applying muriate of potash (@ $800 /t) for wheat (@ $240 /t) with a potential yield of 2 t/ ha.

Source: The Potassium Model, Department of Agriculture and Food, WA.

Hay crops export about 25kg of potassium per tonne.
Photo credit: Brad Collis.

5.8.1 Fertiliser placement and timing

Muriate of potash (MOP) is the cheapest form of potassium (KCL; 49.5% K) and is applied by top dressing either at seeding or up to five weeks after seeding. Sowing MOP rates >30 kg/ha directly with seed (22 cm row spacing) can significa ntly reduce crop germination and establishment. For this reason, potassium should be banded away from the germinating seed.

Sulphate of potash is less damaging than MOP and can be drilled directly with seed but can beconsiderably more expensive per unit of K.

Banded potassium has been shown to be twice as accessible to crops as top-dressed potassium – probably because the crop is able to access it before the weeds. However it is important not to drill rates higher than 15kg/ha and to band fertiliser away from seed.

In paddocks with severe deficiency (<30ppm) potassium needs to be applied early in the season (0-4 weeks after seeding) to maximise crop response (Figures 10 and 11).

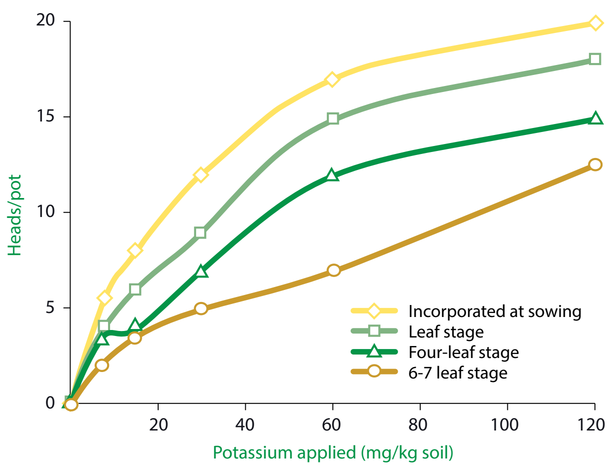


Figure 10: Impact of potassium supplied at different wheat growth stages on the number of wheat heads per pot.

Note to Figures 10 and 11

Applying potassium fertiliser to potassium deficient (22mgK/kg) wheat plants at booting rather than at seeding reduced head number by 60 per cent and halved final grain yield.

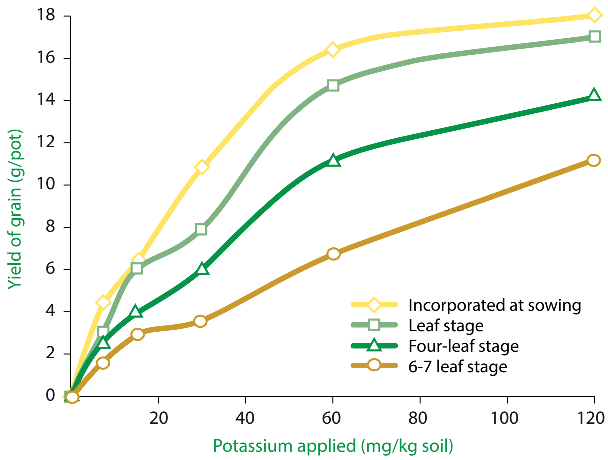


Figure 11: Impact of potassium supplied at different wheat growth stages on wheat grain yield per pot.

Soil compaction, subsoil acidity and waterlogging modify root growth and limit wheat capacity to extract subsoil potassium. Photo credit: Arthur Mostead.

Contact

Dr Craig Scanlan
Department of Agriculture and Food, WA
P: (08) 9368 3333
E: craig.scanlan@agric.wa.gov.au

More information

GRDC: Sulfur strategies for western region.

5.9 Sulfur

Key messages

- Sulfur deficiency is rare in Western Australian wheat systems but can occur when organic matter mineralisation slows during cold weather and following high rainfall on acidic sandy soils.
- Continual use of compound fertilisers that contain little or no sulfur will also increase the risk of sulfur deficiency.
- Visual sulfur deficiency in wheat can be quickly corrected using sulphate of ammonia without significant yield loss.
- There is a poor relationship between the critical soil sulfur test value measured in the 0-10cm layer and wheat yield response. A better relationship exists between the critical soil sulfur test value measured in the 0-30cm layer and wheat yield.
- A tissue test for nitrogen to sulfur ratio higher than 19:1 often indicates sulfur deficiency.

Sulfur is part of all living cells and an important component of three of the 21 amino acids that form proteins. It is also a critical component in the enzyme responsible for converting nitrate nitrogen to amino acids and is essential for nitrogen fixation in legumes and chlorophyll formation.

Previous widespread use of superphosphate (which contains 10 per cent sulfur) means sulfur deficiency is rare in Western Australian cereal crops. Early deficiency is occasionally seen in crops growing on sandy soils in wetter areas but plants generally recover without any yield loss. Continual use of compound fertilisers that contain little or no sulfur will increase the risk of sulfur deficiency.

More than 95 per cent of the sulfur in soils is tied up with organic matter with soluble sulphate released as organic matter is mineralised. Cold weather can slow mineralisation and therefore sulphate release.

Wheatbelt soils in the layer 0-10cm generally have soil pH of less than 5.5. Nevertheless, sulphate sorption is generally low for WA soils in the 0-10cm soil layer due to the low clay content. Also the presence of phosphorus, which is more strongly adsorbed than sulfur, reduces the capacity of the soil to adsorb sulfur. Sulphate adsorption is known to increase with soil depth due to increasing clay content of the soil and decreasing phosphorus and pH. As a result there can be significant amounts of sulfur contained in the subsoil, especially in soil profiles with soil pH less than 5.0.

Crop sulfur requirement is closely linked to the amount of available nitrogen – a reflection of the similar role the nutrients play in protein and chlorophyll formation.

Sulfur deficiency is unlikely to be an issue when the majority of crop nitrogen is sourced from mineralised nitrogen rather than bag (fertiliser) nitrogen.

As a general rule fertiliser nitrogen and sulfur should be supplied in a ratio of 5:1 on sandy textured soils.

Tissue testing of the youngest emerged leaf test can determine crop sulfur status with levels below 0.3% indicative of a deficiency. If using a whole-top plant test, levels below 0.15% in whole shoots at the boot stage are likely to be deficient. Nitrogen to sulfur tissue test ratios higher than 19:1 are also indicative of sulfur deficiency.

Top-dressing 10-15kg/ha of sulfur as gypsum or ammonium sulphate will overcome deficiency symptoms.

Foliar sprays generally cannot supply enough sulfur for plant needs.

More than 95 per cent of soil sulfur is tied up with organic matter - with soluble sulphate released as organic matter is mineralised. Photo credit: Arthur Mostead.

More information

[DAFWA: Diagnosing copper deficiency in wheat.]

[DAFWA: Diagnosing zinc deficiency in wheat.]

[DAFWA: Diagnosing manganese deficiency in wheat.]

[DAFWA: Diagnosing boron deficiency in wheat.]

[DAFWA: Diagnosing calcium deficiency in wheat.]

5.10 Micronutrients

Key messages

- The most likely limiting micronutrients in WA wheat systems are copper (Cu), manganese (Mn), molybdenum (Mo) and zinc (Zn). Inadequate supplies can reduce wheat growth and grain yields and lead to inefficient use of nitrogen and soil moisture.
- Copper and zinc are immobile in the soil, so must be in the pathway of as many crop roots as possible to be accessed by the plant.
- Traditionally, cultivation distributed these micronutrients through the topsoil but the introduction of no-till and one-pass seeding equipment has led to more limited physical distribution.
- Tissue tests are the best way to identify micronutrient deficiencies. In general, soil tests have a low reliability because the micronutrients are present in such low quantities.
- Visual symptoms can also be a guide to micronutrient deficiencies, but some symptoms may mimic other unrelated problems. For example, a copper deficiency in cereals can resemble frost, take-all or drought, and even a molybdenum deficiency can produce white heads. Micronutrient deficiencies may also be temporary or transient due to cold weather, drought or slow root growth.

Micronutrients are required at about one tenth of the rate of macronutrients such as nitrogen, but are equally important for plant growth and maximum production.

Zinc, copper, manganese and molybdenum are the main micronutrients of interest in WA wheat production systems. They are all highly immobile in the soil and therefore do not move far from where they are placed in the fertiliser granule. Crop roots only take up the nutrients when they grow into the fertiliser band. In minimum tillage systems the nutrients are left in concentrated bands where they were applied.

Minimum tillage adoption combined with larger crop yields exporting more micronutrients has resulted in increasing incidence of micronutrient deficiencies in WA wheat crops (Table 6).

Table 7 outlines current best practice for micronutrients in wheat systems. Research is underway in WA to develop more accurate and up-to-date interpretations of micronutrient tissue tests for WA wheat production systems.

Copper is essential for pollen formation and has a role in formation of chlorophyll and cell wall strength. Deficiency causes sterile pollen, which, in turn causes poor grain formation and high yield losses.

Photo credit: Paul Jones.

Table 6: Micronutrient concentration and crop removal in a 4t/ha wheat crop, a 2.5t/ha canola crop and a 2.0t/ha lupin crop.

Nutrient	Wheat grain mg/kg	Removal 4t/ha (g/ha)	Canola grain mg/kg	Removal 2.5t/ha (g/ha)	Lupin content mg/kg	Removal 2.0t/ha (g/ha)
Copper	5	20	4	10	5	10
Manganese	44	176	49	125	40	800
Molybdenum	0.2	0.8	0.3	0.8	2	4
Zinc	25	100	34	85	30	60
Boron	2	8	13	33	20	40

Source: Rob Norton IPNI www.ipni.net

Table 7: Current micronutrient management for wheat production systems in Western Australia.

Micronutrient	Tissue test*	Critical soil level	Characteristics – WA wheat
Copper – essential for plant structural strength.	Tissue test at flag leaf. 1.3-1.6mg/kg = mild deficiency. <1.3mg/kg = moderate deficiency Test for copper deficiency at mid to late tillering so it can be applied if required before flag leaf emergence.	DPTA Cu soil test: <0.2 to 0.4mg/kg	Cu-deficiency widespread in WA soils. Early season deficiency: characteristic 'pig tailing' but may be temporary due to dry conditions or large N applications. Prolonged deficiency: • Weak stems between ear and top node. • Darkened heads with missing/shrivelled grain (similar to frost symptoms). Adequate supply in acidic, wet, compacted heavy soils. 3-9kg/ha copper sulphate corrects deficiency. Copper spray at 200-250g Cu/ha corrects deficiency. Applied Cu: >15 years residual availability.
Zinc – essential in enzymes for chlorophyll and carbohydrate production.	<10mg/kg = deficiency.	DPTA Zn soil test: <0.2 to 0.4mg/kg. Higher on alkaline soils. Critical value varies with pH and clay and OM content.	Zn-deficiency widely reported in WA. Deficiency most likely on alkaline sands with high P concentration. Early deficiency: stunted, irregular growth and two-toning leaves followed by lesion in middle of leaf. Leaf may 'kink' over. Adequate supply most likely on heavy, acidic, high OM soils. 1-2kg/ha zinc oxide (75% Zn) corrects deficiency but must be evenly applied. Zinc spray at 200-250g Zn/ha corrects deficiency. Applied Zn: >15 years of residual availability. Some Group B herbicides lower Zn uptake. More than one Zn application may be needed on soils with high levels of free lime.
Molybdenum – critical in nitrogen metabolism.	<0.07mg/kg = deficiency.	No reliable soil test	Highly deficient in WA acidic soils. Yields can decline by 30% before symptoms seen. Adequate supply on heavy, alkaline soils. Frequently available where acid soils have been limed to pHca>4.8. 75g/ha corrects deficiency on WA soils. Molybdenum spray at 15g Mo/ha corrects deficiency. Declines to 50% after two years, depending on soil pH. On very acidic soils, soil applied Mo may not supply a wheat crop for the whole season. In these situations a seed dressing of Mo is required.
Manganese – role in chlorophyll production.	<20mg/kg = possible deficiency <10mg/kg = definite deficiency	No reliable soil test.	Deficiency most likely on well-drained, alkaline and dry soils. Adequate supply most likely on acidic, waterlogged soils with high OM. Can leach as Mn^{2+} or MnO^{2+} Manganese sulphate at 4kg/ha (spray) or 15kg/ha (fertiliser) drilled with seed corrects deficiency. Shorter residual availability than copper.
Boron	Limited value for toxicity management.	$CaCl_2$ Bo test: >20mg/kg can cause toxicity.	Boron deficiency rare in WA. Boron toxicity of wheat in low rainfall areas. High sub-soil Bo levels in southeast of WA wheatbelt. Yield decreases often small.

*For cereals, take the youngest emerged leaf blade at mid-tillering. Copper can be sampled for at the flag leaf stage, and if it is marginal in the youngest tissue it can be applied as a foliar spray before flowering.

Source: Rob Norton IPNI www.ipni.net and The Wheat Book (2000).

References

Anderson W and Garlinge, J (2000) The Wheat Book: Principles and Practice Published by Western Australia. Dept. of Agriculture.

G. Moore (editor) Soil guide: A handbook for understanding and managing agricultural soils, DAFWA Bulletin 343. First published March 1998; reprinted July 2001.

Contact

Dr Richard Bell
Murdoch University
P: (08) 9360 2370
E: R.Bell@murdoch.edu.au

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

CSA00032 – MCPN II - Improving nutrient use efficiency in wheat – Western Region (S: 1/03/2013 F: 29/02/2016)

DAW00218 - Wheat agronomy – building system profitability in the Western Region (S: 01/07/2011 F: 30/06/2015)

PLN00010 – Soil probes for cheap and accurate soil PH testing (S: 01/12/2013 F: 30/12/2014)

UWA00142 – Molecular Indicators for soil quality (S: 01/08/2010 F: 30/06/2014)

FFC00005 – Validate and integrate canopy management principles into WA cropping systems (S: 31/03/2011 F: 31/03/2014)

Nitrogen:

UWA00133 – Improved nitrogen use efficiency in wheat and barley (S: 7/01/2009 F: 30/6/2014)

UWA00139 – Harnessing the nitrogen cycle through novel solutions (S: 01/06/2010 F: 30/05/2014)

UWA00156 – MPCN II – Nitrogen fertiliser response curves: Filling the gap for Western Australia (S: 1/07/2012 F: 30/06/2015)

CSA00037 – MPCN II – reassessing the value and use of fixed nitrogen (S: 01/07/2012 F: 30/06/2015)

DAS00147 – MPCN II – Benchmarking wheat yield against nitrogen use (S: 1/07/2014 F: 30/06/2017)

Phosphorus:

CSP00165 – MPCN II – Phosphorus use efficiency: Rhizosheath project (S: 01/09/2012 F: 01/09/2015)

DAW00222 – MPCN II – Regional soil testing and nutrient guidelines: West (S: 01/07/2012 F: 30/06/2017)

DAW00223 – More Profit from Crop Nutrition (MPCN II) – Extension and Training: West (S: 1/07/2012 F: 30/06/2017)

UWA00150 – Management of microrganisms to unlock the phosphorus bank in soil (S: 30/6/2011 F: 30/06/2015)

Potassium and Sulfur:

UA00140 - MPCN II – An accurate soil test for available soil sulphur and potassium (S: 01/07/2012 F: 30/09/3014)

UMU00042 – MPCN II – Managing potassium nutrition to alleviate crop stress (S: 1/07/2012 F: 30/06/2015)

GRS10268 - Grains Industry Research Scholarship - Wheat potassium nutrition in saline and/or sodic soils and in drought-prone environments (S: 01/01/2012, F: 20/09/2014)

Micronutrients:

DAW00239 – MPCN II – Managing micronutrient deficiencies in cropping systems of Western Australia (S: 1/06/2014 F: 30/06/2017)

GRS10335 – Scholarship: Foliar fertilisation of wheat plants – phosphorus in combination with other nutrients (S: 13/02/2012, F: 02/12/2015)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC nutrition projects can be found at: www.grdc.com.au

SECTION 6

Integrated weed management

More information

DAFWA: Crop weeds.

Key messages

- Chemical weed control in Western Australian cropping systems is heavily reliant on six Modes of Action (MOAs).
- Multiple herbicide resistance is now the norm for WA's two worst cropping weeds - annual ryegrass and wild radish.
- Glyphosate resistant annual ryegrass, wild radish and red brome have all been found in winter cereals in WA.
- No new herbicide MOAs are on the horizon with the last commercialised in the early 1990s.
- Integrated weed management prolongs the useful life of herbicides and controls resistant weeds by stopping weed seeds from entering the seed bank.

Australian research shows it is possible to drive the seed bank of certain weeds down by as much 95 per cent in three to five years using an integrated approach involving crop competition, herbicide rotation and harvest weed seed management.

The natural genetic variability of weed populations gives them an inherent capacity to adapt to chemical and non-chemical control. They will even develop ways to combat mechanical control if the method is used for long enough.

The only way to extend the life of any herbicide and play weeds at their own resistance game is to use a range of chemical and non-chemical methods, such as rotating herbicides, harvest weed seed control and growing competitive crops, to prevent viable seeds from survivors entering the seed bank.

If weed densities are kept low, then the likelihood of resistance genes evolving within the population is also kept low, and herbicide usefulness is extended.

There are no right or wrong weed control tactics – each grower needs to choose tactics that suit their particular farming system. The aim is to implement and rotate a diversity of tactics to keep the weed seedbank low.

A low weed seedbank adds flexibility to crop sowing times with less competition and less in-crop weed control.

Herbicide resistance is now the norm for WA's two worst cropping weeds - annual ryegrass and wild radish (pictured). Integrated weed management is the only way to extend the useful life of herbicides.

Photo credit: Melissa Williams.

The primary goal of integrated weed management is to prevent viable weed seeds from entering the soil seed bank. This requires a long-term and committed strategy using chemical, cultural and mechanical control measures rather than just a year-to-year approach using herbicides alone (Table 1).

Flaxleaf fleabane, windmill grass and melons are the major summer weeds of WA cropping systems (Table 3). Left uncontrolled these weeds rob subsequent crops of soil moisture and nitrogen.

Table 1: Ten-point plan to prevent weed seeds from entering the soil seed bank.

Tactic	Mechanism	Weed impact	More information
Develop a weed management plan	Understand the biology of your weeds (see Table 2 below). Be strategic and committed.	Knowledge of a weed's biology helps target its weaknesses.	Section 5 of the Integrated Weed Management Manual www.weedsmart.org.au/10-point-plan/act-now-to-stop-weed-seed-set/
Capture weeds at harvest	Consider your options – chaff cart, narrow windrow burning, baling, Harrington Seed Destructor. Compare the financial cost per hectare.	Research across southern Australia shows, on average, about 80% of annual ryegrass and wild radish seed entering the harvester can be collected via harvest weed seed control methods.	Section 4 of the Integrated Weed Management Manual www.weedsmart.org.au/10-point-plan/capture-weed-seeds-at-harvest/
Rotate crops and herbicide MOAs	Repeated application of effective herbicides with the same MOA is the single greatest risk factor for herbicide resistance evolution.	Crop rotation enables rotation of different herbicides and targeting of specific weeds. For example, sowing field peas enables delayed sowing, swathing and late herbicide application.	www.weedsmart.org.au/10-point-plan/rotate-crops-and-herbicide-modes-of-action/
Test for resistance	Measure resistance so you can manage it. Sample weed seeds before harvest for resistance testing.	Knowing your resistance status allows you to choose the most effective herbicides.	www.weedsmart.org.au/10-point-plan/test-for-resistance-to-establish-a-clear-picture-of-paddock-by-paddock-farm-status/

Tactic	Mechanism	Weed impact	More information
Never cut the rate	Always use the label rate. Using low herbicide rates can result in weeds with tolerance/resistance to multiple herbicides.	Herbicide resistance will develop faster in weeds exposed to low chemical rates. AHRI laboratory-based research demonstrated that ryegrass populations developed resistance to Sakura® after only three years of low application rates.	www.weedsmart.org.au/10-point-plan/never-cut-the-rate/ http://ahri.uwa.edu.au/creating-a-cross-resistant-monster/
Don't automatically reach for glyphosate	Diversity, diversity, diversity. Rotate to alternative knockdown herbicides. Consider strategic tillage.	Glyphosate resistance can be slowed by using alternative herbicides and introducing non-chemical weed control tactics.	www.weedsmart.org.au/10-point-plan/dont-automatically-reach-for-glyphosate/ www.glyphosateresistance.org.au/factsheets/Glyphosate_Resistant_weeds-beat_them_before_they_beat_you_DAFWA_Aug2014.pdf
Carefully manage spray events	Use best management practice to stop spray drift and maximise weed kill.	Monitor and destroy all weed escapes. Patch spray resistant weeds if required.	www.weedsmart.org.au/10-point-plan/carefully-manage-spray-events/ Refer to GRDC factsheet series on best practice spray application: www.grdc.com.au/GRDC-FS-SprayPracticalTips
Plant clean seed into clean paddocks with clean borders	Plant weed-free crop seed. The density, diversity and fecundity of weeds is generally greatest along paddock borders and areas such as roadsides, channel banks and fencelines.	Recent AHRI* research showed nearly 75% of cleaned grain samples from 74 WA farms had some level of weed seed contamination. About 25% of the 347 Australian sites documented with glyphosate resistant annual ryegrass are from fence lines.	Section 4 of the Integrated Weed Management Manual www.weedsmart.org.au/10-point-plan/plant-clean-seed-into-clean-paddocks-with-clean-borders/ www.grdc.com.au/Resources/Factsheets/2010/11/Glyphosate-Resistance-fact-sheet
Use the double knock technique	Any combination of weed control that involves two sequential strategies (chemical and non-chemical). The second application/tactic is used to control survivors from the first.	The glyphosate/ paraquat double knock uses different MOAs to eliminate weeds. Ensure the paraquat rate is high and start the double knock shortly after rainfall to tackle weeds while they are small.	Section 4 of the Integrated Weed Management Manual www.weedsmart.org.au/10-point-plan/use-the-double-knock-technique/
Use crop competitiveness to combat weeds	Increase your crop's competitiveness to win the war against weeds. Row spacing, seeding rate and crop orientation can help crops fight weeds and competitive cultivar eg barley.	Narrow rows out-compete weeds and deliver higher yields than wider rows. Sowing crops east-west instead of north-south can halve weed seed set.	Section 3 of the Integrated Weed Management Manual www.weedsmart.org.au/consider-narrow-row-spacing/

Source: adapted from WEEDSMART www.weedsmart.org.au and the Integrated Weed Management Manual www.grdc.com.au/IWMM

Table 2: Characteristics and herbicide status of major weeds of winter cereals in Western Australia.

Refer to Section 6 of the Integrated Weed Management Manual for detailed biological information on major WA weeds. www.grdc.com.au/IWMM

Weed and WA herbicide resistance status	Biological strengths and weaknesses
Wild radish	Prolific seeder and highly competitive can cause yield losses of 10-90%.
Group B — sulfonylureas	Wild radish has significant seedbank dormancy: one year of seed allowed to escape into the soil can mean more than seven years of subsequent weed germinations.
Group B — sulfonamides	Up to 70% of the seeds are still dormant at the start of the next cropping season: many seeds will not germinate until the second season after their formation (about 18 months later).
Group B — imidazolinones	Wild radish seeds become viable within three weeks from the appearance of first flowers: important to kill in-crop wild radish while small (less than 5cm diameter).
Group C — triazines	Most non-dormant seed germinates during autumn and winter but can emerge throughout the year provided there is sufficient soil moisture.
Group C — triazinones	Produces seed very quickly from germinations late in spring or during summer.
Group F — nicotinanalides	Easily distributed (along with herbicide resistance) as an impurity in hay, chaff and grain.
Group I — phenoxys	Retains seed at harvest height: late flushes and early survivors can be removed via the harvester.
Group M — glyphosate	
Annual ryegrass	Highly competitive - can compete as early as the two-leaf crop stage.
Group A — 'fops'	Less competitive when emerging after crop: competitive crops can out-compete.
Group A — 'dims'	Produces up to 45,000 seed/m^2 under ideal conditions: seed bank quickly replenished by uncontrolled survivors.
Group B — sulfonylureas	80% of seed germinates at break after two falls of rain exceeding 20mm: good control possible with early start to season.
Group B — imidazolinones	Can emerge from late autumn-early spring depending on rainfall and seedbank levels: control early survivors and late flushes with harvest weed seed control.
Group C — triazines	Germination drops with increasing seed depth seed, stopping at about 100mm: strategic mouldboard ploughing can control bad infestations.
Group C — substituted ureas	Viable seed relatively short-lived in soil: can reduce seedbank by 75% per year with concerted control.
Group D — trifluralin	Retains seed at harvest height: late flushes and early survivors can be removed during the harvesting operation.
Group M — glyphosate	
Group Q — triazoles	
*95% of resistant populations are resistant to both Group A and B herbicides.	
Wild oats	Highly competitive when left uncontrolled, can reduce wheat yields by up to 80%.
Group A — 'fops'	Up to 20,000 seeds/m^2 produced in uncontrolled infestations.
Group A — 'dims'	40% germinates with opening rains with further 10-30% germinating during season.
	Viable seed short-lived in soil: can deplete seed bank by 75% per year with concerted control.
Brome grass	Highly competitive in wheat: keep seeding rate high and rows narrow to enable wheat to out-compete.
Group B — sulfonylureas	More drought tolerant and responsive to nitrogen than wheat: N can aggravate brome grass problem.
Group B — imidazolinones	Can produce 600-3000 seeds per plant.
Group C — triazines	Most seed shed before crop harvest: harvest weed seed control less effective than wild radish and ryegrass.

Table 3: Characteristics and control measures of major summer weeds of WA wheat production systems.

Weed	Characteristics and control
Flaxleaf fleabane Confirmed glyphosate resistance in eastern states. Overseas, fleabane has developed resistance to herbicides from Groups B, C, L and M, with some populations resistant to multiple chemicals. Herbicide resistance has the potential to spread due to the weed's highly mobile seed. Research in WA found that fleabane seed could travel on the wind up to 800 metres from its parent plant but most falls within two metres. For information on controlling fleabane read: www.agronomo.com.au/storage/newsletters/10-Spring-2014.pdf	Can produce two or three generations each year but most common in spring. Up to 110,000 seeds per plant: control before seed set critical. 90-95% of seeds lose their viability within 12 to 18 months on the soil surface: stop seed set to reduce seed bank. Poor competitor: use crop competition to curb weed growth and seed set. Flourishes along fences and roadsides: good farm hygiene critical to slowing spread. Registered Group I options include Amicide Advance 700, Lontrel Advanced, Hotshot, Fallowboss TORDOM. Trials have shown that late autumn and early winter flushes of flaxleaf fleabane in wheat can also be controlled with several group I (phenoxy and pyridine) and group B (sulfonylurea) herbicides. Plants older than one month tolerant to most herbicides. Use 'double-knock' approach for large fleabane in stubble with a range of primary herbicides followed by paraquat 7 to 10 days later. No single measure consistently gives 100% weed control. Monitor for, and control, survivors to prevent seed set.
Windmill grass	Even small plants <1 g dry biomass can produce seed heads with each head holding 300-500 seeds. Maximum seed production can be 60 000 seeds/m^2. Plants commence germination in spring in standing crops. Control using non-selective (knockdown) herbicides over summer or pre-seeding.
Melons	Control using a mixture of triclopyr, 2,4-D and metsulfuron in the early morning when plants are not stressed.

Refer to Section 6 of the Integrated Weed Management Manual for comprehensive information on summer weed control.

Only integrated weed management can prolong the useful life of herbicides. Pictured is the Harrington Seed Destructor developed by WA grower Ray Harrington. The machine crushes and destroys up to 95% of the ryegrass and wild radish seed that enter the harvester.

Photo credit: AHRI.

About 25% of the 347 Australian sites documented with glyphosate resistant annual ryegrass come from fence lines. Resistant ryegrass seed can spread into cropping paddocks so keeping fence lines clean of weeds is essential to slowing the spread of herbicide resistance.

Photo credit: GRDC.

A 2013 pre-harvest and targeted survey across WA by the Department of Agriculture and Food, WA found more than 40% of 172 annual ryegrass samples tested had some level of resistance to glyphosate.

Photo credit: GRDC.

6.1 Weeds of WA wheat systems

Wild radish, annual ryegrass, wild oats and brome grass are the most important weeds of wheat production systems in WA (Table 2). Each of these weeds has developed some level of herbicide resistance and cases of herbicide resistant weed populations in WA cropping systems continue to rise.

Multiple resistance to selective and non-selective herbicides is now the norm for WA's two worst cropping weeds – annual ryegrass and wild radish. Only two per cent of annual ryegrass populations remain fully susceptible to herbicide control, with all others resistant to one or more herbicide modes of action.

A similar story exists for wild radish, with more than 90 per cent of populations resistant to one or more herbicides. A 2010 survey by the Australian Herbicide Resistance Initiative (AHRI) found that 84 per cent of 96 wild radish populations tested from Geraldton in the north to Esperance in the south had some level of resistance to the Group B herbicide chlorsulfuron (Glean®).

More information

DAFWA: Wild oats.

AHRI: Sow west young man (east-west sowing rows enhance weed suppression)

Other herbicides such as glyphosate, atrazine and Velocity® (bromoxynil + pyrasulfotole) are still providing good control of wild radish – but the first cases of glyphosate resistant radish have recently been documented in WA.

Flaxleaf fleabane, windmill grass and melons are the major summer weeds of WA cropping systems (Table 3). Left uncontrolled these weeds rob subsequent crops of soil moisture and nitrogen.

6.2 Herbicide resistance

More information

For a summary of the current state of herbicide resistance among WA weeds read: www.agronomo.com.au/storage/newsletters/08-Autumn-2014.pdf

For more information: www.grdc.com.au/GRDC-Manual-SummerFallowWeedManagement

For more information on testing for herbicide resistance see the GRDC fact sheet: www.grdc.com.au/GRDC-FS-TestForHerbicideResistance

Herbicide resistance would not be a problem if a constant stream of new, effective herbicide modes of action became available as old herbicides failed. Old chemistries would simply be replaced with new ones to control weeds.

But the reality is that there are no new herbicide modes of action on the horizon.

The previous new herbicide mode of action was commercialised in the early 1990s. Since 1980 there has been an 80 per cent drop in the number of companies actively pursuing new chemistries.

Herbicide resistance will never be solved with herbicides.

Only integrated weed management and a zero tolerance for weed escapes will enable long-term control of resistant weed populations.

Table 4 provides an indication of the time it will take for weeds to develop resistance to applications of the major herbicide groups. The 'years of application' do not need to be consecutive applications.

Table 4: Predicted time (years) for weeds to develop resistance to each of the major herbicide groups.

Herbicide group	Years of application
B	4
A 'fop'	6
A 'dim'	8
C	10-15
D	10-15
E	>15
F	10
G	>15
H	10
I	>20
K	>15
L	>15
M	>12

Source: Section 2 of the Integrated Weed Management Manual

Group A and B herbicides are the most prone to weed resistance. The important thing to note is that all herbicides will eventually become redundant with repeated application. The goal is to use a range of chemical and non-chemical means to ensure complete weed control so that herbicide resistant seed does not enter the seedbank.

Paddocks at high risk of developing herbicide resistance are those where there has been a long history of herbicide use and no management to prevent herbicide survivors from setting seed. These paddocks often have high weed numbers.

The goal is to use a range of chemical and non-chemical means to ensure complete weed control so that herbicide resistant seed does not enter the seedbank.

Flaxleaf fleabane is difficult to control when large. Best control in-fallow is achieved using a double-knock when fleabane is small (as pictured).

Photo credit: Ben Fleet.

6.3 Annual ryegrass

Rising and multiple herbicide resistance is now the norm for WA ryegrass populations (Table 5). Survey work by the Australian Herbicide Resistance Initiative (AHRI) shows there has been a large increase in the level of ryegrass resistance to the Group A and B herbicides. More encouragingly, atrazine and trifluralin resistance remains low with resistance to these herbicides not changing greatly between the 2007 and 2010 surveys (Table 5).

Note to Table 5

Ryegrass populations can quickly accumulate and stack herbicide-resistance traits due to several in-built genetic mechanisms and their prolific pollen production, which enables herbicide resistance to move easily between plants.

Table 5: Proportion (%) of annual ryegrass populations across the Western Australian Wheatbelt classified as resistant (R) or susceptible (S) over an eleven year period. Resistant (1-100% survival) or Susceptible (S) (0% survival), (NT- herbicide was not tested).

Herbicide	1999		2003		2010	
	R	S	R	S	R	S
Diclofop	46	54	68	32	96	4
Clethodim (250ml)	0.5	99.5	8	92	65	35
Sulfometuron	64	36	88	12	98	2
Trifluralin	NT	NT	25	75	27	73
Atrazine	NT	NT	1	99	2	98
Glyphosate	NT	NT	1	99	7	93

Source: Australian Herbicide Resistance Initiative.

6.4 Wild radish

Wild radish with multiple herbicide resistance is also on the rise (Figure 1). The 2010 AHRI survey of 96 wild radish populations (466 paddocks) across the WA wheatbelt found:

- 84% of populations contained plants resistant to chlorsulfuron (Glean®; Group B); a 30% increase since 2003
- 49% of populations were resistant to Intervix® (Group B)
- 76% of populations were resistant to 2,4-D amine, especially in the northern and central WA wheatbelt
- Resistance to Brodal® (diflufenican)was present in 49% of populations
- Only one population had atrazine resistant plants
- As in 2003, no populations were found with resistance to Velocity® or glyphosate

Wild radish with multiple resistance is on the rise across WA. Exhausting the wild radish seedbank requires a concerted and integrated approach over 5-10 years.

Photo credit: Simon Craig.

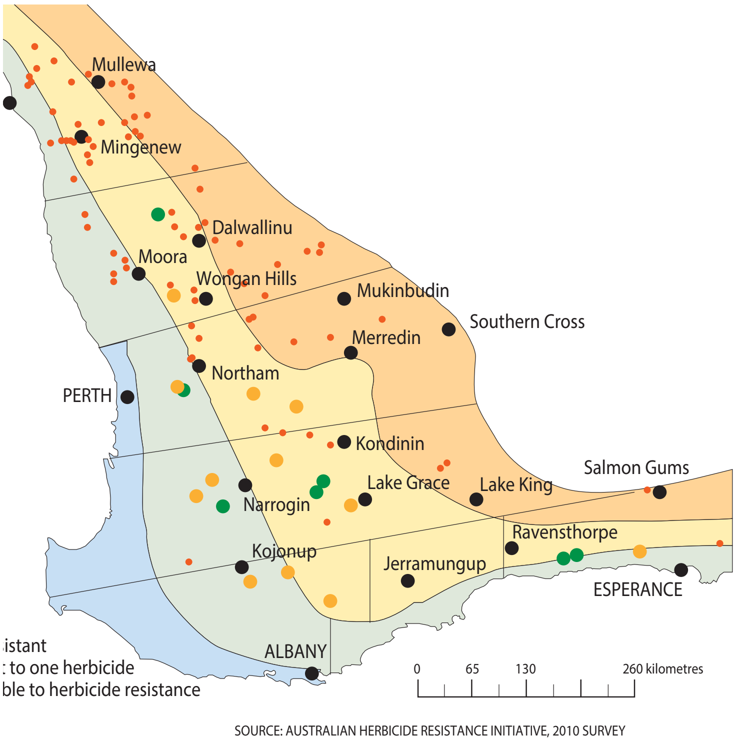


Figure 1: Incidence of multi-resistant wild radish across Western Australian cropping zone.

Wild radish dormancy

Wild radish dormancy is controlled at three levels – the pod, the seed coat and the embryo.

The seed pod acts as a sponge to slow water uptake by the seed and contains alkaloids that protect it from microbial attack. This ensures the seed only germinates when there is enough soil moisture. The seed coat acts as a second barrier to germination – with seeds only germinating once the seed coat has been ruptured to allow water to enter.

Once these physical barriers have broken down the embryo senses the environment and allows germination only when conditions are right. For buried seeds, conditions for germination are optimum in autumn/early winter, with a secondary peak in spring.

The presence of the pod and seed coat mean fresh seed is unlikely to germinate until it has been weathered or physically damaged via harvest, tillage or stock.

This explains why an ‘autumn tickle’ is so effective in promoting wild radish germination, provided there is enough moisture, and conversely why, in no-till systems, seed can remain dormant for longer, making other factors such as predation and natural seed death much more important in driving down the seed bank (Peltzer and Matson 2012).

6.5 Glyphosate resistance

Glyphosate-resistant weeds are on the rise across Australia, with ten species now confirmed with resistant populations – annual ryegrass, barnyard grass, liverseed grass, windmill grass, brome grass and fleabane.

There are six weed species with documented glyphosate resistant populations in WA (August 2014); annual ryegrass, wild radish, windmill grass, barnyard grass, red brome grass and fleabane.

In a world-first, three populations of glyphosate resistant wild radish have been documented in the northern WA wheatbelt. It is believed two of the populations have been exposed to at least one and often two glyphosate applications annually over two decades.

Annual ryegrass has the most documented glyphosate-resistant populations in WA with cases increasing each year (Figure 2).

A 2013 pre-harvest and targeted survey across WA by the Department of Agriculture and Food found more than 40 per cent of 172 annual ryegrass samples tested had some level of resistance to glyphosate.

A 2010 random survey of WA cropping paddocks by AHRI found that 7 per cent of 362 samples tested contained annual ryegrass with some level of resistance, up from 1 per cent in 2003.

There are no easy replacement options for glyphosate. The rapid development of glyphosate-resistant weeds will have a large impact on the cost and ease of weed management in Australian cropping systems.

Complete control of glyphosate resistant populations using integrated weed management principles is the only way to minimise the amount of resistant weed seed entering seed banks and extend the useful life of glyphosate.

6.6 Starving the weed seedbank

Despite rising herbicide resistance issues some WA growers are keeping their weed seedbanks low.

Burning of narrow windrows (pictured) coupled with effective in-crop weed control can drive down weed seedbanks to very low levels within five years.

Photo credit: Peter Newman.

WA research shows the weed seedbank of annual ryegrass can be reduced by 95 per cent within three years, and wild radish by 95 per cent within five years, with a concerted and integrated approach to weed control (Figures 3a & 3b).

Note to Figure 2

The Liverpool Plains of northern New South Wales has many populations of glyphosate resistant annual ryegrass. These populations formed following repeated use of glyphosate for winter fallow weed control. There are currently (2013) 574 documented cases of ryegrass resistant to glyphosate across Australia

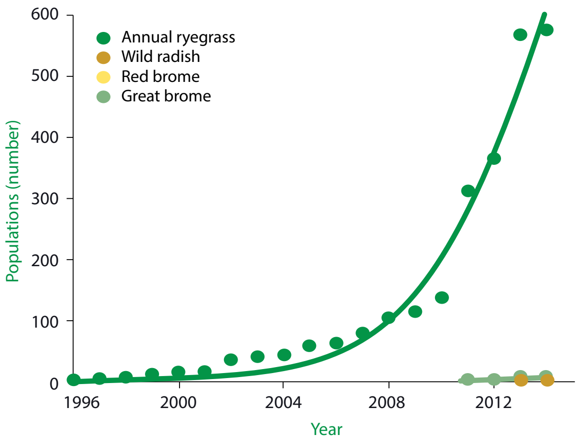


Figure 2: The number of populations of ryegrass, brome grass and wild radish with confirmed glyphosate resistance (by testing) in Australia as reported by the Australian Glyphosate Sustainability Working Group, led by Chris Preston. These are the confirmed populations only. The actual number of glyphosate resistant populations is likely to be much higher.

Note to Figure 3

For wild radish the last remaining five per cent of the seed bank is difficult to remove and will take a further five years of integrated management to reduce to zero.

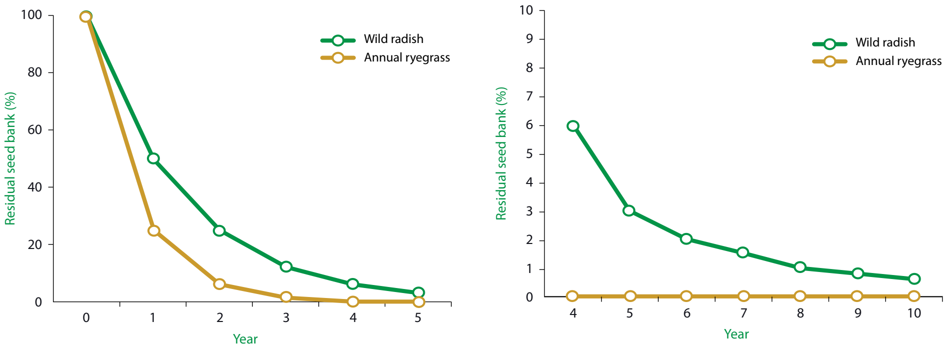


Figure 3: Decline in wild radish and annual ryegrass seed bank with no new addition of seed.

Source: Peter Newman, DAFWA.

6.7 Wild radish – control

Wild radish has a high and complicated seed dormancy that makes it difficult to control because up to 70 per cent of seed set in one season does not germinate for about 18 months. To exhaust the seed bank completely can take up to a decade of concerted weed management. Any wild radish plants that survive to set seed will result in the seed bank being replenished with a new wave of dormant seed.

Unlike ryegrass, wild radish seed survives for longer the deeper it is buried in the soil. Seed ecology research in the late 1980s showed just over 40 per cent of the wild radish seed bank remained viable after burial at 10 cm for four years compared to three per cent viability when buried at 1cm for four years. However by year six the majority of seed buried at depth had lost viability (Code et al 1987).

Wild radish control in cropping systems requires a three-pronged approach:

1. Spray wild radish plants twice in-crop while they are small (two-leaf) at GS12 and again no later than GS31 (first node). Ensure excellent herbicide application.
2. Use narrow row spacing and east-west crop rows to out-compete weeds.
3. Use harvest weed seed control to destroy seed set of surviving weeds.

More information

For more information see: www.grdc.com.au/GRDC-FS-WildRadishManagement and http://ahri.uwa.edu.au/glyphosate-resistant-wild-radish/

For more information on managing the seedbank read: www.grdc.com.au/GRDC-FS-WeedSeedbank

Videos

Watch a video on wild radish control: www.grdc.com.au/GCTV-WildRadish

6.8 Spray twice and early

Research in Geraldton, WA in 2013 confirmed the value of a two-spray approach for wild radish control and wheat yield (Figure 4). Wheat paddocks with 200 wild radish plants/m^2 sprayed twice while small (two-leaf stage) with either Bromicide® 200 (Group C), Jaguar® (Group C + F) or Velocity® (Group H + C) followed by one of a range of herbicides at the five-leaf stage out-yielded wheat plots sprayed only once (at the later stage) by 400-500 kg/ha.

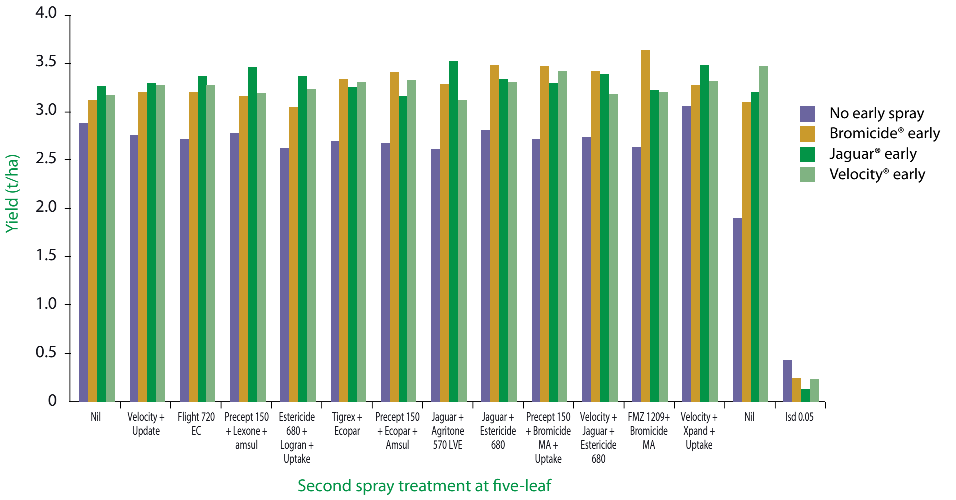


Figure 4: Impact of herbicide control of wild radish on wheat yields in northern WA wheatbelt. Wild radish was either sprayed twice (at two-leaf and five-leaf) or once (five-leaf) using a range of herbicide combinations. Purple bars represent wheat yields of plots sprayed only once at the five-leaf stage.

Source: Thompson (2014).

Note to Figure 4

The return on investment from the early spray treatments was significant. Spraying twice cost $19-$29/ha while returning a net increase in profit of about $90-$130/ha (based on an average wheat yield increase of 400-500 kg/ha @ wheat price of $290/t).

Videos

Watch video on narrow row spacing and weed competition: www.grdc.com.au/Media-Centre/Over-the-Fence/Over-The-Fence-Videos/Over-the-Fence-Western-Region/Nv6hGUGmdel

More information

Read a case study on using narrow row spacing for ryegrass control: https://agric.wa.gov.au/n/3195

Spraying wild radish only once at the 5-6-leaf stage will fail to kill all plants. The remainder to contribute to the seed bank if not captured during harvest. Later sprays can also fail due to poor penetration of herbicide into the crop canopy.

6.9 Crop competition

Ensuring wheat crops can out-compete weeds through increased seeding rate, narrow row spacing and east-west row orientation will reduce all in-crop weeds including wild radish, annual ryegrass, wild oats and brome grass.

6.10 Row spacing

Narrowing row spacing increases crop competition against weeds while lifting wheat yields (Figure 5). Long-term (27 years) row spacing research by the Department of Agriculture and Food at Merredin, WA showed narrow row spacing (9-18mm) out-competed ryegrass in wheat. Wider rows (27-36mm) had significantly higher ryegrass heads/m^2 than narrower rows (Riethmuller, cited in Newman 2014).

The narrower row spacings also yielded more wheat with a one per cent yield increase with each 2.5cm reduction in row width to 18cm.

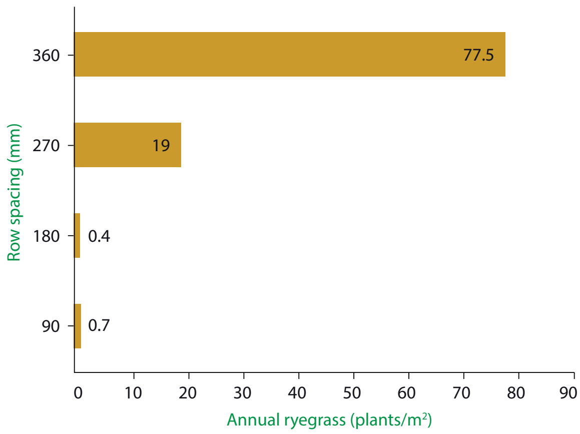


Figure 5: Impact of row spacing on annual ryegrass seed set in wheat during a 27 year trial.
Source: Glen Riethmuller, DAFWA.

6.11 Row orientation

Running wheat rows east-west rather than north-south significantly reduces weed density in-crop (Table 6). The research by the Department of Agriculture and Food, WA found an east-west orientation halved ryegrass seed set compared to a north-south row orientation (Borger 2014).

Table 6: Annual ryegrass seed production (seeds/m²) in east-west or north-south orientated crops of wheat (2010) or wheat and barley (2011), with low or high seeding rates. Means for each factor within each trial are separated by least significant diff (Lsd), where NS indicates that the means were not different.

Treatments	2010			2011		
	Merredin	Wongan Hills	Katanning	Merredin	Wongan Hills	Katanning
East-west	503	24	529	27	2610	14113
North-south	910	300	465	125	6155	26276
Lsd (P<0.05)	331	36	NS	35	3469	1342
Barley	*	*	*	19	4420	16410
Wheat	*	*	*	146	4345	23378
Lsd (P<0.05)				18	NS	271
Low seeding rate	1032	130	151	119	5029	24087
High seeding rate	381	21	132	30	3736	15826
Lsd (P<0.05)	275	NS	NS	18	NS	271

*Treatment not included in trial. Source: Borger et al (2014).

6.12 Annual ryegrass – control

Newly set seed of annual ryegrass is mostly dormant. While most of this dormancy is lost over summer some seed can remain dormant at the break, limiting the proportion of the seedbank that can emerge and be controlled.

Ryegrass emergence will be greatest at the autumn break when:

- The seed has formed during hot dry springs in the previous year as these conditions produce seeds with less dormancy than usual.
- The summer is very hot (faster dormancy release).
- Heavy rainfall events during a hot summer will speed dormancy loss even further.
- There is a late break to the growing season, which provides more time for the ryegrass to lose dormancy.

If these conditions occur in unison it offers a valuable opportunity to delay seeding in problem ryegrass paddocks to allow maximum germination and kill pre-sowing.

Rising glyphosate resistance levels in ryegrass populations makes the double knock (glyphosate followed by paraquat), where possible, the best pre-sowing herbicide tactic. The most effective double knock interval between the glyphosate and paraquat sprays is between two and 10 days for seedling annual ryegrass.

Maximum control of annual ryegrass results from an application of herbicide at the three to four-leaf stage. Annual ryegrass sprayed at the zero to one-leaf stage can potentially regrow from seed reserves.

More information

[DAFWA: Herbicide tolerance, p24-26. Herbicide tolerance tables, p28-36.]

[DAFWA: Herbicide tolerant varieties.]

[DAFWA: Diagnosing Group A herbicide damage.]

6.13 Stubble and herbicides

Stubble cover of 50-90 per cent can reduce the performance of pre-emergent herbicides such as trifluralin. Increasing the carrier volume of these herbicides can significantly increase ryegrass kill.

Burying ryegrass seed deep using a mouldboard plough operation every 10-20 years can reduce the ryegrass seedbank by as much as 99 per cent – enabling problem paddocks to be 're-set' in terms of ryegrass numbers.

Combining herbicide control with harvest weed seed management has reduced ryegrass seed bank levels to near zero in some northern WA wheatbelt paddocks (Figure 6).

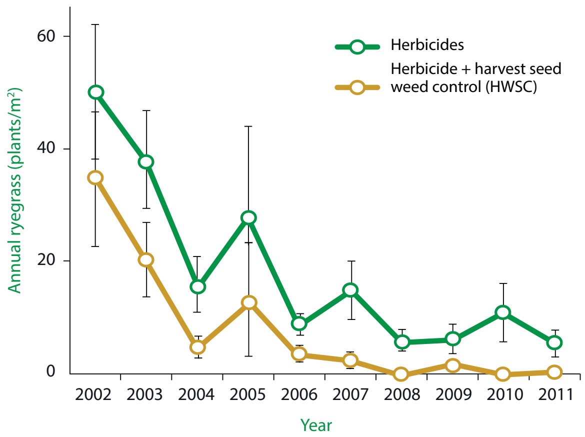


Figure 6: Influence of the long-term (2002-2011) use of herbicides alone and herbicides plus harvest weed seed control (HWSC) on in-crop annual ryegrass plant densities in northern WA cropping fields. Capped bars represent the standard error values showing variation around the mean annual ryegrass populations in 17 fields (Herbicides) or 8 fields (Herbicides plus HWSC).

Source Peter Newman, DAFWA.

While herbicide treatments were very effective in reducing in-crop annual ryegrass populations within five consecutive growing seasons, it was only in the paddocks where both early-season herbicides and harvest weed seed control were routinely practised that very low weed densities were achieved.

Resources

GRDC Integrated Weed Management hub
www.grdc.com.au/Resources/IWMhub

WeedSmart website
www.weedsmart.org.au

Australian Herbicide Resistance Initiative
http://www.ahri.uwa.edu.au

Australian Glyphosate Sustainability Working Group
http://www.glyphosateresistance.org.au/database/index.php

Department of Agriculture and Food e-weed newsletter https://www.agric.wa.gov.au/newsletters/eweed

Giving a Rats newsletter
http://www.agronomo.com.au/giving-a-rats/

References

Borger, C., Hashem, A. and Wilkins, N. (2003). The double knockdown effect on annual ryegrass. In A. Douglas (ed.) Crop Updates 2003 Weeds, Perth, pp. 25–26.

Borger, C., Hashem, A. and Wilkins, N. (2004). Double knockdown herbicides – preserving glyphosate. In A. Douglas (ed.) Crop Updates 2004 Weeds, Perth, pp. 34–35.

Borger, C Hashem, A Powles, P (2014) Manipulating crop row orientation and crop density to suppress annual ryegrass. Proceedings 2014 WA Crop Updates.

Code, G.R., Walsh, M.J. and Reeves, T.G. (1987). Effect of depth and duration of burial of wild radish seed on seed viability and seedling emergence. In Proceedings of the Weed Seed Biology Workshop, Orange, New South Wales, pp. 136–1 38.

Newman, P. (2013) Remaining weeds are hard to control. Proceedings 2013 WA Crop Updates. www.giwa.org.au/2013-crop-updates

Newman, P (2014) Aim for the narrowest possible row spacing. Proceedings 2014 WA Crop Updates. www.giwa.org.au/2014-crop-updates

Peltzer, S and Matson, P (2002) How fast do the seedbanks of five annual cropping weeds deplete in the absence of weed seed input?

Thompson, G and Alderman, R (2014) Spray resistant radish early for best efficacy and yield. Proceedings 2014 WA Crop Updates.

Walsh, M. J. (2012) Harrington Seed Destructor - comparison with chaff carts and windrow burning systems. Proceedings 2012 WA Crop Updates.

Walsh, M. J. and Powles, S. B. (2014) High seed retention at maturity of annual weeds infesting crop fields highlights the potential for harvest weed seed control. Weed Technology, Vol. 28, No 3, July-September.

Contacts

Dr Sally Peltzer
Department of Agriculture and Food, WA
Phone: (08) 9892 8504
Email: sally.peltzer@agric.wa.gov.au

Andrew Storrie
Integrated Weed Management Manual
Phone: (08) 9842 3598
Email: andrew@agronomo.com.au

Peter Newman
Australian Herbicide Resistance Initiative
Phone: 08 9964 1170
Email: petern@planfarm.com.au

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

UWA00155 – New chemistry options for wild radish control
(S: 01/07/3012 F: 30/6/2015)

UWA00125 – Weed Seed Wizard: validation and improvement of a weed management decision (S: 30/06/2008 to 31/12/2013)

UA00149 – Improving IWM practice of emerging weeds in the southern and western regions (S: 30/06/2014 F: 30/06/2017)

ICN00013 – Weeds instructional videos, online version of the IWM manual, on-line web cam content (S: 25/06/2012 F: 30/06/2015)

RDP00011 - National coordination of weeds research (S: 30/06/2013 F: 30/06/2015)

UCS00023 – Mechanisms of weed suppression by early vigour and other novel wheat genotypes (S: 01/03/2014 F: 01/03/2017)

UWA00146 – Australian Herbicide Resistance Initiative – Phase 4 –
(S: 1/07/2010 F: 30/06/2015)

CRC00003 - Development of best management practice for wild radish management in cereals (S: 07/01/2012 F: 31/12/2013)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC integrated weed management projects can be found at: www.grdc.com.au

SECTION 7

Pre-season

More information

[CSIRO: Break crop benefits to wheat in Western Australia.]

[CSIRO: Crop sequence effects on productivity in wheat-based cropping system at Wongan Hills, Western Australia.]

7.1 Crop sequencing

Key messages

- Continuous wheat is rarely as productive or economically viable in the long term as rotations involving either a pasture or break crop.
- Under a continuous wheat rotation disease, weed and nutrition constraints increase to a point when growing wheat becomes unprofitable.
- Break crops need to be viewed from the perspective of their economic return and the benefit they confer to the subsequent cereal crops.
- Optimal crop rotation sequences will vary according to grower preference, past experience, attitude to risk and agronomic factors such as soil type and paddock conditions.
- The goal is to stay abreast of weed and disease issues within the wheat crop and consider if a break crop or tactical fallow is the most reliable and efficient means to tackle the problem.

Crop rotation is defined as 'the growing of crops and pastures in a sequence with the aim of maximising the long term productivity and profitability of the farm.'

However, like so many aspects of agriculture, how this definition translates into practice will differ widely according to the specific physical, biological and financial circumstances of individual farming systems.

While there are no hard and fast rules about when a non-cereal crop should be grown to maximise long-term farm productivity and profitability it is well established that continuous wheat is rarely as productive or economically viable in the long term as wheat rotations involving either a pasture or break crop (Seymour et al 2012).

The goal of successful crop rotation is to become intimate with the wheat yield margins of specific paddocks and soil types and tactically implement a specific rotation to address the particular weed and disease issues.

Videos

Watch a video on yield decline in wheat on wheat systems in WA: www.grdc.com.au/OTFW0612

Wheat on wheat is rarely as productive or as profitable in the long term as wheat rotations involving either a pasture or break crop.

Photo credit: GRDC.

The objective is to restore the paddock to a weed and disease free state to maximise the yield of the following cereal crop within the confines of the season.

However, the risks and rewards of growing a break crop are often site and season specific and the exact nature of the 'break effect' not always easy to quantify.

Many break crops are associated with an opportunity cost because they are more costly and higher risk to grow than wheat.

For rotations to be successful in the long-term, the profit of subsequent cereal crops must increase sufficiently to at least cover the opportunity cost of growing the break crop. In addition, weeds and diseases must be controlled during the break crop or there is unlikely to be a break crop benefit.

7.1.1 Yield decline in continuous wheat

CSIRO modelling work based on a crop sequencing trial by the Facey grower group in Katanning, WA illustrates the principles of wheat-on-wheat yield decline and the impact of a non-cereal break crop on farm profit (Figure 1).

In the continuous wheat scenario, annual profit declined steadily from $48/ha to just $12/ha over the five-year period due to the increasing impact of disease and weeds on wheat yields (Figure 1).

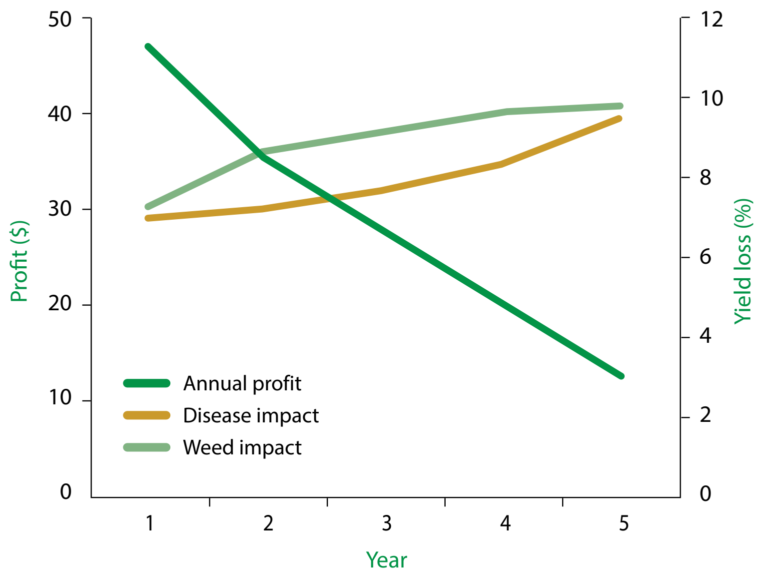


Figure 1: Annual profit, disease impact on yield and weed impact on yield for wheat grown in sequence for 5 years.

Source: Lawes and Renton (2010).

Inserting a non-cereal rotation in the third year of the wheat sequence resulted in a significant drop in profits for that year compared to continuous wheat (Figure 2).

However, because weeds were controlled, disease was managed and in the case of lupins and pasture, nitrogen was added to the system, profits increased considerably in the fourth and fifth years of the sequence (Figure 2).

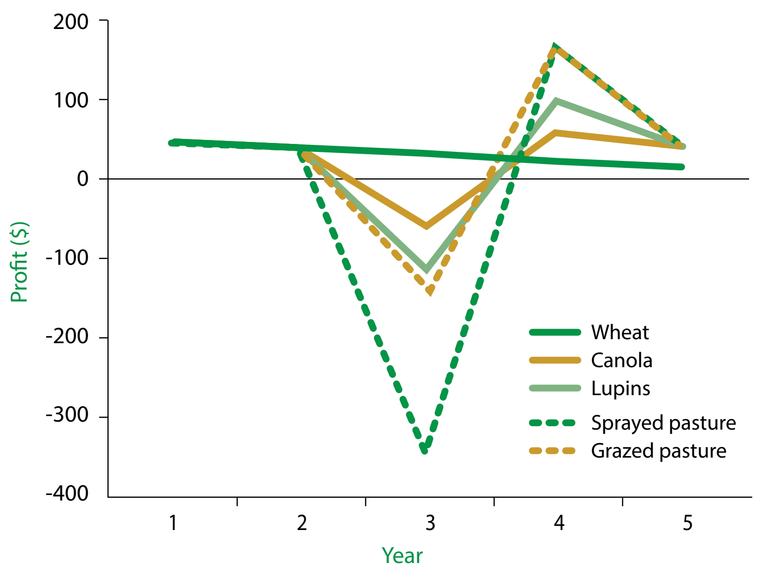


Figure 2: A comparison of annual profit from a 5 year cropping sequence, where wheat, canola, lupins, grazed pasture or sprayed pasture are grown in the 3rd year of the crop sequence.

Source: Lawes and Renton (2010).

Note to Figure 2

It is not possible to provide a prescriptive rotation sequence to suit all wheat systems. Each rotation needs to be developed in relation to the soil type and condition of each paddock and grower perception of risk in relation to production and marketing of the break crop.

The CSIRO simulation assumed that weeds could be managed effectively in the wheat and break crop phases. Weed populations that cannot be controlled such as herbicide resistant radish and annual ryegrass may require different crop sequences.

7.1.2 History of rotations in WA

The value of crop rotations in managing weeds and disease in wheat is well recognised among WA wheat producers (Figure 3).

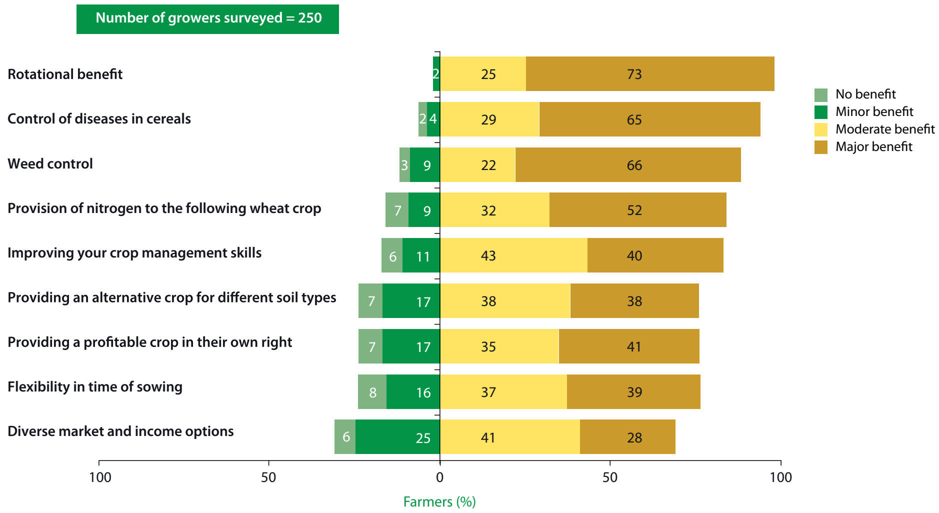


Figure 3: Rotational benefits, disease control and weed control are considered the key benefits offered by break crops.

Source: Department of Agriculture and Food, WA.

However, while break crops have historically been an important part of WA cropping systems, recent farm and paddock level surveys suggest farmers are growing fewer break crops (10-12 per cent of farm area) than is considered economically optimal from modelling work (20-30 per cent farm area) (Robertson et al 2010).

There has been a significant change in the pattern of crop rotations over time in WA. In 1997, nearly half of all WA wheat crops were sown following lupin and a third after a pasture with just over two per cent grown after canola. In total, more than 80 per cent of wheat crops were grown after a break of some kind. Only about six per cent of wheat crops were grown following wheat.

Within a decade these proportions had changed dramatically. By 2007, the area sown to lupin had declined by 60 per cent over the 1990 plantings due to weed and price issues - resulting in just 16 per cent of wheat crops being grown following a lupin crop. Wheat after canola was at just over six per cent after reaching a peak of about 18 per cent in 2000. Lupin and canola had largely been replaced by wheat, with a third of wheat crops now being sown following a wheat crop, about a quarter following pasture and another two per cent following barley (Lawes, 2010).

Wheat on wheat cropping is now the predominant rotation with the two dominant break crops, lupin and canola, occupying about 6-10 per cent of farm area. Canola has emerged as the dominant broadleaf break crop with about 1.3 million hectares sown across the WA wheatbelt during 2013 – more than four times the area planted in 2009. The canola growth has been driven by plant breeding advances, high returns and an ability to achieve good weed and soil-borne disease control in this rotation phase.

Field pea plantings have dropped by 50 per cent since 2010 largely due to the better gross margins and easier market access of canola.

7.1.3 Rotations and wheat yield

Analysis of more than 150 crop sequence trials spanning 40 years by the Department of Agriculture and Food, WA showed continuous wheat was rarely as productive or economically viable as wheat rotations involving either a pasture or break crop (Seymour et al 2012).

While magnitude of the break-crop response was highly variable, the majority of wheat yield responses to break crops were positive.

The analysis revealed the average yield benefit to wheat, compared with wheat after wheat, was between 300-600kg/ha following lupins, field peas, canola, oats or fallow (Table 1).

Crop rotation

Crop rotation is a key management principle for the top 25 per cent of wheat producers in the eastern wheatbelt of WA. A 2013 survey of the region's top performing growers found break crops made up between 9-16 per cent of arable farm area (McConnell and O'Hare, 2013).

The primary break from cereals in the eastern wheatbelt is pasture at 25-30 per cent of farm area. Other dominant break phases include chemical fallow, canola and lupin. Only two out of 34 rotations surveyed did not include any break crops.

Based on a six-year gross-margin analysis the highest ranked rotation for the most profitable 25 per cent of growers surveyed was canola/wheat/barley, closely followed by pasture/wheat/canola/wheat.

Wheat/canola/wheat/fallow produced an average gross margin of about $159/ha across the six-year period. Wheat after pasture had an average gross margin of about $146/ha; wheat on lupin or field peas produced an average gross margin of about $120/ha; and wheat/wheat an average gross margin of $69/ha.

All surveyed growers with livestock were willing to run a stocking rate lower than average for their region to provide the flexibility to manipulate pastures and spray top early to achieve complete weed control in the pasture phase. Most growers stated they used the pasture phase to clean up weeds, enabling them to do away with using grass selectives in the subsequent wheat crop.

Table 1: Wheat yield impacts and characteristics of major WA crop rotations.

	Wheat yield impact (t/ha)*	Soil type/pH requirement	Pros	Cons
Lupin	0.6	Acidic to neutral deep sands, sandy loams and duplex soils.	Nitrogen and disease benefits for following wheat crop. Can deliver up to 0.9t/ha benefit in high rainfall zones with high root disease. A 1.5t/ha lupin crop adds about 60kg/ha nitrogen of which about 25kg/ha is available to the following wheat crop. Can deliver up to three years of break benefit to subsequent wheat crops. Crop-topping or swathing possible in problem weed paddocks.	Not always profitable in own right. Poor competitor: ryegrass and wild radish out-compete lupin to reduce lupin yield. Herbicide resistant wild radish makes weed management in the lupin phase more difficult and expensive. Lupin rotation no longer possible where Group C herbicide resistant radish is an issue (fallow instead).
Field pea	0.45**	Slightly acidic loams. Neutral to alkaline clay loams and loams.	Weed benefit: can be sown late and spray-topped to reduce weed density in following cereals. Greater range of post-emergent herbicides available for use in pea than other pulses. Nitrogen benefit: how much? Excellent break crop for root lesion nematode because they are moderately resistant.	Disease (blackspot). Marketing can be problematic.
Canola	0.4	Soils with acid layers of more than 20cm can limit canola productivity.	Profitable break crop in own right – easier to market than peas/lupin. Triazine-tolerant canola has a wider range of in-crop herbicides than pulses. Can help manage problem weed paddocks. Disease benefit if root disease level high but only a small boost to following wheat crop if disease levels low.	Higher production risk than wheat. Disease (sclerotina).
Oats	0.35		Profitable in own right. Can provide wheat yield benefit but mechanism unclear. Insurance against frost.	If paddock relatively free from disease then no boost to following wheat crop. No weed benefit.
Pasture		Range depending on pasture species.	Enables spray-topping: can clean up paddocks for following cereal crop.	Disease if grasses not controlled.
Fallow	0.3***		Good for controlling herbicide resistant weeds and conserving soil moisture. More benefit on northern region soils? Disease control. Soil moisture benefit largest when following season is dry.	Erosion risk on some soils. Requires a large farm to afford to do 'nothing' with some of it each year. Weeds must be fully controlled for subsequent wheat benefit.

* Source Seymour et al (2012)

** The higher response to lupins vs field peas could be due to do with soil type – lupins are grown in sandier soils which are inherently less fertile and prone to root disease.

*** Not known how many of these fallows were weed-free.

Videos

Watch a video on using a break-crop to manage grassy weeds: www.digitalfarmtv.com/component/k2/itemlist/category/73-grdc-ground-cover-videos

While break crops provided a boost to following wheat crops, in about 10 per cent of instances wheat following lupin or field pea was no higher yielding than wheat after wheat. This may have been due to failure to adequately control weeds in the break crop or the nitrogen boost of the legume break leading to wheat growth in excess of what the following season (particularly a dry spring) could support. In addition, it could be that in a few of the trials there might simply have been no limiting factor for wheat production and the inclusion of a break crop was not warranted (Seymour et al, 2012).

7.1.4 Rotations - weed benefits

Wheat on wheat rotations lack diversity in options for chemical weed control. Including break crops in the cropping rotation opens up weed control options unavailable or not suitable in wheat.

Crop rotations can broaden the range of pre-emergent herbicides that can be used. Rotating herbicide groups assists in delaying the onset of trifluralin resistance. Growing oaten hay or break crops to control ryegrass seed-set and including competitive crops, such as barley, are important management tools.

Growing field peas or pasture allows for the use of late herbicide applications (crop/pasture-topping) for weed seed-set control.

Problem weeds like herbicide resistant radish and ryegrass can also be targeted with the inclusion of break crops in the cropping rotation as weeds resistant to one herbicide mode of action group can be controlled using herbicides with a different mode of action.

For example, timely use of canola in the rotation has the ability to reduce the number of grass weeds for following crops through the use of Group C herbicides and Imidazolinone-tolerant and Roundup Ready technologies in combination with non-herbicide weed control methods (Figure 4).

Note to Figure 4

Canola following two years of wheat enabled grass weed numbers to be reduced from a high of 47 plants/m² in autumn to fewer than five plants/m² by spring.

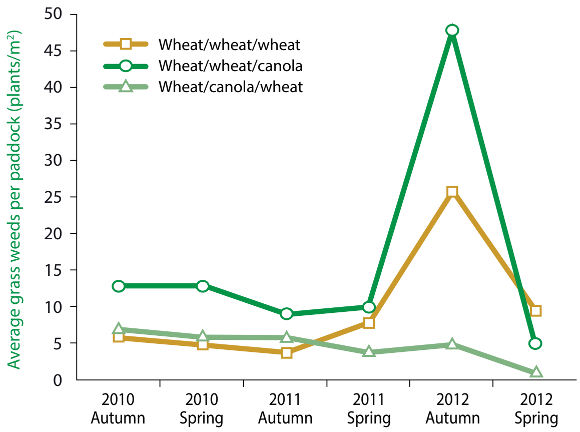


Figure 4: Impact of crop rotation on grass weed numbers in paddocks under a range of crop sequences.

Source: DAFWA Profitable Crop Sequences Project.

Weeds, particularly ryegrass and radish, have become increasingly more resistant to many of the herbicides commonly used in the wheat:lupin rotation. Weeds are now more difficult and more expensive to kill. In response, growers are using rotations

More information

Read a case study on the use of fallows for weed control: page 21 of: www.glyphosateresistance.org.au/factsheets/Glyphosate_Resistant_weeds-beat_them_before_they_beat_you_DAFWA_Aug2014.pdf

Read a case study on growing field pea in rotation with wheat: www.liebegroup.org.au/wp-content/uploads/2012/01/Growing-field-Peas-and-chickpeas-in-low-rainfall-zones.pdf

Note to Figure 5

Mace wheat following summer-sown serradella in 2012 with no added nitrogen produced a five tonne per hectare yield and returns of $1360/ha.

Videos

Watch a video on the serradella research at: www.grdc.com.au/GC113V-Serradella

involving herbicide-tolerant canola, swathed barley hay and well managed annual pastures to widen the traditional wheat:lupin system and clean up weedy paddocks. The broader rotation enables a wider range of methods to be used to control weeds instead of relying on the narrow range of herbicides applicable to wheat:lupin rotations.

Widening rotations adds stability to weed control because if one method fails, others can compensate to keep weed levels low, and there is less pressure on weeds to develop resistance to any one method.

7.1.5 Pasture rotations

Summer sowing of the hard-seeded pasture legume Margurita serradella provides an opportunity to use alternative herbicide groups for weed control while also providing free crop nitrogen and productive sheep feed during the autumn gap (Figure 5).

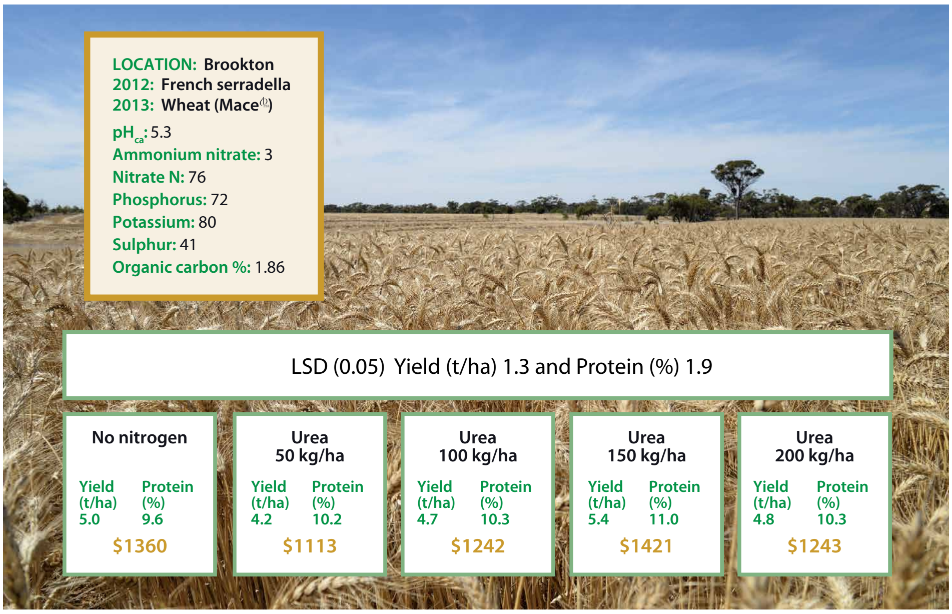


Figure 5: Yield and returns comparison for Mace wheat in 2013 following serradella in 2012 on the Butcher property in Brookton. Source: Department of Agriculture and Food, WA.

Photo credit: Megan Hele.

French serradella varieties initially developed as a pasture option for WA's acid soils are now being used in a low-cost summer-sowing system that exploits their unique seed dormancy to provide delayed and valuable autumn feed for livestock plus nitrogen for crops.

The summer sowing system involves sowing unprocessed pods from the serradella varieties Margurita and Erica and offers opportunities to:

- establish pastures cheaper, earlier and more reliably than traditional annual pasture legumes;
- fast-track the transition between crops and pastures;
- improve pasture biomass production;
- achieve good seed-set;

More information

Read about the summer serradella research: www.grdc.com.au/GC113-SummerSerradella

- achieve high N fixation in the first year of the pasture phase; and
- avoid interference with winter crop sowing at the season break.

7.1.6 Disease

Many common diseases and pests of wheat including take-all, crown rot, common root rot, septoria, yellow spot, barley yellow dwarf virus, rusts, mildew, root lesion nematode and cereal cyst nematode are not carried by non-cereal break crops.

A wheat crop grown after a canola or a legume crop/pasture will be affected less by these pests and diseases than if grown after wheat. Oats and barley can also offer specific wheat disease benefits.

Rhizoctonia bare patch has a wide host range but research indicates canola can provide an effective break for the disease following cereals. Survey work by the Department of Agriculture and Food, WA as part of the Profitable Crop Sequences Project shows including canola in the rotation can reduce rhizoctonia levels by between 30-40 per cent (Table 2).

The impact of grass weeds on the incidence of take-all and wheat yield is well established (Table 3) and there is evidence that the continuous wheat systems in WA are showing signs of increased take-all levels (Table 4).

Table 2: Impact of crop sequence on level of rhizoctonia inoculum in cropping paddocks across the WA wheatbelt between 2010-13.

Crop sequence	No. of paddocks surveyed	Rhizoctonia 2010	Rhizoctonia 2013	Change (%)
wheat/wheat/wheat	21	3.4	18.4	547
wheat/wheat/barley	5	1.0	5.6	553
wheat/wheat/canola	16	4.4	1.7	38
wheat/canola/wheat	19	40.2	11.2	28
wheat/lupin/wheat	19	10.9	62.3	570
wheat/pasture/wheat	12	3.4	8.1	237

Source: Department of Agriculture and Food; Profitable Crop Sequences Project.

Table 3: Relationship between grass weed control, take-all disease and wheat yield.

Treatment in pasture in previous year	Grass dry matter in previous pasture (t/ha)	Take-All		Wheat yield (t/ha)
		Incidence (%)	Severity (%)	
Nil	0.90	20	30	1.10
Grass selective	0.30	7	15	1.95
Spraytop	0.40	10	18	1.85
Broad spectrum herbicide	0.25	5	7	2.10

Source: MacLeod et al (1993).

Table 4: Impact of crop sequence on take-all incidence in cropping paddocks across the WA wheatbelt.

Crop sequence	No. of paddocks surveyed	Take-All 2010	Take-All 2013	Change (%)
wheat/wheat/wheat	21	0.5	1.2	257
wheat/wheat/lupin	4	0.4	1.0	238
wheat/wheat/canola	16	1.4	1.8	135
wheat/canola/wheat	19	1.8	1.5	80
wheat/lupin/wheat	19	0.7	1.2	178
wheat/pasture/wheat	12	1.3	1.7	126
wheat/pasture/pasture	4	1.4	2.1	152

Source: Department of Agriculture and Food; Profitable Crop Sequences Project.

Resources

Keep up to date with the latest results from the Profitable Crop Sequencing Project being run by the Department of Agriculture and Food, WA. https://agric.wa.gov.au/n/2689

Contact

Martin Harries
Department of Agriculture and Food, WA
P (08) 9956 8553
E martin.harries@agric.wa.gov.au

References

Lawes, R (2010) Using industry information to obtain insight into the use of crop rotations in the Western Australian wheat belt and quantifying their effect on wheat yields. In Proceedings of the 15th Australian Agronomy Conference 15-18 November Lincoln, New Zealand.

Lawes R, Renton M (2010) The Land Use Sequence Optimiser (LUSO): a theoretical framework for analysing crop sequences in response to nitrogen, disease and weed populations. Crop & Pasture Science 61, 835–843.

MacLeod WJ, MacNish GC, Thorn CW (1993). Manipulation of pasture pastures with herbicides to control Take-All. Aust. J. Agric. Res. 44, 1235

McConnell, G and O'Hare, N (2013) Break crop economics for the Kwinana East Regional Solutions Cropping Network. GRDC report prepared by PlanFarm Pty Ltd.

Robertson M, Lawes R, Bathgate A, Byrne F, White P, Sands R 2010. Determinants of the proportion of break crops on Western Australian broadacre farms. Crop & Pasture Science 61, 203-213.

Seymour M, Kirkegaard J A, Peoples M B, White PF, French R J (2012) Break-crop benefits to wheat in Western Australia- insights from over three decades of research. Crop & Pasture Science 63. 1-16.

7.2 Summer weeds

Key messages

- Early and total control of summer weeds optimises soil moisture storage in the fallow.
- About 20-30 per cent of summer rain events greater than 25mm are still available in the soil by seeding if fallows are kept weed-free.
- As much as 30mm of soil moisture can be available at the start of the Western Australian growing season in weed-free fallows. Such deep stored soil water usually produces more grain per millimetre than growing season rainfall.
- Uncontrolled summer weeds also tie up nitrogen that would otherwise be available to the next crop.
- Summer weeds need to be killed soon after emergence when they are small and actively growing as weeds will stress fast in hot summer growing conditions and become more difficult to control.

Weed management has the largest impact on the amount of plant available water stored during a fallow period (Hunt and Kirkegaard, 2011).

Growing season rainfall has dropped by 10 per cent since the mid-1970s in south-west Western Australia with the amount and intensity of summer rain events (December-February) increasing during this same period.

These rainfall trends highlight the importance of summer weed control to conserve soil moisture for use during below-average rainfall seasons. Summer weeds also reduce the amount of nitrogen available to crops because they use and tie-up nitrogen mineralised after summer and autumn rainfall.

Fleabane seedling.
Photo credit: GRDC.

More information

GRDC: Herbicides for the fallow, p30.

GRDC: Storing soil water during the fallow period, p7, p12.

Videos

Watch a video on the value of conserving soil moisture over summer: www.grdc.com.au/GCTV5-SummerFallow

CSIRO modelling suggests 20-30 per cent of moisture from November-April rainfall events greater than 25-30mm is often still available in the soil at seeding. Water from events less than 25mm generally evaporates before sowing starts, especially on sandy soils (Hunt and Kirkegaard, 2011).

The CSIRO analysis demonstrated that under WA conditions, summer rainfall events could increase soil water storage by about 30mm, which could contribute up to 1.0t/ha on average to grain yields in the subsequent crop (Tables 5 and 6).

Note to Table 5

CSIRO research across southern Australia demonstrated an average $3.50 return in higher crop yields for every dollar spent on summer weed control.

Table 5: Simulated impact of summer rainfall on crop yields for locations in WA.

			Grain yield	
Location	Total plant available water content (mm)	Plant available water in May (mm)	+ summer rain	- summer rain
Buntine	89	28	2.8	2.3
Migenew	135	33	3	2.9
Morawa	147	26	2.5	1.9
Wongan Hills	78	33	3.1	2.9
Kellerberrin	117	34	2.7	2.2
Borden	105	40	3.1	2.0
Salmon Gums	88	38	2.1	1.1

Source: Hunt and Kirkegaard (2011).

More information

Tools like the CliMate app can estimate how much soil moisture is present at seeding: www.grdc.com.au/GCS106-SimpleToolGuidesSowingAndNitrogenDecisions

Read two case studies on how WA growers manage summer weeds (pages 53-58) at: www.grdc.com.au/GRDC-Manual-SummerFallowWeedManagement

Table 6: The percentage of years in which modelled summer weed control was necessary, the percentage of those years where weed control was profitable, and the mean profit from summer weed control.

Location	Proportion of years in which weed control was necessary (%)	Proportion of years in which weed control was profitable (%)	Mean profit ($/ha)
Buntine	43	73	118
Mingenew	34	34	2
Morawa	43	88	156
Wongan Hills	45	44	17
Kellerberrin	48	82	129
Borden	53	58	34
Salmon Gums	62	92	213

Source: Hunt and Kirkegaard (2011).

Fallow weeds are more difficult to control in mid-summer due to size and temperature stress and require top label rates and/or a double knock strategy.

Benefits from increased soil water storage at sowing were more likely on soils with larger water holding capacities, and in drier locations. In all locations the mean return on investment from summer weed control was positive, but there were years in which control was not profitable.

The analysis concluded that summer weed control is profitable in 30-40 per cent of years in lower-rainfall areas and 50-60 per cent of years in wetter areas with higher yield potential.

Summer weeds often germinate in winter crops after the last post emergent herbicides have been applied with the weeds then growing through to the summer fallow after the winter crop is harvested.

Fallow weeds are more difficult to control in mid-summer due to size and temperature stress and require top label rates and/or a double knock strategy. It is important to control summer weeds early and completely. Table 7 lists the latest timing for effective control of various summer weed species.

*Table 7: Latest spray timing for summer weeds to avoid seed set and problems with seeder blockages.**

Weed	Latest time to spray
Fleabane	Spray as early as possible after harvest; fleabane very difficult to control when large.
Melons	Important to distinguish between paddy melons and afghan melons as paddy melons more difficult to kill and require higher herbicide rate. Spray pre-vine when plant is about dinner-plate size.
Caltrop	Spray at flowering; very quickly develops viable seed so monitor closely. Alleopathic: can reduce wheat emergence.
Button grass	Spray from three-leaf to tillering; high rates required.
Wire weed/tar vine	Spray early; very difficult to control when large and causes seeder bloackages.
Iceplant	Spray while small. Becomes palatable and poisonous to stock as it dries off so if sprayed late remove stock.
Small crumbweed (mintweed/ goosefoot)	Atrazine in many mixes can be used in southern areas to provide good control and ongoing residual control following summer rain.
Wild radish	Spray when pods are the thickness of a lead pencil.
Winter grasses - ryegrass	Spray when first heads fully emerged.

Source: Department of Agriculture and Food, WA.

*For comprehensive information on summer weed management including fallow herbicides read: www.grdc.com.au/GRDC-Manual-SummerFallowWeedManagement

More information

Read a case study on the benefits of summer weed control to grain yield: www.grdc.com.au/GC112-TheMalleeLessonFarmTheRain

Read a case study on the use of weed seeker technology to control summer weeds: www.weedsmart.org.au/bulletin-board/success-in-tackling-weeds/

Read an article on the impact of residual herbicides on different crops: www.weedsmart.org.au/bulletin-board/watch-out-for-residuals/

Summer weed control: best practice

- Many summer weeds can be controlled using a well-timed double knock.
- Determine rain fast periods for effective herbicide control.
- Water rates should be kept high (at least 60 L/ ha).
- Add a surfactant and/or spraying oil to all post-emergent treatments unless otherwise directed on the label.
- Do not spray stressed plants.
- Dust on weeds can reduce herbicide efficacy.
- Residual herbicides have a role – particularly in the face of increasing resistance levels to post-emergent herbicides. But be aware of plant-back intervals when using pre-emergent herbicides.
- Crop failure is likely if susceptible crops are sown before the plant back period is complete.
- Night spraying can take pressure off spray logistics, but extreme care is needed as inversion and high drift conditions are far more common at night.
- Weedseeker® and Weedit® technologies can reduce required herbicide volume by as much as 90 per cent when targeting low-density weed populations in fallow.

References

Hunt JR and Kirkegaard JA (2011). Re-evaluating the contribution of summer fallow rain to wheat yield in southern Australia. Crop and Pasture Science 62: 915-929.

Ward, P Oliver, Y and Hollamby N (2013) What to do with a wet summer: summer weeds, soil water, and subsequent crop yield. CSIRO and Liebe Group 2013 Crop Updates

Contacts

Dr Sally Peltzer
Department of Agriculture and Food, WA
P (08) 9892 8504
E sally.peltzer@agric.wa.gov.au

7.3 Soil acidity

Key messages

- More than 70 per cent of WA wheatbelt surface soils and almost half of subsurface soils are below productive pH levels for wheat production.
- This translates into an estimated production loss of nearly $500,000 or about 10 per cent of the State's annual crop.
- Nutrient export and the acidifying nature of nitrogen fertilisers means a typical WA cropping system has an acidification rate equivalent to 25–345kg/ha per year of pure calcium carbonate.
- Current (2014) lime use is only 60 per cent of the estimated 2.5Mt/year required over the next decade to reach the recommended pH target.
- Results from more than 100 lime response trials by the Department of Agriculture and Food, WA show an average wheat yield increase of 0.25t/ha or 12 per cent following the application of 2t/ha or more of good quality lime to acidic soils.

More information

To view the full soil acidity assessment: https://agric.wa.gov.au/n/2082

Read case studies on the impact of liming on grain yield: https://agric.wa.gov.au/n/2624

Videos

Watch a video on the soil acidity program led by the Department of Agriculture and Food, WA: www.grdc.com.au/GCTV8-LimingAcidSoils

A 2013 assessment of soil acidity levels across the WA wheatbelt by the Department of Agriculture and Food, WA found more than 70 per cent of surface (0–10cm) and almost half of subsurface (10–20 and 20– 30cm) samples were below the recommended pH level of 5.5 (surface) and 4.8 (subsurface). The extent and severity of acidity varied regionally and with soil type (Table 8).

*Table 8: Proportion of WA soil samples with topsoil and subsurface pH levels below target for optimum crop yield.**

WA agricultural zone	Main soil type	Samples (%) below pH target	
		Topsoil (<pH_{Ca} 5.5)	Subsurface (<pH_{Ca} 4.8)
Central northern	Sandy earths	72	66
Darling Range/South Coast	Gravels	89	34
Southern wheatbelt	Deep sandy duplex	84	36

* Based on 161,000 soil samples, including about 67,000 from the subsurface, collected from more than 93,000 sites across the south-west agricultural area from 2005–2012. Source: Department of Agriculture and Food, WA.

A comparison of samples collected in 2004–2006 and 2010–2012 showed that for most of the south-west of WA the soil acidity situation has remained static. In some areas, particularly in the central northern wheatbelt, the situation has improved but 50–75 per cent of samples were still below target.

Lime application during 2014 was only just over half the estimated 2.5Mt/year required over the next 10 years to reach recommended pH targets.

*Please note all references to pH in this chapter refer to pH_{Ca}

Results from more than 100 lime response trials by the Department of Agriculture and Food, WA show an average wheat yield increase of 0.25t/ha or 12 per cent following the application of 2t/ha or more of good quality lime to acidic soils (Table 9).

Table 9: Average wheat yield response to surface-applied lime as a proportion (%) of un-limed controls in Department of Agriculture and Food, WA soil acidity trials.

	Grain yield response (%) following years after liming		
Lime rate (t/ha)	**0 years**	**1-4 years**	**5+ years**
1-1.5	1 (16 trials)	8 (34 trials)	6 (11 trials)
2-2.5	2 (19 trials)	13 (35 trials)	12 (18 trials)

Source: Chris Gazey, Department of Agriculture and Food, WA.

The time taken to observe a lime yield response depends on the starting pH profile, the amount, frequency and quality of lime applied and how reliant the crop is on subsoil moisture at the end of the season.

Typically, amelioration and potential yield responses can take four or more years after liming and there is usually little or no yield response for wheat in the year of lime application.

The initial soil pH and soil type are important. Topsoil pH responds quickly to liming. Surface applied lime usually takes four to seven years to treat acidity in the subsurface layers, provided that sufficient lime is applied to raise and maintain the topsoil pH above 5.5.

Lime with a high proportion of fine particles increases pH more rapidly.

7.3.1 Soil acidity impacts

In WA the major problem when soils acidify is aluminium toxicity in the subsurface soil layer.

When soil pH drops, aluminium becomes soluble and the amount of aluminium in the soil solution increases. In most wheatbelt soils aluminium will reach toxic levels when subsurface pH falls below 4.8 (Figure 6).

Surface applied lime usually takes four to seven years to treat acidity in the soil subsurface layers, provided that sufficient lime is applied to raise and maintain the topsoil pH above 5.5.

Photo credit: Evan Collis.

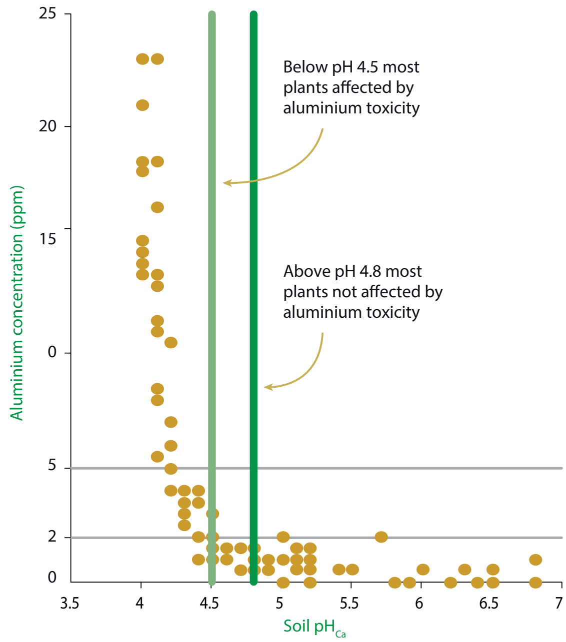


Figure 6: The relationship between pH_{Ca} and aluminium concentration in subsurface soils from a farm near Beacon, WA.

More information

Lime Comparison Calculator: www.soilquality.org.au/calculators/lime_comparison

Determine the $ value of applying lime: www.liebegroup.org.au/lime-profit-calculator/

Read a case study on a grower who has used the lime profit calculator to manage soil acidity profitably: www.grdc.com.au/GC104-UnearthingLimeProfitsInTheMidWest

For a list of accredited lime suppliers visit: www.limewa.com.au

There is generally sufficient organic matter in topsoil to ensure aluminium remains bound and not toxic to plant roots. Low pH in topsoils primarily impacts crop nutrient availability, legume nodulation and nitrogen fixation. These problems are minimised if the topsoil pH is maintained above 5.5.

Toxic levels of aluminium in the soil solution affect root cell division and elongation. Root tips become deformed and brittle and root growth and branching is reduced making it more difficult for plants to extract soil moisture and nutrients.

Aluminium toxicity is most noticeable in seasons with a dry finish as roots are unable to access stored subsoil water for grain fill from the acidic subsurface layer.

7.3.2 Developing a liming program

It is best to maintain pH at or above 5.5 in the topsoil and 4.8 in the subsurface. If the topsoil pH falls below 5.5, there will be insufficient alkalinity to move down and treat subsurface acidification. The best practice is to sample and test the soil every three to four years and apply lime if the pH falls below targets.

Videos

Watch a video on the benefits of applying variable rather than blanket rates of lime: www.grdc.com.au/OTFW0714-BigGainsAtLowCost

The amount of lime required to lift pH will depend on the current pH profile, soil type, rainfall, farming system and lime quality. Pure calcium carbonate (100 per cent neutralising value) applied at 1t/ha will increase topsoil pH by about 0.7 on sand, 0.5 on loam and 0.3 on clay. Greater quantities of agricultural lime will be required to achieve these pH changes, with the actual amount dependent on the neutralising value (purity) of the lime.

A typical WA wheatbelt farming system operating a winter crop/pasture rotation has an acidification rate equivalent to 25–345 kg/ha/year of pure calcium carbonate. This is the amount of calcium carbonate (lime) that must be applied to keep up with the seasonal acidification caused by grain exports and the use of acidifying nitrogen fertilisers.

Additional lime will be required to rectify pH levels below pH 5.5 (surface soils) and pH 4.8 (subsurface soils) (Table 10).

*Table 10: Rule-of-thumb lime amounts required for sandy soil types using a lime with neutralising value above 90%. The prescribed lime amount over five years is for each soil layer so the total required is the sum of each layer.**

Soil depth	pHCa	Lime amount over five years (t/ha)
0-10	<5.0	2
0-10	<5.5	1
0-20	<4.5	2
0-20	<4.8	1
20-30	<4.5	1
20-30	<4.8	Measure pH in 3 years

*Table 10 indicates of the amount of lime that may be required on sandy soils over five years to achieve pH above 5.5 in the topsoil and 4.8 in the subsurface after 10 years. Increases in pH will depend on soil type, rainfall, lime quality and quantity applied and other farming practices as well as the soil pH profile. Expert advice should be sought for individual recommendations.

Source: Department of Agriculture and Food, WA.

Neutralising value and particle size are the key indicators of lime quality. Limes with a higher neutralising value will treat more acidity in the soil while limes with a higher proportion of fine particles will increase soil pH more quickly (Figures 7 and 8).

Note to Figure 7

1.7t/ha of lime with a neutralising value (NV) of 60% is required to achieve the same pH change as 1.1t/ha of 90% NV lime

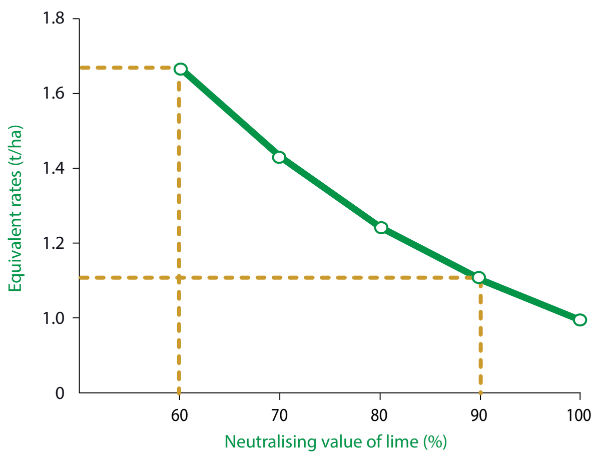


Figure 7: Amount of lime of varying neutralising values required to achieve the same pH change.

Note to Figure 8

Finer particles of agricultural lime are more efficient at changing soil pH

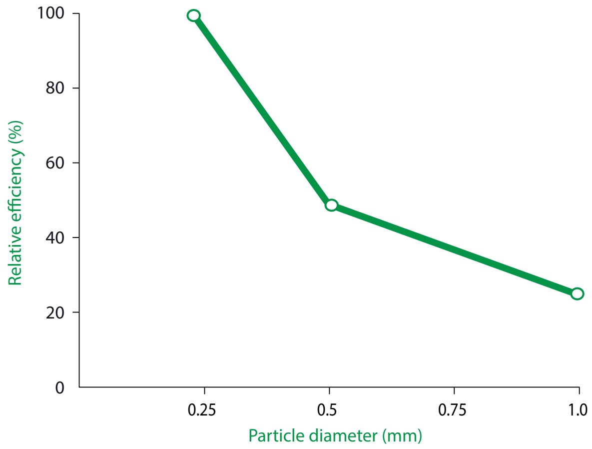


Figure 8: Impact of particle size on pH change for lime applied at 2.5t/ha.
Source: Cregan et al (1989).

A useful tool for calculating and comparing the cost effectiveness of agricultural limes is the Lime Comparison Calculator.

The calculator takes into account the cost of the lime and its transport and spreading as well as its particle size distribution and neutralising value. Limes with high neutralising value can be more cost-effective than those with lower associated transport costs and less neutralising value.

7.3.3 Incorporating lime to depth

Incorporating lime using deep cultivation is likely to ameliorate subsoil acidity at least two or three years faster than if lime was top-dressed.

Deep incorporation of lime is likely to work best where subsoil acidity occurs in a distinct layer, typically between 15-35cm, rather than down the whole profile. Once this subsurface acidity layer is fixed the crop roots then have unrestricted access to soil and can grow to their maximum potential. Soil testing to depth (preferably to 50cm) is therefore critical before considering deep lime incorporation.

The soil pH profile should be tested again in 10cm increments (preferably to 60cm) a year or two after lime incorporation. This will allow time for the lime to react and to determine if it has moved beyond the ploughs working depth.

Many of the deep working tools such as deep ripping, rotary spading and mouldboard ploughing will result in uneven mixing, which can make soil sampling difficult. Having a good vertical mix of lime from the surface down into the subsoil will provide a pathway of amended soil that roots can grow through into the subsoil below.

Lower benefits from deep incorporation occur in soils that are inherently acidic to depth such as Wodjil sands. Incorporating lime to depth in these soils will only improve root growth to the depth of amelioration. Beyond this depth, root growth will

More information

Read a case study on the value of lime incorporation: www.grdc.com.au/GC109-SpadingTakesTheLimelight

Read a factsheet on incorporating lime: www.liebegroup.org.au/wp-content/uploads/2012/01/factsheet-subsoil-acidity-final-12022013.pdf

remain restricted. Similarly if other subsoil constraints like hardpans exist root growth will remain restricted even if a subsurface acidity layer is fixed.

Central WA wheatbelt GRDC funded trials established in 2013 by the Department of Agriculture and Food, WA indicate cultivation to incorporate lime in that region can be more economic than topdressing where:

- soil pH_{Ca} in the 0-10cm layer is well below the recommended 5.5;
- soil pH_{Ca} in the 10-20cm layer is well below the recommended 4.8;
- the cultivation implement mixes at the depth of the pH constraint.

The trial compared the net margins achieved from incorporating lime with deep cultivation with and without nutrients (Table 11). The results showed that net margin (income from grain minus all fertiliser, tillage and lime costs) was about the same for no or very high rates of fertiliser when incorporating lime.

At both sites there were yield benefits of 0.4-0.6t/ha from cultivation, which offset the costs of the cultivation and some lime application.

Table 11: Soil pH_{Ca} profiles measured 17 weeks after lime application and cultivation, grain yield and net margins achieved through cultivation alone or cultivation + lime with and without nutrients.

Soil depth	Dalwallinu			Dandaragan		
	Control	Cultivation	Lime + cultivation	Control	Cultivation	Lime + cultivation
0-10	5.8	4.9	5.4	6.4	5.8	6.2
10-20	4.8	5.0	5.1	5.3	5.7	6.2
20-30	4.6	4.6	4.6	4.9	5.0	5.7
30-40	4.4	4.5	4.4	4.7	4.7	4.9
Wheat yield – no nutrients (kg/ha)	1094	1786	1671	1936	2603	2910
Net margin: no nutrients ($)	241	333	203	426	408	400
Net margin: all nutrients ($)	209	230	86	355	279	206

* The net margin for the nil nutrient treatments at these two sites show that a positive net margin was achieved when shifting investment from fertilisers to cultivation with or without lime. Source: Scanlan et al (2014).

7.3.4 Long-term yield response to liming

A DAFWA small-plot lime trial established near Mingenew, WA in 1994 illustrates the long-term crop yield benefits of liming and the need to apply at least 2t/ha to ameliorate soil pH to depth (Table 11 and Figure 9).

Agricultural limesand was applied at 0, 0.5, 1, 2 and 4t/ha to plots 1.8m wide and 30m long. There were four replicates. Subsequent to the initial treatments, the farmer applied 1t/ha lime in 1998, 1999, 2003 and 2012 (total of 4t/ha lime) to the whole trial as part of normal paddock operations.

The trial was relocated in 2013 and the trial plot yields measured using a small plot harvester and soil samples collected to a depth of 50cm.

Application of 1t/ha lime by the grower in 1998, 1999, 2003 and 2012 (4t/ha total) increased or maintained the topsoil (0–10 cm) pH above 5.5–6 for all initial lime treatments. However, only the plots that received the initial 4t/ha lime and the subsequent grower-applied 4t/ha had subsurface pH that close to target (≥ pH 4.8) (Figure 9).

Note to Figure 9

Plots that initially received 2t/ ha lime or less had continued to acidify below 20cm. In addition, the lowest pH is now deeper in the soil profile, meaning that it will now require more lime and take longer to recover.

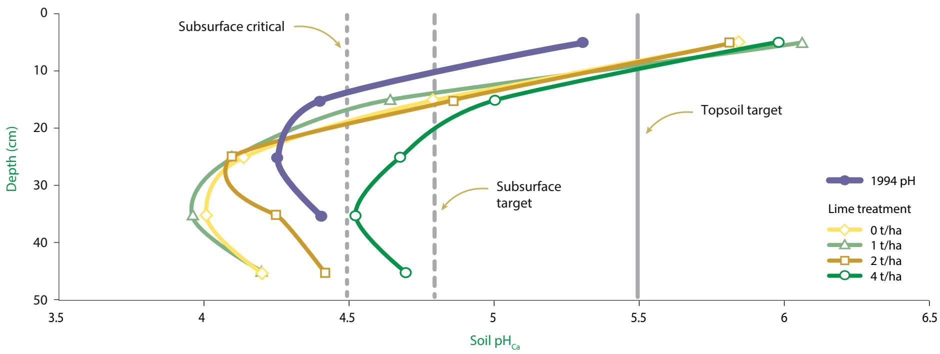


Figure 9: Soil pH profiles in 2013 for different lime treatments compared to the starting pH 20 years ago in a trial near Mingenew, WA.

Source: Department of Agriculture and Food, WA.

The 2013 wheat yield was 10 per cent higher in the treatment that had received a total of 8t/ha lime (initial trial 4 t/ha plus 4 t/ha in farmer applications) and six per cent higher for the treatment that had received a total of 6t/ha lime (initial trial 2t/ha plus 4t/ha in grower applications) than the plot that received a total of 4t/ha lime (nil in-trial and 4t/ha in grower applications)
(Table 12).

Table 12: Impact of lime on wheat yields 20 years after first application at Migenew, WA.

1994 lime treatment (t/ha)	2013 wheat yield (t/ha)*
0	4.43 a
1	4.56 ab
2	4.69 b
4	4.85 c
LSD p=0.05	0.14

*Yields followed by different letters are significantly different.
Source: Department of Agriculture and Food, WA.

Soil sampling for soil acidity

Sampling 25 per cent of a farm each year enables a four-year rotation. This is an adequate time frame to detect changes and allow adjustment of liming practices.

Samples need to be taken at 0–10, 10–20 and 20–30cm to determine the soil pH profile because subsurface acidity cannot be detected or estimated by knowing the topsoil pH.

To minimise sample variation soil sampling should ideally be done during summer using a calcium chloride solution rather than water.

Re-sampling every three to four years will enable the liming program to be refined as the soil pH increases or if it does not respond as expected. It is essential to maintain the topsoil pH_{Ca} above 5.5 for alkalinity to move down to treat acidity in the subsurface soil.

To capture pH variation within a paddock, tracking pH changes requires that samples are collected from the same location over time. Samples need to be properly geo-located, preferably by GPS, to allow comparable repeat sampling.

References

Cregan, P Hirth, J Conyers, M (1989) Amelioration of soil acidity by liming and other amendments. In 'Soil Acidity and Plant Growth'. (Ed. A. D. Robson) pp. 205-264. (Academic Press: Sydney).

Gazey C, Davies S and Master R (2014) 'Soil acidity; a guide for WA farmers and consultants, second edition'. Department of Agriculture and Food, Western Australia. Bulletin 4858. https://www.agric.wa.gov.au/climate-land-water/soils/soil-constraints/soil-acidity

Gazey C, Oliver, Y, Fisher J, Andrew J, and Carr S (2014) 20 years of soil acidity RD and E in Western Australia—what have we learnt? Proceedings 2014 WA Crop Updates. http://www.giwa.org.au/2014-crop-updates

Gazey C, Andrew J and Griffin E (2013). 'Soil acidity'. In: Report card on sustainable natural resource use in agriculture, Department of Agriculture and Food, Western Australia. https://agric.wa.gov.au/n/2082

Scanlan C, Brennan R, Sarre G (2014) Shifting investment from nutrients to lime and cultivation on acid soils: is an immediate payback possible? Proceedings 2014 WA Crop Updates. http://www.giwa.org.au/2014-crop-updates

Contact

Dr Chris Gazey
Department of Agriculture and Food, WA
P (08) 9690 2000
E chris.gazey@agric.wa.gov.au

7.4 Non-wetting soils

Key messages

- Non-wetting soils cost Western Australian growers up to $300M in lost production each year.
- Management strategies for non-wetting soils involve mitigation options such as furrow and on-row sowing with or without wetting agents or more expensive amelioration methods such as claying and deep cultivation.
- The optimum mix of mitigation and amelioration methods differs for each farm and will depend on the extent and severity of the non-wetting problem and the likelihood of receiving a yield response.
- A range of adaptations to furrow sowing have been shown to improve crop establishment and crop yields on non-wetting soils.
- Deep cultivation with or without clay is expensive but can result in considerable and economic yield improvements on some non-wetting soils - especially in higher rainfall areas.

Non-wetting soils are estimated to cost Western Australian growers up to $300M in lost production each year.

Photo credit: Evan Collis.

Non-wetting soils develop when plant-derived waxes coat soil particles in the topsoil, which prevents water from infiltrating the soil.

In Western Australia about 3.3M hectares of agricultural soils are at high risk of soil water repellence with a further 6.9M/ha at moderate risk. The cost of non-wetting soils to production is estimated to be about $250-300M per year. Two-thirds of high-risk non-wetting soils are in the southern wheatbelt of WA with a third in the northern wheatbelt.

In non-wetting soils water tends to enter the soil via preferred pathways resulting in patches of soil remaining persistently dry. Crop, pasture and weed emergence on non-wetting soils is often patchy and delayed and crop and pasture productivity is compromised. Soil water and nutrient use is inefficient and weed control can be poor due to staggered germination and poor herbicide efficacy.

Water repellent soils are at higher risk of erosion due to poor ground cover and lateral water flow. Fertiliser, inactivated pesticides and ungerminated seeds tend to become isolated in dry soil patches.

A perceived increase in the occurrence of non-wetting soils in WA is likely the result of:

- drier autumns;
- increased concentration of organic matter at the soil surface from minimum tillage;
- higher frequency of dry and early seeding;
- widespread use of narrow knife points, which cause dry repellent soil to concentrate in the furrow with seed and fertiliser.

7.4.1 Managing water repellence

Managing non-wetting soils falls into three categories:

- Mitigation
- Amelioration
- Avoidance

The best option or mix of options will depend on the extent and severity of the non-wetting problem.

Small patches might best be ameliorated while large areas of water repellence are best treated initially using mitigation strategies followed by tactical amelioration of specific areas – especially those with weed, subsoil acidity or compaction issues.

The optimal mix between amelioration and mitigation sowing will differ between farms, depending on the severity and size of water repellent area as well as the cost and expected yield benefit of different treatment options (Table 13).

Modelling work by the Department of Agriculture and Food, WA suggests when 80 per cent of the farm is affected by repellence, and 80 per cent is dry sown, the best distribution of a $20,000/year non-wetting soils investment is about 40 per cent

More information

For a comprehensive review of management options for non-wetting soils refer to: https://agric.wa.gov.au/n/1693

to amelioration and 60 per cent to mitigation. If 20 per cent of the farm or less is repellent all investment should generally be in amelioration (Blackwell 2014).

Table 13: Management options for non-wetting soils.

Management type	Examples	Impact
Mitigation	Furrow seeding. Wetting agents. On-row seeding. Minimum tillage with stubble retention – protects established water infiltration pathways and may facilitate microbial degradation of waxy compounds.	Less expense than amelioration methods but have smaller, inconsistent impact on crop yields. Can be applied over a large area cost-effectively.
Amelioration	Claying. Deep cultivation.	Expensive and can have serious environmental impacts if not done properly. Can have large, positive impact on crop yields.
Avoidance	Remove affected areas from annual crop production and replace with perennial forage species.	

Mouldboard ploughing is proving effective against non-wetting soils on some soil types but erosion risks must be carefully considered. Pictured is a paddock that has been mouldboard ploughed before seeding.

Photo credit: Evan Collis.

7.4.2 Soil water repellence – southern wheatbelt

Water repellent soils are found throughout the southern wheatbelt with large areas around Albany and Esperance and the Great Southern and Lakes regions.

The soils most affected are the sandy duplex soils and loamy or sandy forest gravels.

The depth of sand over clay in affected duplex soils can vary from less than 30cm to 30-80cm.

In the shallow duplex soils water often becomes perched on the clay layer with the repellent sand wetting up from underneath.

In the deeper duplex soils water repellence has typically been managed using furrow sowing or by clay spreading or delving (provided the clay is within 50-60cm of the surface). Use of winged points for furrow seeding in combination with paired or ribbon row seeding can help to grade the repellent soil out of the furrow.

Deep cultivation methods such as soil inversion and rotary spading have been used with mixed success especially on shallow duplex soils where too much clay from depth can result in surface sealing.

Water repellence on the sandy and loamy forest gravels has commonly been managed using furrow sowing in combination with wetting agents. Deep soil cultivation has been shown to reduce repellence on these soils but impacts on crop establishment and productivity have been variable.

7.4.3 Soil water repellence – northern wheatbelt

The soils most affected by water repellence in the northern wheatbelt are the pale and coloured deep sands, sand gravels and some sandy duplex soils. The most affected areas are those in the medium to high rainfall western part of the region – from north of Geraldton to south of Moora where deep sands of low clay content dominate.

Water repellence in deep sands has typically been managed using furrow sowing but this is not always successful when dry seeding using narrow points because water repellant soil flows into the furrow to mix with seed and fertiliser.

Photo credit: Evan Collis.

7.4.4 Furrow sowing

Water repellence in the deep sands has typically been managed using furrow sowing but this is not always successful when dry seeding using narrow points as water repellent soil flows into the furrow to mix with seed and fertiliser. Winged seeding systems can filter out the repellent sand and have been shown to lift wheat establishment rates over narrow points (Figures 10-12). Paired row seeding increases the chance of seed coming into contact with moist soil.

More information

Read case studies on non-wetting research in the southern wheatbelt: www.grdc.com.au/GRDC-Booklet-CombattingNonWettingSoils

For more information on wetting agents for managing non-wetting soils see: https://agric.wa.gov.au/n/280

Videos

Watch a video on a successful mouldboard plough operation to ameliorate non-wetting soils on the south coast: www.grdc.com.au/OTFW0613

Watch a video on research into wetting agents for non-wetting soils: www.grdc.com.au/GCTV13-PolymerPotential

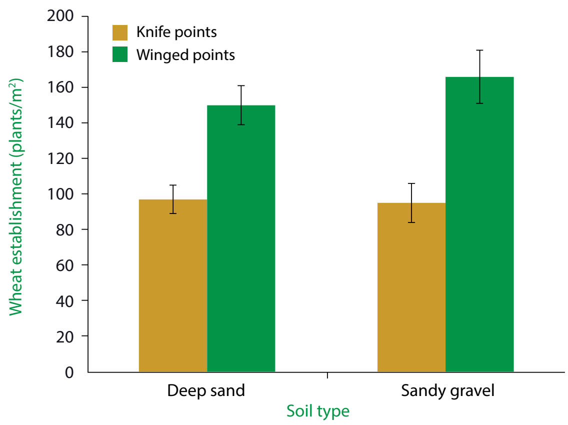


Figure 10: Wheat establishment (plants/m^2) on a moderately repellent pale deep sand and severely repellent sandy gravel at Badgingarra, WA using either a knife points or winged point-paired row seeder system.

Source: Department of Agriculture and Food, WA.

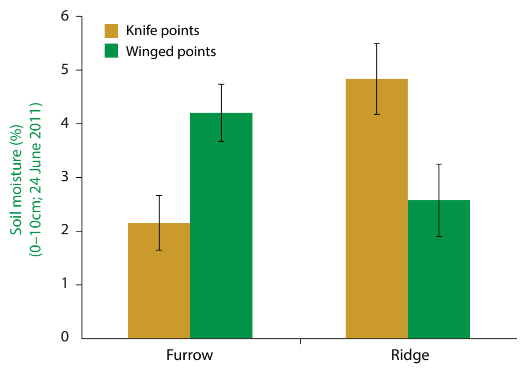


Figure 11: Volumetric soil water in the furrows and ridges for a knife point versus winged point-paired row seeder comparison in severely water repellent sandly gravel, measured once on 24 June 2011 at Badgingarra.

Source: Department of Agriculture and Food, WA.

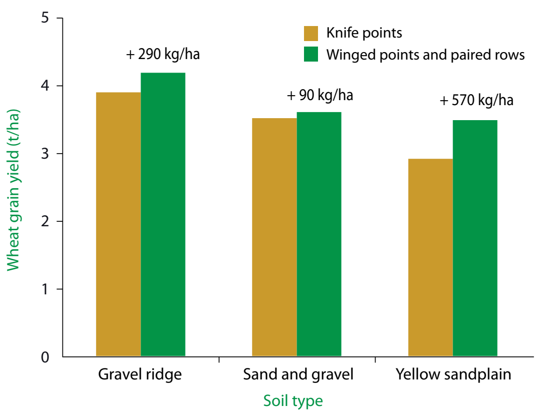


Figure 12: Grain yield (t/ha) on a moderately repellent pale deep sand, severely repellent sandy gravel and mildly repellent yellow deep sandplain at Badgingarra, WA using either a knife points or winged point-paired row seeder system.

Source: Department of Agriculture and Food, WA.

A range of adaptations to furrow sowing have been shown to improve crop establishment and yields on non-wetting soils (Table 14).

Analysis of a range of GRDC funded Department of Agriculture and Food, WA non-wetting soil trials showed winged boots in combination with paired seeding lifted crop yields on non-wetting soils by about 20 per cent compared to five per cent for narrow points alone (Blackwell et al 2014).

The same analysis showed an average 10 per cent yield increase using banded wetting agents with knife points compared to knife points alone (particularly when sowing dry) across a range of crop types in repellent sand and gravel. However, banded wetting agents also delivered a negative or nil yield response when the soil was mostly wet or where there was significant rain soon after seeding (Blackwell et al 2014).

The current range of wetting agents is most effective on repellent loamy gravels and less effective on sands. Blanket application of the wetting agent is expensive ($50-200/ha) and is best suited for use on highly repellent patches or parts of paddocks, particularly those areas with a high weed burden.

Table 14: Adapted furrow sowing methods for improved management of soil water repellence.

Furrow sowing method	Mechanism	Implications
Delay seeding and wet sow.	Soil has time to wet up. Less dry soil to flow into furrows.	Opportunity for weed control. Reduced yield potential. Delays seeding program.
Higher seeding rates.	More seed through more soil.	Increased cost. Reduced seeding efficiency.
Winged points or boots.	Increased grading of repellent topsoil. Less flow of repellent topsoil into seed zone.	Larger furrows and ridges. Increased disturbance. Pre-emergent herbicide graded into ridges. Stubble handling issues?
Paired rows, ribbon seeding or narrow row spacing.	Seed distributed through more soil – more chance of hitting moisture. Seed can be sown onto undisturbed or firmed soil (under paired-row wings).	Increased weed competition.
On-row seeding.	Place seed near remnant root of previous crop (acts as a pathway to aid water entry).	Requires accurate steering. Possible stubble handling and disease issues. Build-up of fertile zones associated with the crop row. Microbe activity likely to be higher on old rows (increased wax degradation). Old rows have shallow depressions that help harvest water. Exceptions have been observed.
Zero and minimal disturbance.	Maintain residual roots to act as water infiltration pathways into repellent soil.	Can be difficult to build up root mass in severely repellent soils and drier areas. Stubble handling issues.
Banded soil wetting agents applied at seeding.	Improve wetting of furrow base and more effective wetting from smaller rainfall events.	Reduced soil water retention unless water-holding humectant included in formulation. No weed germination benefit.
Blanket wetting agents applied pre-seeding.	Improved water infiltration in to soil surface.	May improve weed germination and subsequent control. Can be expensive at the rates sometimes needed to get a significant benefit.

Source: Department of Agriculture and Food, WA and Combatting non-wetting soils booklet: www.grdc.com.au/GRDC-Booklet-CombattingNonWettingSoils

7.4.5 On-row seeding

On-farm observations and CSIRO research results indicate plant establishment on non-wetting soils can be improved when seed is sown on the previous year's cropping row rather than the inter-row, as old root channels act as water infiltration pathways into non-wetting soils.

GRDC funded research at Pingrup on the south coast of WA showed soil water contents were significantly higher in the row than the inter-row regardless of the season. Water-repellence drops over time in the 'on-row' compared to the inter-row (Figures 13a and 13b).

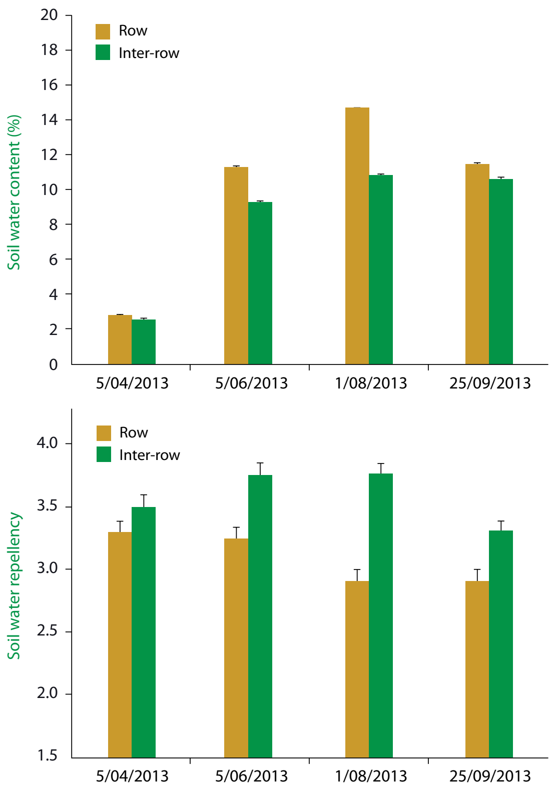


Figure 13: Soil water content and repellency levels over time 'on the row' and the 'inter-row' of non-wetting soils sown to wheat at Pingrup, WA.

Source: Margaret Roper, CSIRO.

Dry seeding can worsen water repellence with CSIRO research showing soil disturbance of non-wetting soils results in much slower water infiltration than the same soils sown using minimum-tillage (Figure 14). It is thought that disturbing dry non-wetting soil leads to soil particles collapsing into a higher density – reducing water pathways and increasing repellence (Roper et al 2013).

It is recommended that, where possible, water repellent soils are not dry seeded. Ongoing research into disturbance of dry non-wetting soils could lead to modified seeding equipment being developed for these soils.

More information

Read a case study about on-row seeding in non-wetting soils: www.grdc.com.au/GC107-SmartNewWayToPlaceSeedOverMoisture

For more information on the benefits of on-row seeding to manage non-wetting soils: www.grdc.com.au/GC109-OffRowSeeding

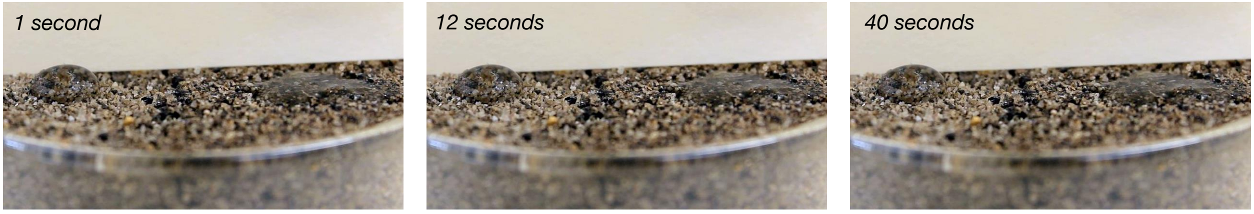


Figure 14: Time course of water drop infiltration into dry water repellent soil which has been disturbed dry (LHS) compared with the same soil which has been dried in a similar way but not distrubed (RHS). The water droplet on the 'dry-disturbed' soil still remained on the soil surface after 40 seconds, whereas in the undisturbed soil, the water droplet entered the soil shortly after 12 seconds.

Source: Roper et al (2013).

7.4.6 Deep cultivation

One-off deep cultivation using either a complete soil inversion (mouldboard plough) or deep mixing (rotary spade) has been used successfully to overcome soil water repellence in the northern region deep sands.

Deep one-off cultivation with a rotary spader can be particularly helpful on deep sandy earths as the clay content of these soils increases with depth and spading can increase the clay content of the topsoil (Table 15).

Table 15: Soil size and water repellence analysis of untreated and rotary spaded deep yellow loamy sand at Coorow, WA.

Treatment	Water droplet penetration (seconds)	Particle size analysis (% @ 0-10cm)			
		Clay	Fine sand	Coarse sand	Silt
Untreated	182 (moderate non-wetting)	4.6	10.2	83.2	2.0
Spaded	5 (nil non-wetting)	6.2*	13.9	78.6	1.3

* Note increase in clay in topsoil and elimination of water repellence. Source: Department of Agriculture and Food, WA and the Liebe Group.

Increasing the clay content of the topsoil to five per cent or more is equivalent to spreading and incorporating clay, with long-term trials indicating the resultant water repellence benefits can last for more than a decade. Deep sands with less clay content at depth will have a shorter yield response to spading. In general the longevity of the rotary spading response is still unclear with some research showing a five-year wheat yield response following spading and others about three years. Drier seasons can also limit the potential yield response.

Given the variability of depth to clay across paddocks knowledge of clay depth is important before embarking on delving or spading to bring it to the surface.

Depth to clay can be determined to some extent by drilling (augering) or mapping using electromagnetic surveys. Incorporating the clay evenly post delving can be an issue as the paddock surface can be rough.

Videos

Watch a video on the use of spading to manage non-wetting soils in the northern wheatbelt: www.grdc.com.au/OTFW0711

Delving mallee soils needs careful consideration as some clay subsoils have high salt and boron levels and can lead to surface sealing when applied at high rates. Testing subsoil clays and using strip trials to evaluate the impacts of delving on crop establishment and yield is recommended.

7.4.7 Claying

Most of the water repellent soils have clay contents of less than one per cent. If the clay rich subsoil is deeper than 60cm, spreading and incorporation of clay is the only option to increase the clay content of the soil surface.

Adding clay-textured soil provides the longest-term solution to soil water repellence. The high expense of claying ($500-$800/ha) will usually need a few seasons to recover costs and clay spreading and incorporation is best suited to higher rainfall environments with higher yield potential. Poor incorporation of clay-rich subsoil can hinder productivity gains.

The method involves excavating clay from the subsoil in a pit close to a deep sandy area and spreading it (using a scraper or multi-spreader for example) onto the soil surface. The clay rich subsoil is then incorporated soon after it is applied. The incorporation can be achieved with tines, off-set discs, heavy harrows, or rotary hoe and rotary spader.

Poorly incorporated clay can result in surface sealing and poor root exploration into the subsoil which, when coupled with increased evaporation, can often result in crops on clayed paddocks haying off due to the lack of water during grain fill.

The aim after clay spreading is to achieve clay content in water repellent topsoil of 3-4 per cent if the soil has an organic carbon content of less than one per cent or 5-6 per cent if the organic carbon content is more than one per cent.

Subsoils used for claying typically contain 30-40 per cent clay but the range can be as low as 20 per cent and as high as 50 per cent. Knowing the clay content and the depth of incorporation is critical to knowing what rate of clay to apply to achieve the targeted clay content.

Incorporating 100t/ha of subsoil with a clay content of 30 per cent into the top 10cm will increase the clay content of the topsoil by 3-4 per cent. Clay content can be estimated using hand texturing where moist soil is formed into a ribbon between the thumb and forefinger. A continuous unbroken soil ribbon of about 75mm is indicative of a clay content of about 30 per cent.

On-farm research at Bolgart, WA illustrates the yield benefits possible from clay incorporation on non-wetting sands (Figure 15). The aim was to establish the most effective application rate and incorporation method to lift clay content in the top 20cm of soil.

Deep cultivation with a rotary spreader with no additional clay increased yield by 850kg/ha over the control and there was a trend for higher yields with clay incorporation using the spader but not the offset discs (Figure 16).

More information

For more information on claying see: www.grdc.com.au/GRDC-Booklet-SpreadDelveSpadeInvert

Videos

Watch a video on clay spreading and delving for combatting non-wetting soils: www.grdc.com.au/OTFW0711-SpadingAwayNonWettingSoils

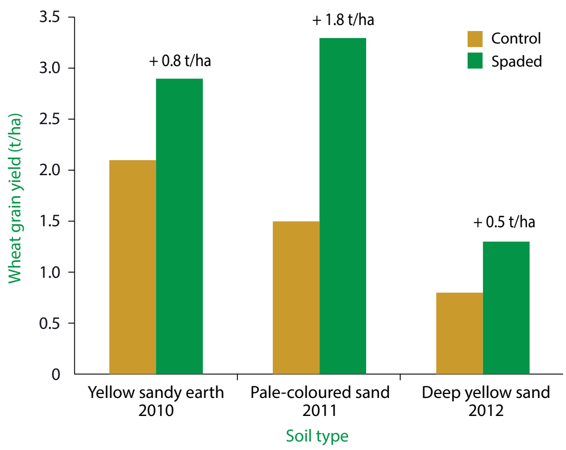


Figure 15: Wheat grain yield in untreated non-wetting soil (control) and one year following spading on different soil types at Coorow, WA.

Source: DAFWA and the Liebe Group.

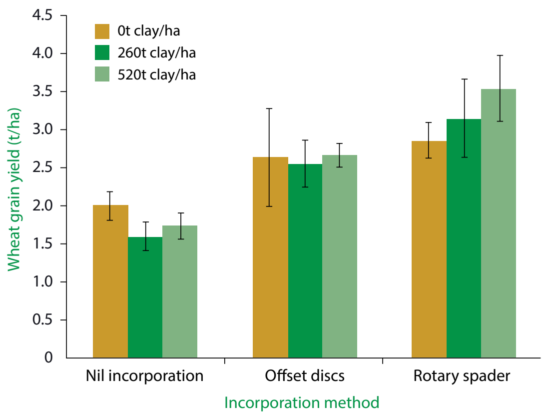


Figure 16: Wheat grain yield on untreated non-wetting soil (control) and ameliorated with clay either to depth or on surface at Bolgart, WA in 2011. Clay treatments were applied in 2010.

Source: DAFWA and the Liebe Group.

Clay that was once in the subsurface has been incorporated into the topsoil using spading.

Photo credit: GRDC.

More information

For more information on claying to ameliorate non-wetting soils see: https://agric.wa.gov.au/n/172

Acknowledgement

Most of the material for the non-wetting soil section was sourced from the GRDC publication *Combatting non-wetting soils* which details WA research aimed at developing management options for non-wetting soils in WA cropping systems.
www.grdc.com.au/GRDC-Booklet-CombattingNonWettingSoils

Contact

Stephen Davies
Department of Agriculture and Food, WA
P (08) 9956 8515
E stephen.davies@agric.wa.gov.au

References

Bakker D, Bowden B, Poulish G, Hulse K, Stephen Davies S, Scanlan C (2014) Managing non-wetting and crop nutrition of forest gravels. In 'Proceedings 2014 Agribusiness Crop Updates'. Department of Agriculture and Food and the Grains Research and Development Corporation: Perth, WA. http://www.giwa.org.au/2014-crop-updates

Blackwell P, Hagan J, Davies S, Bakker D, Hall D, Roper M, Ward P, Matthews A (2014) Smart no-till furrow sowing to optimise whole-farm profit on non-wetting soil In 'Proceedings 2014 Agribusiness Crop Updates'. Department of Agriculture and Food and the Grains Research and Development Corporation: Perth, WA. http://www.giwa.org.au/2014-crop-updates

Davies S, Blackwell P, Bakker D, Scanlan C, Roper M, Ward P (2012) Developing and assessing agronomic strategies for water repellent soils. In 'Proceedings 2012 Agribusiness Crop Updates'. Department of Agriculture and Food and the Grains Research and Development Corporation: Perth, WA. http://www.giwa.org.au/2012-crop-updates

Roper MM, Ward PR, Keulen AF, Hill JR (2013) Under no- tillage and stubble retention, soil water content and crop growth are poorly related to soil water repellency. Soil & Tillage Research 126: 143-150.

7.5 Soil compaction

Key messages

- Compacted layers that restrict wheat growth exist on virtually all soils with a loamy-sand or sandy texture, a soil type that represents nearly 50 per cent of Western Australian agricultural land.
- Duplex soils are also prone to compaction if there is sufficient depth to clay.
- The depth of the compaction layer depends on soil type – with lower clay content leading to deeper compaction.
- Deep ripping to remove the compacted layer can significantly increase the yield potential of some soils – especially deep light-textured soils where there is softer soil below the hard layer.
- To prolong the benefits of deep ripping it is best done in combination with controlled traffic farming.Wheeled cropping machinery compacts soil to depths of 30-50cm. Severity and depth of compaction is related to soil type, soil moisture, axle load and the size of the tyre 'footprint' related to tyre pressure.

Sandy soils with no clay content will compact to greater depth than soils with some clay content, such as northern wheatbelt loamy sands.

On sandy soils in the northern agricultural areas of Western Australia, peak soil compaction from wheeled machinery occurs at about 30cm depth, but on the deep sands of the south coast sandplain, high soil strength can extend from a depth of 30cm to 50cm.

Sandy soils do not shrink and swell through wetting and drying cycles so do not loosen themselves through time. Roots only grow freely through soil when soil strength is less than 2.0 MPa. At 2.5-3.0MPa root growth is slowed and beyond this effectively stops.

Deep ripping to break up compacted sandy soil needs to be deeper than in the last century because modern cropping machinery is heavier and compacts the soil deeper. Deep ripping uses strong deep working tines to penetrate compacted soil and mechanically break up and shatter the soil hard pan.

For deep ripping to be effective:

- The ripping tines must be able to penetrate below the compacted soil layer.
- Soil must be moist enough to allow penetration of the ripping tines but not so moist that the tines cause smearing without fracturing and shattering the soil.

Tine spacing, working depth, shallow leading tines or discs, soil moisture content, timing and soil type all need to be taken into account and not all soils and crops respond every season. Benefits of deep ripping usually diminish over about three seasons but can persist for more than ten seasons when used in combination with controlled traffic systems.

7.5.1 Economics

The cost of deep ripping is between $40–50/ha for sandplain soils, much of which is related to the draft force and associated fuel required to pull the deep working tines through the soil.

Traditionally, deep ripper tines have been set to the same depth to penetrate and fracture the soil but recent research has shown that single, shallow leading tines working in-line and ahead of the deep ripping tine reduce the draft force on clay soils by up to 18 per cent and sandy-textured soils by 10-15 per cent (Table 16).

Table 16: Force required to deep rip a compacted loamy sand at Merredin, WA using either a classic ripper (single tine at 33cm) or a classic ripper + a single or double leading tine at various depths.

Ripper set-up	Surface area disturbed	Force required	Proportion of classic ripper force (%)
Classic ripper (one tine@ 33cm)	0.29	95	
Single leading tine 8cm	0.25	84.5	-11
Single leading tine 13cm	0.27	80	-15
Single leading tine 18cm	0.28	100	+6
Double leading tine (one @18cm & one @23cm)	0.26	100	+8

Source: Hamza et al (2013).

The shallow leading tine loosens the upper soil layers reducing the resistance and amount of soil the ripping tine is required to fracture. Shallow leading tine rippers are also ideally suited to placing lime or other soil amendments at a range of depths into the soil profile behind the tines.

Attaching wings to the tines helps to break out the soil between tines when ripping at greater depths. Single pass ripping to depth often results in slotting at the base of the tine furrow rather than soil breakout between the tines. Using a roller or soil packer behind the deep ripper firms the soil surface, which can help avoid seeding depth and crop establishment issues on deep ripped soil.

Loosened soils can be more susceptible to compaction after deep ripping and it is recommended that deep ripped soil is left to settle for at least two weeks before sowing. Ripping can be done the spring and summer before sowing if paddock use and conditions allow. Some growers rip paddocks immediately after sowing to avoid seeding machinery sinking and deep seed placement.

7.5.2 Yield benefits

Deep ripping is most effective in deep sandy-textured soils where roots need access to deep subsoil moisture (Table 16). However if the soil below the depth of ripping contains other constraints, such as acidity, poor structure or subsoil salinity, the benefit of deep ripping will be limited.

Grain yield responses to deep ripping on deep sands and sandy earths have tended to be large (25-35 per cent) and reliable especially in areas receiving more than 350mm rainfall (Table 16). Benefits from deep ripping these soils appear to last for at least three years, depending on crop rotation.

Deep ripping of heavier textured soils such as the sandy clay loams, loams and even sodic clays has often been less reliable.

Deep ripping duplex soils can be beneficial but only when the sandy or loamy A-horizon is deeper than about 35cm, the common depth of ripping (Table 17). In shallow duplex soils, where the clay subsoil starts higher in the profile, nutrients and water may be held higher in the profile, allowing access by shallower roots and reducing the benefit of roots being able to explore a greater depth of soil.

It is important to remember that compact soil is often not the only constraint to plant growth and nutrition in subsoils. Large areas of sandplain soils are acid enough to cause aluminium toxicity to root growth. In addition layers of rock in many types of subsoil are hostile to root growth and plant nutrition.

In the more southern and central parts of the wheatbelt the valleys often have duplex and clay soils with very saline and boron rich subsoils which inhibit root exploration and are not economic to rectify.

One of the largest potential downsides associated with deep ripping is that it increases the risk of haying off when soil water reserves are low and the finish to the season is dry. This occurs when subsoil constraints are moderate, slowing root growth but not preventing eventual root growth to depth.

Table 17: Summary of published average wheat grain yield increases in response to deep ripping.

	Number of comparisons	Average yield response		Reference
		t/ha	%	
Various: sand-clay	65	0.48	25	Davies et al 2006
Yellow loamy sands	46	0.65	37	Jarvis 2000
Duplex with A horizon < 30cm	13	0.06	4	Crabtree 1989
Duplex with A horizon > 30cm	22	0.33	22	Crabtree 1989

Source: Davies and Lacey (2011).

7.5.3 Controlled traffic farming

Even in the best no-till system 40 per cent of cropping paddocks are traversed by crop machinery wheels each season, with the average land area covered being closer to 70 per cent. Controlled traffic systems can reduce the area affected by traffic (and compaction) to 10-15 per cent.

Benefits of controlled traffic farming

- Inputs reduced by 3–10 per cent because of less overlap.
- Up to 25 per cent savings in fuel use.
- Crop yield increases of 5–15 per cent depending on conditions.
- Firm tramlines provide easier access when soil is wet.
- Reduced driver fatigue when auto-steer used.
- More agronomic options including shielded inter-row spraying, relay planting and inter-row or on-row seed and fertiliser placement.

The optimum strategy for managing subsurface compaction involves deep ripping to remove subsoil compaction followed by implementation of a controlled traffic farming system to prevent compaction from recurring.

Typically, the benefits of deep ripping diminish over two to three seasons as soils begin to re-compact. However, under controlled traffic systems the reduced soil strength of deep ripped soils can last beyond three years (Figure 17).

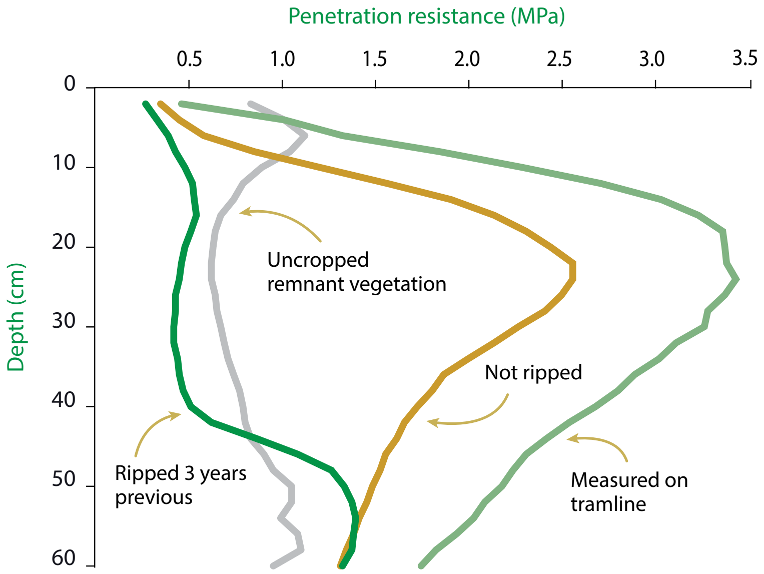


Figure 17: Soil strength measured on yellow sandy earth soil at field capacity three years after deep ripping to 50cm (dark green line) compared with unripped soil, soil compacted under wheel tracks and uncropped soil with remnant vegetation nearby. Note there is no evidence of re-compaction of the ripped soil under the controlled traffic farming system.

Source: Davies and Lacey (2011).

Tramline or controlled traffic farming allows machinery access to paddocks for timely operations but restricts wheel and track compaction to defined tramlines.

The main benefits of controlled traffic are higher grain yields and quality and lower input costs due to less overlap and lower fuel use.

Economic modelling of controlled traffic trials in WA between 1997-2004 showed controlled traffic delivered up to a $45/ha benefit in higher grain income and lower input costs (Figure 18).

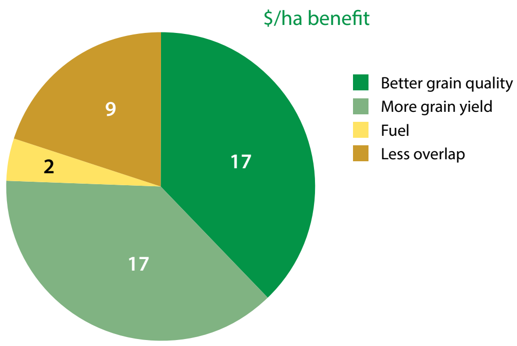


Figure 18: Economic modelling of controlled traffic trials in WA between 1997-2004 showed controlled traffic delivered up to a $45/ha benefit in higher grain income and lower input costs.
Source: Kingwell and Fuchsbichler (2011).

More information

For more information on controlled traffic farming in WA read: www.nacc.com.au/sites/nacc.com.au/files/1090/pdf/NACC_Controlled_Traffic_Farming_Technical_Manual.pdf

The modelling study conservatively estimated that in a 1.2 t/ha wheat year in WA at 2011 wheat prices the economic benefit of implementing tramlining was about $36/ha if auto steer was already being used and $45/ha if auto steer had yet to be adopted. The pie chart (Figure18) shows the amount gained from improved grain income and less use of inputs. If auto steer is already in use there are no gains in overlap reduction.

The analysis was based on a conservative five per cent grain yield increase, a 2.5 per cent shift to a better wheat grade and a 10 per cent reduction in inputs. The analysis assumed the residual soil compaction between the tramlines was removed when the system was first established.

7.5.4 Farm-scale yield trials

Farm scale investigations of controlled traffic farming between 1997 and 2000 in WA showed they delivered about 10 per cent more yield and better grain quality than uncontrolled traffic systems (Table 18).

The trial used a 90-foot farm sprayer, 30-foot farm header and a 30-foot research seeder with a small tractor for the controlled traffic system. The normal traffic system used the 50-foot farm seeder with a larger tractor. The whole paddock was deep ripped in the first year. For the controlled traffic system the two ripper-tines were lifted to keep firm tramlines.

Table 18: Long-term tramline impacts on crop yield at Mullewa, WA (on yellow sand).

Year	1997	1998	1999	2000
Crop	Wheat	Lupin	Wheat	Canola
Yield -Tramlines (t/ha)*	2.4	1.1	2.45	0.94
Yield +Tramlines (t/ha)	2.6	1.2	2.77	1.06
Tramline benefit (%)	8	10	13	12
Grain quality			Fewer screenings	Higher oil

Source: Department of Agriculture and Food, WA. * All yields used the farm header and included bare tramlines.

Resources

GRDC Fact Sheet on deep ripping

www.grdc.com.au/uploads/documents/GRDC_DeepRipping_6pp_.pdf

GRDC Fact Sheet on controlled traffic

www.grdc.com.au/GRDC-FS-ControlledTraffic

Contact

David Hall

Department of Agriculture and Food, WA

P (08) 9083 1142

E david.hall@agric.wa.gov.au

References

Blackwell P and Davies S (2013) Controlled Traffic Farming value to low rainfall croppers; especially using deep tillage; Liebe Local Research and Development Results. P 141-147.

Blackwell P, Hagan J, Davies S, Riethmuller G, Bakker D, Hall D, Knight Q, Lemon J, Yokwe S and Isbister B (2013) Pathways to more grain farming profit by CTF in 2013 WA Agribusiness Crop Updates; Burswood Perth.

Crabtree, WL, 1989, 'Cereal grain yield responses to deep ripping on duplex soils', Australian Journal of Experimental Agriculture, vol. 29, pp 691–694.

Davies, SL, Gazey, C, Gilkes, RJ, Evans, D and Liaghati, T 2006, 'What lies beneath? Understanding constraints to productivity below the soil surface', 2006 Regional Crop Updates, Geraldton, Department of Agriculture and Food, Western Australia.

Davies D L and Lacey A (2011) Subsurface compaction - A guide for WA farmers and consultants. Department of Agriculture and Food, Western Australia Bulletin 4818

Jarvis, R 2000, 'Deep tillage', In: WK Anderson and JR Garlinge (Eds.) The Wheat Book. Principles and practice, pp. 185–187, Bulletin 4443, Department of Agriculture, Western Australia.

Kingwell R and Fuchsbichler A (2011) The whole-farm benefits of controlled traffic farming: An Australian appraisal. Agricultural Systems 104: p513–521.

7.6 Stubble management

Key messages

- Burning narrow windrows rather than entire paddocks results in higher weed kill and less erosion risk.
- Concentrating residues in narrow windrows increases the temperature of the burn, resulting in higher weed kill.
- Best results are achieved when windrows are burnt during light cross or head winds of (5 -10 km/hour) as the wind fuels the fire all the way to the soil surface where the majority of weed seeds are located.
- Consult the local shire or fire warden for burning regulations and always have fire fighting equipment on hand.
- Windrows must be burnt under the right conditions (wind, temperature and humidity) to achieve high levels of weed seed kill while minimising fire escapes. Use the McArthur 'grass fire index' to determine suitable burning conditions. Narrow windrow burning

To kill annual ryegrass seed requires a temperature of 400°C for 10 seconds while complete kill of wild radish seed retained in pod segments requires 500°C for 10 seconds (Walsh and Newman 2007).

During traditional whole paddock stubble burning, the very high temperatures needed for weed seed destruction are not sustained for long enough to kill most weed seeds.

By concentrating harvest residues and weed seed into a narrow windrow (0.6-1.5m wide), fuel load is increased and the period of high temperature extended to several minutes, improving the kill of weed seeds (Figure 19).

Concentrating harvest residues into narrow windrows increases fuel load, which in turn extends the period of high temperatures to several minutes and improves weed kill.

Photo credit: Evan Collis.

Note to Figure 19

The narrow windrow provides a longer and hotter burn for weed seed kill.

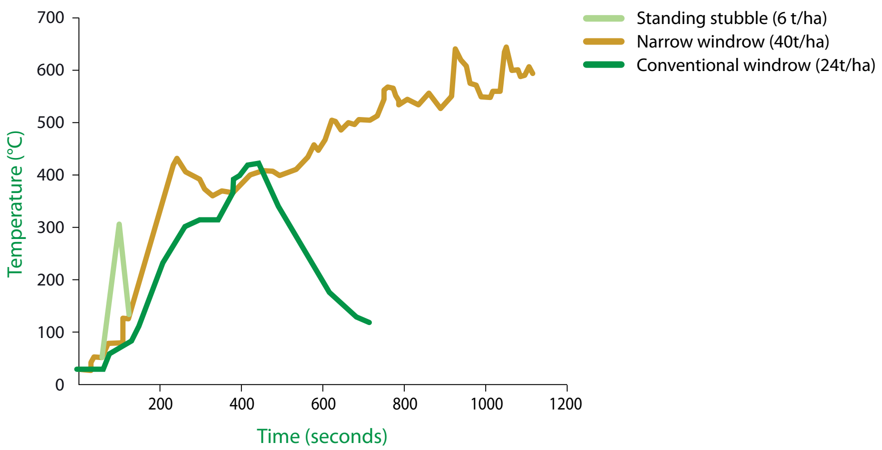


Figure 19: Temperature and duration of stubble fire in standing stubble, narrow windrows and conventional windrows.

Source: Newman and Walsh (2007).

Narrow windrow burning can control up to 99 per cent of annual ryegrass and wild radish seed present in the windrow (Walsh and Newman 2007) but the kill rate is more likely to be in the range of 30 to 90 per cent (Walsh 2012) (Figures 20 & 21).

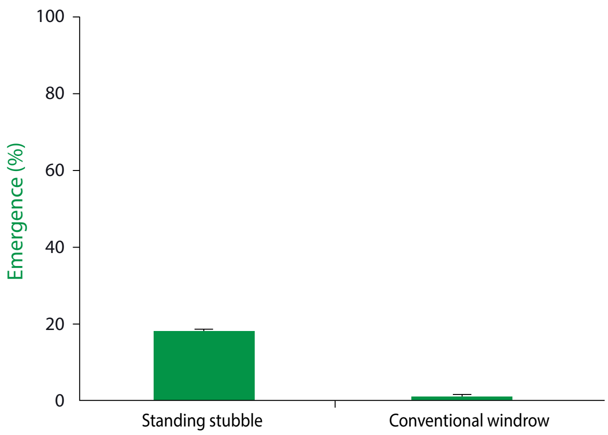


Figure 20: Impact of burning standing stubble or conventional windrows on ryegrass emergence in autumn. (Proportion of unburnt control).

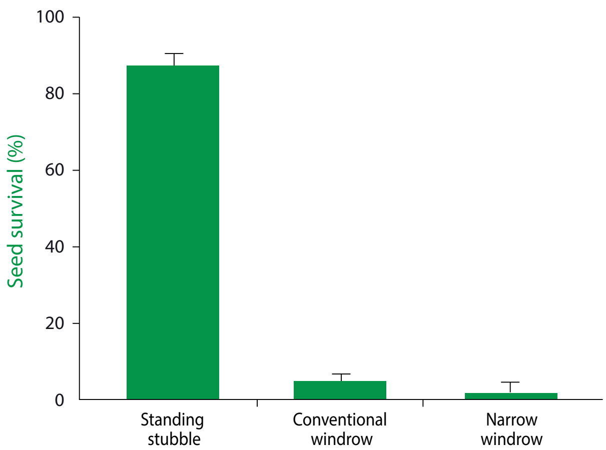


Figure 21: Proportion of ryegrass seed surviving burning of standing stubble, conventional windrow or narrow windrow compared to unburnt control.

By the time the burning season begins in March-April, the majority of weed seeds have settled to the soil surface beneath the windrow. Consequently, temperatures of 400-500°C are required to ensure complete weed seed kill. This is best achieved when windrows are burnt when there are light (5 to 10km/hour) cross or head winds, as this helps achieve a slow burn, with windrows burning to the soil surface (Figure 22).

Note to Figure 22

Burning during very still conditions can also create a slow burn but the fire tends to become starved of oxygen and does not burn to the soil surface. Waiting for a light crosswind overcomes this problem.

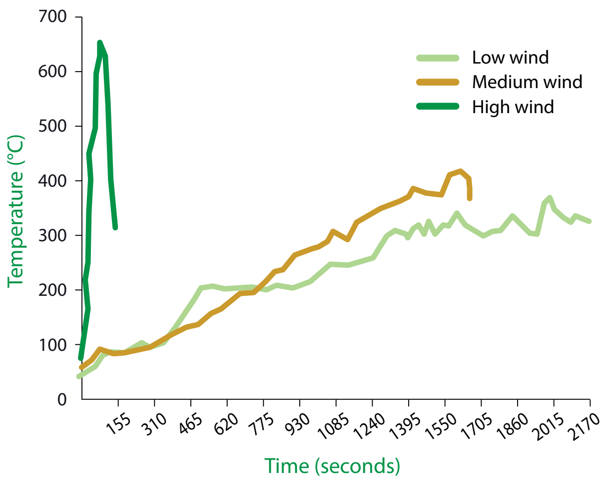


Figure 22: Length and intensity of fire generated from burning narrow windrows in low, medium and high winds conditions.

7.6.1 Timing

Although burning early in the season is likely to achieve best weed seed control, in many instances this is not practical due to weather conditions creating high risk of fire spread. In addition, premature removal of stubble can increase erosion risk and reduce the efficiency of water conservation.

Burn the outside two laps of the paddock first before commencing the remainder of the paddock.

To minimise the risk of fire escapes, the McArthur 'grass fire index' can be used to predict the best conditions for burning windows. The grass fire index is available by downloading an App called 'NSW PocketFire', which is applicable across Australia. The app calculates a grass fire index using current ambient temperature, humidity and wind speed data. A grass fire index between 2 and 10 will minimise the risk of fire escapes.

As a rule of thumb, a grass fire index of:

- less than 15 will give a reasonable windrow burn;
- 8-10 is probably ideal;
- below two is too cold and humid to give a good burn;
- more than 15 has a high risk of the fire getting out of control.

More information

Read an article on burning large windrows: http://ausgrain.com.au/Back%20Issues/244ndgrn14/Burning%20windrows.pdf

More information

For more information on narrow windrow burning read: www.agronomo.com.au/storage/e-weed/e-weed%20April%202014.pdf

Videos

Watch a video on the principles of windrow burning to control weeds: https://www.youtube.com/watch?v=btKeORv8PyM

Narrow windrow burning tips

- It is important not to 'over-thresh' the straw as it will become too fine and will not burn well come March.
- Light the windrows when the wind is at 90 degrees across or diagonal to the windrow (rather than parallel) as this prevents the fire developing a face, which can carry between the rows (Figure 23).
- Light up across the windrows every 75m in good conditions and closer as conditions cool down. The fires will burn to meet each other.
- Best burning conditions are in the second half of March for southern Australia.
- Plan to commence burning just on dark when it is cooler but also plan to have the burning finished when the dew falls, as this will limit stubble smouldering and flare-ups during the next day.
- Usually only about 200-300 hectares per team can be burnt each night.
- Move windrows each year to prevent concentration of potassium (Newman 2012).

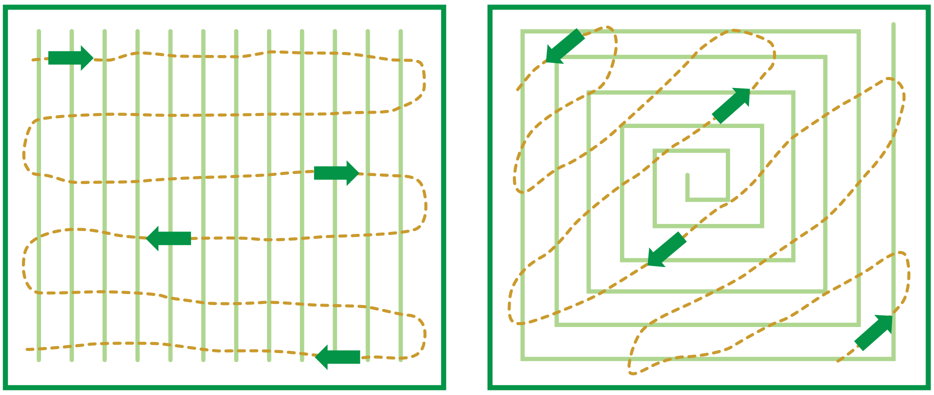


Figure 23: Recommended lighting patterns for narrow windrow burning in relation to harvesting pattern.

Source: Section 4 of the Integrated Weed Management Manual.

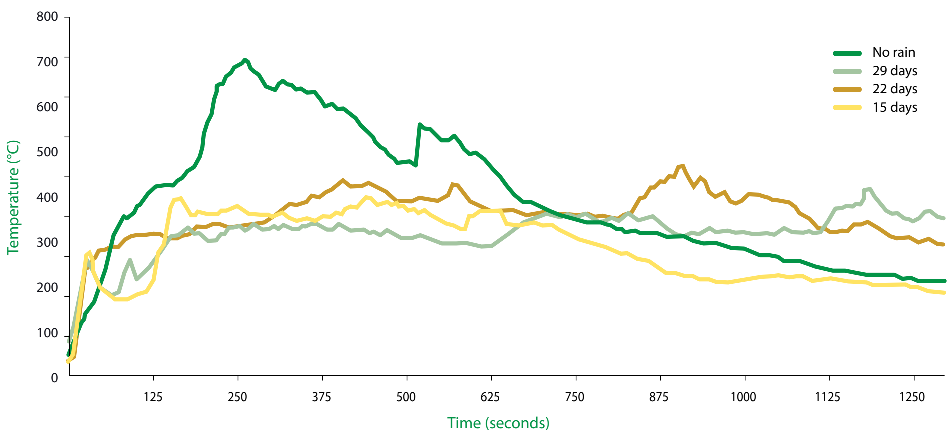


Figure 24: Impact of a simulated 50mm rainfall event 15, 22 or 29 days before windrow burning on the length and intensity of the subsequent fire.

Note to Figure 24

Sections of wheat windrow were either left dry ('nil treatment') or wet with the equivalent of 50mm rainfall 15, 22 or 29 days before burning in late March. Rainfall at any stage before burning reduced the maximum burning temperature relative to the nil rainfall treatment. However, even in the wet treatments burning temperatures of 300-400°C were achieved for at least 10 minutes, which is adequate to destroy weed seeds.

7.6.2 Wet windrows

Summer rain will lower the burning temperature achieved in narrow windrows however good weed seed kill is possible as long as the windrows are given two weeks or more to dry before burning (Figure 24).

Resources

Australian Herbicide Resistance Initiative
www.ahri.uwa.edu.au

GRDC Integrated Weed Management hub
www.grdc.com.au/Resources/IWMhub

WeedSmart website
www.weedsmart.org.au

Contact

Peter Newman
Australian Herbicide Resistance Initiative
P (08) 9964 1170
E petern@planfarm.com.au

References

Newman, P (2012) Nutrient removal – the hidden cost of chaff carts and windrow burning. 2012 Agribusiness Crop Updates, pp. 194–197. Department of Agriculture and Food, Western Australia, Perth, Australia.

Walsh, M and Newman, P (2007) Burning narrow windrows for weed seed destruction. Field Crops Research 104: 24–40.

Walsh, M and Powles, S (2007) Management strategies for herbicide-resistant weed populations in Australian dryland crop production systems. Weed Technology, 21(2), 332-338.

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

Crop Sequencing:

CSA00029 – National integration of crop sequence strategies and tactics
(S: 01/07/2010 F: 30/06/2015)

CSA00037 - MPCN II - Reassessing the value and use of fixed nitrogen
(S: 7/1/2012 F: 6/30/2015)

DAW00213 – Putting the focus on profitable break crop and pasture sequences in WA
(S: 01/07/2010 F: 30/06/2015)

DAW00242 – Subsoil constraints – understanding and management
(S: 01/07/2014 F: 30/06/2019)

PLN00007 - Break crop economics for Kwinana East, (F: 01/01/2013 S: 30/06/2013)

RAI00004 - Soil constraints and management options are poorly understood (RCSN) (S: 01/07/2014 F: 30/06/2015)

RSS00011 – Mapping the extent of subsoil constraints and identifying the cost of subsoil constraints across the southern and western grains regions
(S: 01/04/2014 F: 30/12/2014)

Summer Weeds:

CSP00128 - Maximizing crop yield in the HRZ of WA through efficient use of water and nutrients (S: 01/07/2009, F: 30/06/2013)

PRE00002 – Measuring the impacts of different timings of summer weed control in the Kwinana Zone (S: 1/01/2014 F: 01/02/2016)

SDI00015 – Summer weed spraying (RCSN) (S: 02/02/2013 F: 01/02/2014)

Soil Acidity:

CWF00019 - Soil acidity and pH management for Central West farming districts (part of DAW00236 project - Soil acidity is limiting grain yield)
(S: 01/01/2014 F: 30/06/2018)

DAW00218 – Wheat agronomy – building system profitability in the Western Region
(S: 01/07/2011 F: 30/06/2015)

DAW00236 - Soil acidity is limiting grain yield – (S: 01/01/2014 F: 30/06/2018)

PLN00010 – Soil probes for cheap and accurate soil PH testing (S: 01/12/2013 F: 30/12/2014)

Non-wetting Soils:

CSP00139 - Novel solutions for managing non-wetting soils (S: 01/07/2010 F: 30/06/2015)

DAW00204 - Delivering agronomic strategies for water repellent soils in Western Australia,
(S: 01/07/2010 F: 30/06/2015)

DAW00244 – Delivering enhanced agronomic strategies for improved crop performance on water repellent soils in Western Australia (S: 01/07/2014 F: 30/06/2019)

POL00001 – Polymers probed in novel non-wetting research (S: 01/07/2012 F: 30/06/2015)

SDI00016 - Extension of management methods to address non-wetting soils in the Albany and Kwinana West Zone (Combatting non-wetting soils booklet – a tour of on-farm research in Western Australia – 2014) (S: 01/07/2012 F: 30/06/2014).

SDI00008 - Management options of non-wetting soils in the southern coastal region
(S: 01/07/2012 F: 01/01/2014)

SDI00006 – Management of non-wetting soils – Kwinana West (S: 01/06/2012 F: 01/04/2013)

SDI00005 - Soil and water relationships during variable seasons Kwinana East (S:01/06/2012 F: 01/04/2013)

SDI00003 – Soil and Water relationships during variable seasons – Albany (S:01/05/2012 F: 02/2013)

UMU00041 – MPCN II – Assessing nutritional benefits of clay amendment & cultivation of sands (S: 01/02/2013 F: 31/01/2016)

UMU00042 - MPCN II - Managing potassium nutrition to alleviate crop stress (S: 01/07/2012 F: 30/06/2015)

Soil compaction:

DAW00243 – Minimising the impact of soil compaction on crop yield
(S: 01/07/2014 F: 30/06/2019)

Stubble management:

DAW00218 - Wheat agronomy - building system profitability in the Western Region
(S: 01/07/2011 F: 30/06/2015)

LIE00006 – Improved stubble and soil management practices for sustainable farming systems in the Liebe area (S: 30/07/2009 F: 31/12/2012)

DAW00193 – The agronomy jigsaw: Finding the pieces that maximise water use efficiency (S: 01/07/2009 F: 30/06/2012)

WAN00020 - Dry Seeding into crop residues in the WA wheatbelt
(S: 01/07/2012 F: 01/07/2013)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC pre-season projects can be found at: www.grdc.com.au

SECTION 8

Pre-sowing

8.1 Soil moisture monitoring

Key messages

- Monitoring soil moisture supply underpins major management decisions like sowing time and the matching of nitrogen to crop yield potential as the season progresses.
- An estimate of the capacity of a soil to supply water to plants (plant available water capacity) is required before potential crop yield can be calculated.
- Plant available water capacity (PAWC) is time-consuming and costly to quantify but can be estimated using soil information stored in the CSIRO APSoil database.
- Soil moisture (plant available water) can be estimated using tools that range from easy-to-use methods providing a generalised soil moisture estimate through to complex and more accurate crop production models and soil moisture probes requiring full soil characterisation.

Plant available water capacity (PAWC) is the amount of water a soil can hold that is available to a crop (Figure 1).

PAWC can be thought of as the size of the soil moisture bucket. Heavier soils can hold more water than lighter soils and therefore have a larger PAWC bucket. Plant available water (PAW) is a measure of how full the soil moisture bucket is. PAW changes throughout the season in response to rainfall, weed density and soil constraints.

The PAWC bucket is refilled by rain and drawn down by crop water use.

PAWC is measured in the field by filling and emptying the bucket. The full bucket is called the drained upper limit (DUL) and the empty bucket is called the crop lower limit (CLL) (Figure 1).

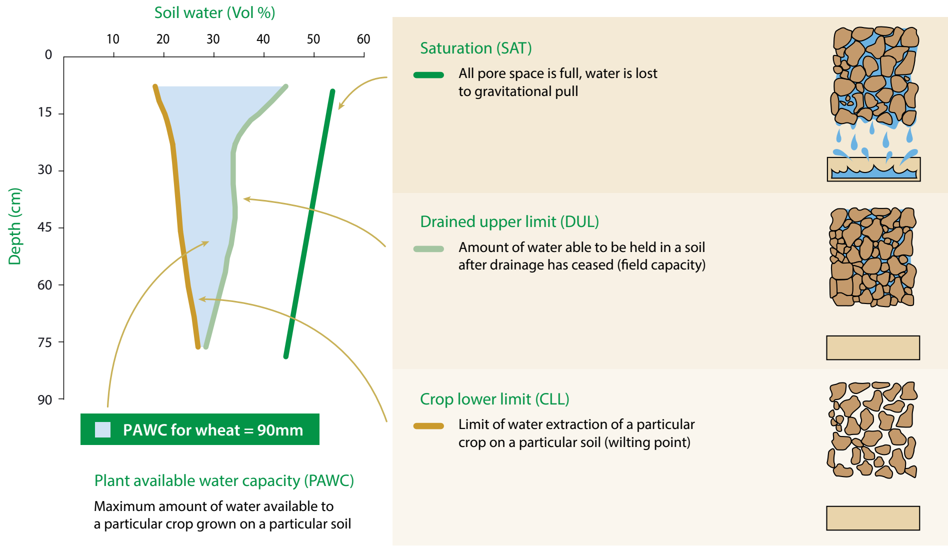


Figure 1: Components of the plant available water capacity of a soil. Re-drawn from Dalgliesh (2009).

The DUL is taken as the maximum amount of water a soil can store. It is measured by ponding water on an area of soil over a few days and then measuring its moisture content after the soil has finished draining.

The CLL is measured at the end of a dry season and is the amount of water remaining in the soil after a crop has extracted all it can over its full rooting depth. The CLL is water bound tightly to soil particles that remain unavailable for crop use. CLL varies from 2-3 per cent of total soil water capacity in coarse sands to 20-25 per cent in clays.

PAWC varies with soil texture because clays and loams hold more water than sands. It also varies with crop type because different crops have different rooting depths, and as such access shallower or deeper buckets (Figure 2).

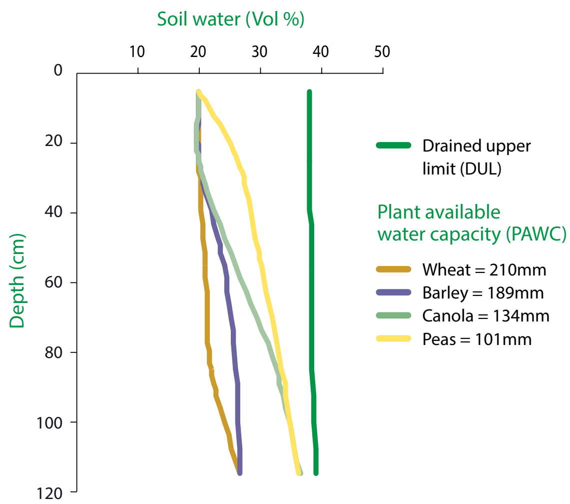


Figure 2: Impact of crop type on the amount of soil water that can extracted to depth. Note: Field peas and canola use less soil moisture than wheat.

Source: Dalgleish (2009).

PAWC varies spatially across paddocks and farms due to differences in soil texture and rooting depth, with sandy soils having less PAWC than clay soils (Table 1). However, while heavy soils with high PAWC can hold more water for use by a crop in wet years, they can lose significantly more water to evaporation than lighter soils in dry years.

Table 1: Plant available water capacity across a paddock varying in soil type in the northern wheatbelt of Western Australia.

Soil type	Shallow gravel	Shallow sandy gravel	Sand, gravel going into red clay	Pale gravel sand over clay	Deep yellow sand	Duplex deep yellow sand
Average productivity	low	medium	medium	high	high	high
Apparent rooting depth (cm)	60	60	100	200	200	200
Subsoil constraint	Shallow soil	pH 4.1 (100cm)	Shallow soil	none	none	none
PAWC (mm)	74	46	54	80	124	151

Source: Oliver et al (2006).

Note to Table 1

Table 1 forms part of a dataset of PAWC measured on several contrasting soil types on properties in WA's northern cropping region. The soil types varied from deep yellow sands through to shallow gravels. Even across one paddock, it can be seen that PAWC can vary from 45 to 150mm.

Subsoil constraints that limit deep root penetration (for example, acidity and salinity) will also effectively reduce a soil's maximum PAWC value. For example, while a deep-yellow sand can have a plant available water capacity of 100mm, the water capacity of the same sand with an acidity problem can be reduced to just 30mm. Overcoming low soil pH with lime can deliver a significant increase in the yield potential of such a soil (Oliver et al 2012).

When the PAWC is combined with measures of a soil's physical and chemical constraints, soils can be compared for potential productivity, and yield variations between soils can be better understood.

Allocation of fertiliser, seed, lime, clay and other inputs can then be made in accordance with variations in PAWC to lift overall productivity and crop returns.

Plant available soil moisture (PAW) can be monitored throughout the season using real-time methods such as soil moisture probes or models such as CliMate and the Department of Agriculture and Food, WA's AgSeasons service, which use an estimate of PAWC based on soil type. The crop production model Yield Prophet® also provides a soil water balance through the season (based on estimates of PAWC and rainfall to date) and couples this with a sophisticated yield potential outlook and nitrogen application requirements (Table 2).

Measuring PAWC is a slow process as it takes an entire season to obtain the first set of CLL measurements, and several seasons of CLL data to generate a precise measure of CLL for a single crop.

PAWC can be estimated for a soil type (with no constraints) using information stored in the APSoil database.

More information

Read a case study on lifting water use efficiency in the eastern wheatbelt of Western Australia: www.grdc.com.au/GCS103-SecuringYieldsOnTheEdge

Read a case study on matching inputs to plant available water content: www.grdc.com.au/GC111-PlantAvailableWaterGuidesRiskManagement

More information

For more information on plant available water capacity and the value of monitoring soil moisture through the season read: www.grdc.com.au/2014-Dalgliesh-SoilWaterManagement and www.grdc.com.au/GRDC-Booklet-WUE

Use the SoilMapp app: www.csiro.au/soilmapp and the DAFWA MySoil tool: https://www.agric.wa.gov.au/mysoil to gather soil information relevant to WA.

2014 research update paper - who is going what in WA? www.grdc.com.au/research-and-development/GRDC-Update-Papers/2014/05/measuring-and-managing-soil-water-who-is-doing-what-in-WA

The expected soil types and constraints in a region can be determined from DAFWA soil maps and reports on the MySoil website.

Quantifying a soil's plant available water capacity (PAWC) is a slow and tedious process that can take several seasons. Estimates of PAWC for soils (with no constraints) can be obtained from the CSIRO APSoil database, which feeds into crop production models like Yield Prophet and APSIM.

Photo credit: Arthur Mostead.

Research in the pipe-line

A soil moisture research project has been established in WA with GRDC funding to assess how the WA cropping industry uses soil moisture information and to implement training opportunities for soil moisture measurement and monitoring.

The project will characterise 105 soils in WA over three years, targeting regional gaps in the ApSoil database and the heavier soils, and gravel and duplex soils often considered difficult to characterise (Oliver, 2014).

A panel of 'Soil Water Champions' has been established as part of the project to provide linkage between CSIRO, DAFWA, grower groups and consultants operating in the soil moisture RD&E area.

Table 2: Comparison of the various soil moisture monitoring methods available to WA wheat producers.

	Soil water probes	DAFWA AgSeasons	CliMate - HowWet	Yield Prophet®
Cost and complexity	From $6000 plus annual fee. Requires technical support.	Free on line. Simple to use.	Free online. Simple to use.	About $500 for soil analysis and subscription. Best used with some form of consultancy support.
Frequency	Near live data.	Updated monthly (sometimes twice monthly).	Run on user demand using meteorology data up to previous day.	Access daily meteorology data daily. Farm rainfall as entered.
PAWC and transpiration	Needs to be calibrated for DUL*, CLL* and rainfall. PAWC by profile measured in real-time.	Estimates built in. No PAWC by profile.	Estimates built in. No PAWC by profile.	Estimates built in. PAWC by profile.
Potential yield estimates	Yield not included but Yield Prophet link being developed. No management decisions (nitrogen) currently provided.	Yield estimates provided but no management decisions.	No yield estimates or management decisions provided.	Yield probability range provided and excellent integration with sowing time and nitrogen tactics.
Accuracy of PAWC estimate	Needs to be calibrated for each site for actual PAWC, top 20 cm soil profile not included.	Acceptable.	Calibrated to Queensland and appears to estimate higher PAWC than WA soil probes or AgSeasons.	PAWC simulated following initial sampling. Soil type characteristics critical. User skill can improve accuracy.
Other information	Rainfall included and extra weather data at extra cost.	DAFWA state weather station coverage provided.	BoM weather station and patch point data analysis for main weather variables.	Rain to date, nitrogen and water balances, crop development and BoM climate outlook.
Locations	Specific location and soil type for each probe.	Generic location for selected soil type and nearby station.	Generic location based on for Queensland selection of uniform soil profiles.	Specific to site or zone chosen.
Major weaknesses	High cost. Potential errors from reliance on specific location and crop/paddock history. Soil moisture only measured <10cm from probe. Requires mobile phone signal for telemetry.	Very general information and does not yet provide management recommendations.	Provides general information on soil water. Does not account for transpiration (based on bare earth).	Difficult to get soil characterisation correct without experience and extensive testing. Nitrogen simulations poor for WA.
Main strengths	Live data, optional weather parameters at cost. Reflects actual paddock management. Link to Yield Prophet in pipeline.	Soil type selection linked to potential crop yields. Provides seasonal outlook on same page.	Available as an easy-to-use iOS app. Offers full climate parameter analyses and can refer to website for more comprehensive information.	Soil water, potential crop yield and season to date and season outlook fully integrated. Provides water and nitrogen budgets.

*DUL Drained Upper Limit, *CLL Crop Lower Limit. Source: Jeremy Lemon Department of Agriculture and Food, WA.

References

Dalgliesh, N (2009) Soil water in cropping systems: concepts and language. Presentation to the Grains Research and Development Corporation National Water-Use Efficiency Initiative meeting held in Canberra in July, 2009. Source: www.csiro.au/Organisation-Structure/Divisions/Plant-Industry/Cropping-systems-soil-water-concepts-lanaguage.aspx

Oliver, Y and Roth, C (2014) Measuring and managing soil water – who is doing what in WA. Proceedings 2014 Crop Updates, Perth, WA.www.giwa.org.au/2014-crop-updates

Oliver, Y Robertson, M Lawes, R (2012) Bridging the Yield Gap: diagnosing poor performing patches from paddock to farm scale. Proceedings of the 16th Australian Agronomy Conference, 14-18th October, 2012 Armidale, New South Wales. www.regional.org.au/au/asa/2012/precision-agriculture/8115_oliverym.htm

Oliver Y, Wong M, Robertson R, Wittwer K (2006) PAWC determines spatial variability in grain yield and nitrogen requirement by interacting with rainfall on northern WA sandplain. Proceedings of the 13th Australian Agronomy Conference, 10-14 September 2006, Perth, Western Australia. www.regional.org.au/au/asa/2006/concurrent/water/4570_oliver.htm#TopOfPage

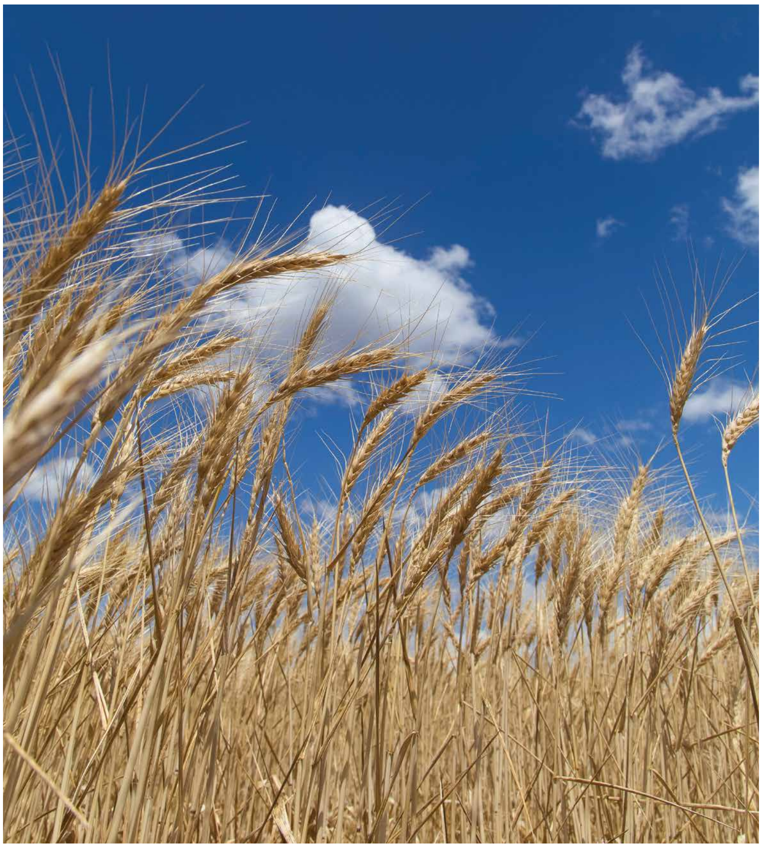
Contact

Dr Yvette Oliver
CSIRO
P (08) 9333 6469
E yvette.oliver@csiro.au

8.2 Variety choice

Key messages

- Wheat variety choice and sowing date underpin grain yield.
- Variety selection needs to account for yield, grain quality and disease attributes.
- Varieties sown to flower during their optimum flowering window have the best chance of avoiding frost damage and terminal drought.
- Flower Power is a decision support tool that can be used to determine the sowing time of WA wheat varieties least likely to encounter frost events after flowering and high temperatures during grain fill.
- Sowing at least two varieties of varying maturity or spreading sowing time of a single variety will spread flowering time and reduce the risk of frost and disease damage.



Wheat variety choice and sowing date underpin grain yield.

Photo credit: Chris Stacey.

More information

To access Flower Power visit: https://www.agric.wa.gov.au/frost/flower-power

To download the current wheat variety guide for WA: www.grdc.com.au/WAWheatVarietyGuide

For more information on wheat varieties: www.nvtonline.com.au

Read case studies on a noodle wheat grower and the noodle wheat market: www.grdc.com.au/GC111-NoodlesStillOnRonsCroppingMenu

www.grdc.com.au/GC111-NoodleWheats

More information

[DAFWA: New way to assess variety performance.](#)

[GRDC Update Paper: 2014 Wheat NVT Results, Peter Burgess; Rachel Thomson. Production Value PLUS System.](#)

[GRDC Update Paper: Ben Biddulph, Preliminary ratings of wheat varieties for susceptibility to reproductive frost damage.](#)

The Western Australian wheat variety guide summarises performance characteristics of commercially available wheats that have undergone testing in the National Variety Trials (NVT) and in western region trials coordinated through the wheat agronomy project run by the Department of Agriculture and Food, WA.

The guide includes variety summaries, agronomic, disease and herbicide tolerance characteristics and medium to long-term yield performance.

WA has a range of wheat varieties on offer with each characterised by their inherent grain hardness and quality and suitability for specific end-uses (Table 3).

The area sown to the Australian Hard wheat variety Mace⁽ᵖ⁾ has increased to more than 50 per cent of the WA wheat crop since its release in 2009 (Figure 3). Productivity and grain quality have driven the adoption of the variety.

Table 3: Classes and end-uses of wheat grown in Western Australia.

Wheat classification	Characteristics	Example WA wheat variety
Australian Hard (AH) Generally segregated at minimum protein levels of 11.5% (H2) and 13% (H1).	White, hard grained with high quality protein and strong dough characteristics. Excellent milling qualities. End-use: Asian breads and noodle products including instant and fresh yellow alkaline noodles and dry white salted noodles. European style pan and hearth breads, middle eastern-style flat breads and Chinese steamed products.	Mace⁽ᵖ⁾ Emu Rock⁽ᵖ⁾ Yitpi⁽ᵖ⁾ Bonnie Rock⁽ᵖ⁾ Cobra⁽ᵖ⁾
Australian Premium White (APW) Guaranteed minimum protein level of 10%.	Multi-purpose wheat of white, hard grained varieties with protein slightly lower than Australian Hard. End-use: Middle Eastern and Indian flat breads, pocket breads and tandoori breads, Asian noodles and other Asian products such as Chinese steamed bread.	Magenta⁽ᵖ⁾ Corack⁽ᵖ⁾ Estoc⁽ᵖ⁾ Wyalkatchem⁽ᵖ⁾ Justica CL Plus⁽ᵖ⁾ Scout⁽ᵖ⁾
Australian Premium White Noodle (APWN) Grain protein strictly controlled between 10-11.5%.	Developed specifically for the production of white salted noodles. Comprised of selected soft-grained wheat varieties with medium protein level.	
Australian Noodle (ANW) Ideal grain protein is 10.5% with varieties segregated based on protein of between 9.5 to 11.5%.	End-use: Japanese- style udon noodle market and the Korean-style ramen noodle market.	Supreme⁽ᵖ⁾ Calingiri⁽ᵖ⁾
Australian Standard White (ASW) No protein restrictions.	Multi-purpose wheat class consisting of white, hard grained wheat with a medium to low protein range. End-use: Middle Eastern, Iranian and Indian style breads such as lavash, naan and chapatti.	
Australian Soft (ASFT) Segregated at maximum protein level of 9.5% and 10.5%.	Comprised of very specific soft-grained wheat varieties. End-use: biscuits, cakes, steamed buns and extruded snack foods. Flour significantly whiter and brighter than other grades.	Kunjin⁽ᵖ⁾ Wedin⁽ᵖ⁾, EGA2248⁽ᵖ⁾ Bullaring⁽ᵖ⁾

Source: Australian Export Grain Innovation Centre and the Department of Agriculture and Food, WA.

Note Figure 3

In recent years premiums for noodle wheats such as Calingiri⁽ᵖ⁾ have not been enough to offset the benefits of alternative wheat varieties, such as the higher-yielding hard wheat Mace⁽ᵖ⁾, which made up more than half of WA plantings in 2013. This has contributed to reductions in noodle wheat planting in Australia from a high of about 30 per cent in 2004-05 to about 10 per cent of plantings in 2013. See more at: www.grdc.com.au/GC111-NoodlesStillOnRonsCroppingMenu

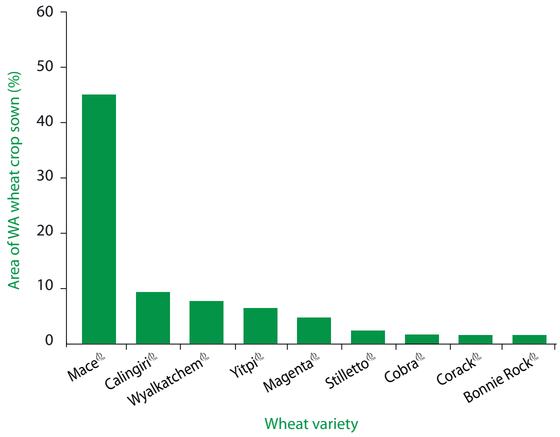


Figure 3: Proportion of total WA wheat area sown to the top ten wheat varieties in 2013. Source: CBH Group.

History – WA wheat varieties

Developed in the 1980s, the wheat varieties Gutha, Kulin and Amery were among the first wheat varieties bred specifically for WA conditions and the varietal trio made up a significant share of the WA wheat crop for the next 15-20 years. The release of the breakthrough varieties Westonia, Carnamah and Calingiri saw these varieties dominate WA plantings by 1999. Westonia, Carnamah and Calingiri combined yellow leaf spot resistance with acid soil tolerance and an ability to fill large plump grain under the stresses of the WA wheat belt. The release in 2002 of Wyalkatchem, which combined short stiff straw and a high harvest index with all of the disease and agronomic qualities of Westonia, Carnamah and Calingiri set a new benchmark for yield in WA (Figure 4).

Wyalkatchem dominated until Mace was released in 2009. Bred from Wyalkatchem and Stylet (a Spear family wheat from Roseworthy, South Australia), Mace combines many of the best traits from both families. This combination effectively lifted grain yield by an average of about five per cent and quality from Australian Premium White (APW) to Australian Hard (AH).

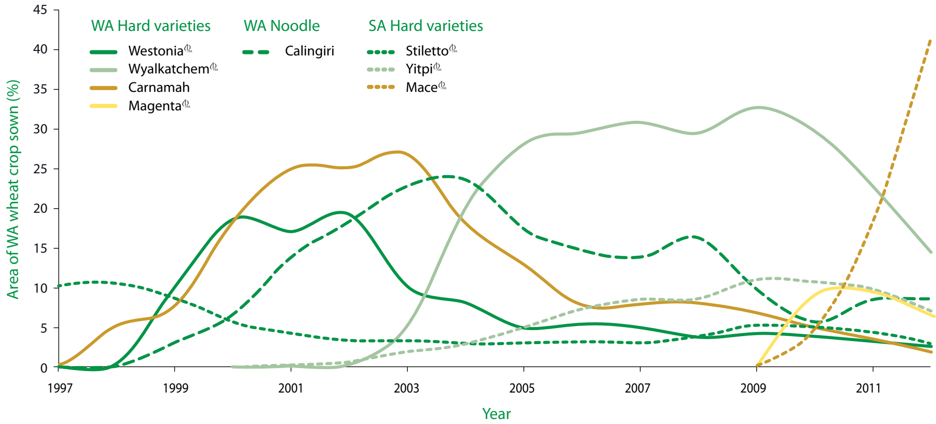


Figure 4: Percentage of area sown to the wheat varieties that have exceeded ten per cent of area sown to wheat in WA from 1997 to 2012. Data provided by Co-operative Bulk Handling Ltd. Source: Young (2013).

The rapid adoption of Mace in WA is due to its consistently high yields compared to other varieties in NVT trials over the past five seasons. Mace also provides good disease resistance, grain quality and better tolerance to sprouting than its other main competitors such as Wyalkatchem and Magenta.

However, there are alternative varieties released in the past five years that have shown specific production qualities to warrant them being considered as either a complement or viable alternative to Mace (Table 4) (Young 2013).

Table 4: Strengths of some WA wheat varieties relative to the most-widely grown variety Mace.

Variety	Strengths relative to Mace
Magenta (APW)	Mid-long maturing variety best suited to early sowing and where there is a high probability of yellow spot.
Emu Rock (AH)	Early maturing variety that is the most competitive with Mace at yields up to 2t/ha and so may have an important role in the lower rainfall regions.
Corack (APW)	Competitive with Mace where protein is likely to be restricted restricted to APW grade and yellow spot is prevalent. Note: Variable falling number and susceptibility to powdery mildew and black point make Corack unsuitable for the higher rainfall coastal regions.
Cobra (AH)	Yields well relative to Mace in very high yielding scenarios with similiar tolerance of yellow spot. Cobra has out-yielded MaceA on low pH soils where yields are above 2.5t/ha and has the same yellow spot rating as Mace.
Estoc (APW)	Yitpi background wheat with similar maturity that is a rust resistant alternative to Yitpi with a possible yield advantage, particularly in Agzones 5 and 6.
Scout (APW) and Envoy (APW)	Yitpi background wheats but earlier maturing and more competitive with Mace in the south where yellow spot is less prevalent and sprouting tolerance is important.
Justica CL Plus (APW) and Grenade CL Plus (APW)	Imidazolinone tolerant wheats with options for weed control that put them in a class of their own. Justica is better suited to the medium to high rainfall regions.

Source: Department of Agriculture and Food, WA.

Growers on the south coast of WA have capitalised on the early sowing options provided by Yitpi, which has a long maturity and reduced risk of low falling number following pre-harvest rain. Trojan and Harper are possible long season replacements

Videos

Watch a video on the performance of WA wheat varieties in the 2014 season: www.grdc.com.au/GCTV15-WheatVarietyPerformanceWA

for Yitpi - they have a similar falling number risk as Yitpi, similar maturity or five days earlier, depending on the environment, and yield better than Yitpi.

Two new noodle wheats will be available to WA growers in 2015. Zen is derived from Calingiri and Wyalkatchem parents and has improved disease resistance and higher yield. Supreme is a noodle wheat derived from Arrino and will be suited to later-sowing opportunities.

8.2.1 Variety choice and sowing time

Flowering time of wheat varieties is controlled by the vernalisation (exposure to cold), photoperiod (day length) and thermal time (accumulated temperature) requirements of the variety. The exact flowering date of a variety will vary from season to season, depending on sowing date and local temperatures.

More information

To access Flower Power visit: https://www.agric.wa.gov.au/frost/flower-power

View the latest frost tolerance ratings for wheat at: www.nvtonline.com.au

Recommended flowering times for wheat varieties are determined by assessing the maturity of varieties in different environments and with different sowing times (Table 5). The optimum flowering window is defined as the period between the last frost and the last effective rain.

Table 5: The optimum wheat flowering window for locations across the Western Australian wheatbelt.

North-east	North-west	Eastern	Central*	Lakes*	Great Southern	South Coastal
25 Aug – 15 Sept	3 Sept – 23 Sept	1 Sept – 20 Sept	5 Sept – 25 Sept	1 Sept – 20 Sept	16 Sept – 6 Oct	3 Sept – 2 Oct

Source: Department of Agriculture and Food, WA.
*Indicates that a damaging frost can sometimes occur in the first half of the window in some years.

Flower Power is a tool developed by the Department of Agriculture and Food, WA that provides predicted flowering dates for wheat varieties at a range of sowing times.

The tool determaines the sowing time that will minimise the likelihood of frost after flowering and avoid the incidence of high temperature events during grain fill. It can be used in conjunction with Table 1 to determine the best sowing time for WA wheat varieties.

Videos

Watch a video on how to use Flower Power: https://www.youtube.com/watch?v=3RXXrGH0P9E

Watch a video on the wheat frost ratings research being done through the National Frost Program. Frost ratings for wheat will be available in 2015. www.grdc.com.au/GCTV15-FrostRatings

8.2.2 Grain quality

Sowing time and variety influence grain quality through their impact on staining, falling number and, in some districts, sprouting following late rains.

8.2.3 Staining

Stained grain is defined as “a grain defect caused by either exposure to wet and damp conditions during the growth and maturation phases or a stress-related biochemical reaction, which causes individual grains to become visually discoloured.”

Wheat varieties vary widely in their susceptibility to stained grain but the genetic mechanisms underlying staining are not yet fully understood.

Essentially there are two types of stained grains. The first is commonly referred to as black point and the second is a mould-like discolouration.

While the exact nature of black point is not yet known, the current understanding is that it is caused when oxidising enzymes are released, resulting in oxidisation of compounds in the wheat grain. High concentrations of the enzyme have been found in stained grain tissue.

It is not clear what triggers activation of the enzymes however rainfall or high humidity around mid-grain filling and temperature are possibly involved.

The mould-like discolouration is caused by wet conditions before harvest however the exact cause remains unknown.

The most susceptible growth stage for staining is about four weeks after flowering, although the grain remains susceptible throughout most of grain fill. Flower Power can be used to determine how sowing time of WA wheat varieties could affect their exposure staining risk. Sowing varieties with a high risk of staining too early will increase the staining risk.

8.2.4 Markets

Stained grain impacts negatively on all wheat markets, particularly those where the grain is either processed whole or the final sale is agreed upon by visual grain inspection. Many Middle Eastern and African grain purchases occur within a local market, so appearance is important. Flour processors also have strict thresholds for flour contamination from stained grains.

Grains that exhibit small dots covering less than about five per cent of the surface area of the kernel are not to be classified as stained grains. A maximum limit of five per cent by count applies across all major milling grades with the assessment done on wheat held above a 2mm screen following sieving.

8.2.5 Falling number

The falling numbers test is a measure of the capacity of wheat grain to make quality bread. The test measures the activity of the enzyme alpha amylase within the grain – with the lower the number the worse the bread making performance.

Alpha amylase is the enzyme responsible for converting starch to sugars in germinating grain. When the enzyme is present in harvested grain above a certain threshold it impacts on bread making by converting flour starch into sugars, which compromises bread quality.

More information

To view the latest sprouting and falling number index ratings for WA wheat varieties visit: https://agric.wa.gov.au/n/3124

Read an article on the development of a sprouting tolerance ranking using the falling number index for WA wheat varieties: www.grdc.com.au/GC109-ClearerPictureOfSproutingResistance

Consult the WA wheat variety guide for the latest resistance ratings for staining and falling number index: www.grdc.com.au/WAWheatVarietyGuide

To view the latest production value graphs visit: https://agric.wa.gov.au/n/2426

For information on dealing with a wet harvest read: http://www.sepwa.org.au/index.php/2011-11-13-02-21-59/media-releases?download=347:difficult-harvest-guide

Falling number test

The falling number test is an internationally recognised standard for assessing sprouting damage in wheat. Grain is ground into a powder and mixed with distilled water in a test tube, which is then heated. This makes the starch in the wheat gelatinise, making the mixture viscous.

The falling number relates to the length of time (in seconds) that it takes a stirrer dropped into the test tube, to reach the bottom. The more viscous the mixture, the longer the stirrer takes to reach the bottom and the higher the falling number and associated wheat quality. Alpha amylase activity increases during sprouting and falling number mixtures made from sprouted wheat are less viscous, which makes the falling number lower.

Sprouting

Issues with alpha amylase and falling numbers occur when grain sprouts prematurely before harvest following rainfall. Grain can be heavily discounted depending on the degree of sprouting.

Wheat varieties differ in their sprouting tolerance with grain dormancy the main trait controlling how readily individual varieties germinate in-crop following rainfall events.

Other traits that play a part in sprouting tolerance include seed coat dormancy, dormancy inhibitors that are released from the glumes when they become wet and a range or attributes that relate to the structure of the head such as waxy, awnless or tightly adhering glumes that influence how much water penetrates the head and into the grain.

The falling number index integrates the grain dormancy, falling number value and physical head attributes of wheat varieties to provide an indication of their in-field sprouting susceptibility following pre-harvest rain. It reflects the relative ability of wheat varieties to maintain falling number after a rain event.

Presented as a 1-9 scale the higher the rating the more likely a variety is to maintain falling number. The highest rating currently available for WA wheat varieties is six for Eagle Rock⁽ᴾ⁾, Estoc⁽ᴾ⁾, Scout⁽ᴾ⁾ and Clearfield STL⁽ᴾ⁾.

No varieties are completely sprouting tolerant and any variety left wet enough for long enough will sprout.

8.2.6 Local-level variety comparisons

The National Variety Testing program in association with Statistics for the Australian Grain Industry (SAGI) has developed a method to enable easy comparison of new and current wheat varieties against the wheat variety Wyalkatchem⁽ᴾ⁾ when sown before or after the end of May. Growers can use the outputs of the new method to support wheat variety choice according to the timing of the season break and rainfall outlook.

Graphs generated by the analyses provide an indication of the stability of a variety over several locations and years. These 'production value' graphs show how much more a variety is likely to yield in tonnes per hectare than other varieties in that environment. The approach also highlights the impact of individual seasons and environmental constraints on grain yield (Figure 5).

Note to Figure 5

In 2011 at Mingenew Mace⁽ᴾ delivered a production value of +0.45t/ha and, importantly, displayed a stable production value over several seasons indicating consistent performance over a range of environments. Magenta also delivered a positive (+0.6t/ha) production value in 2011 but its yield over seasons was unstable indicating environment plays a large part in the performance of this variety.

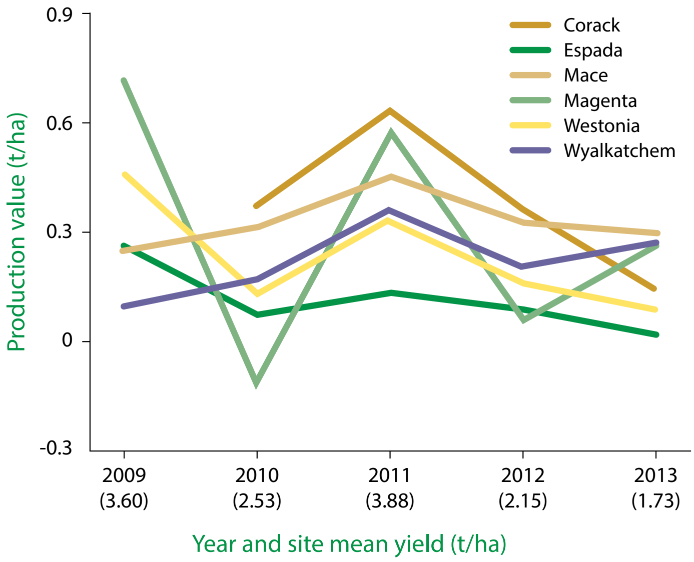


Figure 5: Production values of six wheat varieties at National Variety Trials in Mingenew between 2009-13.

References

Young, K (2013) Wheat 2012 NVT trial results and key agronomy issues. Proceedings 2013 Crop Updates Proceedings, Perth, WA. www.giwa.org.au/2013-crop-updates

Zaicou-Kunesch, C D'Antuono, M Reeves, K Choosing the right wheat variety for the system (part A) Proceedings 2014 Crop Updates Proceedings, Perth, WA. www.giwa.org.au/2013-crop-updates

Zaicou-Kunesch, C Choosing the right wheat variety for the system (part B) Proceedings 2014 Crop Updates Proceedings, Perth, WA. www.giwa.org.au/2014-crop-updates

8.3 Pre-emergent herbicides

Key messages

- Effective use of pre-emergent herbicides requires knowledge of soil type-herbicide interactions and the predicted type and density of weeds to be controlled.
- The behaviour of pre-emergent herbicides in soil is driven by three factors: (1) herbicide solubility,
(2) how tightly the herbicide binds to soil components, and (3) how rapidly the herbicide breaks down in the soil.
- Solubility influences how much rain is required for herbicide incorporation, how easily a herbicide can be taken up by a germinating weed and crop, and if a herbicide is likely to move down the profile potentially causing crop injury or loss to leaching.
- Herbicides that bind tightly to soil and organic matter generally require higher application rates, stay close to where they are applied (unless the soil moves), and persist for longer.
- Herbicide persistence and the way in which it breaks down will dictate the length of residual control and plant-back constraints to sensitive crops.

Pre-emergent herbicides are becoming increasingly important in WA wheat systems with the growing incidence of weeds with resistance to post-emergent herbicides. Understanding how pre-emergent herbicides behave in soil underpins their successful management.

Photo credit: GRDC.

More information

For more information on pre-emergent herbicides read the GRDC factsheet: www.grdc.com.au/GRDC-FS-PreEmergentHerbicide

Pre-emergent herbicides are becoming more important for weed control in Western Australian farming systems due to the increasing resistance of weeds to post-emergent herbicides (knockdown and selective).

Pre-emergent herbicides are also the only practical option for early-weed control in dry sowing situations.

Chosen and applied correctly pre-emergent herbicides can provide excellent cost effective in-crop and fallow weed control. However, because pre-emergent herbicides are applied before weed germination they can be more complex to use than post-emergent herbicides. Understanding the behaviour of the various pre-emergent herbicides in soil underpins their successful management.

To kill weeds, pre-emergent herbicides must be absorbed from the soil by the germinating seedling and for this to happen the herbicides need to have some water solubility and be in a position in the soil to be absorbed by the roots or emerging shoot. The dinitroaniline herbicides, such as trifluralin, are an exception to this rule because weed seedlings absorb them in gaseous form. However water is still required to convert the herbicide to gas and weed control will be compromised under dry conditions.

The behaviour of pre-emergent herbicides in soil is driven by three factors:

- Herbicide solubility;
- How tightly the herbicide binds to soil components; and
- How rapidly the herbicide breaks down in the soil.

The water solubility, binding capacity and degradation rates of some common pre-emergent herbicides are outlined in Table 6.

Note to Table 6

Water solubility of pre-emergent herbicides ranges from highly insoluble (trifluralin) through to highly soluble (chlorsulfuron). Solubility influences herbicide movement in soil and needs to be accounted for when choosing a pre-emergent for weed control.

Table 6: Water solubility, binding characteristics and degradation half-life for some common pre-emergent herbicides.

	Water solubility		Potential for soil binding		Degradation half-life (days)
Herbicide	mg/L*	Rating	mL/g**	Rating	
Trifluralin	0.22	Very Low	15,800	Very High	181
Pendimethalin	0.33	Very Low	17,800	Very High	90
Pyroxasulfone	3.9	Low	223	Medium	22
Triallate	4.1	Low	3000	High	82
Prosulfocarb	13	Low	2000	High	12
Atrazine	35	Medium	100	Medium	75
Diuron	36	Medium	813	High	76
S-metolachlor	480	High	200	Medium	15
Triasulfuron	815	High	60	Low	23
Chlorsulfuron	12,500	Very High	40	Low	180

Source: Chris Preston, University of Adelaide. *at 20°C and neutral pH. **In typical neutral soils.

Water solubility influences how far the herbicide can move in the soil profile in response to rainfall. Herbicides with very low water solubility are unlikely to move far from where they are applied. However, herbicides with high solubility are more easily moved into the seeding row following rainfall, which can potentially cause crop damage. In addition, if the herbicides move too far through the soil profile they can move out of the weed root zone and fail to control the weed.

Pre-emergent herbicides control weeds at the early stages of the life cycle, between radical (root shoot) emergence from the seed and seedling leaf emergence through the soil. Some pre-emergent herbicides also have post-emergent activity through leaf absorption and as such can be applied to newly emerging weeds.

The residual activity of a pre-emergent herbicide controls the first few flushes of germinating weeds (cohorts) while the crop is too small to compete. As a result, pre-emergent herbicides are often excellent at protecting the crop from early weed competition.

Table 7 lists the positive and negative attributes of pre-emergent herbicides.

Note to Table 7

All pre-emergent (and some post-emergent) herbicides persist in the soil to some degree and consequently herbicides can carry over into the next cropping period to impact crop growth. The time between spraying and safely sowing a specific crop or pasture without residual herbicide effects (the plant-back period) will depend on herbicide, environmental conditions and soil type.

Table 7: Positive and negative attributes of pre-emergent herbicides.

Positives	Negatives
Relatively inexpensive.	Strongly dependent on soil moisture.
Controls early weed germinations; protects crop from early weed competition and helps optimises potential yield.	Requires knowledge of paddock history and previous weeds because weeds not visible when herbicide applied.
Different modes of action available for rotation.	Plant-back periods limit crop rotation choice.
Application timing has wide window of opportunity.	Can damage crops if sown too shallow or if high amounts of herbicide move into root zone.
Best option for some crops where there are limited post-emergent options.	Possible need for cultivation and herbicide incorporation can lead to erosion, soil structural decline and loss of sowing moisture.
Effective on some weeds that are hard to control with post-emergent herbicides, such as wireweed and black bindweed.	Not suitable when dense plant residues or cloddy soils are present.
Extended period of control; good for weeds with multiple germination times.	Varying soil types and soil moisture across paddock can compromise herbicide efficacy.

Source: Andrew Storrie, Integrated Weed Management Hub www.grdc.com.au/Resources/IWMhub.

8.3.1 Using pre-emergent herbicides successfully

Achieving a good result from pre-emergent herbicides requires attention to every part of the application process, from matching the best herbicide to the weed spectrum present through to careful monitoring of the spray results.

The aim is to maximise a uniform deposit of pre-emergent herbicide across the soil surface. The level of evenness required will depend on the solubility of the product and its ability to move within the soil (see Table 6). The time between application and incorporation can also be critical with more volatile products requiring incorporation soon after application.

More information

For more information on using pre-emergent herbicides successfully read: www.grdc.com.au/Paper-2011-AchievingGoodPreemergentSprayResults

Identifying the weed(s) to target underpins the choice of pre-emergent herbicide.

Many factors need to be considered including:

- Previous weed burden;
- Potential herbicide resistance;
- Residual activity of the product (Table 6);
- Solubility and soil moisture requirements (Table 6);
- Ability to tank mix; and
- Ground cover and stubble load of target area.

Always consult product labels and refer to manufacturers technical data to make an informed decision.

8.3.2 Spray technique

Many small adjustments to the sprayer setup can improve the deposit onto the soil and minimise losses, such as tie up on stubble and loss to atmosphere.

The heavier the stubble load, the greater the need for a coarse spray quality or larger droplets. Larger droplets usually require greater application volumes (more than 80L/ha) to ensure uniformity of the deposit, particularly for pre-emergent herbicides with a low solubility in the soil (Borger 2013).

GRDC funded research by the Department of Agriculture and Food, WA across the WA wheatbelt found increasing carrier volume of trifluralin and Sakura® from 30L water/ha to 150L water/ ha improved ryegrass control from about 50 per cent to nearly 80 per cent. Interestingly, Sakura® efficacy increased to the same extent as trifluralin when carrier volume was increased, despite Sakura® (pyroxasulfone) being more soluble than trifluralin (Table 6, Figure 6).

Note to Figure 6

Crop residue groundcover was high at all sites; 50–90 per cent and none of the sites were grazed with livestock over the summer leading up to the trials.

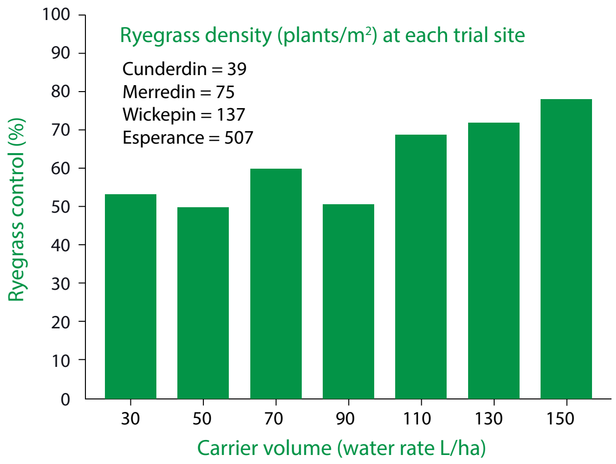


Figure 6: Impact of pre-emergent herbicides Sakura® (full label rate) and trifluralin (2.5L/ha) on ryegrass control using various carrier volumes at wheatbelt sites across WA. Bars are averages of four sites.

Source: Borger et al (2013).

Water sensitive spray cards placed between stubble rows at two of the trial sites showed a significant increase in spray coverage as carrier (water) volume was increased.

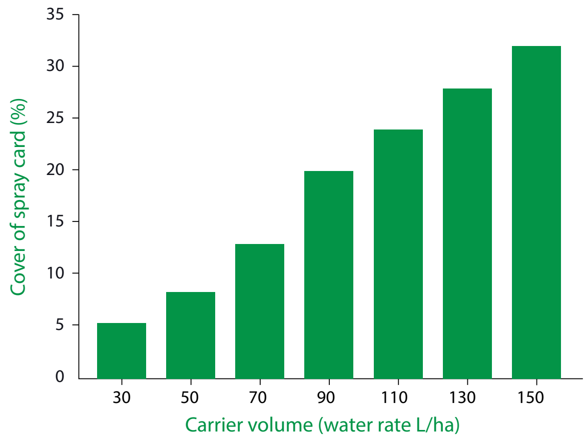


Figure 7: Impact of carrier volume on spray card coverage.

Source: Borger et al (2013).

8.3.3 Soil condition

Cloddy soil surfaces, large amounts of stubble or excessive ash from burning can reduce the performance of some pre-emergent herbicides. For example, simazine has a low-solubility and needs to be mixed with topsoil for best results. Atrazine needs to be incorporated or covered to prevent losses from ultra-violet light exposure and trifluralin needs to be incorporated to limit volatilisation.

More mobile (soluble) herbicides such as the sulfonylureas and imidazolinones do not necessarily need mechanical incorporation because the can move into the topsoil with rain.

More information

Download the nozzle selection poster from: www.grdc.com.au/NozzleSelectionGuide

A spray management app – *SprayCard,* developed by the Department of Agriculture and Food, WA predicts spray coverage based on tractor speed, size of spray nozzles, spray volume and addition of adjuvant, along with weather conditions including temperature, humidity and wind speed. The app records, measures and archives all aspects of spray treatments so that effective spray settings can be saved and re-used into the future. The app can also be used in conjunction with water-sensitive spray cards so that actual spray coverage can be compared with the app's predicted coverage.

Download the SprayCard app from iTunes or Google Play https://agric.wa.gov.au/n/1186

Spray conditions

Suitable conditions for spraying pre-emergent products are the same as for any spraying operation. Extremes of temperature, relative humidity and wind speed all affect the amount of product deposited on to the target area. Often these factors will interact with droplet size, speed and boom height.

Always refer to the product label for appropriate conditions for spraying, but as a rule of thumb, the following guidelines may be useful:

Always measure and record conditions at the site of application, before, during and at day's end of the spraying operation.

Never spray when the wind speed is less than 3km/h and avoid spraying when wind speeds exceed an average of 15km/h.

Always follow label directions including downwind buffer zones to protect sensitive areas.

Never spray during highly stable conditions, such as surface temperature inversion conditions, especially in the hours leading up to and immediately after sunrise.

Carefully monitor the Delta T value (temperature and relative humidity).

When the Delta T exceeds 10 it is probably time to stop spraying. The only situation where it may be reasonable to continue would be when you are using a spray quality that is larger than coarse (very coarse or extremely coarse), and you have adequate soil moisture and ground cover, such that the delta T value at the target (soil level) is below 8.

Continue to monitor and record factors such as rainfall after application.

More information

For more information on best practice spray technique read: www.grdc.com.au/GRDC-FS-SprayPracticalTips and www.grdc.com.au/uploads/documents/GRDC_FS_Spray.pdf and www.grdc.com.au/GRDC-Booklet-WeatherEssentials

Videos

Watch a video on herbicide efficacy and travel speed: https://www.youtube.com/watch?v=tosW4sLh_5Y

Note to Table 8

Boxer Gold® and Sakura® provided effective weed control and crop safety with a range of seeding machinery, however these herbicides are not currently recommended for use with disc seeders in Australia.

8.3.4 Pre-emergent herbicides and disc seeders

Research in South Australia found incorporating trifluralin with a triple disc rather than single disc seeder improved weed control and lifted crop establishment and wheat yield significantly (Table 8) (Kleemann et al, 2014).

Grain yields were lowest when trifluralin was incorporated using a single disc seeder – with wheat establishment reduced by nearly 60 per cent in this treatment (Table 8).

Incorporating trifluralin with a triple disc rather than a single disc seeder was shown to improve weed control and lift crop establishment and grain yield significantly in SA research.
Photo credit: Brad Collis.

Table 8: Impact of seeder type (single or triple disc) on wheat yield sown with a range of pre-emergent herbicide treatments at Roseworthy, South Australia in 2012.

Seed system	Wheat grain yield (kg/ha)			
	Nil	Trifluralin	Boxer Gold*	Sakura*
K Hart triple disc	3340	3880	4290	4220
JD90 single disc	3420	3260	4130	4360
LSD 390 (p=0.05)				

Source: Kleemann et al (2014). *not currently recommended for use with disc seeders in Australia.

8.4 Knockdown herbicides

Key messages

- Knockdown herbicides like glyphosate and paraquat/diquat are non-selective and can be used to kill a wide range of weeds in fallow or before sowing.
- A double knock approach commonly involves spraying weeds with glyphosate followed
  by an application of paraquat or paraquat/ diquat 2-14 days later to control remaining survivors.
- Using a double knock strategy reduces the number of glyphosate resistant weeds that need to be controlled in-crop.
- Using a double knock strategy combined with crop competition and harvest weed seed control will significantly reduce the weed seedbank and is likely to also significantly delay the evolution of herbicide resistance.
- Using glyphosate and paraquat without the addition of non-herbicide control methods increases the risk of multiple herbicide resistance developing.

Grass weeds become easier to control as they grow larger. Neither glyphosate nor paraquat can effectively control half-leaf grass weeds; with trials showing only a 40 per cent control rate when either herbicide was used at 1L/ha.

Photo credit: Evan Collis.

More information

For more information on pre-sowing weed control: www.grdc.com.au/Resources/IWMhub/Section-4-Managing-weed-seedlings#4.3

For more information on managing the weed seedbank: www.grdc.com.au/GRDC-FS-WeedSeedbank

8.4.1 Double knock weed control

The 'double knock' is the sequential application of two different weed control tactics where the second tactic controls any survivors from the first tactic.

The most common double knockdown is the sequential application of glyphosate (Group M) followed by paraquat/diquat (Group L), at an interval of between one and 14 days. Each herbicide in the double knockdown must be applied at a rate that would be sufficient to control weeds if it was used alone. The second herbicide is applied to control any survivors from the first herbicide application.

Other double knock strategies include following herbicide application with burning, grazing or weed seed capture and removal/destruction.

Using a double knock strategy reduces the number of glyphosate resistant weeds that need to be controlled in-crop.

Seasonal conditions and spraying capacity will determine the scale of the double knock operation. Double knocking a proportion of land each year requires forward planning, as it will add logistical stress to spray operations.

A good approach is to target paddocks with the highest weed populations as these are at higher risk for selecting resistance.

8.4.2 Key issues for double knocking

When glyphosate and paraquat are used, glyphosate should be applied first followed by paraquat or
paraquat/diquat.

The ideal time between applications will vary with the main target weed species.

Almost all annual species benefit from at least one day or more between applications. In some species, longer delays of 1-2 weeks are beneficial, but delaying too long can lead to regrowth of weeds and result in poorer results.

Applying the first herbicide when the weeds are small and actively growing will give the best control.

Maximum control of annual ryegrass results from an application of herbicide at the three- to four-leaf stage. Annual ryegrass sprayed at the zero- to one-leaf stage can potentially regrow from seed reserves (Borger et al, 2003; 2004).

8.4.3 Herbicide resistance

Rotating glyphosate and paraquat combined with crop competition and harvest weed seed control will significantly reduce the weed seedbank and is likely to also significantly delay the evolution of herbicide resistance.

Ryegrass is the only weed with documented multiple-resistance to paraquat and glyphosate in Australia. However, paraquat and glyphosate still work in most parts of

More information

For more information on managing herbicide resistance: http://ahri.uwa.edu.au/rotation-plus/ and www.grdc.com.au/GRDC-FS-HerbicideResistance

For more information on slowing glyphosate resistance: http://ahri.uwa.edu.au/break-the-glyphosate-habit/

Australia and used with diversity (crop competition and harvest weed seed control) these knockdown herbicides will remain effective on a broad spectrum of weeds for many years.

In all situations where glyphosate and paraquat multiple resistance have been documented, the ryegrass populations evolved resistance by being sprayed almost exclusively with glyphosate and paraquat with no follow up weed control of any form (Yu et al, 2006).

Ryegrass is a cross pollinator so multiple resistance can occur when a glyphosate resistant plant crosses with a paraquat resistant plant to result in offspring with resistance to both herbicides.

8.4.4 Manage the seed bank

The only long-term solution to effective weed control using the double knock or any other herbicide is to focus on reducing the weed seedbank to very low levels using a combination of chemical and non-chemical methods and to be vigilant about removing any weed survivors.

Over-reliance on glyphosate alone will lead to widespread glyphosate resistance in Australian cropping systems. The last new herbicide chemistries released in Australia occurred more than 30 years ago in 1982. With no new post-emergent herbicides on the commercial horizon, losing glyphosate would be very costly to the Australian agricultural industry.

Twenty-five populations of ryegrass have now been documented with glyphosate resistance in WA with more than 570 populations Australia-wide (Figure 8).
In addition, a 2013 pre-harvest and targeted survey across WA by the Department of Agriculture and Food, WA found more than 40 per cent of 172 annual ryegrass samples tested had some level of resistance to glyphosate.

Note to Figure 8

The Liverpool Plains of northern New South Wales has many populations of glyphosate resistant annual ryegrass. These populations formed following repeated use of glyphosate for winter fallow weed control. There are currently (2013) 574 documented cases of ryegrass resistant to glyphosate across Australia.

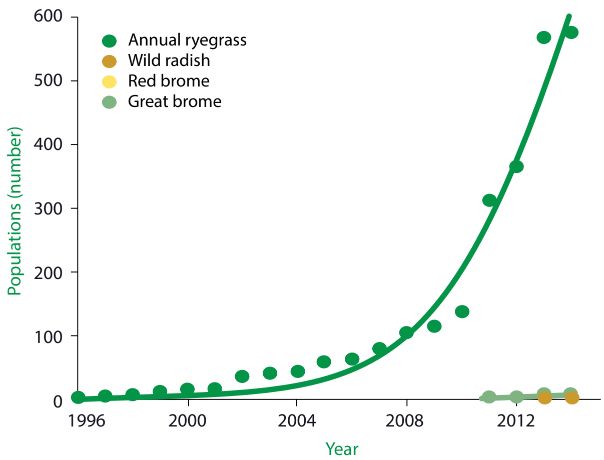


Figure 8: The number of populations of ryegrass, brome grass and wild radish with confirmed glyphosate resistance (by testing) in Australia as reported by the Australian Glyphosate Sustainability Working Group, led by Chris Preston. These are the confirmed populations only. The actual number of glyphosate resistant populations is likely to be much higher.

8.4.5 Paraquat

Paraquat based products are now cost effective and offer a viable knockdown alternative to glyphosate for small weeds. Using paraquat herbicides as the sole knock down in specific situations (small weeds) will help to prolong the useful life of glyphosate. However, as with all herbicides, sole use of paraquat without any additional non-chemical weed control will speed the development of paraquat resistance among cropping weeds.

Neither glyphosate nor paraquat can provide effective control of half leaf grasses – with only about 40 per cent control possible using either herbicide at 1L/ha.

Department of Agriculture and Food, WA GRDC funded trials showed paraquat could control small grass weeds well when the second leaf was visible and when mixed with a pre-emergent herbicide such as trifluralin. The herbicide mix is best sprayed in overcast or low light situations to enhance translocation through the plants. The trifluralin acts on the roots while the paraquat acts on the weed tops.

Controlling one-leaf grass weeds will require higher herbicide rates than three-leaf weeds and all weeds will be more difficult to control when stressed.

When grasses get to about the three-leaf stage or larger, it can be more cost effective to switch to glyphosate alone or the double knockdown (glyphosate followed by paraquat based herbicides) in combination with non-chemical herbicide control methods.

Resources

GRDC Integrated Weed Management hub
www.grdc.com.au/Resources/IWMhub

WeedSmart website
www.weedsmart.org.au

Australian Herbicide Resistance Initiative
http://www.ahri.uwa.edu.au

Australian Glyphosate Sustainability Working Group
http://www.glyphosateresistance.org.au/database/index.php

Department of Agriculture and Food e-weed newsletter
https://www.agric.wa.gov.au/newsletters/eweed

Giving a Rats newsletter
http://www.agronomo.com.au/giving-a-rats/

References

Borger, C., Hashem, A. and Wilkins, N. (2003). The double knockdown effect on annual ryegrass. In A. Douglas (ed.) Crop Updates 2003 Weeds, Perth, pp. 25–26.

Borger, C., Hashem, A. and Wilkins, N. (2004). Double knockdown herbicides – preserving glyphosate. In A. Douglas (ed.) Crop Updates 2004 Weeds, Perth, pp. 34–35.

Borger, C Riethmuller, G Ashworth, M Minkey, D Hashem, A and Powles, S. (2013) Increased Carrier Volume Improves Preemergence Control of Rigid Ryegrass (Lolium rigidum) in Zero-Tillage Seeding Systems. Weed Technology 2013 27:649–655

Kleemann, S Preston, C and Gill, G (2014) Influence of Seeding System Disturbance on Preplant Incorporated Herbicide Control of Rigid Ryegrass (Lolium rigidum) in Wheat in Southern Australia. Weed Technology 28:323–331

Newman, P and Adam, G (2005) Knockdowns for large wild radish, single and double. In Proceedings of the 2005 Crop Updates, Perth, WA.

Yu, Q Cairns, A Powles, S (2006) Glyphosate, paraquat and ACCase multiple herbicide resistance evolved in a Lolium rigidum biotype

8.5 Soil nutrient testing

Key messages

- Ensuring adequate crop nutrition before sowing is a balance between crop demand in light of potential yield and seasonal conditions.
- The first step is to determine the current nutritional status of the soil before sowing with a pre-sowing soil test program.
- If current soil nutrient levels are adequate then there is no requirement for additional fertiliser at sowing.
- Continual export of high levels of plant nutrients will deplete reserves which will eventually show in lower soil test levels.
- The largest source of error in any soil test comes from the soil sample so it is critical that the samples taken are representative of the paddock as a whole.

Profitable grain production In Western Australia depends on applied fertiliser, particularly nitrogen, phosphorus, potassium and sulfur.

Fertiliser is a major variable cost for grain growers, however crop nutrition is a major driver of profit. Both under and over-fertilisation can lead to economic losses due to unrealised potential or wasted inputs.

Profitable fertiliser decisions rely on an understanding of the fertility status of each paddock and the nutritional requirements of each crop to achieve a target yield. These decisions need to account for the nutrient requirements of plants for growth, nutrient availability in soils and nutrient losses that can occur during crop growth (e.g. de-nitrification, erosion, leaching).

It is also important to consider whether a fertiliser strategy aims to build, maintain or mine the soil reserves of a particular nutrient.

Taking soil samples and interpreting the data they provide is essential to making informed crop nutrition and management decisions. Soil test critical values indicate if the crop is likely to respond to added fertiliser, but these figures do not predict optimum fertiliser rates (Figure 9).

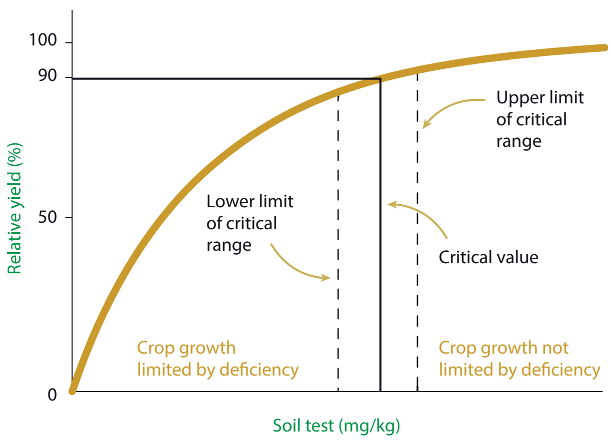


Figure 9: A generalised soil test–crop response relationship defining the relationship between soil test value and per cent grain yield expected. A critical value and critical range are defined from this relationship. The relative yield is the unfertilised yield divided by maximum yield, expressed as a percentage. Normally 90 per cent of maximum yield is used to define the critical value but critical values and ranges at 80 per cent and 95 per cent of maximum yield can also be produced.

Source: DAFWA and Murdoch University.

Soil test results can be compared against critical nutrient values and ranges, which indicate nutrients that are limiting or adequate. When making fertiliser decisions soil test results need to be considered in combination with information about potential yield, the previous year's nutrient removal and soil type (Table 9).

Table 9: Summary table of critical values (mg/kg) and critical ranges for the 0 to 10cm sampling layer for wheat.

Nutrient	Soil types	Critical values (mg/kg)	Critical range (mg/kg)
Phosphorus	Grey sands	14	13–16
	Other soils	23	22–24
Potassium	All	41	39–45
	Yellow sands	44	34–57
	Loams	49	45–52
	Duplexes	41	37–44
Sulfur	All	4.5	3.5–5.9

Source: GRDC Fact Sheet Soil testing for crop nutrition Western Region 2014.

Note to Table 9

Soil testing is unreliable for determining crop nitrogen requirements because soil nitrogen availability and crop demand for nitrogen are both highly influenced by seasonal conditions.

More information

For more information on micronutrient testing read:
www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients

For more information on crop nutrition visit:
www.soilquality.org.au

Ideally, soil tests and their analysis need to be done well before sowing to ensure a well-planned nutrient strategy for each paddock and crop.

8.5.1 Soil test information

Soil tests can provide a range of information including: soil nutritional status, water storage capacity, depth of root barriers or subsoil constraints such as acidity, levels of crop growth inhibitors such as boron and aluminium or salinity and potential for soil-borne disease.

Principal reasons for soil testing for nutrition include:

- monitoring soil fertility levels;
- estimating which nutrients are likely to limit yield;
- measuring properties such as pH, sodium (sodicity) and salinity, which affect the availability of nutrients to crops;
- zoning paddocks for variable application rates;
- comparing areas of varying production; and
- as a diagnostic tool, to identify reasons for poor plant performance.

Soil testing can help support decisions about fertiliser rate, timing and placement.

Micronutrient status is more reliably determined through plant tissue testing during the growing season.

8.5.2 Critical values and ranges

A soil test critical value is the soil test value required to achieve 90 per cent of crop yield potential.

The critical range around the critical value indicates the reliability of the test; the narrower the range the more reliable the data (see Table 9).

The critical value indicates if a nutrient is likely to limit crop yield based on whether the value is greater than or less than the upper or lower critical range value (see Figure 9).

If the soil test value is less than the lower limit, the site is likely to respond to an application of the nutrient.

For values within the range there is less certainty about whether a response will occur. In this case, exercise your own judgement about the costs and benefits of adding fertiliser in the forthcoming season, versus those associated with not applying.

If the soil test is above the critical range, fertiliser is applied only to maintain soil levels or to lower the risk of encountering deficiency.

The larger the range around the critical value, the lower the accuracy of the critical value.

More information

For more information on how to interpret and use critical soil test values read: www.grdc.com.au/Paper-2014-BFDCInterrogator

8.5.3 Types of tests

Appropriate soil tests for measuring soil extractable or plant available nutrients in WA include:

- bicarbonate extractable phosphorus (Colwell-P);
- bicarbonate extractable potassium (Colwell-K);
- KCl-40 extractable sulfur; and
- 2M KCl extractable inorganic nitrogen, which measures nitrate-nitrogen and ammonium-nitrogen.

Other measurements that aid the interpretation of soil nutrient tests include soil pH, percentage of gravel in the soil, soil carbon/organic matter content, phopshorus sorption capacity (currently measured as phosphorus buffering Index (PBI)), electrical conductivity (EC), chloride and exchangeable cations (CEC) including aluminium.

8.5.4 Soil-testing principles

Deeper soil sampling (up to 100cm) provides more appropriate critical soil values and ranges for many soil types in WA (see Tables 9 and 10).

Table 10: Summary table of critical values (mg/kg and kg/ha) and critical ranges for the 0 to 30cm sampling layer for wheat.

Nutrient	Critical values (mg/kg)	Critical range (mg/kg)
Phosphorus	11	10–11
Potassium	n/a	n/a
Sulfur	4.6	4.0 – 5.3

Source: GRDC Fact Sheet Soil testing for crop nutrition Western Region 2014.

Soil sampling depth has traditionally been set at 0-10cm because nutrients, especially phosphorus, and plant roots are generally concentrated within this layer. However, there is an increasing need to assess production constraints, including acidity, in both the surface (10cm) and subsoil (30cm) soil layers.

The more soil samples taken, the more accurate the results — aim for at least six cores across a paddock. Recommended depths are 0 to 10cm, 10 to 40cm, 40 to 70cm and 70 to 100cm to obtain more comprehensive soil data.

The optimal number of samples will be a balance between cost and accuracy — the more layers: the more accurate the results, but the greater the expense.

One suggested approach is to run a comprehensive suite of soil tests on all 0 to 10cm samples and only test for nitrogen, potassium, sulfur and salinity in 10 to 30cm samples.

On sands, phosphorus can also be tested for at depth.

Note that pH samples need to be taken at 10cm increments to depth. If sampling to 30cm, test the 0 to 10cm, 10 to 20cm and 0 to 30cm soil layer samples for pH so soil acidity levels can be better understood.

8.5.5 Sampling guidelines

The greatest source of error in any soil test comes from the soil sample.

For a soil test to be a reliable decision-making tool, the sample must accurately reflect the soil in the area to be sampled. Averaging soil types across a paddock is ineffective — if the soil type is variable across a paddock, sample the predominant soil type only.

Ultimately only a teaspoon-sized soil sample is used for a specific soil test at the laboratory so it is critical that this teaspoon-sized sample is as representative as possible of the approximately 1500 tonnes of soil per hectare (to 10cm depth) from which it originated.

To ensure that a sample is representative:

- check that the soil type and plant growth from where the sample is collected are typical of the whole area;
- avoid areas such as stock camps, old fence lines, gateways and headlands;
- take each sub-sample to the full sampling depth;
- do not sample in very wet conditions;
- avoid shortcuts in sampling such as taking only one or two cores, a handful or a spadeful of soil; and
- avoid contaminating the sample, the sampling equipment and the sample storage bag with fertilisers or other sources of nutrients such as sunscreen containing zinc.

When sampling the 0 to 10cm soil layer, 20 to 30 cores per site are required, while the 10 to 30cm soil layer will require 8 to 10 cores per site.

After taking samples, combine uniform samples (bulked) according to the depth interval from which they were taken. Break up any lumps and thoroughly mix soils before sending samples (a few hundred grams) for analysis.

Record the location of sample sites using a rough map or description, or with a GPS, to ensure samples to be taken from the same place each year.

To maintain the integrity of the samples:

- store samples in an esky while in the paddock to minimise further evaporation and changes in nitrate levels (water will start to evaporate as soon as a core is taken from the ground, so work quickly and place the samples into sealed plastic bags as soon as possible);
- when all samples have been taken, store the soil samples in the fridge until they are sent for analysis;
- try to express post soil samples early in the week so they do not sit waiting for delivery over the weekend; and
- label soil samples clearly – a zip-lock bag is ideal, marked with a permanent, waterproof marker.

More information

A list of participating laboratories and the test methods for which they are accredited can be found at www.aspac-australasia.com

Soil sampling can be difficult and time-consuming work without the correct equipment and contractors are available in most regions if help is needed.

Choose a laboratory that has Australasian Soil and Plant Analysis Council certification for the most important tests (for example, Colwell-P, DGT-P, nitrate nitrogen, sulphate sulfur and exchangeable cations).

Resources

GRDC Fact Sheet: Soil testing for crop nutrition: Western region
http://www.grdc.com.au/GRDC-FS-SoilTestingW

GRDC Fact Sheet: Phosphorus management: Western region
http://www.grdc.com.au/GRDC-FS-PhosphorusManagement

GRDC Fact Sheet: Micronutrients and trace elements
www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients

GRDC Supplement: More Profit from Crop Nutrition
www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS108

Better Fertiliser Decisions for Cropping
https://www.bfdc.com.au

DAFWA workshops: Get to know your soils deeper
For further information contact soils.forum@agric.wa.gov.au or call +61 0(8) 9690 2081.

More information

[GRDC Tips and Tactics: Root lesion nematodes (Western region)]

To hear Dr Sarah Collins, DAFWA discuss root lesion nematodes at the GRDC Agribusiness Crop Updates in 2014, visit https://www.youtube.com/watch?v=XjtdPy7f0ks

8.6 Nematode management

Key messages

- Wheat is susceptible to *P. neglectus*, *P. quasitereoides* (formerly *P. teres*) and *P. penetrans*.
- The host range for root lesion nematodes (RLN) is broad and includes cereals, oilseeds, grain legumes and pastures, as well as many broad leaf and grass weeds.
- There are no in-crop management options to control root lesion nematodes.
- Nematode species will influence the choice of suitable rotational options.
- Well-managed rotations minimise the damage caused by root lesion nematodes in cereal production systems.
- Susceptible wheat crops may require more than one resistant crop rotation in the sequence to sufficiently lower nematode levels if RLN population is high.

Root lesion nematode (RLN) levels are on the rise across the Western Australian wheatbelt according to research and survey work by the Department of Agriculture and Food, WA.

RLN species were found in 90 per cent of 130 paddocks surveyed in 2013, with levels in 48 per cent of paddocks high enough to cause 15 to 50 per cent yield loss. In 2014, nematode populations have continued to rise. For example, Agwest Plant Laboratory nematode tests for the season has seen the average number of RLN detected in samples submitted rise from around 13,000 to
31,000 RLN/g root.

Root lesion nematode (*Pratylenchus* spp) are microscopic worm-like animals that inhabit soil and feed on plant roots. Several damaging species of nematodes occur in cropping areas of WA: *P. neglectus, P. teres, P. penetrans and P. thornei.*

While population densities of all RLN species can increase under intensive cereal production systems, canola is also susceptible to nematodes and the increasing adoption of canola throughout the wheatbelt may be contributing to the rise in RLN populations.

Above-ground symptoms of nematode infection are often indistinct and difficult to identify. Affected cereal plants are often yellow, stunted and tiller poorly and may wilt despite moist soil. Crops appear patchy with uneven growth.

Roots may have indistinct brown lesions or, more often, generalised root browning.

When roots are infested with high numbers of RLN, they are thin and poorly branched and lateral root branches are reduced in both length and number.

Sections of the root system may appear dead, with the crown roots often less affected than the primary roots.

Above-ground symptoms of root lesion nematodes are often indistinct and difficult to identify. Laboratory testing is required to correctly diagnose the presence of root lesion nematode.
Photo credit: GRDC.

8.6.1 Nematode identification

Due to the differences in susceptibility of break crops to different species of nematode it is important to identify the species present.

Soil samples from paddocks with suspected nematode damage can be sent to AGWEST Plant Laboratories or through accredited agronomists to SARDI's PredictaB® service for confirmation and species identification. Correct diagnosis will help plan crop rotations to help manage RLN.

Sample collection for nematode ID

Soil samples for nematode analysis must be taken from plants and moist soils:

Plant samples:

- Collect plants from a number of locations towards the margins of poor crop growth areas;
- Make sure to use a trowel or shovel to keep the root system intact; and
- Keep the soil ball intact to protect the roots in transit.

Soil samples:

- Use a soil corer or trowel to sample 0-10cm;
- Always take samples in the crop rows, aiming close to root systems;
- Collect samples from 6–12 locations towards the margins of poor crop growth areas;
- Place soil samples in a bucket and mix gently but thoroughly;
- Remove a 500 gram sample and seal in a plastic bag.

It is important to collect a second sample from healthy areas in the crop to be used as a comparison (this sample is NOT charged). Be sure to label all bags and include notes on relevant paddock symptoms.

Alternatively, after harvest and into autumn, soil samples can be assessed using the SARDI PredictaB® service through accredited agronomists.

More information

For more information on the ongoing RLN survey visit: https://agric.wa.gov.au/n/302

For more information on RLN and how to diagnose their presence in-crop use the MyCrop diagnostic tool: https://agric.wa.gov.au/n/2166

To identify RLN species send plant samples to: www.agric.wa.gov.au/bacteria/plant-disease-diagnostics

To identify RLN from soil samples: www.sardi.sa.gov.au/diagnostic_services/predicta_b

Videos

Watch a video on how to sample for root lesion nematode diagnosis: https://www.youtube.com/watch?v=ttFltE-B4qA

8.6.2 Managing nematodes

With no in-crop options available to curb damage, nematode management relies on:

- Observation and monitoring of above and below ground plant disease symptoms, followed by diagnosis of the cause (or causes) of any root disease is the first crucial step to implement effective management. Although there is little that can be done during the current cropping season to ameliorate nematodes, the information will be crucial in planning effective rotations of crop species and varieties in following seasons;
- As a general rule, well-managed rotations with resistant or non-host break crops are vital. Avoid consecutive host crops to limit RLN populations;
- Healthy soils and good nutrition can, to some extent, ameliorate RLN damage through good crop establishment, and healthier plants may recover more readily from infestation under more suitable growing conditions; and
- Using wheat or barley varieties with tolerance to the RLN species in a paddock; keeping in mind that some tolerant varieties can further increase nematode numbers.

Choosing the most profitable crop for a paddock depends on the type and population size of the nematode species and the nematode tolerance or resistance rating of the crop.

If RLN levels in a paddock are high to very high, consider growing a moderately resistant (MR) or resistant (R) crop or pasture. More than one cropping season will probably be necessary to bring high populations to levels that are not yield limiting.

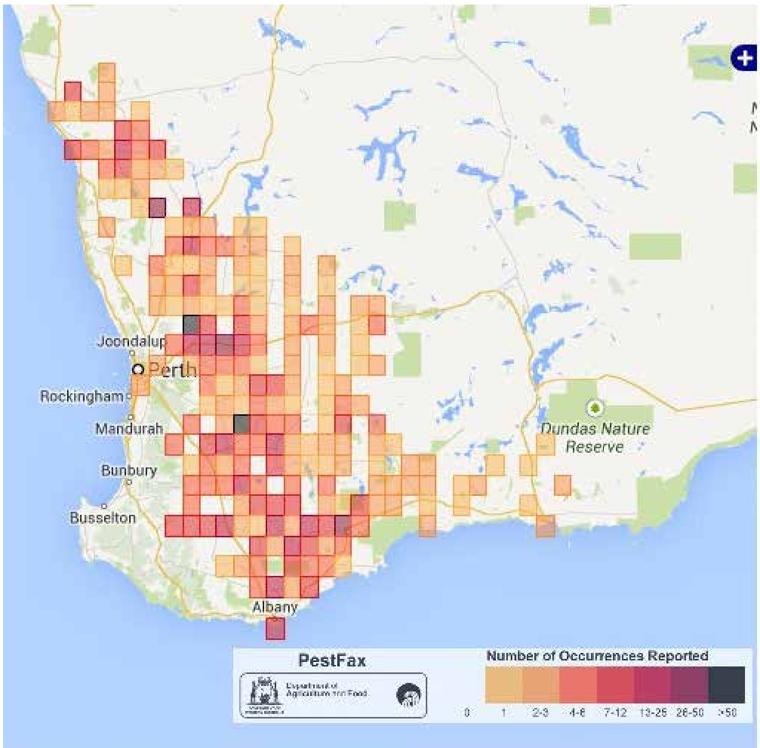


Figure 10: Positive detection of root-lesion nematodes in Western Australian broadacre cropping between 1997 and 2013

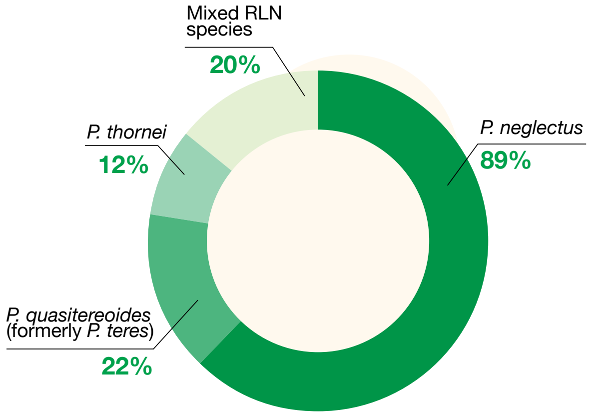


Figure 11: Relative abundance of the main root-lesion nematode species identified in infested broadacre paddocks in Western Australia

More information

[DAFWA: Diagnosing root lesion nematode in cereals.]

[DAFWA: Diagnosing cereal cyst nematode.]

[DAFWA: Diagnosing seed gall nematode.]

[DAFWA: Control of green bridge (see RLN half way down).]

[DAFWA: Cereal cyst nematode.]

[DAFWA: Root lesion nematode.]

8.6.3 Life cycle

The life cycle of RLN Root-lesion nematodes are migratory plant parasitic nematodes, meaning that they migrate freely between roots and soil if the soil is moist. In the western region, the life cycle of RLN begins after the opening rains in autumn. Juvenile and adult nematodes rehydrate, become active and invade plant roots, where they feed and multiply as they move through the root (Figure 12). Individual eggs are laid within the root, from which juvenile nematodes hatch and grow to adults, which in turn lay more eggs. They develop from egg to adult in 40–45 days (~6 weeks) depending on soil temperature and host (Figure 12). There may be 3–5 life cycles within the plant host each season. As plants and soil dry out in late spring, RLN enter a dehydrated state called anhydrobiosis and can survive high soil temperatures and desiccation over summer. As the nematodes feed and multiply, lesions and/ or sections of brown discoloration are formed on the plant root. Other symptoms include reduction in the number and size of lateral roots and root hairs.

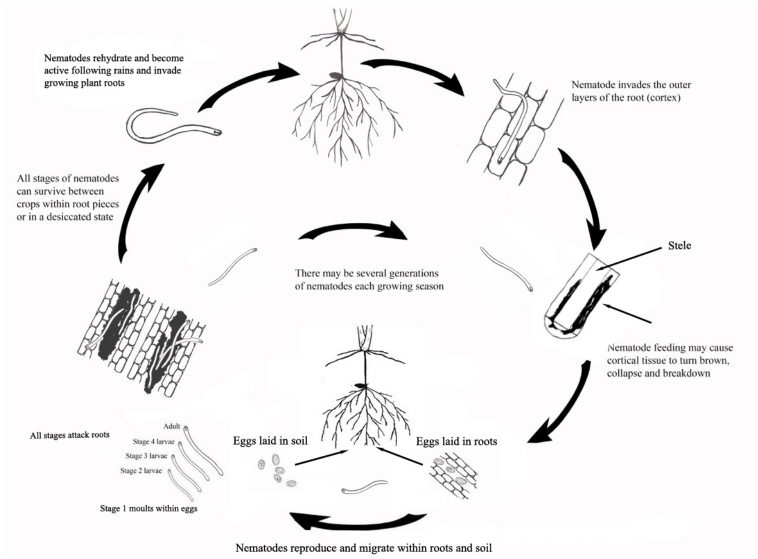


Figure 12: Disease cycle of rootlesion nematode, adapted from: GN Agrios (1997) Plant pathology, 5th edn (Academic Press: New York). (Illustration by Kylie Fowler)

8.6.4 Economic impact

A nationally coordinated nematode research program, which commenced during July 2013, is quantifying the yield and economic impacts of root lesion nematodes (RLN) in crop production systems across the GRDC growing regions.

The project will also further refine management options for these costly soil pathogens and improve relationships between PreDicta B® test results and likely on-farm yield loss to better guide on-farm management of nematodes.

To quantify the impact of nematodes, trial sites with high and low nematode numbers are being used to evaluate the nematode resistance and tolerance ratings of a range of crops.

For tolerant cultivars, there will be little difference in yield between the ‘high’ and ‘low’ nematode populations but RLN numbers may increase if the crop is suseptible. Subsequent analysis will determine the yield risk of varying nematode levels for a range of crop varieties.

The western region research is focussing on the resistance and tolerance of wheat, barley, lupin and canola varieties to the root lesion nematode species *Pratylenchus neglectus, P. quasitereoides* (*P. teres*) and *P. penetrans.*

Resources

DAFWA's Wheat variety guide
https://agric.wa.gov.au/n/2426

DAFWA Focus Paddock Project
https://agric.wa.gov.au/n/302

DAFWA How to diagnose root lesion nematode
https://www.youtube.com/watch?v=ttFltE-B4qA

GRDC GroundCover TV
http://www.grdc.com.au/GCTV6-RootLesionNematode

GRDC GroundCover Root and Crown Disease Supplement
http://www.grdc.com.au/GCS111

Contact

Dr Sarah Collins
Department of Agriculture and Food, WA
P (08) 9368 3612
E sarah.collins@agric.wa.gov.au

8.7 Mouse control

Key messages

- Mouse damage at sowing can devastate emerging wheat crops.
- Limiting available food sources, monitoring mouse populations throughout the year and baiting as necessary, are the best strategies to control mice populations.
- Critical periods for mouse activity include autumn and spring.
- Bait for mice within 24 hours of sowing, post sowing and at crop emergence to protect newly-sown seed from mouse attack.
- Managing mice during flowering and seed set is also critical to protect potential grain yields.
- Managing grain and weed seed residues throughout the year will reduce the costs associated with mouse control the following season.The frequency of mouse plagues has increased in the past 20 years from one in every five to six years to one in every four years. Mice are now affecting crop types, crop stages and cropping regions that have historically had few problems, such as the WA wheatbelt.

Conditions that favour mouse breeding and activity include:

- prolonged availability of high-quality feed;
- high crop yields and poor harvesting efficiency;
- seasonal conditions that favour weed development (for mouse habitat);
- favourable burrowing conditions such as cracking or light soils;
- heavy crop residues; and
- absence of livestock.

Intensive cropping rotations, minimum tillage and stubble retention, more diverse crops, higher grain yields and fewer livestock are all contributing factors. These conditions provide mice with abundant food and cover as well as a favourable habitat for breeding.

Plague proportions usually follow high yielding cropping years, particularly with heavy early or late season rain. Critical periods for mouse activity include autumn and spring.

Hygiene in and around paddocks, grain storage facilities and fodder storage facilities, combined with tactical baiting programs remain the key control options. Clean up grain spills in the paddock and around yards at sowing and harvest, and remove rubbish and nesting material from sheds.

8.7.1 Monitoring mouse numbers

Mouse numbers build and decline rapidly depending on seasonal conditions and feed availability. Mice can move up to 300m each day, so it is important to monitor on a paddock-by-paddock basis as opposed to monitoring a single site on the farm regularly.

Mouse activity generally declines during winter, however if autumn numbers were high it is important to continue monitoring throughout the growing season and over the

More information

Mouse damage and activity in WA can be reported to the GRDC-supported PestFax service, with reports mapped on PestFax Map and included in the PestFax newsletter: https://agric.wa.gov.au/n/1588

summer as carryover populations of mice from autumn can severely damage crops at flowering and seed-set e.g. five per cent crop yield loss per night.

Keep an eye open for subtle signs of mouse activity, which can help indicate the level of damage that could occur during the growing season. Such signs include:

- burrows and active holes;
- mouse droppings on soil and plants;
- a typical mousey smell around grain and fodder storage sites;
- large numbers of mice seen at night in paddocks or on roads;
- an increased presence of birds of prey;
- signs of seeds being dug up, plants being gnawed (cereal nodes) or pod and head damage (particularly evident in flowering canola and maturing cereals); and
- frequent daytime sightings.

Monitoring can also be done using live trapping, counting active holes, together with 'census cards' soaked in canola oil and pegged at intervals across paddocks.

8.7.2 Live trapping

Trapping with 'snap traps' throughout the year can indicate the population level and its breeding status (see guide to trapping).

Females with prominent mammary glands and the presence of small, juvenile mice indicate breeding has started.

A trapping rate of 10 per cent indicates an emerging issue, while a trapping rate of 20 per cent or more in an early-maturing crop indicates a problem.

Mouse plagues are on the rise in the WA wheatbelt. Wheat is most vulnerable to mice attack in the first two to three weeks following sowing as every seed removed is one less plant to provide yield.
Photo credit: Emma Leonard.

Laying mouse traps

Set out a straight line of 20 to 25 traps, spaced 10m between each trap, for three consecutive nights.

Lay traps in a variety of habitats: along paddock boundaries, in-paddock and in-crop.

Trap success is calculated by multiplying the number of traps per line by the number of nights the traps were out, and dividing the total number of mice caught by this number.

For example: 20 mice from 25 traps over three nights = 20/(25x3) = 26 per cent.

For ease of baiting, permanently attach a small piece of leather to the trigger and occasionally add a few drops of linseed oil (or similar). Alternatively, smear peanut butter on the trigger each time the trap is set.

Always wear gloves when handling mice — they carry diseases.

8.7.3 Active holes

To identify active holes, sprinkle talcum powder around the holes on rain-free nights and inspect for disturbance the following morning.

Five active holes per 100m^2 (100m by 1m transect) indicate a population density of up to 1000 mice per hectare, although this varies with soil type.

Hole counts vary by soil type — in cracking soils, holes can be difficult to identify. In sandy soils, mice can dig many holes while looking for seed, which can look similar to nesting burrows. In hard-setting soils, there can be few holes but each can contain many mice — up to 40 per hole during plagues.

8.7.4 Census cards

Mice are attracted to census cards soaked in canola oil and laying census cards can provide information about mouse activity. However, keep in mind that as the crop matures and other food becomes available, census cards become less attractive and less reliable as a measure of mouse numbers.

8.7.5 Crop damage

Mouse damage to wheat crops is most severe for about two to three weeks following crop emergence and again at flowering and early seed-set. However, mice can cause substantial damage to tillering cereals.

Although mouse breeding and activity slow during winter, monitor crops throughout the growing season, and bait as soon as evidence of damage is found.

8.7.6 Crop establishment

Mice typically damage crops at sowing, by digging into the soil and eating the seed, or just after emergence when they feed on the seedling.

Wheat is most vulnerable during the first two to three weeks (when every seed removed is one less plant to provide yield).

8.7.7 Vegetative stages

Although there is generally less crop damage during the vegetative stages, mice can chew crops to supplement their diet. Severe damage in tillering wheat is not always obvious until the first few warm days cause heads to die off rapidly, so inspect crops carefully.

Mice chew into nodes or the side of the tiller to access the growing tips inside the leaf sheath. This can be confused with disease or moisture stress until closer examination reveals chewing damage underneath.

Damage may be seen at different heights in different tillers as the growing tip elevates.

8.7.8 Crop maturation

When cereal heads emerge, mice will eat the top node, where the sugars are most concentrated. From flowering onwards, they remove and eat the head.

In the worst cases, they can reduce yield by 50 per cent during flowering.

After grain fill, the risk of damage slows as the animal can obtain more nutrients from less feed.

8.7.9 Mouse control

Baiting is the only control option available in crop. Several baits are registered for mice control — although registration details change frequently and not all products are registered for use in crop, so check with your agronomist, retailer or the AVPMA website for current control options

Effective bait management

- Bait can be applied to crops by Chemcert registered landholders or commercial operators from the ground or air. Always consult the label for use instructions.
- Wherever possible, lay baits within 24 hours of sowing. This is because the existing food source has been covered by cultivation, the mice have yet to discover the buried seed and the bait is the only food source available.
- Lay baits during late afternoon – early evening when birds have finished feeding and more than 50m away from areas of remnant native vegetation, which may be habitat for birds and mammals.
- Advise any beekeepers with hives near the paddock in question well in advance of baiting.

- Always wear personal protection equipment (PPE) when handling baits.
- Check paddock and surrounding areas for non-target animal mortalities.
- Only chemicals registered to control mice can be legally used.
- Handling mice is a disease risk — always wear gloves.
- Continue to monitor mouse activity after baiting.

Cost of control

The total cost of controlling mice is a combination of product cost and application method.

Rebaiting is more effective than increasing bait rates, but adds to the overall seasonal cost of control.

Aim to manage mouse numbers throughout the year to limit costs associated with mouse damage in the following season.

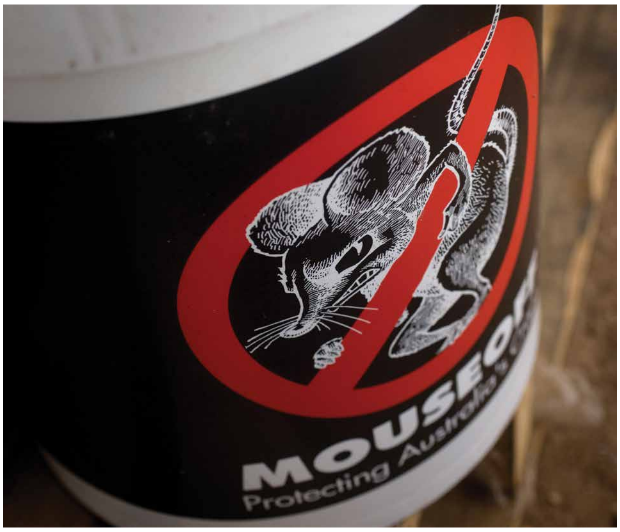
Limiting the food sources available to mice, combined with baiting when necessary, is the most effective way to control mice.

Farm hygiene around sheds, grain and fodder storages is important, as is weed control and monitoring paddocks for evidence of mouse activity.

If baiting is likely to be required, obtain bait early to avoid being caught in the event of product shortages, and have the necessary protective equipment on hand to apply bait safely.

More information

For a current list of registered products and minor use permits for mice control download the APVMA iphone app available from the iTunes store https://itunes.apple.com/au/app/apvma/id564121943?mt=8



Mouse bait can be applied from the ground or air and ideally should be laid within 24 hours of sowing.
Photo credit: GRDC.

Key seasonal management actions

Pre-sowing and sowing

- Control summer weeds and volunteers.
- Remove weeds along fencelines to eliminate habitat.
- Bait within 24 hours of sowing to protect seed.
- Sow to an even depth and as early as possible.
- Sow seed as deep as appropriate for crop type.

In-crop

- Control weeds and grasses along crop margins before seed-set by spraying or slashing.
- Cut hay early to keep it free of seed.
- Spraytop or graze pasture hard to minimise grass and weed seed-set.

Harvest

- Set harvesters to minimise grain loss.
- Harvest before crops are overripe and grain loss occurs.
- Minimise grain loss through sieve settings and harvester speed.
- Avoid leaving strips of unharvested grain.
- Use chaff carts or other forms of harvest seed management.
- Clean up any grain spills in and around field bins, augers, silo bags and other grain stores.
- Remove or reduce potential cover including plant material and rubbish around buildings, silos and fodder storage.
- Graze residues and weeds immediately following harvest but leave enough ground cover to minimise erosion.

MouseAlert

http://www.feralscan.org.au/mousealert/

MouseAlert provides a way for farmers to record mouse activity, damage and control on their farms, and a way to stay informed about changes in mouse numbers in their local area. Combined records allow real-time mapping of mouse activity and can provide early warnings of potential mouse problems. Recording data in your local area can help you to track changes over time, and help groups such as GRDC to forecast future mouse plagues.

Resources

GRDC Mouse management factsheet, Western region
www.grdc.com.au/GRDC-FS-MouseManagement2012//

Invasive Animals CRC
www.feral.org.au/wp-content/uploads/2010/03/Monitoring-techniques-for-vertebrate-pests---mice.pdf

8.8 Snail and slug control

Key messages

- Conservation farming practices have seen slug and snail populations across WA cropping regions increase significantly.
- Snails can impact returns through yield losses and grain contamination at harvest.
- Monitor snail numbers during and after harvest to determine whether control pre-sowing is necessary.
- A combination of control measures is required for effective control including stubble management, summer weed control and baiting.
- While all bait formulations can kill snails none result in 100 per cent mortality.Slug and snail numbers have increased in cropping systems across Western Australia under minimum tillage and stubble-retention, as these systems increase soil organic matter and moisture levels to facilitate greater survival of slugs and snails.

More information

For more information on identifying snail species in WA cropping systems refer to: https://agric.wa.gov.au/n/2671

Videos

Watch a video on the growing snail problem in WA cropping systems: www.grdc.com.au/GCTV13-Snails

Slugs are pests of crops, especially emerging canola, in the higher-rainfall regions of WA but tend to be restricted to clay soils. Snails are found on all soil types. White Italian (*Theba pisana*) and vineyard snails (*Cernuella virgata*) prefer alkaline sandy soils; the small pointed snail (*Prietocella barbara*) can survive on all soil types - even acidic soils.

Snails cause significant economic losses through yield loss and grain contamination. Some growers first discover snails are a problem in their crops when their grain is rejected. Rejection occurs if more than half a dead or one live snail is found in a 0.5 litre wheat sample (confirm details with your grain buyer).

The small pointed snails are only known to cause economic crop damage in high-rainfall areas, while the vineyard and white Italian snails cause crop damage in the Geraldton region and in Greenough flats; the region between Dongara to Geraldton.

Identifying the snail species and sizes in a paddock paddocks underpins selection of management options. While mature snails (larger than 7mm diameter or length) of all species will feed on bait, many of the controls or grain-cleaning techniques following harvest are less effective on juvenile snails. The most effective control program will be an integrated program that uses the most appropriate option for each stage of the snail life cycle (see Figure 13).

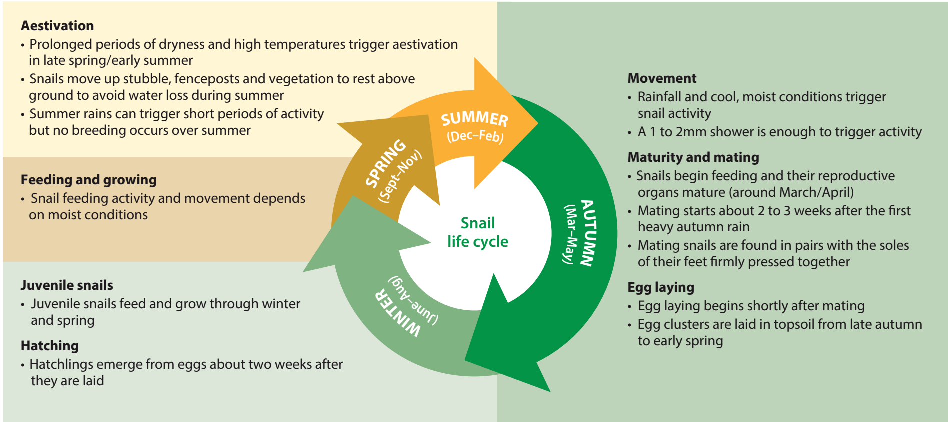


Figure 13: The snail life cycle.

8.8.1 The snail lifecycle

From a management perspective, all snail species of concern to wheat growers have a similar lifecycle, with seven main stages (see Figure 13). Applying the appropriate control options at each stage of the life cycle is critical for successful snail control.

During summer snails are dormant (aestivate). Egg laying starts after snails are activated by autumn rain and continues while soil is moist. Eggs are laid in the soil and hatch after about two weeks (each snail lays up to 400 eggs a year).

8.8.2 Monitor and manage

Monitor snails regularly to establish numbers, types, activity and success of control measures. Check for snails in the early morning or in the evening when conditions are cooler and snails are more active.

During summer round snails favour resting places off the ground on stubble, vegetation and fence posts, while pointed snails are often found on the ground in cool shady places. By autumn, snails are generally found on the ground and on the youngest leaves as crops grow. Numbers are often higher around the paddock perimeter. Look closely in the crowns of last year's stubble; snails can be easily missed on a casual inspection.

A wide range of snail sizes in an area indicates snails are breeding: if most snails are the same size, they are moving in from other areas.

During summer and leading up to sowing, monitor paddocks regularly to estimate snail population size and determine the appropriate control measures if necessary.

Snail numbers, especially the small conical snail, are easily misjudged as these snails live under stubble, in canola stalks, under rocks or on fence posts.

8.8.3 Estimating numbers

To estimate snail numbers sample 10cm by 10cm quadrats at 50 locations across the paddock and around the paddock boundary. Take samples from the perimeter to the interior of the paddock and note the densities in different areas.

Simple sieve boxes can be used to separate snails by size — snails larger than 7mm are more likely to take bait.

Key times to monitor include:

- January/February to assess options for stubble management.
- March/April to assess options for burning and/or baiting.
- May/August to assess options for baiting, particularly along fencelines.
- Three to four weeks before harvest to assess the need for header modifications.

More information

For more information on header modifications to control snails read: www.grdc.com.au/GRDC-FS-SnailManagement

For more information on cabling, rolling and slashing read: www.grdc.com.au/GRDC-FS-SnailManagement

Thresholds for snails in various crops and pastures are shown in Table 11.

Table 11: Thresholds for snail control.

Snail species	Crops: Cereals (wheat)	Oilseeds (canola)	Pulses (lupins)	Pastures
Small pointed snail	40/m²	20/m²	5/seedling	100/m²
White Italian snail	20/m²	5/m²	5/m²	80/m²

Taking control

Effective snail control requires a targeted and integrated approach throughout the year (see Figures 13 and 14).

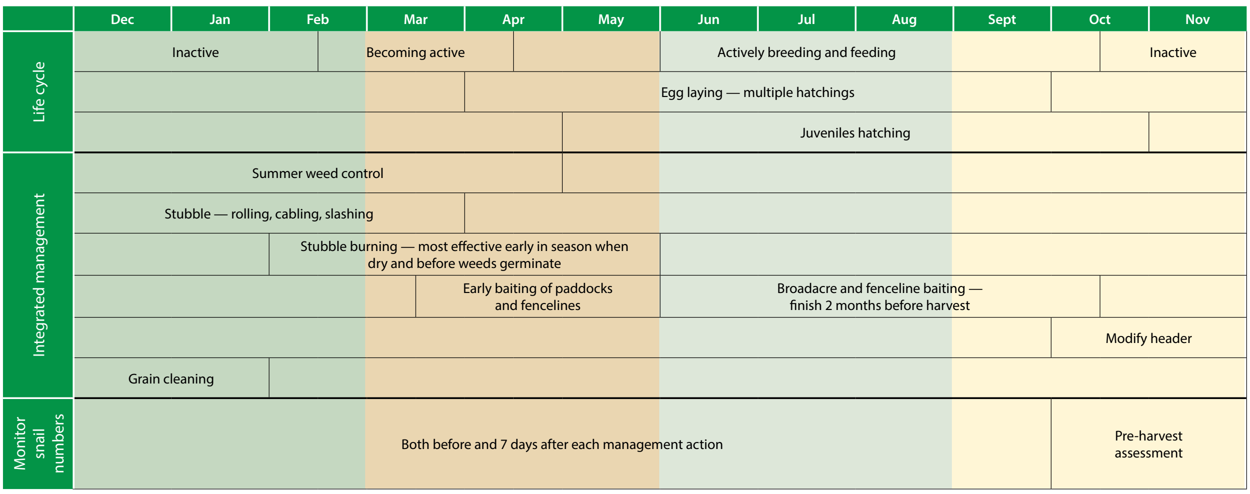


Figure 14: Integrated snail management. Source: GRDC.

Pre-sowing options

A combination of effective summer weed control and approaches such as bashing, burning or grazing stubbles and using snail baits can reduce snail numbers by up to 95 per cent.

The aim of pre-sowing control options is to reduce the habitat in which snails can shelter and reproduce — high stubble loads and uncontrolled summer weeds provide habitat and food sources for snails.

Grazing crop stubble can reduce snail numbers as livestock knock snails from stubble and trample them. Livestock also reduce stubble loads and groundcover, reducing the habitat and food sources for the snails. Snail control levels under grazing vary according to stock numbers and movement.

Cabling, rolling, slashing and grazing are all stubble management options that knock snails onto the hot soil surface causing them to dehydrate, starve and die. Stubble management is most suited to controlling round snails as conical snails hide beneath rocks.

Carry out mechanical stubble management options on sunny days over 35°C. Ideally, several hot days should follow. Stubble management can kill 50 to 90 per cent of snails when temperatures exceed 35°C.

Less success will be achieved in dense cereal stubbles or when green summer weeds are present. It is important to maintain a weed-free zone about two metres from either side of a fence line to remove potential breeding grounds.

Stubble burning is still the most effective pre-sowing method of controlling snails, as long as an even burn is achieved. Only burn stubbles in paddocks with highest snail numbers to reduce the negative impacts on soil properties and the risk of erosion.

Burning is most effective on round snails and less effective against conicals unless rocks are turned before burning.
A complete, even burn can achieve a 100 per cent kill, while a patchy burn results in a 50 to 80 per cent kill.

Kill summer weeds before burning to improve efficacy of the burn. Broader baiting can be required to prevent re-invasion of burnt paddocks later in the season.

8.8.4 Baiting

Baiting is an effective control measure when snails are mobile and actively seeking food. It is important to lay pellets along fence lines and paddock boundaries as well as within the paddock itself.

Whole paddock, border and fenceline baiting is most effective when rain or moisture triggers snail activity in autumn and before significant egg laying starts (during early autumn). Killing mature snails before autumn egg laying reduces the potential population build-up for that season. Later baiting is less effective, especially when lots of green material provides an alternative food source for the snails.

Baiting can start before heavy dew or light rainfall (1 to 2mm) occurs. In cool, moist summers, baiting pastures or stubbles after harvest in December has seen good kill rates. Moisture softens the bait and it may disintegrate but the chemical is still active.

Growers have had success baiting after substantial summer rainfall has encouraged snails down to the soil surface.

Bait degrades in UV light; degradation rates are reduced as day length shortens. In trials, the concentration of metaldehyde fell from 15 to 4.9 per cent in four weeks when bait was spread in February, but to 7.5 per cent when spread a month later.

Baiting must finish two months before harvest to avoid baits being detected in grain samples.

Target mature snails – round snails larger than 7mm in diameter and conicals larger than 7mm in length – as baits are largely ineffective against juvenile snails.

A 60 to 90 per cent kill is achievable for round snails and 50 to 70 per cent kill for conical snails. This depends on timing, snail activity and bait rate.

Calculate bait rates on the number of mature snails (see Table 12). As snail numbers increase higher bait rates are likely to be beneficial. If snail invasion is high it could be worth increasing bait rates along paddock perimeters.

*Table 12: Bait rates in cereals.**

Snail type	Snail density (smails/m^2)	Label bait rate* (kg/ha)
Mature round and pointed	20 to 80	5
Mature round	More than 80	10
Mature pointed	More than 80	2 x 5 applications two weeks apart

Source: GRDC Snail management factsheet, Southern and Western Region 2012

**Note: registered rate varies between products so refer to product label for correct rates.*

More information

For more information on snail baiting trials read: www.grdc.com.au/GC108-SpreaderTrialSlugsSnails

Snails are only marginally attracted to the bait but will eat a pellet if they happen to bump into it. Baits with smaller bait size achieve more bait points per hectare and increase the potential for snails to hit a bait pellet.

The best time to apply snail pellets is early in the season when morning temperatures are low and dew forms and after the first germinating rains — this is when snails start to emerge and look for food.

The more bait points per square metre the better the kill rate as snails feed on baits only as they come across them.

Better calibration of bait spreaders = better baiting, saving time and money. Recent trials found that farmers can spend between $15 and $85 per hectare on baits but may not be applying them effectively. Spreaders that were not calibrated correctly result in an uneven distribution of baits.

The more even the bait distribution the more likely snails will come into contact with the bait, which results in better control.

Resources

GRDC Snail management factsheet, Southern and Western region
www.grdc.com.au/GRDC-FS-SnailManagement

GRDC Snail Identification and Control Back Pocket Guide
www.grdc.com.au/BPG-SnailIdentificationAndControl

GRDC Bash 'em, Burn 'em, Bait 'em: Integrated snail management in crops and pastures
www.grdc.com.au/GRDC-Snails-BashBurnBait

GRDC Slugs: The Back Pocket Guide
www.grdc.com.au/GRDC-BPG-Slugs

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

Soil moisture monitoring:

DAW00219 - Characterising and exploiting genetic diversity in wheat and barley for tolerance to water deficit during germination and crop establishment
(S: 01/07/2011 F: 30/06/2015)

PRE00001 – Understanding and managing spatial variation in stored soil moisture for better crop management decisions (S: 01/12/2013 F: 30/12/2014)

CSP00170 – Measuring and managing soil water in Australian agriculture
(S: 01/07/2013 F: 30/06/2016)

Variety choice:

DAW00191 – Evaluating herbicide tolerance of new crop varieties in western region with national coordination (S: 01/07/2014 F: 30/06/2019)

DAN00174 - Managing on-farm biosecurity risk in wheat through pre-emptive breeding (S: 30/06/2013 F: 31/05/2018)

Pre-emergent herbicides:

ICN00016 - IWM extension Northern Region (includes development of a national pre-emergent herbicides technical manual) (S: 01/07/2013 F:30/06/2016)

Soil nutrient testing:

DAW00222 – MPCN II – Regional soil testing and nutrient guidelines: West
(S: 01/07/2012 F: 30/06/2017)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC pre-sowing projects can be found at: www.grdc.com.au

SECTION 9

Sowing

More information

[DAFWA: Yield graph, p5; Predicted yields of varieties, p13-14.]

[DAFWA: Wheat yield constraint calculator.]

[GRDC: Yield using production value graphs, p5.]

[GRDC: Long season wheat.]

9.1 Tactical decisions re sowing time*

Key messages

- Flowering time is a major driver of potential grain yield. Matching the maturity rating of a wheat variety to its optimal sowing time will help ensure the crop flowers during its optimum window.
- Wheat yield indicators such as optimum sowing window, rainfall-to-date and seedbed moisture, rainfall prospects, deep-soil moisture and climate outlook can be assessed to guide sowing and nitrogen fertiliser decisions.
- Calculating and responding to break-even yields will ensure sowing decisions are likely to be profitable especially in dry or financially constrained seasons.There are no right or wrong answers regarding the proportion of crop that should be sown before the true break of the season or into a season in which early rainfall has been sporadic. What is important, however, is a risk assessment based on wheat yield indicators that can be measured or estimated with some skill.

*Information in this section has been taken from (1) the Department of Agriculture and Food, WA's AgTactics newsletter https://agric.wa.gov.au/n/3028, which is released throughout the season in each of the WA cropping zones to aid seeding and crop input decisions and (2) The Wheat Book (Anderson and Garlinge, 2000).

Assessing wheat yield indicators as the season progresses can help guide sowing and crop input decisions.

Photo credit: Emma Leonard.

The aim is to gather factual information about the current and predicted state of the season so that objective decisions about time of sowing and crop inputs can be made.

The wheat yield indicators (ranked in order of importance) are listed in Table 1. It is important to assess the indicators in their order of importance; positive assessments of indicators lower on the list do not override negative assessments of indicators at the top.

Table 1: Seasonal indicators of potential wheat yield (in order of importance).

Yield indicator and ranking	Implication	More information
1. Optimal sowing date	The optimum sowing-window for wheat narrows as the season break lengthens. Grain yield can drop by more than 50kg/ha per day for wheat that flowers past its optimal flowering window (Figure 1). When the season breaks late it is important to determine whether the wheat sowing-window is still open or whether it is time to switch to shorter season varieties. Wheat sown before Anzac day (25 April) has significantly higher frost risk at flowering. Sowing long-season varieties late (mid-June) increases risk of screenings. However, short-season varieties suffer little yield reduction if sown into May or June (Figure 6).	Use Flower Power to determine the optimal sowing/flowering windows for WA wheat varieties: https://www.agric.wa.gov.au/flower-power Consult the current wheat variety guide to determine suitable short and long season wheat varieties: www.grdc.com.au/WAWheatVarietyGuide Calculate the break-even crop yield required to determine the economic viability of wheat sowings (Table 4).
2. Amount of rainfall or seedbed moisture at break.	Moisture stored in surface layers is more prone to evaporation than water stored at depth. Until the crop is established evaporation of surface-stored soil moisture will be the major pathway of soil water loss, which can be as high as 2mm/day in late May. If there is no soil moisture at depth, crops will require regular and significant rainfall events to see the crop through to the end of the season. A large (>25mm) rainfall event will be required to wet the soil profile to depth and compensate for future dry spells (see Figure 2). What rainfall decile is the season tracking on?	Use the CliMate app to estimate the amount of stored moisture and rainfall to date for a specific location (up to the end of June): www.australianclimate.net.au/ Refer to the soil moisture and rainfall to date maps produced fortnightly through the season by the Department of Agriculture and Food, WA: https://www.agric.wa.gov.au/agseasons/seasonal-climate-information
3. Chance of follow-up rain (0-8 days)	The first four days of an eight-day forecast have the highest accuracy. The second four days provides an indication of rain but is less accurate regarding the amount.	Refer to the Bureau of Meteorology site for the latest forecasts. www.bom.gov.au/watl/index.shtml
4. Stored soil moisture at depth.	Sands store less water than loams and clays. For example, a yellow sand can hold a total of about 60mm of water to 100cm depth while a red loam can hold about 100mm water to the same depth. A rainfall event of 60mm will therefore penetrate to 100cm in the sand and to 60cm in the red loam (Figure 2). Stored soil moisture only has a value when the crop can access it. Deep sowing of wheat onto moisture can enable the optimum sowing-window to be achieved. However, it is important not to seed deeper than the coleoptile length of the variety.	Use the CliMate app to estimate the amount of stored moisture and rainfall to date for a specific location: www.australianclimate.net.au/ Refer to the soil moisture and rainfall to date maps produced fortnightly through the season by the Department of Agriculture and Food, WA: https://www.agric.wa.gov.au/agseasons/seasonal-climate-information

Yield indicator and ranking	Implication	More information
5. Climate outlook (3-6 months).	The more models in agreement the better the chance that the seasonal prediction will eventuate. When there is variation in model predictions the outlook is far less certain and it is better to focus on what is happening in the short-term in terms of rainfall forecasts and soil moisture content.	Examine a range of international climate models: www.climatekelpie.com.au/see-forecasts/global-climate-models and climate drivers (Table 2) to determine the likelihood of seasonal rainfall. Subscribe to the Seasonal Outlook newsletter produced monthly by the Department of Agriculture and Food, WA: https://www.agric.wa.gov.au/newsletters/sco

Source: Department of Agriculture and Food, WA AgTactics newsletter - https://www.agric.wa.gov.au/newsletters

Note to Figure 1

Trials across the WA wheatbelt in 2009 showed delayed sowing to 2 June reduced yields only slightly with wheat yields falling by between 14 to 31kg/ha for each day's delay in sowing at Mingenew, Coorow and Mullewa. However, losses were far greater when sowing was delayed beyond 2 June, ranging from 28-55kg/ha a day. Quairading was the only exception because the mid-May sowing into marginal moisture reduced establishment and restricted weed control at this site.

For example, optimal sowing date (and its influence on flowering time) is the major driver of crop yield, so even if there is adequate soil moisture, yield will remain compromised if the optimal sowing window has passed (Figure 1).

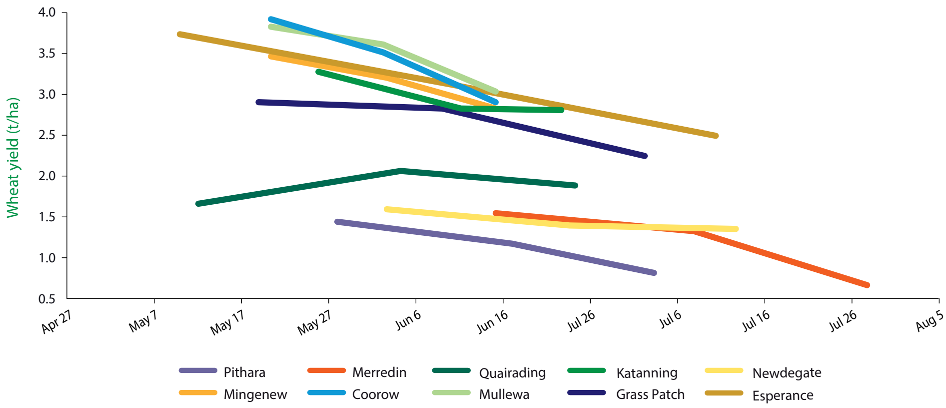


Figure 1: Impact of delayed sowing on wheat yields across the Western Australian wheatbelt.
Source: Department of Agriculture and Food, WA.

The indicators can be assessed regularly throughout the early part of the season to guide sowing time, size of the cropping program and nitrogen decisions. Positive assessments (especially of those indicators higher on the list) provide more confidence about sowing and nitrogen decisions. Negative or neutral assessments issue a caution about the best way forward with sowing and fertiliser programs.

The indicator assessments will be specific to a location and the financial and other circumstances of the farm in question. Positive assessments of the indicators (sowing window still open, good seedbed soil moisture, good prospects of rain) provide more confidence in crop decisions. Negative or neutral assessments offer caution about the best way forward with sowing and nitrogen programs.

Note to Figure 2

A very rough rule of thumb for soil moisture is for every one centimetre of moist soil there is about one millimetre of available soil moisture. If a push probe indicates there is moisture to 50cm then about 50mm soil moisture is available. However, this is a rough guide only and the actual amount of soil moisture will vary considerably with soil type as indicated in Figure 2.

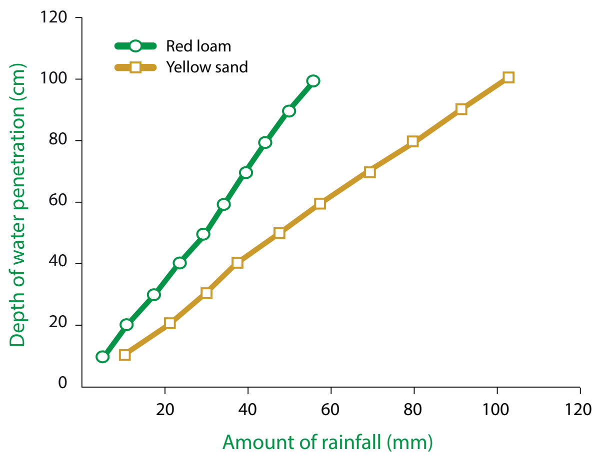


Figure 2: Water storage characteristics of a red loam and a yellow sand.

Source: Department of Agriculture and Food, WA.

Sowing wheat varieties beyond their optimal sowing time can result in yield losses of more than 50kg/ha/day.

Photo credit: Bob Freebairn.

More information

For more information on the drivers of WA climate:

www.grdc.com.au/GRDC-FS-TimeOfSowing

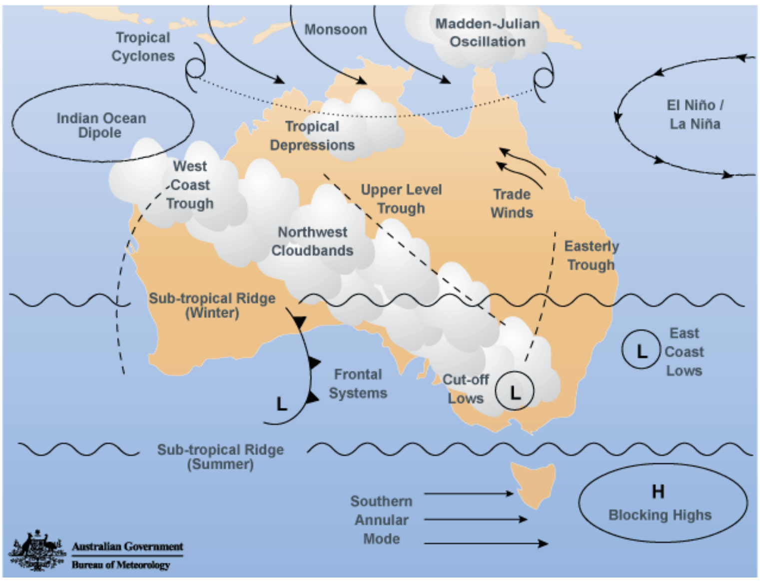
Note to Table 2

During a positive Southern Annular Mode event, the belt of strong westerly winds contracts towards the South Pole. This results in weaker-than-normal westerly winds, higher pressure and fewer storm systems over southern Australia. As a result, autumn and winter rainfall can be reduced in south-west Western Australia and in spring months rainfall can increase over parts of Western Australia.

Table 2: Major drivers of Western Australian wheatbelt weather.

Climate driver	Characteristics	Weather impact	Seasonal influence
Sub-tropical ridge: an extensive area of high pressure that encircles the globe at the middle latitudes.	The position of the ridge varies with the season, allowing cold fronts to pass over southern WA in the winter, but pushing them to the south in summer.	Frontal activity Fine and dry	Winter Summer
Indian Ocean Dipole (positive)	The Indian Ocean Dipole is a measure of changes in sea surface temperature patterns in the northern Indian Ocean. It has a profound impact on rainfall patterns over much of Australia.	Less rain	June-November
Indian Ocean Dipole (negative)		More rain	June-November
Southern Annular Mode (positive phase)	The Southern Annular Mode describes a north-south movement of strong westerly winds associated with cold fronts and storm activity across southern Australia.	Less rain (south-west WA) More rain (south-central WA)	Autumn-winter Spring
Southern Annular Mode (negative phase)		More rain (south-west WA)	Autumn-winter
El Niño – Southern Oscillation (ENSO). ENSO is the oscillation between El Niño (dry) and La Niña (wet) conditions caused by temperature changes in the Pacific Ocean.	ENSO has greatest influence on eastern and central Australian rainfall however northern Australian regions can receive higher than average rainfall during La Niña years.	Mainly northern parts of WA.	May-April

Source: Climate Kelpie website www.climatekelpie.com.au



More information

For more information on the drivers of WA climate: www.climatekelpie.com.au/understand-climate/weather-and-climate-drivers/western-australia

Refer to the statistical seasonal rainfall forecasts released fortnightly by the Department of Agriculture and Food, WA: www.agric.wa.gov.au/agseasons/seasonal-climate-information

Videos

Watch a video on how climate models work and how best to use them: http://epa.gov/climatechange/science/future.html

*Table 3: Major synoptic features of Western Australian wheatbelt weather.**

Synoptic feature	Characteristics	Period of influence	Region of influence
Cut-off lows	Low-pressure systems that form away from the main belt of low pressure that lies across the Southern Ocean. Sustained, often heavy rainfall with strong gusty winds.	All year	Southern
West-coast trough	Semi- permanent feature of the synoptic pressure pattern near the west coast of Australia during the warmer months. West of trough: mild with seas breezes. East of trough: hot with thunderstorms.	September-May	Western
Blocking highs Strong high-pressure systems that form further south than usual and remain almost stationary for a long time. They block the west-to-east progression of weather systems across southern Australia.	Hot and dry conditions in southern WA in winter if the high is in the Bight. Drizzle and showers across south coastal WA in summer if the high is south of the Bight. Increased chance of a cut-off low over southern parts if the high is south of the Bight (all year).		
Cloud bands	An extensive layer of rain-bearing cloud that can stretch across Australia, often from north-west to south-east.	April-September	Statewide
Frontal systems	Generally move from west to east across the Southern Ocean and vary in their intensity and speed with more intense systems generally associated with heavier rainfall.	All year (greater in winter)	Southern
Tropical influences (cyclones/depressions/monsoon)	Heavy rain/high winds.	October-April	Northern and central but can drift into south-west WA.

*Climate drivers in Table 3 can influence these WA synoptic weather systems. Source: Climate Kelpie website www.climatekelpie.com.au

Using climate models

- It is important to compare and contrast a range of climate models.
- Do not weigh all the information equally. Some models and forecasts are more skillful and reliable than others. This should be accounted for when comparing the different forecasts.
- Look for consistency between the forecasts and models. If the models are pointing to the same outcome, then it is more likely to occur. If there is variation, there is increased uncertainty.
- No forecast will ever be certain. The information needs to be used to determine which way to lean, not which way to jump.

9.1.1 Break-even crop yields

Calculating a break-even crop yield is a quick way to determine if continued sowings are economically feasible. The goal is to ensure that crop revenue will exceed the variable costs of production.

Variable costs are those associated only with the growing of the crop (seed, fertiliser, herbicide) and as such are costs that will only be incurred if the crop is sown.

Table 4 can be used to determine the break-even yields required in relation to variable input costs and grain prices.

Table 4: Break-even yield (t/ha) required for a range of variable costs and grain price combinations.

	Variable costs $/ha									
Price $/t	**90**	**100**	**110**	**120**	**130**	**140**	**150**	**160**	**170**	**180**
200	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1.0	1.0	1.1
210	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1.0
220	0.4	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	1.0
230	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9
240	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9
250	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.8
260	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8
270	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.7	0.8
280	0.3	0.4	0.4	0.4	0.4	0.5	0.6	0.6	0.7	0.7
290	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.7
300	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.7

Source: Department of Agriculture and Food, WA Agtactics Newsletter.

Note to Table 4

Reducing input costs will lower the required break-even yield. For example, phosphorus rate can be cut if soil tests indicate levels are adequate. Identifying paddocks or parts of paddocks where net returns are likely to be low can reduce peak debt and possibly lift profits, especially in drier seasons and when finances are stretched. Such paddocks include those with high and problematic weed burdens, poor fertility, potential disease problems or low yield prospects.

Calculating break-even yield

Variable costs = $175/ha
Expected wheat price = $300/t
Expected wheat yield* = 0.75t/ha

Break-even yield = variable costs divided by expected commodity price ($/t)
= $175/ha divided by $300/t
= 0.58t/ha

In this example, the break-even crop yield (0.58t/ha) is less than expected yield (0.75t/ha) so sowing the crop is viable.

*Note: To estimate expected wheat yield use the potential yield calculator: www.soilquality.org.au/calculators/yield_potential or the calculation in the section to the right or refer to Yield Prophet®.

Estimating expected wheat yield

Expected wheat yield can be estimated using a modified French and Schultz (1984) equation (which is the equation used in the potential yield calculator):

Grain yield (t/ha) = {(summer rain + growing season rain) - soil evaporation} x the water use efficiency of the crop.

Summer rain = (rainfall between 1 Nov and 31 Mar) x 0.3 (30% of summer rainfall is assumed to be available for plant use at sowing).

Growing season rainfall = April-Oct rainfall. Take the growing season rainfall to date and add on an expected amount based on past records (use rainfall deciles to gather a range of expected growing season rainfall amounts).

Evaporation for a wheat crop is 110mm (however if growing season rainfall is less than 330mm use one third of growing season rainfall).

Water use efficiency varies according to soil type and management. French and Shultz assumed that every millimetre of available water would produce 20kg of wheat per hectare; however values in WA can vary from 8-24mm/kg. Use historical water use efficiency estimates for different soil types and locations.

Calculating a break-even crop yield is a quick way to determine if continued sowings are economically feasible, especially in seasons with a late break and poor rainfall.

Photo credit: Evan Collis.

9.1.2 Rainfall deciles*

Average is a widely used measure of rainfall and rainfall received can be above average, average or below average. However rainfall records at any location can comprise more low rainfall years than high rainfall years, making measures of average rainfall misleading when the frequency of high, average or low rainfall years is required.

The median (middle) rainfall value gives a better guide to rainfall in that rainfall can be expected to be less than the median in half of all years and more than the median in the other half. Deciles are an extension of this concept. Instead of dividing ranked rainfall records into two groups to give below and above median rainfall categories, rainfall records are divided into 10 (decile) groups, to give a wider range of rainfall categories relative to a defined average range (Table 5).

The Bureau of Meteorology uses a 3:4:3 split to categorise below average, average and above average rainfall. Below and above average rainfall is sometimes further categorised according to the degree of deviation from the average (much above average, very much above average etc.) (Table 5).

Table 5: Rainfall decile groupings in relation to average rainfall descriptors.

Decile range	Extent of range	Seasonal rainfall implication	Descriptive name
1	Lowest 10% of records	9 in 10 seasons received more than this amount of rainfall (or only 1 in 10 received less).	Very much below average
2	Second lowest 10% of records		Much below average
3	Third lowest 10% of records		Below average
4, 5, 6, 7	Middle 40% of records	Decile 5: 5 in 10 seasons received less than this rainfall amount and 5 in 10 received more.	Average
8	Third highest 10% of records		Above average
9	Second highest 10% of records		Much above average
10	Highest 10% of records	9 in 10 seasons received less this amount of rainfall (or 1 in 10 received more).	Very much above average

Source: Department of Agriculture and Food, WA: Farmnote 56/200*

To calculate deciles, a designated period of rainfall records is ranked in ascending order, and then the data are split into 10 equally sized groups. The first group contains the lowest 10 per cent of records, and is known as the decile 1 range. The highest value in the decile 1 range is decile 1. The next 10 per cent of rainfall records becomes the decile 2 range and the highest value in this range is decile 2. This labelling process continues with each successive group to give deciles 1 to 9 ranges and values (Table 6).

Note to Table 6

The 30 years of growing season (April-October) rainfall records for Mingenew (1974-2004) show that rainfall has ranged from a low of 188.4mm through to a high of 550.2mm. Dividing the 30 years into ten lots of three years provides the deciles for the three decades of records. Current growing season rainfall can then be compared against the deciles to see where the season sits within historical records (see Figure 3).

Table 6: Table 6. Rainfall deciles for 30 years of growing season rainfall records (1975-2004) at Mingenew, WA.

Decile	Rainfall range	Decile amount (highest reading within the rainfall range for each decile)
1	188.4 208.9 209.6	Decile 1 rainfall is ≤ 209.6 mm
2	215.2 217.5 218.4	Decile 2 rainfall is ≤ 218.4 mm
3	244.5 248.9 250.4	Decile 3 rainfall is ≤ 250.4 mm
4	252.3 266.1 276.7	Decile 4 rainfall is ≤ 276.7 mm
5	284.8 292.7 306.5	Decile 5 rainfall is ≤ 306.5 mm
6	313.7 333.2 337.9	Decile 6 rainfall is ≤ 337.9 mm
7	339.6 354.8 358.5	Decile 7 rainfall is ≤ 358.5 mm

Decile	Rainfall range	Decile amount (highest reading within the rainfall range for each decile)
8	361.2 367.6 373.0	Decile 8 rainfall is ≤ 373.0 mm
9	376.7 395.4 416.6	Decile 9 rainfall is ≤ 416.6 mm
10	420.4 439.6 550.2	Highest on record = 550.2 mm

Source: Department of Agriculture and Food, WA: Farmnote 56/200*

Table 6 lists the 1975 to 2004 growing season rainfall deciles (April to October) for Mingenew. The 30 years of rainfall records are first listed in ascending order and then split into 10 equal groups. The decile values are the highest rainfall record within each decile group.

Deciles provide a measure of the spread of rainfall experienced in the past. Rainfall in the current year can be compared against decile information to see where it stands in relation to historical records.

Deciles can also provide a guide to the likelihood of rainfall amounts in the current season. For example, a decile 8 rainfall means there is an 80 per cent chance of having the same or less rain and a 20 per cent chance of receiving more than the decile 8 rainfall. So, if a season is tracking at decile 8 (373mm in the example above) there is only a 20 per cent chance (based on historical seasons) that the remaining seasonal rainfall will push the seasonal rainfall higher than 373mm.

Decision support tools such as Yield Prophet® use graphics to show how rainfall in a current or selected year compares against cumulative decile (usually 1, 5 and 9) rainfall totals (Figure 3).

Figure 3 shows that growing season rainfall at Mingenew as of 20 June 2005 was tracking on decile 9 (second highest 10 per cent of rainfall records in the past 30 years). The projected season finishing deciles show that even with only a decile 1 rainfall finish (lowest 10 per cent of rainfall records in the past 30 years), growing season rainfall for Mingenew in 2005 will still be above the growing season median (decile 5). This can provide confidence in nitrogen input and grain marketing decisions.

More information

Read a case study on the use of Yield Prophet® and rainfall deciles to make marketing and nitrogen decisions with more confidence: www.grdc.com.au/GCS106-VirtualApproachBoostsForwardSaleConfidence

Note to Figure 3

Although deciles are a useful tool in looking at climate variability, in practice they cannot provide a complete range of possibilities. For example, a future year's rainfall may be lower than the lowest rainfall event previously on record, or higher than the highest rainfall event on record.

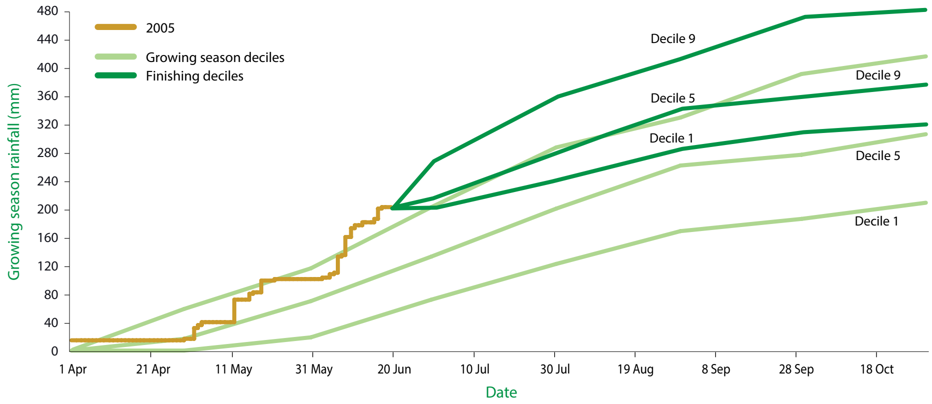


Figure 3: Growing season (April to October) rainfall for Mingenew to 20 June 2005, graphed against the last 30 years' growing season deciles and finishing deciles. By graphing rainfall to date against deciles we can see how it compares to the past.

Source: Department of Agriculture and Food, WA Farmnote 56/2005.

9.1.3 Sowing time

Choice of sowing date and variety underpin wheat yield potential.

Grain yield is influenced more by flowering date than sowing date with long-term research in WA showing crop yields are maximised when flowering occurs within a narrow band or 'window' of time – usually between 10-40 days at any location.

The optimum flowering window is a balance between risk of frost from flowering too early and heat damage from flowering too late (Figure 4).

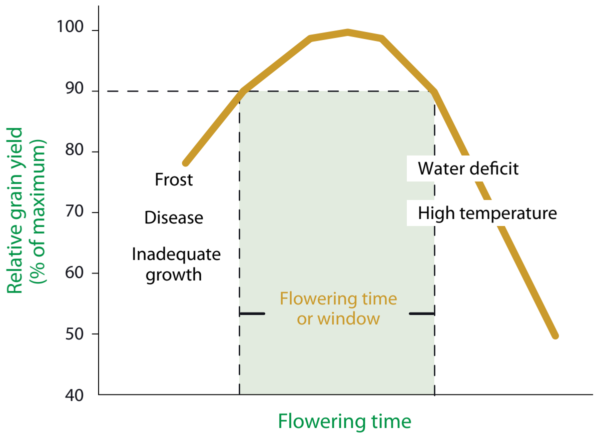


Figure 4: Conceptual relationship between flowering time and wheat yield showing the optimum flowering window defined as 'the period between the last frost and the last effective rain'.

To have the best chance of achieving maximum yield, the wheat crop must flower within its flowering window. Grain yield declines when wheat flowers outside the flowering window – with the rate of decline highest in warmer, short season environments of the northern and eastern wheatbelt than in the cooler, longer season environments of the south coast.

Date of opening rains, seasonal temperatures and the incidence of frosts result in the flowering window for any location being open at different times from season to season.

While the flowering window can be estimated from weather records, such records do not account for the impacts of disease, cultivar adaptation or the vagaries of frost events. The best way to estimate the flowering window is to sow wheat varieties at different sowing times in the field and measure their yield response. Flowering dates of varieties with a wide range of maturities can then be observed and related to grain yields over several seasons.

The best estimate of the flowering window will then be based on an 'average' of many sowing date field trials (Figure 5).

Note to Figure 5

Flowering dates of varieties with a wide range of maturities can only be related to grain yield over several seasons. The best estimate of the flowering window will then be based on an 'average' of many sowing date field trials.

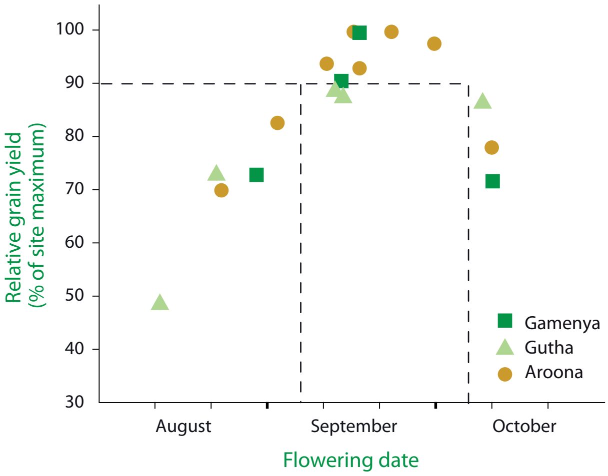


Figure 5: Estimated flowering window for Wongan Hills. Data are from the 1986, 1987 and 1988 growing seasons.

The optimum flowering time for wheat is a balance between the risk of frost from flowering too early and the risk of heat damage from flowering too late. In Western Australia the optimum flowering time is usually between 10-40 days at any location.

Photo credit: Brad Collis.

Table 7 outlines the optimum flowering window for wheat at locations across the WA wheatbelt. The dates are based on hundreds of sowing date trials across many locations over the past few decades.

Once the flowering window is known, the next step is to ensure the variety and its sowing date are correctly matched so that flowering occurs at the desired time. In principle, early sowing will require long-season varieties and late sowing will require short season (early flowering) varieties (Figure 6).

Table 7: The optimum wheat flowering window for locations across the Western Australian wheatbelt.

North-east	North-west	Eastern	Central*	Lakes*	Great Southern	South Coastal
25 Aug – 15 Sept	3 Sept – 23 Sept	1 Sept – 20 Sept	5 Sept – 25 Sept	1 Sept – 20 Sept	16 Sept – 6 Oct	3 Sept – 2 Oct

Source: Department of Agriculture and Food, WA.
*Indicates that a damaging frost can sometimes occur in the first half of the window in some years.

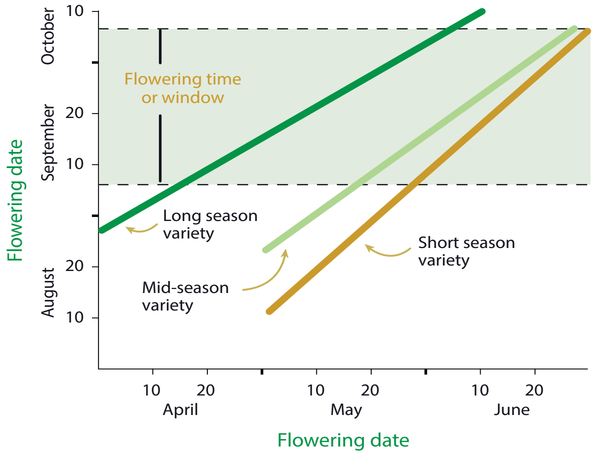


Figure 6: Suggested relationship between sowing date and flowering date for a long season, mid-season, and a short season variety at Wongan Hills, WA.
Source: Anderson and Garlinge (2000).

Grain yield can drop by as much as 50kg/ha per day for wheat that flowers past its optimal flowering window. When the season breaks late, it is important to determine whether the wheat sowing window is still open (Figure 6) or whether it is time to switch to a shorter season variety.
Photo credit: Evan Collis.

Note to Figure 6

Sowing the long season variety into late May and June will result in it missing its flowering window. Similarly, sowing the shorter season varieties too early (mid April to early May) will result in them flowering before the optimum time and place them at higher risk of frost damage. Shorter-season varieties can be sown well into June and will still flower at the optimum time.

More information

For more information on sowing time and flowering window in wheat read: www.grdc.com.au/GRDC-FS-TimeOfSowing

To identify the optimum flowering window use Flower Power: www.agric.wa.gov.au/frost/flower-power

9.2 Plant establishment

9.2.1 Planting density

Under ideal conditions, as plant density increases wheat grain yield increases until a yield plateau is reached. Yields then stay at about the same level until very high plant densities result in a yield decline (Figure 7).

Seeding rate trials by the Department of Agriculture and Food, WA over many decades show that as grain yield increases so too does the required population required to ensure seeding rate does not limit grain yield (Figure 8).

Note to Figure 7

Considerable plasticity exists in wheat yield response to planting density because wheat can compensate for poor stands through tillering. The relationship between grain yield and plant density is therefore not as clear as Figure 7 suggests. However, as other production limitations are removed and yields increase (particularly in high rainfall areas) plant population and row spacing can limit grain yield.

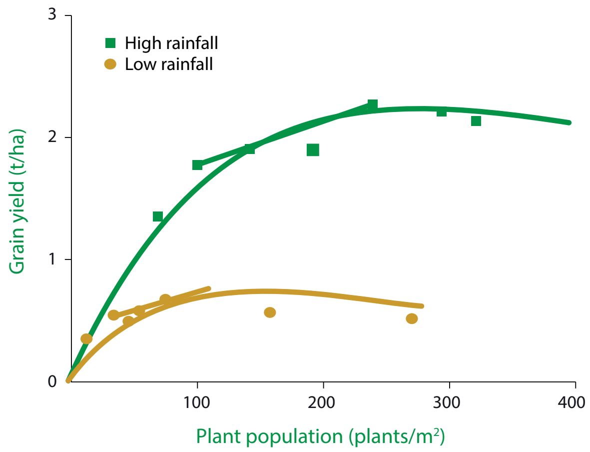


Figure 7: Relationship between wheat seeding rate (plant population) and grain yield in a high rainfall and low rainfall environment. The optimum seeding rate is defined as the point where an extra one-kilogram of seed returns five kilograms of grain yield.

Source: Anderson and Garlinge (2000).

Note to Figure 8

The relationship between optimum plant population and grain yield is:

Optimum plant population = 40.6 + (34.6 x expected grain yield).

Therefore, for an anticipated yield potential of 1t/ha, a plant population of 50/m^2 should be sufficient to ensure that plant density does not limit grain yield. At 4t/ha, a plant population of about 200/m^2 is needed.

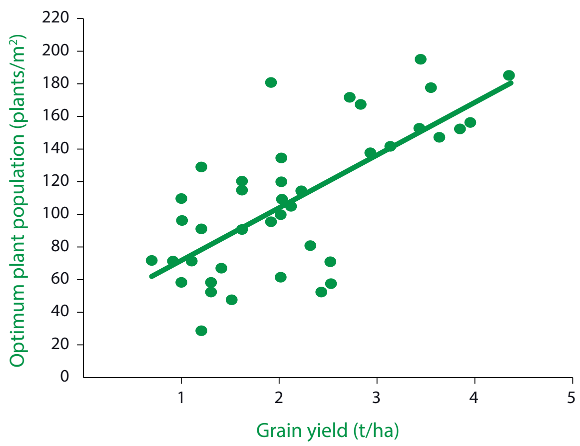


Figure 8: Plant population required for optimum yield – based on WA seed rate trial data.

Source: Anderson and Garlinge (2000)

9.2.2 Seeding rate

For each tonne of grain per hectare the rule of thumb target is 40-50 plants/m^2 and about 100 heads/m^2.

Adjusting seeding rate according to seed weight will ensure plant density and head number are optimised for potential yield.

Knowing the seed weight of a variety can have a real impact on input costs.

For example, a variety with a seed weight of 45g per 1000 grains (45mg/seed) will require 47kg/ha of seed for a yield potential of about 2t/ha (100 plants/m^2). However, if the grain weighs 35g per 1000 grains (35mg/seed), the seeding rate required drops to 37kg/ha for the same yield potential. This 10kg/ha drop in seed requirement translates into a saving of about $6250 at a seed cost of $250/t and a seeding program of 2500 hectares.

To calculate a seeding rate targeting a 2t/ha yield:

$$\text{Seeding rate} = \frac{\text{plant density (number/m}^2\text{) x seed weight (g/1000 seeds)}}{\text{seeding efficiency (\%)}}$$

For example, if the target plant density is 100 plants/m^2 and seed weight is 35mg (35g/1000 seeds) and seeding efficiency (establishment percentage) is 85 per cent then target seeding rate is: 100 x 35/85 or 41kg/ha (Table 8).

Table 9 gives an indication of average seed size of 10 wheat varieties grown in the northern agricultural region of WA.

Table 8: Targeted seeding rate at two levels of seeding efficiency for a range of seed weights and targeted plant densities.

Target plant density (plants/m^2)	Grain weight/1000 seeds (g)	Target seed rate (kg/ha)	
		95% efficiency	85% efficiency
100	35	37	41
100	40	42	47
100	45	47	53
150	35	55	62
150	40	63	71
150	45	71	79

Source: Christine Zaicou-Kunesh, Department of Agriculture and Food, WA.

Note to Table 9

Seed size data collected from 57 National Variety Trials across Western Australia; seed size may vary depending on the environment and management of the crop.

Table 9: Seed size (mg) of a range of commercial wheat varieties grown in Western Australia.

Variety	Seed weight (mg)
Calingiri⁽ᵖ⁾	40
Carnamah⁽ᵖ⁾	38
Corack⁽ᵖ⁾	42
EGA Bonnie Rock⁽ᵖ⁾	37
Emu Rock⁽ᵖ⁾	43
Justica Plus⁽ᵖ⁾	34
Mace⁽ᵖ⁾	40
Magenta⁽ᵖ⁾	38
Westonia⁽ᵖ⁾	39
Wyalkatchem⁽ᵖ⁾	41

Source: Department of Agriculture and Food, WA.

Calibrating seeders for sowing rate accuracy

Source: Glen Riethmuller, Department of Agriculture and Food, WA.

Seeders must be calibrated for each type of seed and fertiliser used. Seeder manufacturers cannot recommend exact settings for all the variations in seed size and fertiliser particle size and density.

Seeders can be calibrated by collecting and weighing the seed and then the fertiliser, as they are discharged through the sowing tubes over a measured distance. Some air seeders can be calibrated while stationary by turning a handle a given number of times for a particular area and weighing the material delivered. However, travelling over a set distance is better because it accounts for the effect of machine vibration on flow rate.

Checking evenness of flow

Distribution accuracy of seed and fertiliser across the machine should also be checked. Tubes that discharge above or below the average indicate there is a problem, especially in air seeder where uneven hose lengths and kinks can dramatically alter air, seed and fertiliser flow rates through the tubes.

The fluted roller on combines can become worn or poorly adjusted. Check combines with coarse and fine settings, as these can be knocked during a previous cleaning and will need resetting.

Bridging above the metering system can cause uneven fertiliser flow. On a combine, unevenness of flow can be caused by partial blockages, loose or broken cut-off plates or shutters and worn out or mismatched stars.

Calibration steps

Calibrate the seed and fertiliser in separate runs.

Step 1

Before testing the machine, calculate the quantity of material that should be collected from the seeder.

Amount to be collected in kg =

$$\frac{\text{Seeding rate (kg/ha) x width (m) x run length (m)}}{10{,}000}$$

Step 2

Check that the tyre pressure of the seeder is correct as this affects the rolling radius of the wheels.

Place sufficient seed and fertiliser in the appropriate hoppers and ensure there is enough to cover all the outlets and that the seed is dry if inoculum has been added.

Mark out a straight calibration run of 200m on a surface similar to that which will be sown.

Refer to the manufacturer's chart for the seeder and select the correct gear ratio and correct openings on the box for the desired output in kilograms per hectare.

Step 3

Do a short run with the sowing points out of the ground to check that all the outlets are delivering seed and fertiliser.

Move up to, and stop at, the start of the measured 200m distance with the seed or fertiliser running and remove each delivery tube from its boot. Secure a plastic bag, freezer bag or similar to the delivery tube using an elastic band, tape or string. If calibrating an air seeder,

a hole must be left for the air to escape and the bag must be big enough so that the material will not block the tube during calibration.

A fertiliser bag may be a better size in this case. Assess at least five rows of the machine.

Operate the seeder over the 200m at near the usual working speed. Then remove the bags, making note of the tube each bag comes from.

Compare the amounts collected in each bag. If they vary considerably, investigate the cause.

Bulk up the bags and measure the total amount of seed or fertiliser - a kitchen or bathroom scale can be used. This amount should be the same as that calculated in Step 1. If it is 10 per cent higher or lower than the desired rate, re-calibrate the machine after adjustment.

Calibration example

This example is based on the desired seeding rate for wheat of 60kg/ha with a 28-row combine on 180mm row spacings, collecting from all rows, on a 200m run.

The total amount collected and weighed should be 6.05kg. If you collect 10 per cent more or less, (more than 6.65kg or less than 5.44kg), then adjustment and re-calibration of the seeder is necessary.

Width (m)
= row number x row spacing (m)
= 28 x 0.18
= 5.04m

Amount collected (kg)
= (kg/ha x width x run length) divided by 10,000
= 6.05kg

Alternative method

If the seeding rate is known to be close to the desired rate, then a simpler calibration method can be used.

However, this method does not give any indication of individual row output.

Fill the combine box to the top and carefully level it. Sow a known area such as one hectare (use the combine area meter if it is accurate). Weigh the amount needed to refill the box with a spring balance scale hanging off a field bin auger attached to a bag.

The accuracy of this method is improved if a large area is sown so the box is nearly emptied before weighing since vibration can pack down the unsown material.

Air seeders

Often only the volume of an air seeder tank is known.

If an estimate of the weight of grain that it holds is required, multiply the grain hectolitre weight by 10 to generate the weight of grain (kg) per cubic metre (1 cubic metre = 1000 litres).

If an estimate of the fertiliser weight (kg) held in the air seeder is required then multiply the cubic metres by about 700 for urea, 900 for DAP, 950 for Agras No. 1, 1050 for double super and 1150 for plain super.

9.2.3 Seeding depth

In a season with a dry start, deep sowing into moisture is a tool that can ensure crops are established in their optimal sowing window. While deeper sowing can reduce crop germination, the yield from the earlier sowing can offset yield losses associated with sowing later in the season.

Deep sowing into moisture may help ensure the wheat crop hits its optimum flowering window while also assisting with the logistics of a large seeding program.

Several factors influence the capacity of wheat seed to emerge from depth:

- coleoptile length
- seed size
- soil conditions including temperature.
- fungicide treatments
- herbicides such as trifluralin.

More information

DAFWA: Deep seeding to chase moisture.

GRDC: Deep sowing wheat.

GRDC Update Paper: Bob French, The importance of wheat cultivar and seed size for deep sowing.

GRDC Update Paper: Wheat variety response to dry sowing and seeding depth.

9.2.4 Coleoptile length

For wheat seed to emerge successfully from the soil, the seed should never be planted deeper than the coleoptile length. Sowing varieties with short coleoptile lengths too deep can cause poor establishment, as the shoot will emerge from the coleoptile underground and it may never reach the soil surface (Figure 9).

Note to Figure 9

After 42 days, plants sown at 60mm deep into a moist loamy sand had almost one leaf fewer than shallower-sown plants. This lack of leaf can have a pronounced effect on tiller formation and final yield.

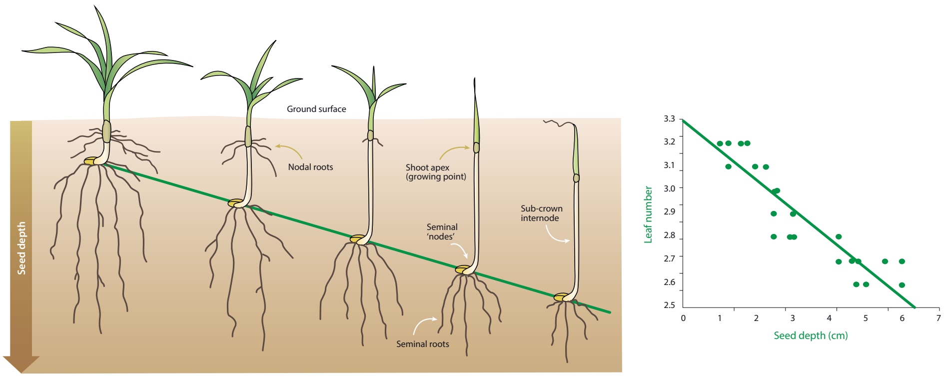


Figure 9: Impact of depth of sowing on seedling establishment. Inset 9b: Impact of sowing depth on the number of leaves measured at 42 days after emergence.

Source: Re-drawn from Anderson and Garlinge (2000).

Riethmuller (1990) found grain yield was reduced by a minimum of 10 per cent when short coleoptile wheats were sown deeper than 50mm.

Coleoptile length is influenced by several factors including variety, seed size, temperature, soil moisture and certain fungicide dressings and pre-emergent herbicides.

More information

For more information refer to the Cereal Growth Stages Guide: www.grdc.com.au/GRDC-Guide-Cereal-Growth-Stages

The semi-dwarf habit genes found in many commercial wheat varieties are also associated with shorter coleoptile length and generally taller varieties will have longer coleoptiles (Figure 10). However, there is still considerable genetic variation for coleoptile length within the semi-dwarf wheat varieties grown in Australia (Table 10) (Cornish and Hindmarsh, 1988).

The ideal seeding depth for wheat is 30 to 35mm for semi-dwarf varieties, through to 50 to 70mm for tall wheat varieties that have a longer coleoptile.

Note to Figure 10

There was very little difference in emergence of the short and long coleoptile variety up to 68mm depth, after which the emergence of Kulin (short coleoptile) dropped rapidly. Kulin sown at 100mm deep took an extra 14 days to emerge with a 35 per cent establishment rate and a 25 per cent drop in grain yield compared to seed sown at 40mm. The long coleoptile variety Gutha was less affected by the deeper sowing.

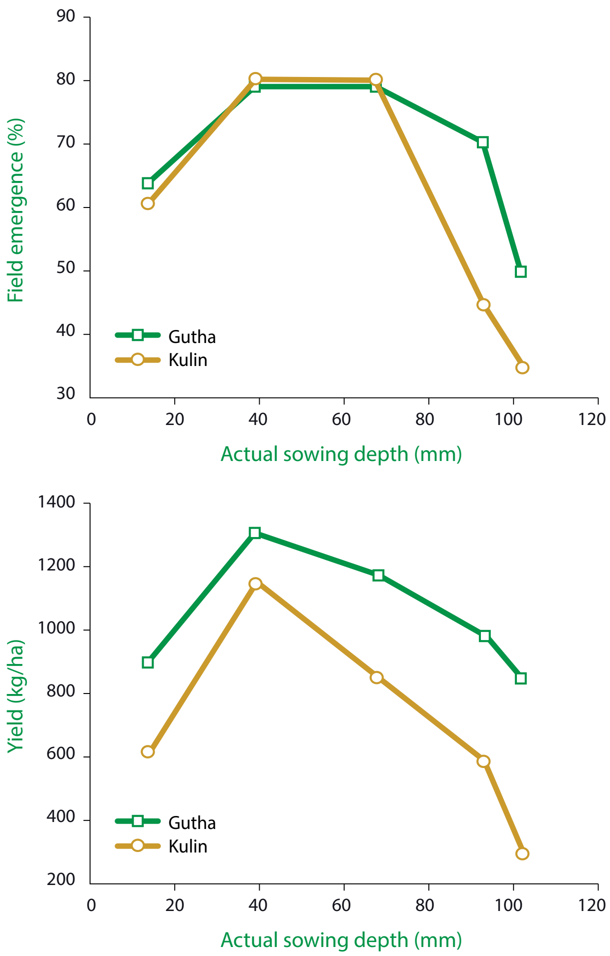


Figure 10: Emergence (%) and grain yield (kg/ha) of a tall wheat variety (Gutha) and a short coleoptile, semi-dwarf variety (Kulin) sown at five depths.

Source: Anderson and Garlinge (2000).

Note to Table 10

While most of the difference in coleoptile length between varieties is genetic, the impact of environmental factors on coleoptile length mean ratings must be gathered over several seasons to be accurate.

Average seed size of a seed sample can be used as a rough guide to the coleoptile length of the variety.

*Table 10: Coleoptile length ratings for the 2014 top ten sown wheat varieties (by area) in Western Australia**

Variety	Coleoptile rating	Length (mm)
Magenta⟇	Very long	> 79
Yitpi⟇	Long	70 to 79
Corack⟇	Medium-long	> 69
Bonnie Rock⟇	Medium	60 to 69
Mace⟇	Medium	60 to 69
Stilletto⟇	Medium	60 to 69
Calingiri⟇	Short	< 60
Wyalkatchem⟇	Very short	< 55
Cobra⟇	Not yet rated	–

Source: 2014 WA Wheat Variety Guide. www.grdc.com.au/WAWheatVarietyGuide

* data not updated since 2011.

More information

GRDC Update Paper: Bob French, The importance of wheat cultivar and seed size for deep sowing.

Note to Figure 11

Seed size had very little effect on crop establishment when sown at a conventional depth of 40mm (data not shown), however it had a significant impact when sown deep at 80mm. Small seed reduced establishment by as much as 50 per cent compared with large seed of the same variety.

Note to Figure 12

To collect seed of at least 35mg grade using a three-millimeter sieve and ensure the seed comes from productive paddocks with good nutrition. Seed for sowing should be stored under cool, dry conditions in sealed silos.

9.2.5 Seed size

Grading out smaller seed to retain larger, high quality seed will improve crop establishment especially in crops sown deep on residual soil moisture.

Department of Agriculture and Food, WA research shows sowing large seed (at least 35-38mg) 80mm deep into marginal moisture can lift plant establishment for a range of wheat varieties – even those with shorter coleoptiles like Wyalkatchem (Figure 11).

Large seed produces more vigorous seedlings that are better able to tolerate early season stresses (Figure 12).

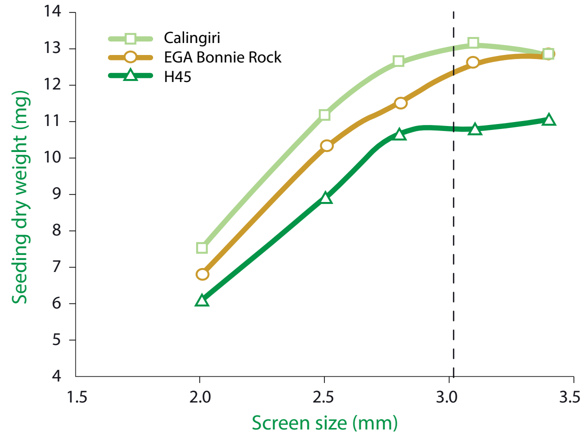


Figure 11: Influence of seed size on crop establishment of a range of commercial wheat varieties sown at 80mm at Mullewa, WA.

Source: Department of Agriculture and Food, WA.

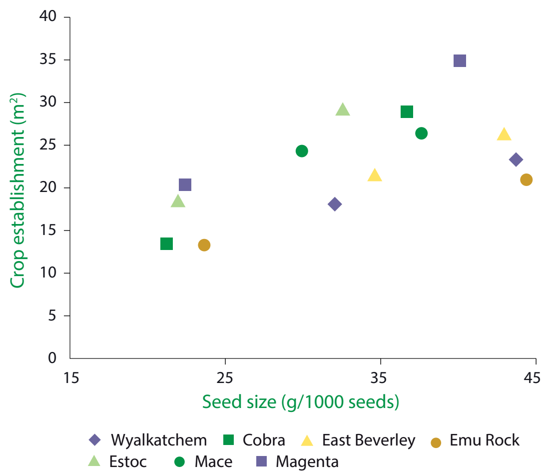


Figure 12: Influence of seed size on seedling size of three commercial wheat varieties grown at Mullewa, WA.

Source: Department of Agriculture and Food, WA.

Sowing wheat into marginal moisture

Increasing the weight of the press wheels can be necessary when seeding into marginal soil moisture (especially in clay soils).

To determine if more weight is required cut a face of soil across a row with a shovel to just below the depth of the soil disturbance and using a knife gently dig around the seed. If there is poor seed-soil contact or pockets of air between soil clods around the seed then press wheel weight may need increasing. However, be aware that increasing the weight too much can increase wear on the wheel bearings and lift the rear of the seeder bar.

A good rule of thumb for the weight required during a normal cereal seeding operation is 4kg/cm. This means an 8cm wide press wheel would normally require a weight of 32kg.

If the operator manual does not indicate the press wheel weight settings scales can be used to adjust the weight. For walking press wheels use bathroom scales or hook spring balance scales onto the axle. Ensure the press wheel is positioned at the same height as its working height in the field. For gang press wheels heavier scales such as wool scales will be needed, again ensuring weighing is done at the field working height.

Source: Glen Riethmulller, Department of Agriculture and Food, WA.

Note to Table 11

Use average monthly temperatures and Table 4 to calculate days to emergence in moist soil. For a crop sown on June 1 at Wongan Hills, WA it is best to use an average of May/June temperatures (12.9°C) to determine emergence rate. Using Table 4 the crop would therefore be expected to emerge in about 10 days.

9.2.6 Soil temperature

When soil moisture is adequate the time from sowing to emergence is determined by depth of sowing and ambient temperature. Average WA wheatbelt temperatures can vary from 10-15°C during sowing and, depending on depth, seedlings will emerge in about 7-21 days (Table 11).

Table 11: Impact of average temperature and depth of sowing on wheat emergence in Western Australia.

Temperature (°C)	Days to emergence			
	Seeding depth (mm)			
	30	50	100	150
20	5.1	6.0	8.8	10.7
15	6.9	8.2	11.4	14.6
12.5	8.5	10.0	13.8	17.6
10	11.0	12.9	17.7	21.5
7.5	17.7	20.2	26.6	33.1

Source: Anderson and Garlinge (2000).

More information

For more information on herbicide and fungicide impact on coleoptile length and wheat emergence: https://agric.wa.gov.au/n/1979

9.2.7 Seed treatments and herbicides

Registered seed dressing and in-furrow fungicides are particularly important for early-sown and long-season wheat crops and in some cases can replace the need for a foliar spray before flag leaf emergence. However, some fungicide seed dressings can reduce coleoptile length and cause 'silly seedling syndrome' where leaves grow under the soil surface but do not emerge.

Coleoptile shortening can also occur with dinitroaniline herbicides (trifluralin, pendimethalin and oryzalin). Care should be taken when using coleoptile-shortening seed dressings together with these herbicides, particularly in sandy soils where it is difficult to obtain good depth control of herbicide incorporation and seed placement.

More information

DAFWA: Seed dressing and in-furrow fungicides.

GRDC Update Paper: Aim for narrowest possible row spacing.

9.2.8 Row spacing

Choice of wheat row spacing is a compromise between ease of stubble handling, effective use of pre-emergent herbicides, managing weed competition and crop yield.

The impact of row spacing on cereal yield varies depending on the growing season rainfall, the time of sowing and the potential yield of the crop. The higher the yield potential, the greater the negative impact of wider rows on wheat yield (Table 12).

Wider row spacing reduces the impact of soil treated with pre- emergent herbicide being thrown from one row into an adjacent row where it can reduce crop emergence. Soil throw distance increases with the square of speed, for example, doubling the speed will increase soil throw distance four times. Speed can increase about 1.4 times if row spacing is doubled (Table 13).

Table 12: Benefits and costs of a wider row spacing in wheat.

Benefits	Costs
Easier stubble management at sowing and faster sowing speeds.	Lower yields.
Lower fuel and machinery costs during sowing	Increased weed competition.
Subsequent crops can be sown on the inter-row.	Slower canopy closure (more weeds and soil evaporation).
Higher rates of trifluralin can be used without crop damage.	Fertiliser toxicity if seeding pattern not altered.
Less soil disturbance and greater moisture conservation for grain filling in some seasons and lower rainfall areas.	Higher potential for lodging.

Source: GRDC.

Note to Table 13

Yield was reduced by an average of eight per cent for each 9cm increase in row spacing from nine to 54cm.

Table 13: Impact of row spacing on wheat yield in the absence of stubble in WA trials (yield from 18cm row spacing taken as 100 per cent).

Number of trials	Row spacing (cm)					
	9	18	27	36	45	54
7	-	100	92	94	-	-
19	115	100	95	90	77	75
16	112	100	93	-	-	-
Average yield response (%)	+14	-	-7	-8	-23	-25
kg grain/ha per cm change in row spacing	+24	-	-11	-5	-23	-5

Source: Riethmuller (2004).

More information

Read a comprehensive research summary of row spacing and its impact on weeds and yield: http://www.csu.edu.au/research/grahamcentre/publications/monograph/row-spacing-monograph

Read a case study on the use of wider rows in low rainfall areas: www.grdc.com.au/GC100-WideRowResearchDeliversAPLantBreedingChallenge

There is now considerable evidence that wide rows decrease grain yield, especially in higher rainfall areas. In an Australia-wide review of row spacing trials Scott et al (2013) found that at wheat yields of 2000kg/ha, widening rows to 36cm reduced yield to 1860kg/ha. At wheat yields of 4000kg/ha, yield was reduced to 3640kg/ha with a 36cm row spacing. At yields below 700kg/ha, widening row spacing beyond 18cm increased estimated grain yield. For example, at yields of 500 kg/ha, doubling the row space to 36cm increased yield to 520kg/ha – reflecting the moisture saving benefits of wider rows in drier regions.

WA wheat trials on row spacing from nine to 54cm found wider spacing decreased grain yield (Table 13). The research found an average eight per cent decrease in yield for each 9cm increase in row spacing from nine to 54cm.

Yield response to row spacing is also influenced by time of sowing. Trials at Meckering, WA, examined the impact of row spacing and two sowing times (19 May and 14 June) on wheat yield (Figure 13). The trial found there was a higher rate of yield reduction with wide rows in later sown crops, which had less time for canopy development.

Note to Figure 13

High seed rates and narrow row spacing significantly suppressed ryegrass growth.

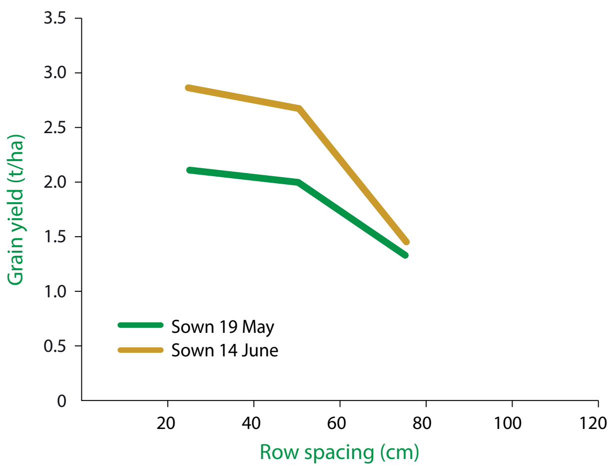


Figure 13: Impact of row spacing and time of sowing on wheat yield at Meckering, WA. Source: Department of Agriculture and Food, WA.

More information

Read and watch a case study on the use of ribbon seeding to achieve narrower rows: www.grdc.com.au/GC109-SeedSpacing

www.grdc.com.au/GRDC-FS-CropPlacementWest

Note to Figure 14

Growers are often reluctant to change their seeding equipment to achieve narrow row spacing and there is little to be gained by increasing seeding rates at wide row spacing. One option to reduce the effective row spacing without buying a new machine is to consider ribbon seeding. This involves attaching a seed boot that spreads the seed in a band 5 to 10cm wide. Source: Peter Newman, AHRI.

Note to Figure 15

Narrow row spacing and high seeding rate (200kg/ha) maximises wheat yield for crops yielding more than 2t/ha.

9.2.9 Row spacing and weeds

Increasing row spacing can create major weed problems, especially with ryegrass.

Wider spacings (Figure 16) reduce the crop's ability to close the canopy and compete with weeds between rows. This delays inter-row weed suppression, with the wider the rows the longer the delay. As row spacing increases to more than 40cm in cereals, canopy closure may never occur.

Narrow rows spread crop plants more evenly over a paddock making them more competitive against weeds, particularly at seeding rates of 100kg/ha and higher.

Narrow row spacing and high seeding rate maximises wheat yield for crops yielding more than 2 t/ha while having a significant impact on weed densities (Figures 13 and 14).

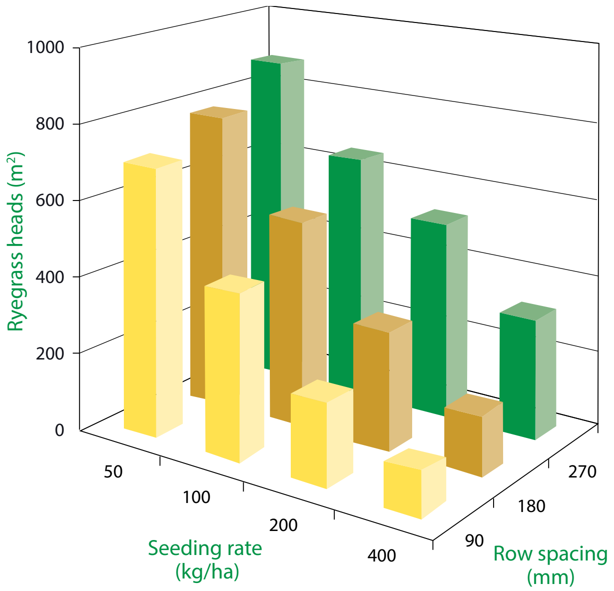


Figure 14: Impact of seeding rate and row spacing of wheat (cv. Arrino) on weed growth.
Source: Minkey et al (1999).

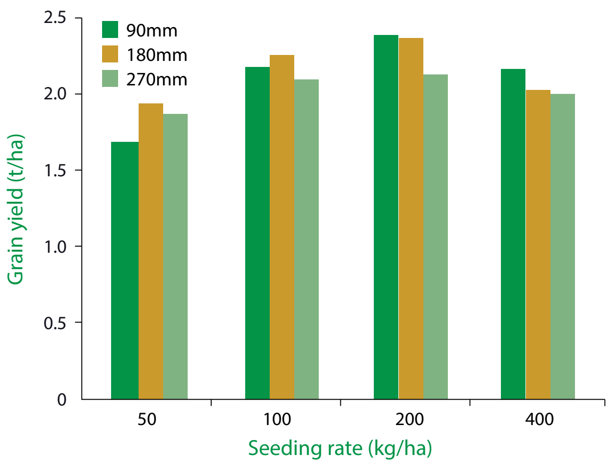


Figure 15: Interaction between seeding rate, row spacing and applied trifluralin on wheat grain yield at Merredin, WA.
Source: Minkey et al (1999).

9.2.10 Row spacing and fertiliser

Increased row spacing and zero-till seeding can result in more fertiliser being placed in the seeding row, causing damage to emerging seedlings. This risk can be reduced by increasing the spread of seed and fertiliser in the row, reducing in-furrow fertiliser rates or separating seed and fertiliser bands.

If row spacing is increased but the fertiliser rate per hectare remains constant, then the amount of fertiliser in each row increases. In addition, the narrow seed spread typically created by disc seeders can also increase the potential for seedling damage by fertiliser.

Nearly all fertilisers are capable of causing damage to germinating seeds if they are in close proximity to each other and in a concentrated band. Urea is most likely to cause damage, unless twin shoot boots are used. Diammonium phosphate is also a potential problem with wide rows on light soils.

In chemical terms fertilisers are salts and can affect the ability of the seedling to absorb water by osmosis. Too much fertiliser (salt) near the seed can cause desiccation or 'burning'.

However, fertilisers vary in salt index or burn potential depending on composition. As a general rule, most common nitrogen and potassium fertilisers have a higher salt index than phosphorus fertilisers.

Fertilisers that have the potential to release free ammonia can cause ammonia toxicity in seed and because of this in-furrow placement of ammonium phosphate and urea-containing fertilisers is usually not advisable. A solution of urea and ammonium nitrate can be applied successfully in-furrow but there is a risk of ammonia damage where high rates are used especially when germinating seedlings are stressed.

Soil conditions that tend to concentrate salts or stress the germinating seed increase the potential for damage. Therefore, the safe limit for in-furrow fertilisation is reduced in lighter soil texture (sands) and in drier soil conditions. It is also reduced when environmental conditions such as cool temperatures induce stress or slow germination as this can prolong fertiliser-seed contact and increase the likelihood of damage.

Good rain immediately after sowing can reduce the potential for damage as salts are diluted and ammonia is dissolved, which reduces the concentrations around the seed.

The toxic effects on germination can be avoided by banding fertilisers away from the seed or by topdressing (Table 14). Banding about 5cm below or to the side of the seed rows is usually sufficient to avoid germination problems.

More information

Details of the salt index for different fertiliser products and how it can be calculated can be found on the International Plant Nutrition Institute website: http://anz.ipni.net/article/ANZ-3076

For information on how to configure seeding equipment to reduce fertiliser toxicity read: www.grdc.com.au/GRDC-FS-CropPlacementWest

Table 14: The effect of placement of N fertiliser (urea) on the reduction of wheat plant establishment on light sand, East Hyden.

Placement of fertiliser	Reduction in plant establishment (%)	
	40 kg/ha N	80 kg/ha N
Topdressed across seed rows	Nil	Nil
Drilled in seed rows	48	77
Topdressed above each seed row	13	33
Deep banded below each row	Nil	Nil

Source: Department of Agriculture and Food, WA.

References

Cornish, P and Hindmarsh, S (1988) Seed size influences the coleoptile length of wheat. Australian Journal of Experimental Agriculture 28(4) 521 – 523.

French, R (2014) Wheat variety response to dry sowing and seeding depth. In Proceedings 2014 Crop Updates, Perth, Western Australia.

Riethmuller G (2004) Row spacing and stubble effect on wheat yield and ryegrass seed set, Agribusiness Crop Updates - Cereals. Perth, WA. (Department of Agriculture, WA).

Riethmuller, G (1990) Machinery for improved crop establishment in Western Australia. In ‘Agricultural Engineering Conference 1990’ pp 40-45 (Institute of Engineers: Australia).

Scott B, Martin P, Riethmuller, G (2013). Graham Centre Monograph No. 3: Row spacing of winter crops in broad scale agriculture in southern Australia. Eds T Nugent and C Nicholls. NSW Department of Primary Industries, Orange. Available at: www.grahamcentre.net

Contact

Christine Zaicou-Kunesch
Department of Agriculture and Food, WA
P (08) 9956 8549
E christine.zaicou-kunesch@agric.wa.gov.au

9.3 Dry sowing

Key messages

- CSIRO modelling suggests dry sowing a proportion of the wheat crop is profitable over time especially in large cropping operations in drier areas and on heavier soils.
- Sowing into weed free paddocks is critical for dry sown crops.
- Using a pre-emergent herbicide and implementing an integrated weed management plan that includes weed seed harvest can drive down the weed seedbank and enable earlier, cleaner sowing.
- Keeping input costs low drives down the required break-even yield but this will require strong soil nutrition – especially phosphorus.
- Spreading flowering time through variety choice in dry-sown systems will help reduce frost and heat risks.Dry sowing has steadily increased in Western Australia in response to increasingly variable, and often later, opening season rains and larger cropping programs placing logistical pressure on seeding programs.

Dry sowing has steadily increased in Western Australia in response to increasingly variable, and often later, opening season rains and larger cropping programs placing logistical pressure on seeding programs.

About 40 per cent of WA growers in low rainfall areas and 20-25 per cent of those in higher rainfall areas dry sow a proportion of their wheat crop each year (Figure 16) (Celenza et al 2013).

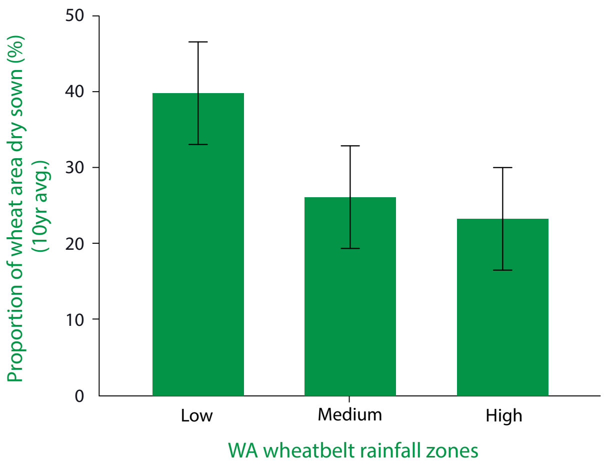


Figure 16: Proportion of wheat sown dry in the past decade (2003-13) for low, medium and high rainfall areas of the WA wheatbelt.

Source: Celenza et al (2013).

However, despite its growing popularity the impact of early season moisture stress and weeds on dry sown crops remains problematic. Ongoing research is examining how dry seeding interacts with soil type and location to influence wheat yield at the paddock and farm scale.

9.3.1 Potential yield benefits

CSIRO analysis for Merredin and Mullewa, WA shows up until the mid 1970s the timing of the break and subsequent period to achieve the first 10 days of seeding were fairly consistent from year to year. However since then the timing of the break has been more variable with a high occurrence of long periods (>20 days) to achieve 10 days of wet seeding. Variability has been particularly obvious during the past 15 years. Dry seeding opportunities have increased from 15-20 days up until the mid 1990s to about 25 days since then with a consistent trend for fewer wet seeding days (Robertson et al 2011).

Wheat is suited to dry seeding because it has a wider optimum sowing window than other crops such as canola and lupin and the yield advantage arising from getting the crop in early can be as high as 40-50kg/ha/day (Figure 17). Wheat is also the most resilient crop - an important trait given dry and late seeding can put the crop under early moisture and heat stress (see French 2014).

9.3.2 Yield risks

Financial loss from failed dry seeded crops is often a concern. Table 15 presents the partial gross margins for a typical low-rainfall scenario (Robertson et al 2011).

Note to Table 15

It is important to remember that dry sown crops might not germinate for some time and that this will drive down potential yield. Long season varieties are not recommended for dry sowing as delayed flowering of late emerging crops can hit periods of high heat risk.

Table 15: Partial gross margins of wheat at a range of yields and prices.

Yield (t/ha)	0	0.3	0.6	0.9	1.2	1.5
Wheat price ($/t)	0	75	150	225	300	375
Income ($/ha)	0	75	150	225	300	375
Variable expenditure ($/ha)*	119.6	127.3	128.0	128.6	161.3	162.0
Gross margin ($/ha)	-119.6	-52.3	22.1	96.4	138.7	213.0

Source: Robertson et al (2011. *Costs included are those that are remaining and truly variable from the day the seeder enters the paddock.

The risk of making an operating loss is based around a complete failure through to a 0.3-0.5t/ha crop. At a wheat price of $250/t, yields above 0.5t/ha are likely to break even. Even a poor yield of 0.9t/ha generates a useful profit of $96.40/ha. The range of outcomes can be used to assess the yield loss risks of dry seeding wheat based on past performance during dry years.

Keeping input costs low (predominantly fertiliser) drives down the required breakeven yield. To do this successfully soil nutrition – particularly phosphorus needs to be strong. If soil phosphorus is high the crop can be sown with a low rate (30-40kg/ha DAP) and if the crop ends up high yielding the phosphorus deficit can be replaced the following season.

Other CSIRO modelling suggests yield benefits of up to 35 per cent (or 0.5-1.2t/ha) over time and at the farm-scale from dry seeding before autumn rains, compared to wet sowing after the season break. The modelling covered seven WA wheat growing sites and suggested the largest yield benefits of dry sowing could come from:

- heavy soils
- drier locations
- large cropping programs relative to sowing capacity
- years with low-medium yield potential.

Dry seeding leads to more of the crop flowering earlier and at the same time. This increased frost risk slightly in some areas but significantly reduced the risk of heat stress during grain fill. There was therefore a direct trade-off between frost and heat risk. The modelling also suggested that early season moisture stress of dry sown crops could be an issue and ongoing research is being done to assess this risk across soil types and regions.

About 40 per cent of WA growers in low rainfall areas and 20-25 per cent in medium-high rainfall areas dry sow a proportion of their wheat crop each year. Ongoing GRDC-funded research is examining how dry seeding interacts with soil type and location to influence wheat yield at the paddock and farm level.

Photo credit: Evan Collis.

The modelling suggested average yield difference between a farm with up to 100 per cent dry seeding and a farm with no dry seeding ranged from a 0.5 t/ha increase to a 0.2t/ha loss. However, it is important to emphasise that weed impact on grain yield was not included in the modelling.

Modelled yield increases were highest for large cropping programs where up to a third of the total crop was dry sown, on heavier soils and in lower rainfall areas, a finding that supports survey work showing the highest uptake of dry seeding in lower rainfall areas (Figure 16). The yield increase was driven by both increased crop yield and increased cropped area. In general, the potential yield from dry sowing was predicted to be lower in smaller cropping programs because in most years there were sufficient wet seeding days.

The modelling predicted that dry sowing reduced yield variability between seasons by shifting several low-medium expected yield years into medium-high yield years. For example, at Dalwallinu the probability of getting more than 1.5t/ha was higher (13 years in every 20) with up to 100 per cent dry sowing, than no dry sowing (seven years in every 20) over a 6000ha-cropping program.

9.3.3 Weed management

Poor weed control is a primary concern with dry sowing due to the lack of opportunity to use pre-seeding knockdown herbicides and the reduced efficacy of some residual herbicides in dry soil conditions (Figure 3a).

Research by the Western Australian No Tillage Farmers Association (WANTFA) found trifuluralin efficacy was compromised on heavier soil types with dry seeding because it failed to properly incorporate into the soil. Boxer Gold® (prosulfocarb and s-metolachlor) and Sakura® (pyroxasulfone) both proved suitable pre-emergents for annual ryegrass control in the dry seeding environment (Figure 17a).

The research compared wheat seeded under dry conditions on April 21 with wheat seeded on May 31 under wet conditions after a knockdown herbicide was applied.

Sakura® provided the best control for early and late germinations of annual ryegrass, and even better weed control and wheat yields compared with delayed seeding with Sakura® after a knockdown was applied. Early, dry seeded wheat where Sakura® was applied yielded 3.5t/ha, compared with yields of 2.5t/ha where wheat was seeded on May 31 with Sakura® after the use of a knockdown herbicide (Figure 3b).

Boxer Gold® was the best treatment for early germinations of annual ryegrass, but failed to control subsequent germinations, yielding just under 2.5t/ha (Figures 17a and 17b).

Trifluralin was not properly incorporated with early dry seeding on the heavier soil types, reducing its efficacy and resulting in yields of about 1.3t/ha (Figures 17a and 17b) however the same herbicide performed well against ryegrass on sandier soils.

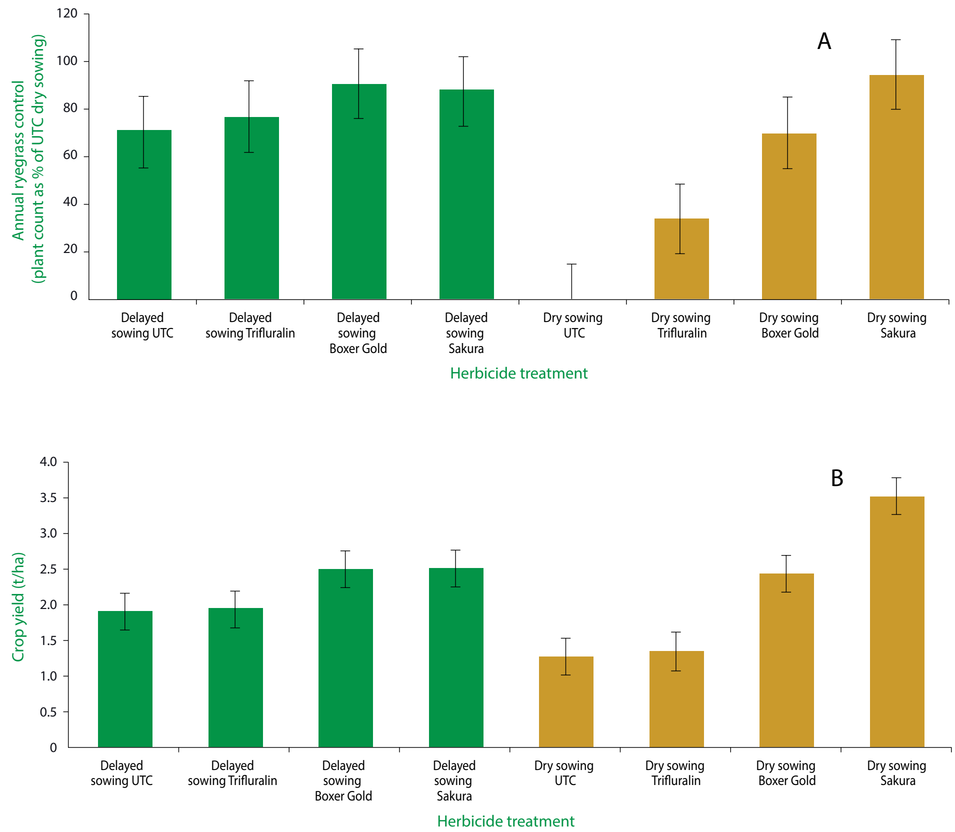


Figure 17: Impact of various pre-emergent herbicides on (A) ryegrass control and (B) grain yields in wheat either dry sown on April 21 or wet sown ('delayed sowing') on May 31. UTC = untreated control.

Source: WA No-Tillage Farmers Association.

9.3.4 Early season drought

Dry periods after starting rains can cause poor crop emergence and lead to heat and water stress due to potentially higher crop biomass production of early or dry sown crops.

However, preliminary results from Department of Agriculture and Food, WA research indicate that the type of water deficits commonly experienced in the WA wheatbelt following establishment are rarely severe enough to cause crop death; with the sensitivity of seedling establishment to water deficit varying between genotypes (Figure 18). It is thought early vigour could be influencing this sensitivity but further research is required to confirm this.

For example:

Starting run: dry-sown Yitpi

Subsequent run(s): Has the previous run germinated?

If the answer is yes, then sow more Yitpi rather than a mid-season variety, as the already germinated Yitpi will now flower close to any mid-season varieties sown now.

If the answer is no, then mid and short season varieties such as Carnamah, Wyalkatchem, Mace or Corack should be considered, as another seeding run of Yitpi will germinate at the same time as the previous Yitpi run.

However, if a long-season maturity group is still desired then exploiting the different flowering mechanisms, (photoperiod sensitivity/ vernalisation) of varieties such Calingiri, Magenta or Fortune could also help to spread flowering time.

Source: Department of Agriculture and Food, WA

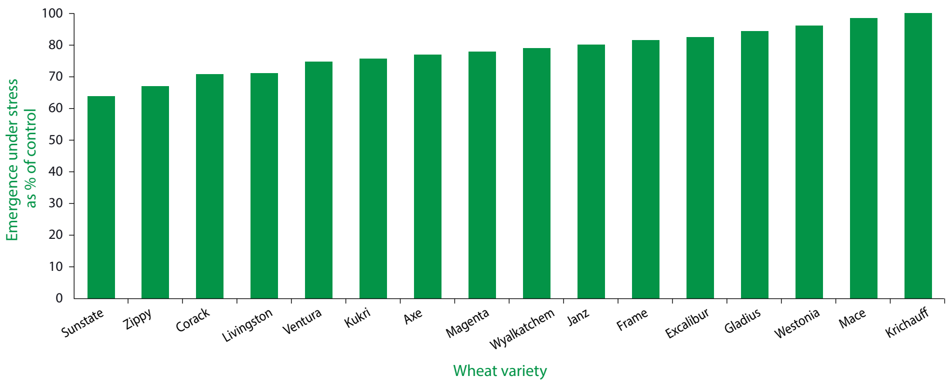


Figure 18: Impact of dry sowing on emergence percentage of a range of wheat varieties relative to a wet-sown control.

9.3.5 Flowering time

Dry sowing can result in the majority of the wheat crop emerging and flowering at the same time, which in turn synchronises grain fill and exposes crops to risks of frost or heat and terminal water deficit in spring. (Sharma and Abrecht, 2013)

Dry sowing can reduce the spread of flowering for two reasons:

- Dry sown seed germinates soon after a rain event and seed from a range of sowing days may germinate, emerge and flower at the same time. In contrast, a wet sown crop will germinate soon after sowing and the timing of emergence and flowering will reflect the range of sowing days.
- Choice of variety for a dry sown crop is done with little knowledge of the likely timing of opening rains, germination or flowering.

Variety selection can be used to manipulate a spread of flowering dates of dry sown crops.

Flower Power is a tool developed by the Department of Agriculture and Food, WA that provides predicted flowering dates for wheat varieties at a range of sowing times.

The tool determines the sowing time that will minimise the likelihood of frost after flowering and avoid the incidence of high temperature events during grain fill.

As sowing date gets later the difference in flowering time between early, mid and late season varieties is condensed (Figure 19).

To ensure that flowering date is well spread each seeding run (dry or wet) needs to be assessed for predicted flowering date.

The first step is to identify the intended flowering window.

Then, at every sowing opportunity, dry or wet, use Flower Power to predict the flowering date of the previously sown crop so that the required maturity group of the next sowing run can be determined.

Note to Figure 19

Difference in the predicted flowering dates of the shortest (Zippy) and the longest maturity (Spear, Yitpi) varieties narrowed from about 35 days for an Anzac Day sowing to about 17 days for a late June sowing. This spread will narrow by about 2-7 days if Westonia is the early maturing variety used.

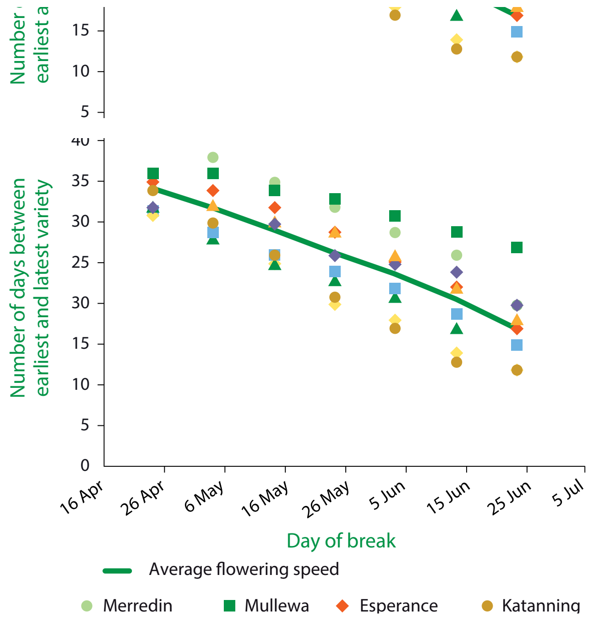


Figure 19: Difference in flowering time between a short and long season wheat varieties sown at a range of sowing times.

Source: Sharma and Abrecht (2013).

More information

For more information on sowing time and weed control read: http://ahri.uwa.edu.au/more-resistance-more-dormancy/

Use Flower Power to determine the optimal sowing/flowering windows for WA wheat varieties: https://www.agric.wa.gov.au/flower-power

Weeds such as ryegrass (pictured) can be a particular issue with dry sown wheat.

Photo credit: Emma Leonard.

References

Celenza, L McNee, M Minkey, D Fletcher, A Weeks, C (2013) Adoption and management practices of dry seeding across the W.A. wheatbelt. In Proceedings 2013 Crop Updates, Perth, Western Australia. www.giwa.org.au/2013-crop-updates

French, R (2014) Wheat variety response to dry sowing and seeding depth. In Proceedings 2014 Crop Updates, Perth, Western Australia. www.giwa.org.au/2014-crop-updates

French, R.J. and Schultz, J.E. 1984. Water use efficiency of wheat in a Mediterranean-type environment. I. The relationship between yield, water use and climate. Australian Journal of Agricultural Research 35, 743-764.

Minkey, D and Ashworth, M (2012) Weed management in dry seeded wheat. In Proceedings 2012 Crop Updates, Perth, Western Australia. www.giwa.org.au/2013-crop-updates

Sharma, D and Abrecht, D. (2013) Wheat variety selection for managing exposure of dry sown crops to frost and heat damage at flowering. In Proceedings 2013 Crop Updates, Perth, Western Australia. www.giwa.org.au/2013-crop-update

Robertson, M. Weeks, C. O'Conner, M. Abrecht, D. Grima, R. Newman, P. (2011) Pros and cons of dry seeding to counter variable season breaks. In Proceedings of the 2011 Crop Updates, Perth, Western Australia pp 208-11.

Contact

Dr David Minkey
WA No-Tillage Farmers' Association
M 0417 999 304
E david.minkey@wantfa.com.au

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

DAW00201 – Identification and characterisation of disease suppressive soils in the Western Region (S: 01/07/2010 F: 30/04/2014)

UWA00146 - Australian Herbicide Resistance Initiative (AHRI) - Phase 4, Western Region (S: 01/07/2010 F: 30/06/2015)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC sowing projects can be found at: www.grdc.com.au

SECTION 10

Early season

10.1 Disease

More information

[GRDC Update Paper: Brenda Shackley, Getting the most out of our long season wheat varieties.]

[GRDC Update Paper: Choosing right wheat variety. Part A.]

[GRDC Update Paper: Choosing right wheat variety. Part B.]

[WA wheat variety guide 2014.]

Key messages

- Early-sown wheat crops can be particularly vulnerable to leaf spot and rust fungal diseases.
- No seed treatments or in-furrow fungicides are registered for control of the leaf spot diseases yellow spot or *septoria nodorum* blotch.
- A new wheat leaf rust strain discovered in 2013 has altered wheat disease ratings for some prominent WA wheat varieties.
- High disease pressure in continuous and early sown wheat crops before stem elongation can make it economic to apply fungicide at or before early stem elongation (GS31, first node) particularly in medium to high rainfall areas.
- Registered seed dressing and in-furrow fungicides can suppress leaf or stripe rust on wheat seedlings for four to six weeks, depending on the product and rate and in some cases can replace the need for a foliar spray before flag leaf emergence.

10.1.1 Leaf spot disease

No seed treatments or in-furrow fungicides are registered for control of the leaf spot diseases yellow spot or *septoria nodorum* blotch. However, a fluquinconazole based seed dressing is now registered for suppression but not control of *septoria nodorum* blotch.

While all wheat crops are vulnerable to airborne spores of yellow spot and *septoria nodorum* blotch, early sown crops are exposed to infection before later-sown crops, which can provide the diseases with a head start. The milder conditions of April and May also enable the fungal diseases to mature more quickly on earlier sown crops.

Moderate to severe leaf disease in young wheat crops can reduce early growth, however the main impact of early disease is as a source of infection later in the season.

More information

To diagnose leaf spot diseases and rust in-field use the Department of Agriculture and Food, WA MyCrop tool: https://agric.wa.gov.au/n/2155

Report and keep abreast of leaf spot disease and rust outbreaks throughout the season using the Department of Agriculture and Food, WA PestFax service either via email: pestfax@agric.wa.gov.au or the interactive PestFax map: https://agric.wa.gov.au/n/1588

The leaf spot diseases are difficult to distinguish in wheat with both diseases appearing as irregular or oval-shaped spots that initially are small and yellow, and which enlarge to form brown dead centres with yellow edges. Typically, a badly affected leaf will die back from the tip as lesions merge, reducing the photosynthetic area and causing premature leaf death (Figure 1).

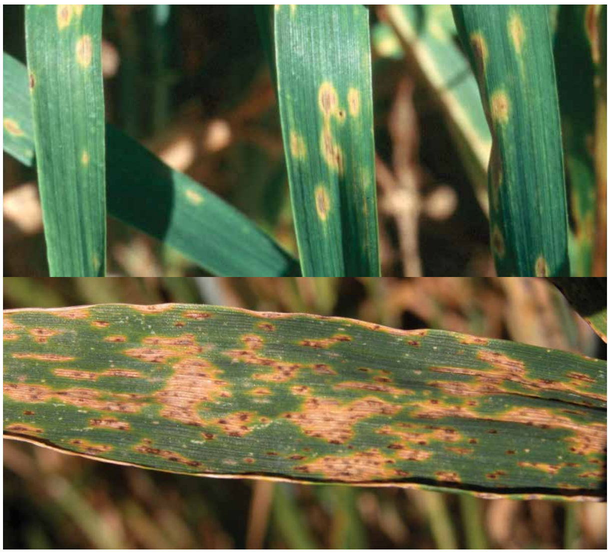


Figure 1: Symptoms of yellow spot disease (A) and septoria nodorum blotch (B) in wheat are difficult to distinguish in the field. Management for the two diseases is the same.

Photo credit: GRDC.

Being stubble-borne, leaf spot diseases are a particular a problem in continuous wheat crops where stubble retention is practised. The diseases have the capacity to reduce yield by up to 30 per cent and compromise grain quality in medium-high rainfall areas and in above-average season in lower rainfall areas.

High disease pressure in continuous and early sown wheat crops before stem elongation can make it economic to apply fungicide at or before early stem elongation (GS31, first node) particularly in medium to high rainfall areas. A second spray may be required at or after flag leaf emergence based on early-season disease pressure.

10.1.2 Rust

The rust fungus cannot survive without a living host.

Removing the green bridge – especially volunteer cereals, reduces the amount of pathogen that survives over summer and therefore the amount of rust present at the start of the growing season.

The green bridge must be totally removed at least four weeks before sowing to minimise the risk of carrying rust into new season crops.

If high levels of rust are present in a green bridge when crops are sown, even crops with moderate levels of rust resistance can potentially be severely affected because the rust will infect crops during the very susceptible establishment phase before adult plant resistance traits have had a chance to develop (Figure 2).

More information

For more information on rust disease see: www.rustbust.com.au

For more information on the economics of early-season control of leaf spot diseases see Section 3 of this GrowNote and refer to the Department of Agriculture and Food, WA website: https://agric.wa.gov.au/n/2196

A list of registered foliar spray fungicides to manage the leaf spot diseases can be downloaded at: https://agric.wa.gov.au/n/1756

Refer to the current wheat variety guide for a comprehensive listing of rust resistance status of all WA wheat varieties: www.grdc.com.au/WAWheatVarietyGuide

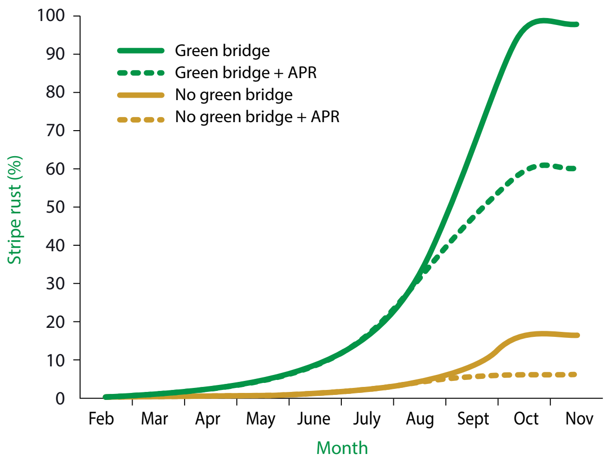


Figure 2: Illustration of the effects of a green bridge and adult plant resistance (APR) on the development of stripe rust in wheat compared with a drier summer.

Source: Department of Agriculture and Food, WA.

Managing rust

- Rust management is all about managing inoculum load and requires a farm, district and regional level approach:
- Remove the green bridge (volunteer cereals) by mid-March;
- Grow varieties with adequate resistance to stem, stripe and leaf rusts;
- Apply fungicides to seed or fertilisers for early season rust suppression in high-risk areas; and
- Monitor crops for rust and if needed apply registered foliar fungicides for disease control.

10.1.3 Wheat leaf rust

A new wheat leaf rust strain, originating in eastern Australia, with virulence for the rust resistance gene Lr13 was detected in WA in 2013 and this has altered wheat disease ratings for some prominent WA wheat varieties.

Department of Agriculture and Food, WA glasshouse trials completed in late 2014 tested the seedling and adult reaction of Mace⁽ᴾ⁾ and other varieties to the new wheat leaf rust strain. The tests showed that the most popular WA wheat variety is moderately susceptible (MS) or worse at all growth stages. The varieties Wyalkatchem⁽ᴾ⁾ and Corack⁽ᴾ⁾ were also moderately susceptible to susceptible. However the varieties Cobra and Carnamah were not adversely affected and appear to be moderately resistant or better.

Seed dressings and in-furrow control

Registered seed dressing and in-furrow fungicides can suppress leaf or stripe rust on wheat seedlings for four to six weeks, depending on the product and rate. They are particularly important for early-sown and long-season crops and in some cases can replace the need for a foliar spray before flag leaf emergence.

Leaf rust

Seed dressings containing fluquinconazole or triticonazole and in-furrow fungicide triadimefon are registered for the suppression of wheat leaf rust. Wheat plants treated with at-sowing fungicides might still display minor levels of infection, but infection will be significantly lower than untreated crops and treating leaf rust early will make the disease easier to manage in spring if follow-up spraying is required.

Stripe rust

Flutriafol or triadimenol seed dressings suppress stripe rust in seedling crops while longer-term control can be achieved with fluquinconazole seed dressings (depending on application rate) and flutriafol in-furrow fungicides.

Stem rust

No seed dressing or in-furrow fungicides are currently registered for control of wheat stem rust.

10.1.4 Rust resistance testing

If rust outbreaks are detected in wheat varieties with rust resistance it is important to send samples for testing to the Australian Cereal Rust Survey as the outbreak may indicate a new virulent rust strain has developed.

Rust samples should be sent in paper envelopes (not plastic bags), marked with your name and contact details, date, location and variety. Leaves and stems with active pustules are required.

Post as soon as possible to: Australian Cereal Rust Survey, Private Bag 4011, Narellan, NSW 2567.

Sampling instructions, posting details and further information on the new pathotypes can be found on the Australian Cereal Rust Control Program website http://sydney.edu.au/agriculture/plant_breeding_institute/cereal_rust/index.shtml

More information

[GIWA: Wheat variety selection for managing exposure of dry sown crops.]

[GRDC: Early sowing.]

[GRDC: Early sowing wheat a winning strategy.]

If high levels of rust are present in the green bridge when crops are sown, even moderately resistant varieties can potentially be severely affected because the rust will infect crops during the very susceptible early establishment phase before adult plant resistance traits have developed (see Figure 2).

Photo credit: GRDC.

High disease pressure in continuous and early-sown wheat crops before stem elongation can make it economic to apply fungicide at or before early stem elongation (GS31, first node) particularly in medium to high rainfall areas. A second spray may be required at or after flag leaf emergence - depending on early season disease pressure.

Photo credit: Kellie Penfold.

10.2 Redlegged earth mites

Key messages

- Insecticide resistance in redlegged earth mites (RLEM) is increasing across Western Australian cropping regions.
- Difficulty in controlling RLEM could indicate resistance to synthetic pyrethroids (SPs; Group 3A) including bifenthrin and alpha-cypermethrin and mites surviving insecticide application should be tested for resistance.
- A south-coast WA RLEM population with tolerance to the widely used insecticide omethoate was confirmed in late 2014. The population is also resistant to the synthetic pyrethroid group of chemicals.
- RLEM should be sprayed only if absolutely necessary (the nominal threshold is 50 mites/m^2).
- Maintaining pasture dry matter levels below two tonnes per hectare will restrict RLEM numbers to low levels.
- To prolong the efficacy of all insecticide groups and minimise resistance risks, it is vital to rotate chemical products within and between seasons and limit 'insurance', or prophylactic, spraying.

More information

To identify different mite species in the field use the Department of Agriculture and Food, WA MyCrop tool: https://agric.wa.gov.au/n/2177

To keep abreast of mite and other pest numbers across the WA wheatbelt subscribe to the Department of Agriculture and Food, WA PestFax service: https://agric.wa.gov.au/n/1588

Download the current insecticide guide for WA crops at: https://agric.wa.gov.au/n/1588

Insecticide resistance in redlegged earth mites is growing across Western Australian cropping regions.

Photo credit: GRDC.

The redlegged earth mite (RLEM) is a sap-sucking pest that attacks most crops and pastures as well as many common weeds and feeds on all stages of plants.

RLEM is particularly damaging to wheat seedlings during autumn and during years when the season break is late. The pest can be a particular problem in late-sown crops and pastures, as the mites are well established by the time seedlings emerge.

RLEM often occur in situations with other mites, such as blue oat mites, bryobia mites and balaustium mites. It is important to correctly identify the pest present because each of the mite species responds differently to registered insecticides and chemical rates. The wrong chemical treatment will cost money and only act to increase the selection pressure for further resistance development.

The pasture snout mite is an important biological control agent against lucerne flea and earth mites. The predatory mites provide a useful level of control of lucerne flea in pastures across most of the WA wheatbelt.

Bare earth treatments

Methidathion at 200mL/ha is registered for bare earth control of both redlegged earth mite (RLEM) and lucerne flea.

Bifenthrin and chlorpyrifos are registered bare earth treatments for RLEM only, and depending on rate may have little effect on lucerne flea.

The efficacy of bare earth insecticide is influenced by the application method. Best results are obtained by applying the insecticide as an unbroken layer over the soil surface just before crop emergence. Application pre-sowing for convenience is not recommended on labels because incorporating chemical in the sowing process reduces efficacy.

The post-emergent insecticides methidathion, dimethoate and omethoate are registered for control of both RLEM and lucerne flea. However it is important to realise that commonly used rates of synthetic pyrethroid will not control lucerne flea.

Lucerne flea hatch any time after a good soaking rain. RLEM can be slower to appear as they need cold conditions before they will hatch.

10.2.1 Rising resistance

WA is the only known state with RLEM resistance to the synthetic pyrethroids (SPs - Group 3A), including bifenthrin and alpha-cypermethrin. The first case of SP resistance was discovered near Esperance in 2006 and since then over 30 properties in WA have been found with mites that are highly resistant to SP insecticides.

In late 2014 a population of RLEM from Capel was confirmed tolerant to the widely used insecticide omethoate (OP insecticides) following poor insecticidal control of the mites. Laboratory tests found the Capel mites were 14,000 times more tolerant to omethoate than a population of RLEM that had never been sprayed.

More information

For more information on resistance testing for RLEM read: www.grdc.com.au/MR-EarthMitesFaceTestingTime

For more information on beneficial insect pests and how to identify them refer to: www.agric.wa.gov.au/n/2922 and www.grdc.com.au/GRDC-BPG-BeneficialInsectsSouthWest

The RLEM on the affected paddock were also confirmed resistant to the SP group of chemicals. University of Melbourne research indicates SP-resistant RLEM are up to 240,000 times more resistant to some SP insecticides than susceptible RLEM. The resistance is genetic and as such can survive through several generations.

It is not yet known whether OP tolerance is genetic (and therefore persistent).

The paddock where the tolerant mites were found is a high production paddock that has received repeated sprays of SP and OP insecticides over many years.

It is unlikely that the Capel property is a rare case of OP tolerance with preliminary testing of a property near Boyup Brook also indicating that omethoate tolerance/SP resistance is present in isolated RLEM populations.

Until now the OP group of chemicals (which includes omethoate) have been the mainstay alternative chemical group providing effective control of RLEM.

RLEM that survive insecticide treatments should be tested for resistance so that spring control strategies can be put in place.

To prolong the efficacy of all insecticide groups and minimise resistance risks, it is vital to rotate chemical products within and between seasons and limit 'insurance', or prophylactic, spraying. Every time an SP is used to control pests such as weevils, caterpillars and aphids, RLEM also receive a dose of this insecticide, despite not necessarily being the primary target.

Weeds, including in-crop weeds and weeds along fencelines, can host residual populations of RLEM, which have the potential to re-infest surrounding paddocks.

10.2.2 DNA test

A new high throughput, DNA-based test for resistance in RLEM is being used to investigate the mechanisms responsible for RLEM resistance to synthetic pyrethroids.

The test requires fewer mite numbers per test and has greater population screening capacity than previous testing services.

The laboratory-based DNA test is undertaken by CSIRO and is available to growers and advisers through a GRDC-funded program. The service helps determine the insecticide resistance status of cropping and pasture paddocks.

To discuss suspected resistance and to facilitate collection of samples for testing contact:

Svetlana Micic
Department of Agriculture and Food, WA
P. 08 9892 8591
E. svetlana.micic@agric.wa.gov.au

More information

For more information on mite biology and control read the GRDC Back Pocket guide for Crop Mites:
www.grdc.com.au/BPG-CropMites
and the Integrated Pest Management factsheet:
http://www.grdc.com.au/Resources/Bookshop/2009/12/Integrated-Pest-Management-Fact-Sheet-National

Redlegged earth mite quick facts

- Redlegged earth mites (RLEM) grow to about one millimetre in length.
- Adults have a velvety black body and eight red legs.
- Newly-hatched mites are pinkish-orange with six legs and are 0.2mm long.
- Nymphs develop into mature adults in four to six weeks.
- During autumn, over-summering eggs hatch when there is significant rainfall and the average daily temperatures fall below 21°C.
- Three generations of RLEM can be produced per season.
- Feeding causes a silver or white discolouration of leaves and distortion. If damage is severe plants shrivel and die.
- Damage is more severe when seedlings are stressed (e.g. cold, waterlogged or very dry conditions).

10.2.3 Managing RLEM

Between emergence and early vegetative stage, particularly in late sown crops, check for mites on the ground, and for mites and plant damage in-crop.

Crop rotations can decrease reliance on pesticides. Cropping paddocks that have been in long-term pasture (with high levels of broad-leafed plants) will have a higher risk of RLEM damage especially where mite populations have been left uncontrolled.

Crops following weed-free canola or wheat crops will generally be at lower risk of RLEM.

Knowing when the first autumn hatchings of RLEM will occur helps to determine if mite emergence will coincide with seedling crops. RLEM hatch in autumn from their over-summering egg stage — after adequate rainfall and at least seven days of average temperatures below 20°C.

Crops sown in seasons with early breaks and maximum temperatures well above 20°C are unlikely to be damaged by RLEM.

Use insecticide seed treatments for vulnerable crops with moderate pest pressure, rather than spraying whole paddocks. Seed treatments allow smaller quantities of pesticide to be used that directly target plant feeding pests, allowing any predatory insects to continue their beneficial role.

Spray only if necessary. Department of Agriculture and Food, WA research has found that growers with populations of resistant RLEM have mostly used repeated applications of SP insecticides. To reduce the rate at which resistance develops, it is best to apply insecticides only on paddocks that have damaging numbers of pests.

Most resistant RLEM populations can currently be controlled using insecticides from the OP group, such as dimethoate or omethoate but the recent confirmation of RLEM tolerance to OP chemicals highlights the importance of integrated pest management in preserving the useful life of insecticides.

In situations where spray failures have occurred, it is important to correctly identify the mite. Blue oat mites are controlled by all chemicals registered for RLEM control, while chemical controls for Bryobia mite and Balaustium mites differ (Table 1).

Where spraying is needed, rotate chemical groups. Rotating chemical groups, such as SPs and OPs, within and between seasons will help to delay RLEM resistance developing.

If spraying other pests, such as aphids, try not to use SPs consecutively. Consider other insecticide options.

Table 1: Distinguishing characteristics of mite species found in Western Australian wheat systems.

Mite	Characteristics
Redlegged earth mite	Black body with red legs. Only found if cold temperature requirement for hatching has been met. Causes extensive leaf bleaching (not white trails as with Bryobria mite).
Blue oat mite	Purplish-blue body with red-orange legs and a red dot on back of body. Only found if cold temperature requirement for hatching has been met (frequently found with redlegged earth mite). Causes extensive leaf bleaching (not white trails as with Bryobria mite).
Balaustium mite	Adults are twice as large as redlegged earth mite and blue oat mite adults (2mm vs 1mm). Stout hairs cover body. Very young mites bright red. Leaves white trails on leaf surface and typically attacks leaf edges and tips. Present at same time of year as Bryobria mite.
Bryobria mite	Reddish-grey pie-shaped body with extended front legs that are 1.5 times the size of other legs. Present at same time of year as Balaustium mite. Leaves white trails on leaf surface.

Source: MyCrop: https://agric.wa.gov.au/n/637

10.2.4 RLEM and spring pastures

Unsprayed and under-grazed pastures favour RLEM during spring. Sustained grazing of pastures during spring to maintain feed on offer (FOO) levels below two tonnes per hectare dry weight – ideally about 1.4t/ha – will restrict mite numbers to low levels. These paddocks will often not require spraying for RLEM.

Applying insecticides to some paddocks – including pastures with FOO more than 3t/ha or legume break crops – during spring to prevent RLEM populations producing diapause (over-summering) eggs will also reduce the pest population the following autumn.

However, routine spraying of all pasture paddocks in spring will not be sustainable and it is important to base a decision to spray during spring on: FOO levels; future grazing management options; seed production requirements; and intended paddock use next season.

Timerite® is a free package that provides a date in spring, specific to a locality, for spraying to stop RLEM from producing over-summering eggs.

CSIRO studies have shown spraying on the optimum date, or two weeks earlier, provides effective RLEM control. Waiting for two weeks after that date can significantly increase the carry-over RLEM population.

10.2.5 Resistance research

New GRDC-supported research is expected to lead to recommendations about insecticide resistance management on improved chemical control methods for the redlegged earth mite (RLEM).

The research, led by the University of Melbourne, is being undertaken in response to the recent emergence of resistance to synthetic pyrethroids in RLEM.

Better understanding of RLEM biology will be used to develop recommendations for long-term management and monitoring guidelines to be implemented across southern Australia.

These guidelines will include recommendations such as

- rotation of chemical products;
- timing of pesticide application;
- controlling weed hosts; and
- the use of insecticide seed treatments

to minimise resistance development due to the over-reliance and poor timing of insecticide applications.

More information

For more information on Timerite® visit: http://www.wool.com/woolgrower-tools/timerite/

10.3 Early season nitrogen

Key messages

- The main uncertainty surrounding nitrogen decision-making is seasonal variability in rainfall and potential final crop yield. Matching nitrogen to yield potential will always be problematic with the correct decision only known retrospectively at the end of the season.
- Decision support tools that track potential yield through the season can increase confidence in nitrogen decision-making.
- The goal is to apply enough early season nitrogen to ensure a low-average final yield and adjust nitrogen inputs as the season (and crop demand) unfolds.
- Splitting nitrogen applications also helps to limit nitrogen losses from leaching, volatilisation and denitrification.
- Mineralised soil nitrogen will be a major source of crop nitrogen and in some seasons little if any fertiliser nitrogen will be required to meet wheat yield potential.

Crop requirement for fertiliser (bag) nitrogen is a function of demand (yield potential) and supply (soil nitrogen supply) (Table 2).

Table 2: Drivers of crop requirement for fertiliser nitrogen.

Driver	Considerations	Implications
Time of sowing	Time of sowing drives flowering time, which in turn underpins yield potential. What is the likely yield potential of the crop?*	Early-sown crops in a high-yielding season will require more applied nitrogen. Late sown crops will generally require less nitrogen, as they will have a lower yield potential. The rule of thumb is 40-50kgN/ha required for each tonne of wheat.
Nitrogen supply	How much soil nitrogen is already available? How much was applied at seeding? What was the starting soil nitrate level? What is the soil's organic carbon percentage? Has there been much summer rain to mineralise soil nitrogen? Was the previous crop a legume? Was the previous wheat crop high-yielding?	If the yield potential of the crop is 1.5-2t/ha and there is already 100kgN/ha in the soil from mineralisation and starter fertiliser then additional nitrogen may not be necessary (Figure 1). A 2t/ha lupin crop in the previous season will deliver about 30-40kgN/ha to the following wheat crop. Soil organic nitrogen (embedded in soil organic matter) is by far the largest source of soil nitrogen. Soil organic nitrogen is related to the organic carbon percentage (OC%) of a soil. A loamy soil with an OC% of one per cent will supply about 48kgN/ha per year.

Note to Table 2

* To estimate expected wheat yield use the potential yield calculator: http://www.soilquality.org.au/calculators/yield_potential, the modified the French-Shultz equation on page14 or a decision support tool such as N Broadacre, iPaddock-Yield, NuLogic or Yield Prophet®.

Driver	Considerations	Implications
Rainfall to date and stored moisture	What rainfall decile is the season tracking on? How much soil moisture is there and to what depth? What rooting depth is the crop at? How much yield can rainfall-to-date and soil moisture realistically deliver if the season keeps tracking at the same decile? How much yield could be expected if the finishing rainfall decile drops considerably?	Rainfall can vary widely across a relatively small area so determining the rainfall decile for a specific area using local rainfall records will provide the most accurate picture. If the season has been tracking at an above-average rainfall decile then the crop will be guaranteed a certain yield (barring frost and disease losses) as long as nitrogen supply is adequate. What is the potential for nitrogen losses via leaching, volatilisation or nitrification?
Seasonal outlook	What are the climate models saying? Are they in agreement or is there variability? What is the skill level?	The more models in agreement the better the chance that the seasonal prediction will eventuate. When there is variation in model predictions the outlook is far less certain and it is better to focus on what is happening in the short-term in terms of rainfall forecasts and soil moisture content.
Crop developmental stage	Tiller development can be influenced up to the 4-5-leaf stage.	If the crop is at the 2-3 leaf stage and rainfall and soil moisture conditions are not ideal there is still time to wait for rainfall before applying nitrogen.
Other drivers	Subsoil constraints.	Any impediment to root growth will restrict plant access to water and nutrients at depth. Assess problem paddocks separately for nitrogen requirements.

The goal is to put on just enough early nitrogen for a low-average yield and then to watch the season unfold and add more at early stem elongation (GS31-33) if yield potential (demand) requires it (Figure 3).

In higher rainfall areas, if the season continues to progress well above average, further nitrogen can be added a few weeks later. In most southern WA areas, cereal stem elongation (GS31 to 33) is the best time for later nitrogen application, which usually occurs sometime in July depending on season and sowing date (Figure 3).

Using moderate nitrogen rates early in the season enables a low to average yield potential to be established without compromising the prospect of higher yields if spring conditions end up being favourable. A deferred approach to nitrogen also limits the amount of nitrogen put at risk of loss from denitrification (waterlogging) or leaching.

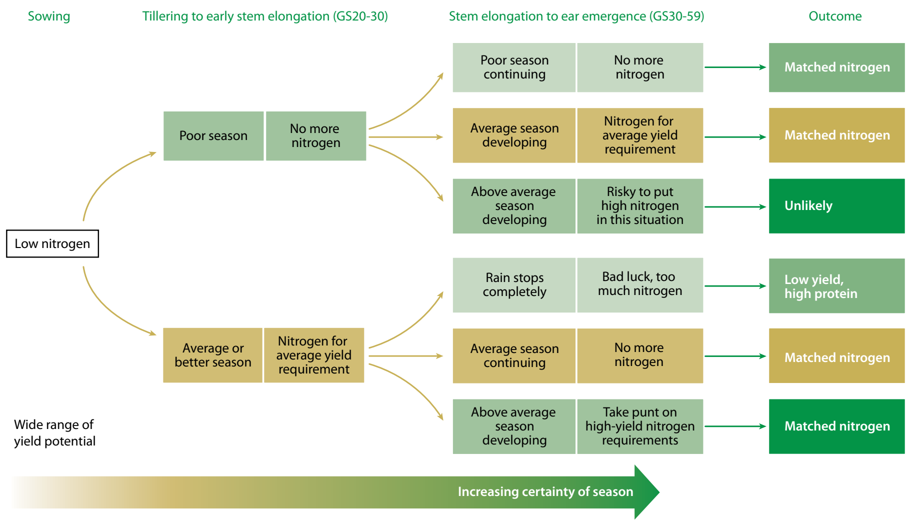


Figure 3: Decision tree for in-season nitrogen applications according to the progress of the season and crop developmental stage.

Source: Jeremy Lemon, Department of Agriculture and Food, WA.

Figures 4 and 5 illustrate the increased demand for nitrogen as yield potential increases. The graphs are outputs from the decision support tool Select Your Nitrogen developed by the Department of Agriculture and Food, WA. Select Your Nitrogen forms the basis of the N-Broadacre iPad app available from the iTunes Store.

The assumption for the high rainfall example is a dry start to the season (no nitrate leaching) and a wheat-legume-wheat rotation delivering about 50kg of mineralised nitrogen per hectare. For the low rainfall example the assumption is a wheat-fallow-fallow rotation (two years of drought) delivering 70kg of mineralised nitrogen per hectare.

For more information on nitrogen management in wheat systems see Section 5 of this GrowNote.

Note to Figure 4

In the high rainfall zone 95% of maximum yield is achieved at 5kgN/ha when yield potential is 1.5kg/ha; 20kgN/ha when yield potential is 2.0t/ha and 40kgN/ha when potential yield is 2.5t/ha.

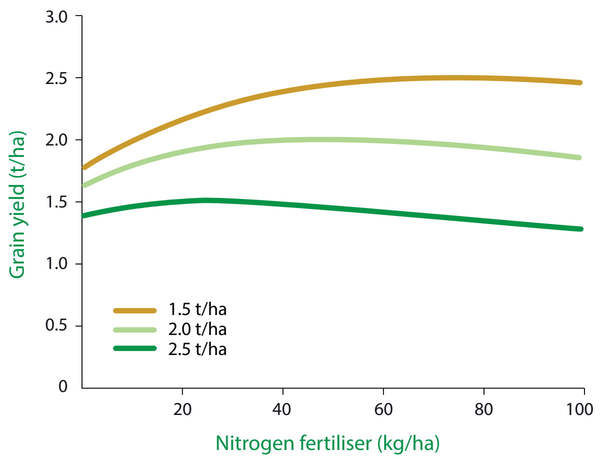


Figure 4: Relationship between nitrogen requirement and grain yield for increasing yield potential in a high rainfall area (with 50kg/ha mineralised N).

Source: Department of Agriculture and Food, WA 'Select Your Nitrogen' model.

Note to Figure 5

In the low rainfall zone 95% of maximum yield is achieved at 0kgN/ha when yield potential is 1.5kg/ha; 0kgN/ha when yield potential is 2.0t/ha and 20kgN/ha when potential yield is 2.5t/ha.

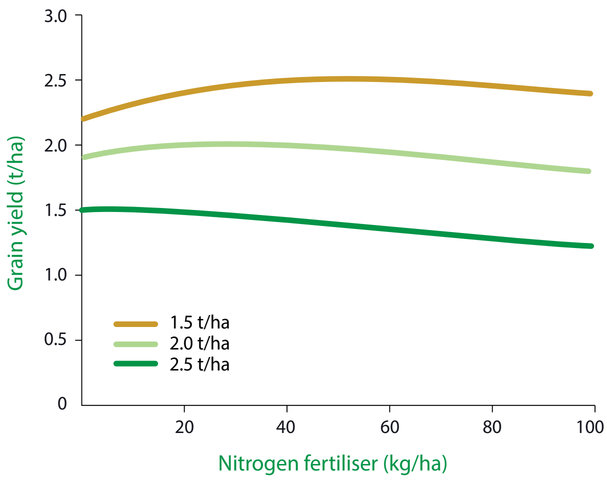


Figure 5: Relationship between nitrogen requirement and grain yield for increasing yield potential in a low rainfall area (with 70kg/ha mineralised N).

Source: Department of Agriculture and Food, WA 'Select Your Nitrogen' model.

Contact

Jeremy Lemon

Department of Agriculture and Food, WA

P: (08) 9892 8413

E: jeremy.lemon@agric.wa.gov.au

10.4 Post-emergent herbicides*

Key messages

- Selective post-emergent herbicides often provide greater than 98 per cent control when applied under recommended conditions.
- Post-emergent herbicides are often more reliable than pre-emergent herbicides, especially under low rainfall conditions.
- Nozzle selection, droplet size, sprayer speed and meteorological conditions require careful attention to maximise spray efficacy.
- Weeds suffering any kind of stress will have lower translocation rates and the herbicide will take more time to reach sites of action.

Selective post-emergent herbicides belong to the herbicide mode-of-action (MOA) Groups A (e.g. diclofop), B (e.g. metsulfuron), C (e.g. diuron), F (e.g. diflufenican), G (e.g. carfentrazone), H (e.g. pyrasulfotole), I (e.g. 2,4-D, dicamba, picloram), J (e.g. flupropanate), R (e.g. asulam) and Z (e.g. flamprop).

There have been no new MOA groups released for nearly 25 years, and it is unlikely that any additional groups will be released in the foreseeable future.

Selective post-emergent herbicides often provide greater than 98 per cent control when applied under recommended conditions. When used early in crop development selective post-emergent herbicides also result in optimum yield and significant economic returns.

Post-emergent herbicides are often more reliable than pre-emergent herbicides. This is particularly true under low rainfall conditions, as pre-emergent herbicides rely on moist soil conditions to achieve high levels of weed control.

Early removal of grass weeds such as annual ryegrass and wild oats reduces competition for resources within the crop (Figure 6).

*Information in this section has been taken from Chapter 4 of the GRDC Integrated Weed Management Manual.

Note to Figure 6

Removing wild oats when wheat was at the 2-3 leaf stage (GS12-13) had the greatest impact on crop yield. Delaying control of wild oats until the flag leaf stage of the wheat crop was not much more effective than no weed control at all.

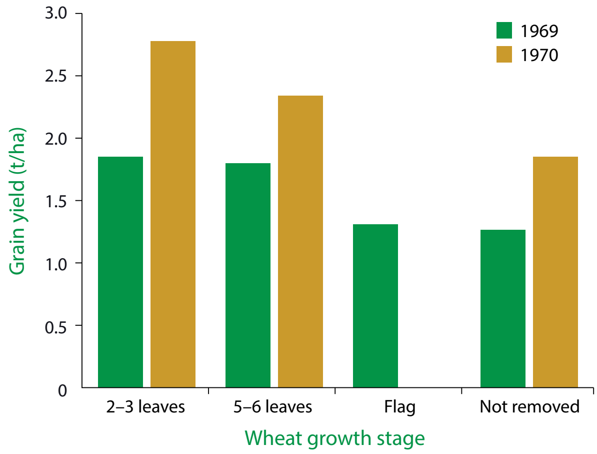


Figure 6: Effect of time of removal of wild oats using selective post-emergent herbicide on wheat yield over two years.

Unlike pre-emergent herbicides, post-emergent herbicides are applied once weeds have emerged. This allows flexibility in herbicide choice and application rate to control the particular suite of weeds in the crop and also identification of the most appropriate rate of application.

Dry conditions following sowing often delay weed emergence. Post-emergent herbicides can be applied after the majority of weeds have emerged, at a time when they are most susceptible to the herbicide being applied.

Many post-emergent herbicides (e.g. bromoxynil and metsulfuron on wheat) have an extended application window due to a wide margin of crop safety.

Depending on application rate, some post-emergent herbicides have a degree of pre-emergent or residual activity on susceptible weeds, which extends their period of weed control. This is particularly the case with some Group B MOA herbicides (e.g. metsulfuron methyl) and Group I MOA herbicides such as 2,4-D and dicamba.

Residual activity is often related to application rate with the higher the rate, the longer the residual effect. In addition, soil moisture, organic matter, clay content, temperature, pH and microbial activity can all greatly influence the longevity or availability of post-emergent herbicides in the soil.

Hot and dry conditions increase the waxiness of leaves, which reduces herbicide absorption. Plants suffering any kind of stress will have lower rates of translocation and the herbicide will take more time to reach sites of action.

Normally herbicide-tolerant crops can be damaged when stressed due to waterlogging, frost or dry conditions because they cannot produce sufficient levels of the enzymes that normally break down the herbicide into harmless compounds.

More information

For more information on best practice application of post-emergent herbicides refer to:

www.grdc.com.au/GRDC-FS-InCropHerbicideUse

www.grdc.com.au/GRDC-FS-SprayPracticalTips

www.grdc.com.au/GRDC-FS-SprayEquipment

www.grdc.com.au/GRDC-FS-SprayHeightControl

www.grdc.com.au/GRDC-FS-SprayInversions

www.grdc.com.au/GRDC-BPG-Nozzle-Selection

www.grdc.com.au/NozzleSelectionGuide

How chemicals move within plants

Knowledge of how a product enters the plant and how it is translocated is important for determining the most appropriate application volume, adjuvant type and nozzle style.

For example, some products such as the contact herbicide paraquat do not move (translocate) well within plants and an even coverage of herbicide across the weed is therefore required for effective control.

Other products, such as soil-applied herbicides and a few fungicides, can only travel upwards in plants through the xylem system and must be deposited onto the lower parts of plants to provide effective control above this point.

Some products such as the glyphosate and phenoxy herbicides can move up and down within plants throughout the phloem and xylem systems but only when the target plants are not stressed.

10.4.1 Application technique

Successful use of selective post-emergent herbicides relies on:

- Equipment (nozzles, pressure, droplet size, mixing in the tank, boom height, ground speed) to maximise the efficiency with which herbicide is applied to the weed target.
- Delta T. Spray conditions are best when Delta T <8°C and air movement is neither excessively windy nor still (Delta T is an indication of evaporation rate and droplet lifetime and is calculated by subtracting the wet bulb temperature from the dry bulb temperature).
- Temperature. Best spray results occur when temperatures are less than 28°C (Figure 7). Medium to very coarse droplets can reduce herbicide loss and drift in conditions of high temperature and low humidity.

Note to Figure 7

Only 60 per cent of the applied herbicide reached the target when the air temperature was 32°C.

More information

For information on pre-harvest herbicide use read: www.grdc.com.au/GRDC-FS-PreHarvestHerbicide

For more information on how water quality can significantly impact adjuvant effectiveness read: www.grdc.com.au/GCS105-WaterQualityInfluencesAdjuvantChoice

For a comprehensive review of adjuvant use refer to the GRDC publication Adjuvants: Oils, surfactants and other additives for farm chemicals http://grdc.com.au/Resources/Publications/2015/04/Adjuvants-Booklet

For more information on wild radish management read: www.grdc.com.au/GRDC-FS-WildRadishManagement and refer to Section 6 of this GrowNote.

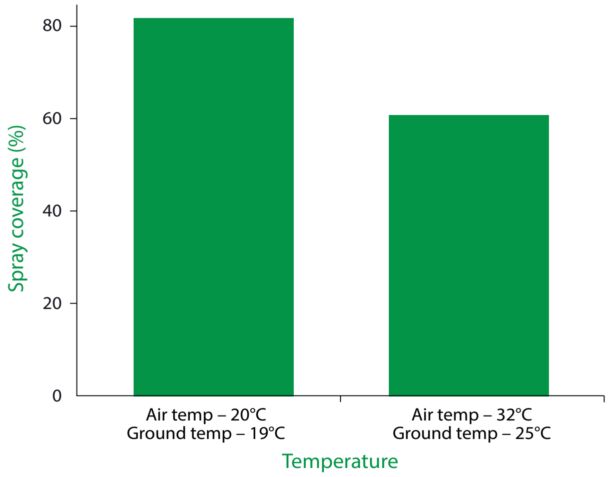


Figure 7: Effect of air temperature on spray coverage using a fine droplet spectrum.
Source: Hughes (2004).

10.4.2 Adjuvants

As plants have different leaf surfaces, an adjuvant may be required to enhance herbicide uptake and leaf coverage. Adjuvants can also increase performance lowered by pH, hard water, compatibility, rain-fastness or drift.

To achieve the best herbicide performance it is important to use the adjuvant recommended on the herbicide label.

10.4.3 Integrated weed management

Early post-emergent herbicides can maximise yield by removing weed competition when the crop is establishing.

By using crop competition (high seeding rate and narrow rows) and harvest weed seed management in combination with post-emergent herbicides, weed seed numbers will significantly reduce over time.

Controlling herbicide-resistant wild radish in wheat crops requires a two-spray post-emergent approach in combination with crop competition and harvest weed seed management.

References

Hughes, P. (2004). Spray right – reduce drift. Queensland Dept. of Primary Industries and Fisheries extension note.

McNamara, D.W. (1976). Wild oat density and the duration of wild oat competition as it influences wheat growth and yield. Australian Journal of Experimental Agriculture and Animal Husbandry 16: 403–406.

Resources

GRDC Integrated Weed Management hub www.grdc.com.au/Resources/IWMhub

Giving a Rats newsletter http://www.agronomo.com.au/giving-a-rats/

Department of Agriculture and Food e-weed newsletter https://www.agric.wa.gov.au/newsletters/eweed

To diagnose post-emergent herbicide damage in wheat refer to the Department of Agriculture and Food, WA MyCrop tool: https://agric.wa.gov.au/n/1976.

For a summary of the key principles underlying successful spray operations read: www.grdc.com.au/GCS105-HowWillYouSprayYourWeedsThisYear

Contact

Andrew Storrie
Integrated Weed Management Manual
Phone: (08) 9842 3598
Email: andrew@agronomo.com.au

10.5 Crop grazing

Key messages

- Grazing wheat crops during the early vegetative stage can provide a range of livestock and crop benefits.
- Crash grazing early-sown crops can delay flowering, which can help with frost risk management in some areas.
- Intensity and timing of grazing needs to be carefully managed in drier seasons and shorter growing zones.
- Stock should be removed before stem elongation (GS30) to avoid removal of emerging wheat ears.
- Yield is a function of crop biomass, so any crop grazing strategy needs to ensure sufficient biomass and recovery time following grazing to minimise yield impacts.

Videos

Watch a video on the value of crop grazing to stocking rate and feed supply for an Esperance mixed farming system: www.grdc.com.au/OTFW-CropGrazing

Grazing wheat crops during the vegetative stage (from tillering to GS30) can provide a range of benefits to mixed farming systems across Western Australia, particularly in higher rainfall areas.

Grazing crops can increase the feed available during the autumn–winter feed gap, when feed is often limited, allowing increased stock numbers or stocking rates during winter, improving animal performance and allowing pastures to be deferred.

Crops sown before or at the break of season can provide an alternative winter-feed option with little or no penalty to crop yield if carefully managed. Grain yield is correlated with crop biomass at harvest, so to reduce any yield impacts, grazing strategies must allow for sufficient biomass recovery before harvest (Figure 8).

Figure 8 indicates that early, hard 'grazing' (during tillering, leaving plants at 0–5cm high) enabled sufficient time for plant recovery, generating sufficient total crop biomass and yield at harvest. Similarly, late light 'grazing' (during early stem elongation, leaving plants 10–15cm high) left sufficient residual biomass following 'grazing' and crops were able to achieve sufficient yield despite the shorter recovery time post 'grazing'.

However, it is important to note that any grazing that removes the developing head will affect yield dramatically.

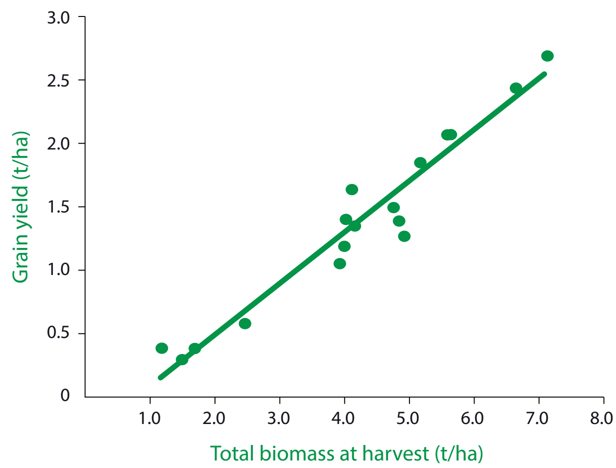


Figure 8: Relationship between amount of wheat biomass remaining after simulated grazing and final grain yield of Mace grown at Dumbleyung, WA in 2012.

Source: Department of Agriculture and Food, WA.

10.5.1 Flowering time

Crop grazing can be used to delay flowering of early-sown crops so that flowering occurs after the high-risk frost period (Table 3).

The later the grazing, the more biomass that must be left behind. An easy way to do this is to monitor the position of the developing head. A rule of thumb is that once stem elongation has started, more than twice the length of stem should be left above the head as well as below the head.

Note to Table 3

The rule of thumb for crop grazing and flowering is that two days of crash grazing will delay flowering by one day.

Table 3: Impact of simulated grazing on flowering time of Yitpi.*

Grazing treatment	Flowering date	Difference from nil grazing
Nil	16 September	-
10 days of grazing	22 September	6
20 days of grazing	27 September	11
30 days of grazing	30 September	14

* Yitpi sown 4 May and 'crash grazed' (whipper-snipped) to 3-5cm at 4-leaf stage with treatments 'grazed' again every 10 days: 1 x cut for 10-day plots, 2 x cuts for 20-day plots and 3 x cuts for 30-day plots). Source: Curtin and Whisson (2014).

10.5.2 Timing of grazing

Final biomass of a grazed crop is a function of the biomass remaining after grazing, the growth rate of the crop following grazing and the time provided for crop recovery.

High harvest biomass can be achieved when:

- there is a long recovery time, even though there may be low residual biomass post grazing; and
- there is a high level of residual biomass after a light grazing, with stock removed later in the season, into the elongation phase, even though there is a shorter recovery period.

More information

More information on crop grazing can be found on the WA section of the Grain and Graze website at: http://westernaustralia.grainandgraze2.com.au/

For more information on crop grazing research read: www.grdc.com.au/GCS113

Note to Table 4

Heavy (crash) and late grazing reduced grain yield significantly relative to ungrazed controls and lighter, earlier grazing in the drier season of 2012. Crops grazed at shorter season locations (Kellerberrin) were more severely affected than those at longer season locations (Cascades and Gibson).

Low stocking rates of 5-10 dry sheep equivalents per hectare (DSE/ha) can be used for up to several weeks. Higher stocking rates can be used with shorter grazing times, for example, 30DSE/ha for 2-5 days. Later grazing allows for higher stocking rates (at least 30DSE/ha), as crop growth rates are usually high, 30-70kg/day, and the accumulated biomass levels are large.

GRDC funded research across the WA wheatbelt in 2011 and 2012 demonstrated that it is possible to graze crops in winter and still maintain grain yield. However, grazing resulted in more frequent yield penalties in the drier 2012 season (decile 1-2) than the equivalent set of trials in 2011 (Table 4).

It is important to determine the grazing value of crops relative to the grain yield penalty when considering the economic implications of crop grazing. For example, in a year when grain prices are high (like 2012) even a small yield penalty from crop grazing can have a large impact on grain income per hectare.

Table 4: Impact of the timing and intensity of crop grazing on grain yield at a range of WA wheatbelt locations in 2012.

Location	Yield impact (% of ungrazed control)	Timing of grazing	Type of grazing
Warradarge	-12	Late July-early August	Crash
Miling	-4	Early-mid July	Clip
Kellerberrin	-15	Early-mid July	Crash
Cascades	-9	Late June	Crash
Gibson	-3	Early-mid July	Clip

Source: Barrett-Lennard et al (2013).

10.5.3 Removing stock (GS30)

Removing stock close to stem elongation (GS30) will ensure they do not remove the emerging wheat heads.

Stem elongation (GS30) commences when the first node (GS31) can be found on the main stem. The first node can be felt as a swelling towards the base of the main stem and can be identified by peeling back the leaves on the main stem to expose the node underneath.

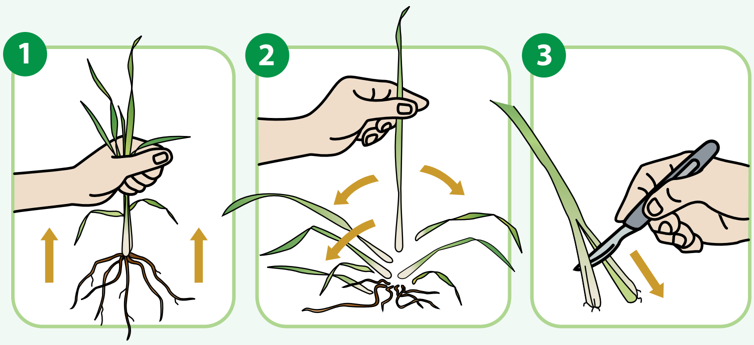
GS30-31 is the start of a rapid period of growth when the wheat plant switches from vegetative growth (leaves) to reproductive growth (wheat ears). The stem begins to elongate and the embryonic wheat ear, which has formed at the base of each tiller, begins to travel up the stem.

Stem elongation is the result of the elongation of the internodes (the hollow-stem spaces that separate each node). The wheat crown at the base of the tiller consists of eight to 14 nodes stacked closely above one another, separated by internodes less than 1mm long. Extension of the first five or six internodes pushes the head higher and elongates the stem. Lower internodes remain compressed at the base, with the number depending on sowing rate and variety. As the internodes elongate the individual nodes become visible.

GS30 cannot be predicted by a calendar date so visual observation of the emerging embryo ear is the only way to determine this growth stage accurately.

How to dissect a cereal plant to determine growth stage 30-31

- Pull up a plant and shake the dirt off the roots
- Pass your hand around the plant and draw upwards to identify the tallest leaf (this will be attached to the main stem of the plant)
- Peel off any dying leaves
- Cut the roots from the plant at the stem base
- Cut the stem lengthwise along the stem to expose the embryonic ear.



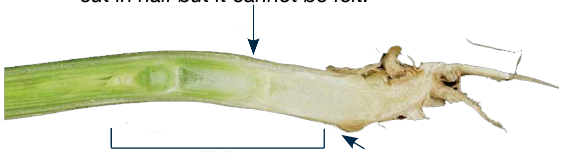
10.5.4 Determining when GS30 is approaching

Grazing delays the transition from tillering to stem elongation by a few days. Also the main stem of a cereal plant is usually more advanced in its development than neighbouring tillers.

To gain an indication that GS30 is approaching, monitor the main stem on plants that have not been grazed. When these plants begin stem elongation, the rest of the grazed crop will not be far behind (Figure 9).

Establishing an exclusion area in a paddock with weldmesh or portable sheep yard panels can provide a point to monitor crop development.

Growth stage 30: *Tip of the embryo ear is 1cm or more from base of the shoot. No node is detectable. Grazing should cease at this stage to avoid damage to the embryo ear and potential grain yield loss.*



Growth stage 31: *The first node on the stem is detectable and is 1cm or more above the base of the shoot. There is a space between the node and the base of the shoot. Grazing at this growth stage will damage the embryo ear and result in grain yield loss.*

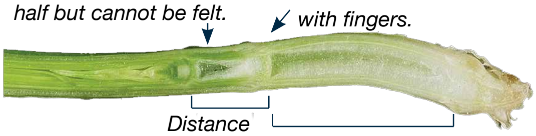


Figure 9: Cross sections of wheat stem at growth stage 30-31 (early stem elongation).

Grazing early-sown crops can help delay flowering past the high frost risk period. The rule of thumb for crop grazing and flowering time is that wheat flowering is delayed by one day for every two days of crash grazing.

Photo credit: GRDC.

Tips for grazing wheat crops

- Ensure a weed-free paddock to achieve best yield results.
- Increasing sowing rate will provide greater biomass for earlier grazing.
- Use varieties with vigorous early growth rates.
- Sow as early as possible with some nitrogen as well as phosphorus.
- Adhere to withholding periods for any crop treatments applied before grazing. Seed dressings and pre-emergent sprays have withholding periods ranging from 4-12 weeks.
- Use the 'twist' test to determine when to start grazing — 3-4 leaf stage. If the top of the plant breaks off after twisting without pulling the roots out, then the crop is ready to graze.
- Graze paddocks in a series, rather than all at once, to allow increased stocking rates and more even grazing while allowing paddocks to be grazed at different times. This can spread flowering times, reducing the impact of frosts at flowering.
- Stocking rate, water placement and electric fencing can be used to manipulate grazing pressure and create a more even graze across a paddock.
- Do not graze past the white line in cereals (leaving 5cm is safer) — leaving some leaf will improve recovery.
- Minimise yield loss by removing stock before the stem elongation process starts (growth stage 30).
- Use a loose lick of equal parts, ground limestone and salt to maximise animal production and include Causmag® in the mix when grazing with sheep to minismise the risk of hypocalcaemia and grass tetany.
- Ensure vaccinations are up to date, especially for pulpy kidney.

References

Curtin, S and Whisson, (2014) Delaying wheat flowering time through grazing to avoid frost damage (Part 1: Time of cutting). In Proceedings 2014 Agribusiness Crop Updates, Perth, Western Australia. http://www.giwa.org.au/2014-crop-updates

Barrett-Lennard, P Quinlan, R Taylor, S Warren, G Handley, M and Pearce, R (2013) Grazing crops in a dry year. In Proceedings 2013 Agribusiness Crop Updates, Perth, Western Australia. http://www.giwa.org.au/2013-crop-updates

Contact

Phil Barrett-Lennard
AgVivo
M 0429 977 042
E phil@agvivo.com.au

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

Disease:

DAW00209 - Genetic options for the management of RLN species in Western Australia (S: 1/07/2010 F: 30/06/2015)

DAW00201 - Identification and characterization of diseases suppressive soils in the Western Region (S: 01/07/2010 F: 30/04/2014)

Redlegged Earth Mites:

CSE00054 - Pest management in grains - research, coordination and industry engagement (S: 01/01/11 F: 30/12/2014)

UM00048 - National coordination of invertebrate pest research and insecticide resistance management (S:01/07/2013 F: 30/06/2018)

UWA00158 - Detection and epidemiology of spring aphids and redlegged earth mites (S: 01/11/12 F: 30/09/2015)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC early season projects can be found at: www.grdc.com.au

SECTION 11

Mid season

11.1 Protecting the flag leaf

Key messages

- Stem elongation (GS30-39) culminates in the emergence of the last wheat leaf produced: the flag leaf.
- Flag leaf photosynthesis can account for about 40 per cent of grain yield in higher rainfall areas.
- Protecting the flag leaf from disease damage is therefore critical to yield potential, especially in high rainfall areas and seasons.Stem elongation (GS30–39) represents the most important time for fungicide application, as it is during this stage that the top four leaves of the canopy are produced – culminating in the flag leaf.

Stem elongation (GS30–39) represents the most important time for fungicide application, as it is during this stage that the top four leaves of the canopy are produced – culminating in the flag leaf.

The top three leaves of wheat (flag-2, flag-1 and flag leaf) contribute significantly to grain yield, especially in high rainfall areas (Figure 1).

Note to Figure 1

Protecting the three top wheat leaves from fungal disease is more important in higher rainfall areas because these regions have a longer grain-fill period and the flag leaves play a proportionally greater role in grain yield than in wheat crops in lower-rainfall regions. However, stem rust is equally destructive in both high and low rainfall environments, since the greatest impact of the disease is on the stem.

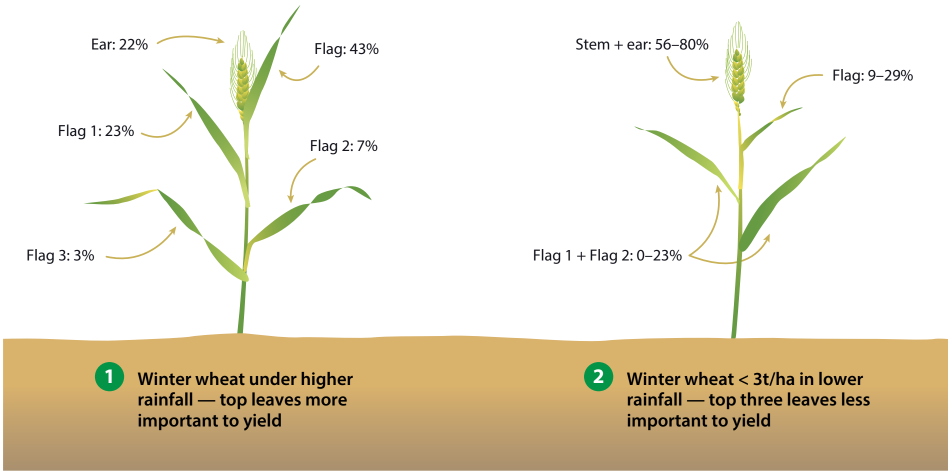


Figure 1: Relative contribution of the top three leaves in wheat to grain yield in higher rainfall (left) and lower rainfall (right) areas.

Source: re-drawn from GRDC (2005).

11.1.1 Stem rust

Stem rust is the most serious of the three wheat rust types as it can cause yield losses of up to 90 per cent depending on variety susceptibility and timing of disease onset. The disease can develop extremely quickly within a susceptible crop and is easily spread by wind.

Stem rust produces large reddish brown oval to elongated spore masses on both sides of a leaf, on leaf sheaths, stems and outside of heads. Pustules of stem rust have conspicuously tattered edges (Figure 2).

Figure 2: Pustules of stem rust have conspicuously tattered edges. The disease produces large reddish brown oval to elongated spore masses on both sides of a leaf, on leaf sheaths, stems and outside of heads.

Photo credit: GRDC.

Stem rust is adapted to warmer conditions (15-30°C) than leaf or stripe rusts and because of this is usually detected later in the season than leaf or stripe rusts.

Fungicide applications as late as pre-head emergence through to grain fill have been shown to be economic in susceptible varieties (Figure 3). High fungicide rates provide longer control and are important if infection is severe.

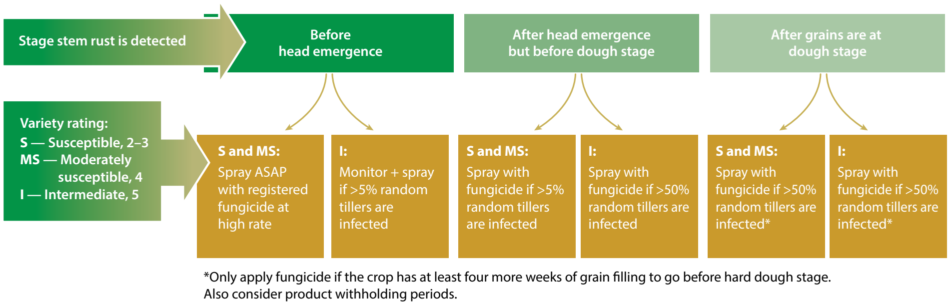


Figure 3: Fungicide timing in relation to stem rust intensity and varietal susceptibility.

11.1.2 Leaf and stripe rust

Leaf rust and stripe rust should be treated with a registered foliar fungicide at the first sign of disease if the crop is rated very susceptible to moderately susceptible (2-4) and has not finished flowering (Table 1).

Follow up sprays can be required at 3-4 week intervals. Applying fungicide at or before heading will optimise stripe rust control on leaves and reduce the risk of head infection.

Partially resistant varieties (5–6 rating) do not need fungicide unless infection occurs early.

Table 1: Foliar fungicide timing for leaf and stripe rusts according to growth stage at which outbreak first detected and resistance rating of wheat variety.

	Crop stage at first sign of stripe rust or leaf rust infection			
Resistance rating	**Pre flag leaf***	**Full flag to late booting**	**Mid to late heading**	**Mid to late flowering**
Very susceptible (VS)	stripe or leaf**	stripe or leaf**	stripe or leaf	n/a
Susceptible (S)	stripe or leaf**	stripe or leaf**	stripe or leaf	n/a
Moderately susceptible (MS)	stripe or leaf	stripe or leaf	stripe or leaf	n/a
Moderately resistant - moderately susceptible (MR-MS)	stripe or leaf	stripe	n/a	n/a
Moderately resistant (MR)	stripe	n/a	n/a	n/a

Source: Department of Agriculture and Food, WA

* Foliar spray required pre-flag leaf if seed dressing or in-furrow fungicide not used

** Higher rates more profitable on more susceptible varieties

n/a Spraying at these stages or for these resistance ratings generally not applicable.

Note to Table 1

Use higher fungicide rates to achieve longer protection in seasons of high rust risk.

Weigh fungicide costs against expected yield potential.

Stripe rust can infect heads and increase screenings. Apply fungicide at or before heading and ensure optimal rust control on leaves to reduce risk of head infection.

Spraying after crop flowering is normally not economic for stripe or leaf rusts.

11.1.3 Leaf spot disease

Most WA wheat varieties are moderately susceptible or worse to the leaf spot diseases yellow spot and *Septoria nodorum*. Spread of the diseases is facilitated by periods of regular rainfall.

A single application of foliar fungicide applied to susceptible varieties at or around flag leaf emergence (GS39), will protect the flag leaf and the leaf below (flag-1) from leaf spot diseases (Table 2).

Yield responses to leaf spot sprays are more likely:

- in well-grown crops in medium to high rainfall areas;
- when the disease is moving rapidly from lower leaves to upper canopy leaves; and
- when there is a good chance of August-September rainfall of about 100mm.

Ensuring good control of *Septoria nodorum* on leaves before heading will reduce the risk of head infection, which can cause shrivelled grain and even complete seed loss.

For more information on wheat disease management refer to Section 3 of this GrowNote.

Note to Table 2

A second spray at flag leaf emergence is generally considered profitable when there are good prospects of about 100mm rain in the two months after flag leaf emergence. Consult historical records or climate tools such as CliMate to determine likelihood of receiving 100mm. http://www.australianclimate.net.au

Table 2: Impact of fungicide applications for leaf spot disease at various wheat growth stages on wheat yield and profit.*

Fungicide treatment	Yield increase (t/ha)**	Profit increase ($/ha)**
Single spray GS15 or GS25	0.2	57
Single spray GS31	0.3	75
Single spray GS41	0.3	57
Double spray GS15/GS25 and GS39	0.3	56
Double spray GS31 and GS39	0.5	109

Source: Department of Agriculture and Food, WA.

* Results are summary of eight trials across the WA wheatbelt between 2010-2011.

** Results are averages of eight trials. Profit depended on fungicide product and rate used. Wheat price used 2011 = $270/t and 2010 = $313/t. Cost of fungicide application = $8/ha. Fungicides used: Prosaro® at 300mL/ha = $19.80, Tilt® at 500mL/ha = $9.

Disease monitoring

Mid-late season disease management requires regular monitoring of cereal crops from early stem elongation (GS31).

Crops need to be monitored every 7-10 days with priority given to the most susceptible, earliest sown crops.

Crossing the paddock in a 'W' pattern, plants should be monitored from top to bottom at regular intervals.

When disease is found, collect 10 stems from 10 locations (100 stems in total) recording crop growth stage, date, severity of infection and location on the plant by leaf or stem position.

Samples for disease diagnosis can be submitted to AgWest Plant Laboratories. For information on sending samples and costs refer to:
https://agric.wa.gov.au/n/1766

Monitor and report disease occurrences in crops to the Department of Agriculture and Food, WA by emailing to PestFax@agric.wa.gov.au or completing an online report at
https://www.agric.wa.gov.au/diseases/pestfax-map

11.1.4 Mid-season yield potential

Yield potential pivots on soil moisture availability.

Wheat crops require a minimum of 50mm of plant available water (from either the soil or rain) after flowering to achieve yield potential, especially if yield potentials are greater than 2.0t/ha.

This equates to about 2-3mm of water per day.

By determining how much soil moisture is available it is possible to estimate how many days the crop can go before more rainfall is required to reach yield potential.

Soil moisture following flowering can be estimated by referring to Yield Prophet® or soil moisture probe reports with similar rainfall, soil types and rooting depths as the area in question. Alternatively a hole can be dug in the crop to determine the depth of the wetting zone.

A very rough rule of thumb is one millimetre of soil moisture for each centimetre of wetting front. So, if the soil is wet to 50cm then there will be 50mm of soil moisture available to the crop.

Note

The iPaddockYield app can also be used to estimate expected yield from historical farm rainfall and production data. The app can be downloaded from the iTunes store.

Assessing yield potential

Wheat grain potential is a function of the number of ears per square metre, the number of grain per ear and average grain weight:

$$\text{Grain yield (t/ha)} = \frac{\text{Ears/m}^2 \times \text{spikelets per ear} \times \text{grains/spikelet} \times \text{grain weight (mg)}}{100{,}000}$$

Example wheat crop

Ears/m^2: 300

Spikelets/ear: 8

Grains/spikelets: 2

Grain weight: 33mg

$$\text{Grain yield (t/ha)} = \frac{300 \times 8 \times 2 \times 33}{100{,}000}$$

$$= 1.58\text{t/ha}$$

This yield potential is likely to be reached provided there is sufficient soil water and rain following flowering (about 50mm) and nutrition, frost, heat and disease do not limit grain production.

11.2 Frost identification

Key messages

- Frost damage is not always obvious. Inspect for frost damage through the season especially five to seven days after frost damage is suspected.
- Plants are most susceptible to frost during ear emergence and flowering.
- In the event of severe frost, monitoring needs to occur for up to two weeks after the event to detect all the damage.
- Accurate assessment of frost damage can help with decisions about whether and when to cut for hay or leave for grain harvest.
- Canopy temperature is of more importance than temperature at the weather station, with the difference sometimes as much as 5°C or more.

More information

For more information on identifying frost download the GRDC Frost Identification Guide at: www.grdc.com.au/GRDC-BPG-FrostCereals

Frost can occur during any stage of the growing season, but the susceptibility of the crop to damage depends on the growth stage of the crop — damage before stem elongation (GS30) is rare.

Up to GS30, plants can suffer from vegetative frost, which mostly just slows growth, but in extreme cases can cause plant death. This kind of damage is uncommon in Western Australia.

From GS30 to start of ear emergence (GS49) there can be elongation or stem frost. Frost during this stage can directly damage the developing ear or 'ringbark' the stem below the ear, resulting in ear death. The symptoms are not immediately visible without dissection.

Plants are most susceptible to frost after GS49, during ear emergence and flowering (GS59–70). Frost after flowering is also possible. During early grain fill (GS80–89) frost can damage the kernels resulting in shrivelled and green-coloured grain at harvest.

11.2.1 Identifying damage

Use paddock-based weather stations or data loggers to identify whether a frost has occurred overnight. Even if the Bureau of Meteorology (BoM) data says the conditions for a frost were not quite reached it is still worth checking crops.

Some symptoms will appear within the first 24 hours, but most frost damage will take at least a few days to appear. The more time that has passed since the frost event, the easier it is to observe symptoms, but fewer management options will be available. Regularly inspect crops, particularly in low-lying areas, to identify frost damage as early as possible.

More information

[GIWA: Wheat variety selection for managing exposure of dry sown crops to frost and heat damage at flowering.]

[DAFWA: Frost rating, p20.]

[WANTFA: Frost.]

[GRDC: Frost rating information, p14.]

[DAFWA: Flower Power flowering predictor for frost and heat.]

[DAFWA: Diagnosing stem and head frost damage.]

[GRDC Update Paper: Paul Telfer, Heat stress tolerance of wheat.]

In frost-prone areas of a farm, inspect cereal heads regularly during the later growing stages to ensure yield losses due to frost are identified well before harvest.

In the event of severe frost, monitor for up to two weeks after the event to detect all the damage. Accurately assessing frost damage can help with decisions about whether and when to cut for hay or leave for grain harvest. An inspection five to 10 days after the frost event will reveal whether grain development has been affected.

Frost damage is affected by many factors and depending on the particular situation symptoms may vary widely. Crops tend to be damaged unevenly and not all plants will show obvious symptoms.

When plant tissue is frozen, ice crystals rupture the cell walls and membranes. Alternatively the cells freeze without structural damage, but the cells can be killed by dehydration. When frozen tissues thaw out they take on a dark, limp and water-soaked appearance similar to frozen lettuce. Several days after the frost, the tissue starts to dry out and turns straw-brown prematurely.

Frosted plants remain high in sugars and nutrients because they have no grain to fill. As a result they are often infected by microbes, which can turn the crop black or brown.

11.2.2 Stem damage

A characteristic symptom of frost damage is the 'white ring' seen on the stem above the highest node and below the ear (Figure 4). Freezing sometimes starts in the water that sits around the collar of the flag leaf, near the stem. For several days after the frost, the ring is pale-green rather than white.

Stems can be damaged just above the nodes and this is usually seen as blistering, cracking or shrivelling. Stems damaged just above the highest node can be pulled out from the plant by the head more easily than normal stems.

Nodes themselves can also be damaged. When nodes or stems are affected on one side, their subsequent growth can be distorted, causing the stem to bend or twist.

Stem damage may not completely disrupt flowering and grain filling. However, the stem is weakened at the point where it was frozen, and if the crop is subjected to strong winds it may fall over and make harvesting difficult.

Figure 4: Frost-affected stems: A pale-green-to-white ring on the stems of wheat plants indicates they are frost-affected. With sufficient soil moisture crops can develop grain even with frost-damaged stems, but it is important to monitor fortnightly after the frost event to assess crop development.
Photo credit: GRDC.

11.2.3 Head damage

If the head is partially emerged during the frost, part or all of the whole head may be blighted (Figure 5). Whether the tip, middle or base of the head is damaged depends on how far the head had emerged from the boot during the frost.

Figure 5: Damaged florets: The most visible type of head damage is the shrivelling, bleaching or dwarfing of florets.
Photo credit: GRDC.

Blighting usually affects only a small proportion of the heads and other head damage is much less conspicuous. The reproductive parts of the floret (the anthers and undeveloped grain) are the most susceptible. These are frequently frozen without any obvious external symptoms (Figure 6).

Figure 6: Healthy floret: A healthy non-frosted floret will have bright yellow anthers.
Photo credit: Ben Biddulph.

Damage can sometimes be gauged soon after the frost by looking at the crop into the sun. The frozen heads appear more translucent than normal. Several days after the frost, the colour of damaged heads begins to fade and several weeks later, the affected parts of the crop are easily recognised as lighter areas.

The only way to examine the reproductive parts of the head is to peel back the glume (outer sheath) of an individual floret. A magnifying glass can help when inspecting the reproductive parts.

A normal undeveloped grain is white and it feels crisp when removed from the floret and squeezed between the forefinger and thumb. Damaged undeveloped grains appear dark green or brown, partially translucent and they feel spongy (Figure 7a-d).

Figure 7.a: Healthy heads: Peel open the floret to inspect the developing grain. Healthy grain is light to dark green, plump and exudes a white milky dough when squeezed.

Photo credit: GRDC.

Figure 7.b: Healthy endosperm: when the developing grain is squeezed between the thumb and forefinger a healthy endosperm will emerge looking pale, plump and smooth in texture.

Photo credit: Ben Biddulph.

Figure 7.c: Frost-affected endosperm: when the frost-affected grain is squeezed between the thumb and forefinger it will appear dark green or brown, partially translucent and will feel spongy.

Photo credit: Ben Biddulph.

Figure 7.d: Frost-damaged heads: Frosted developing grain is white and bleached and fails to develop. As time passes it turns brown and becomes dimpled and crimped in appearance.

Photo credit: Ben Biddulph.

11.2.4 Assessing frost damage

It is difficult to accurately assess the level of frost damage in a crop because it is usually patchy and the crop can compensate for the damage during grain-fill. The unaffected grains tend to fill to a larger size than normal because of the reduced number of grains.

If the crop was sown early and is frosted during late August or early September, there is a chance it will develop new tillers from its base. These may set some grain, particularly if the weather is mild and wet. Mowing or harrowing to remove the damaged stems and promote growth generally reduces the final yield.

Some general advice for assessing frost damage is:

- Inspect crops when they are between ear-emergence and grain-filling, and when temperatures fall below 2°C at your nearest BoM weather station.

More information

For information on the latest frost research in cereals read: www.grdc.com.au/GCS109-Frost

- Examine the crop in the more susceptible low parts of the landscape first and if damaged, proceed to higher ground.
- Walk through the crop and examine a whole plant every 20 or 30 paces.
- Peel back the leaves and look for stem damage. If the head has not emerged from the boot, check that the head has not been damaged. It the crop has flowered, open the florets on the head to check that the grain is developing.
- Tag a few heads with plastic tape and note the stage of grain fill. Return a week later to determine if grain fill is continuing.
- If the damage is very severe (eight or more heads killed out of ten) and a market for hay can be found, consider cutting the crop for hay. Do this as soon as possible after the frost so that the risk of microbial infection and loss of hay quality is small.
- If damage is not severe, yield losses may not be as great as first estimated, because of the compensation during grain filling. Monitor grain fill over the next three or four weeks.

11.2.5 What to do with a frosted crop

Despite proper planning and in-crop management a severe frost can affect crops unexpectedly. Determining what to do after a crop has been frosted starts with assessing the damage.

Frost damage in crops can change with soil type, aspect and elevation, so be sure to check plants in different parts of the affected paddock. Symptoms can take 5 to 7 days to appear in wheat crops.

Wheat is susceptible to frost damage after the growing tip has grown away from the protection of the soil, when the stem starts to elongate, through head emergence, flowering and late grain filling.

Identifying frost damage early is essential in order to achieve the optimum from the crop.

If frost damage is identified there are four main options for managing the crop to the end of the season:

- Harvest the grain: use gross margins to establish the grain yield required to recover harvest costs.
- Fodder conservation: evaluate the demand and opportunity for marketing hay from the frosted crop and the likely costs and returns.
- Grazing: consider whether the affected crop can be grazed to achieve a return. If livestock are not a current part of the farming system consider the viability, cost and return of purchasing or agisting stock to graze the affected crop.
- Green or brown manure.

More information

For more information on managing frost risk download: www.grdc.com.au/GRDC-Booklet-ManagingFrostRisk and view the Department of Agriculture and Food, WA frost web pages: https://agric.wa.gov.au/n/26

Read a case study on the impact of late frosts in 2013: www.grdc.com.au/GCS109-LateFrostsCauseSouthernConcern

A series of severe frost events in October across southern Australia in 2013 resulted in many wheat crops being cut for hay.

Photo credit: Rob Taylor.

Data-logging temperature sensors in the crop canopy can be used to monitor frost events and help make timely decisions about cutting frosted crops for hay before quality declines.

Photo credit: GRDC.

Reference

Cereal Growth Stages - the link to crop management (2005) Grains Research and Development Corporation, Canberra.

Contact

Dr Ben Biddulph
Department of Agriculture and Food, WA
P (08) 9368 3333
E ben.biddulph@agric.wa.gov.au

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

DAW00229 – Improving grower surveillance, management, epidemiology knowledge and tools to manage crop diseases (S: 30/06/2013 F: 30/06/2018) Collaboration between DAFWA and Curtin University.

Rust:

ANU00022 – New strategies for disease resistance to wheat stripe rust: Providing novel resistance to wheat rust disease via RNAi interference (S: 01/07/2013 F: 30/06/2019)

CSP00161 – Triple Rust Resistance Project – ACRCP (S: 30/06/2012 F: 30/06/2017)

FAR00002 - Improved fungicide use for cereal rust control (S: 7/1/12 – F: 6/30/17)

Leaf spot disease:

DAW00206 – Germplasm enhancement for yellow spot resistance in wheat (S: 1/07/2010 F: 30/06/2015)

Frost:

DAW00234 - Determining yield under frost - one degree at a time (S: 01/01/2014 F: 30/06/2018

DAW00241 - Farming systems to improve crop tolerance to frost (S: 01/07/2014 F: 30/06/2016)

FGI00009 - Effect of stubble retention on canopy temperature and frost damage in wheat (S: 01/07/2012 F: 31/03/2014)

SDI00019 - Stubble management to reduce the impact of frost to crops in the Albany and Kwinana West Zone of WA (S: 01/04/2013 F: 28/02/2014)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC mid-season projects can be found at: www.grdc.com.au

SECTION 12

Late season

12.1 Nitrogen top ups

Key messages

- The impact of late-applied nitrogen on grain yield and protein depends on the wheat growth stage at which the nitrogen is applied, previous nitrogen history and soil moisture status.
- Later applications of nitrogen can increase tiller survival and longevity of green leaf area (where the season permits) and in this way can also contribute to yield through larger grain or, depending on time of application, more grain per ear.
- Nitrogen taken up after flowering is more likely to increase grain protein and far less likely to increase grain number or grain size.
- Decision support tools like N Broadacre, NuLogic and Yield Prophet® can be used to explore the economics of late-season nitrogen strategies for a range of seasonal outlooks.
- Applying late nitrogen in anticipation of a follow-up rain is risky because if the season end does not deliver sufficient rain, yield can decline due to 'haying off'. However if nitrogen is applied after a rain that exceeds about 20mm over two days it can result in significant yield increases.

During stem elongation to ear emergence (GS30-39), a further assessment of crop nitrogen requirements can be made according to the season outlook (Figure 1).

Later applications of nitrogen can increase tiller survival and longevity of green leaf area (where the season permits) and can also contribute to yield. However where the season ends more abruptly, later nitrogen in excess of yield potential can cause increases in grain protein at the expense of yield.

Late season nitrogen applications are largely only appropriate in high rainfall areas although rainfall amount and pattern in some seasons in lower and medium rainfall areas can also deliver yield responses to late season nitrogen (Palta et al, 2003; Lemon, 2004).

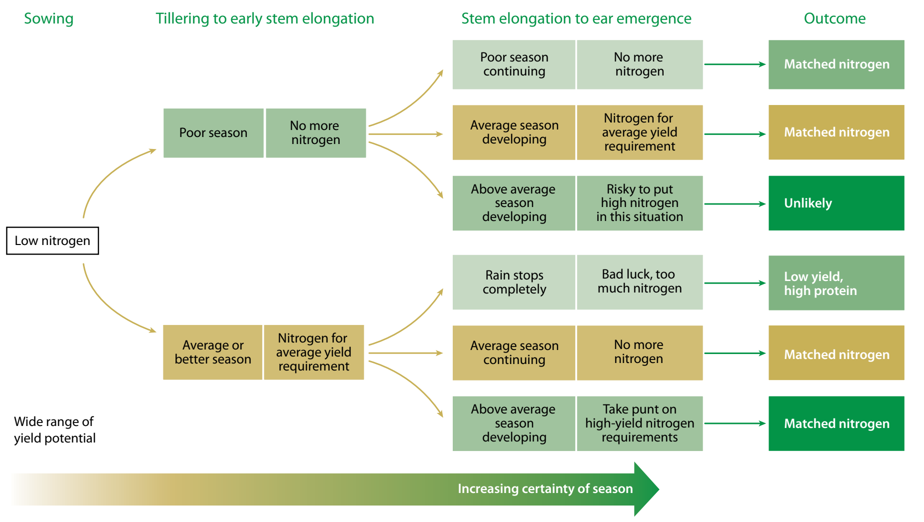


Figure 1: Decision tree for in-season nitrogen applications according to the progress of the season and crop developmental stages.

Source: Jeremy Lemon, Department of Agriculture and Food, WA.

However even in a season tracking above average the rules of in-season nitrogen application still need to be observed – there must be enough soil moisture and a reasonable prospect of follow-up rain to convert the applied nitrogen into yield.

The impact of late-applied nitrogen on grain yield and protein depends on:

- Wheat growth stage
  Grain number per spikelet is set just before and during flowering (GS60-69) and is usually between two and five grains/spikelet for Western Australian wheat varieties. Nitrogen taken up after flowering is more likely to increase grain protein and far less likely to increase grain number or grain size.
- Soil moisture status
  If a good rainfall event occurs just before application then the nitrogen can be taken up quite quickly and can contribute to increasing grain number per head, provided the crop has not passed flowering. Similarly, a good rain event just after application (provided it is not so heavy as to cause leaching in sandy soils) can also increase nitrogen uptake and contribute to increasing grain number per spike and possibly grain size.

Spikelet number is set relatively early in wheat crop development, some time before stem elongation. A typical WA wheat crop has about eight pairs of spikelets. Under conditions that result in an average yield of about 2t/ha these spikelets fill about two grains per spikelet, or 32 grains per ear. If conditions are favourable in the period just before and during flowering, and nutrient supply is sufficient, up to about five grains per ear can be set - 80 grains per ear at eight spikelet pairs. Late-applied nitrogen can help to increase grains per ear.

However, applying late nitrogen in anticipation of a follow-up rain is risky. If the nitrogen is applied and the season end delivers insufficient rain, yield can decline due to ‘haying off’. On the other hand, if the nitrogen is applied after a rain that exceeds about 20mm over two days it can replace nitrogen that may have been leached and result in a yield increase.

Protein premium on offer can also influence the decision to apply nitrogen late in the season.

Premiums for grain protein percentage apply mostly to hard-grained varieties that have been approved for the Australian Hard grade. The protein percentage must exceed a specified amount (such as 11 per cent). High protein wheat is more likely to be produced in the northern and eastern WA wheatbelt on heavy soil types.

However, fertiliser and application costs will be critical to chasing protein premiums from late nitrogen applications. For example, if the nitrogen costs $20/ha and its application $10/ha, the premium must be at least $15/t to break even at a yield of 2t/ha. In reality, it is more likely that any increase in profit from late-applied nitrogen will come from increased grain yield than increased grain protein.

For example, in the high rainfall zone two to three tactical nitrogen applications during the season following rain events exceeding about 20mm can result in increased yields of up to 1t/ha (Table 1). The yield increases do not result from a late application alone but rather are the result of good early season nitrogen management in combination with the later-season applications.

Table 1: Impact of nitrogen on wheat yields, ear numbers, grain protein and screenings for two sites in the high rainfall zone of Western Australia.

Treatment	Grain yield (t/ha)	Ear number (ears/m^2)	Grain protein (%)	Screenings (%)
Cranbrook (2003)				
Nil	2.2	239	9.1	3
All N at sowing	2.2	228	9.1	2
1/3 N at sowing; 2/3 N at GS31	2.7	272	9.1	3
1/3 N at sowing; 2/3 N after waterlogging.	3.5	426	9.5	5
$LSD_{0.05}$	0.6	34	0.8	2
Jingalup (2005)				
Nil	2.8	194	9	7
All N at sowing	5.6	238	8.8	8
Phenology N[c]	6.1	256	10.2	6
Timed N[a]	6.2	236	11.3	6
Demand N[d]	5.9	243	11.3	8
Tactical N[b]	6.4	236	10.6	8
$LSD_{0.05}$	0.4	25	0.6	2

[a]Timed N: nitrogen applied at fixed intervals after sowing. [b]Tactical N: nitrogen applied at sowing and after rainfall events >20mm. [c]Phenology N: nitrogen applied at set development stages, [d]Demand N: nitrogen applied according to tissue test.
Source: Narelle Simpson Department of Agriculture and Food, WA.

Some decision support tools explore the economics of late-season nitrogen strategies for a range of seasonal outlooks:

- N Broadacre based on the Select Your Nitrogen model developed by the Department of Agriculture and Food, WA. The app is available through the iTunes app store and incorporates the expected value of the grain and the cost of the extra nitrogen so that the economics of the nitrogen application can be estimated.
- The Nulogic model developed by CSBP is available with paid and accredited access and can be used to determine the yield and profit response from applied nitrogen.
- Yield Prophet® examines the likely agronomic and economic responses to nitrogen rates and timing while providing a range of possible yield outcomes based on historical weather data.

Other, simpler support systems for nitrogen decisions include tissue testing and crop reflectance methods such as GreenSeeker® that correlate plant greenness with plant nitrogen status. These tools can help determine if nitrogen might be limiting but do not generate nitrogen recommendations or deal with the economics of nitrogen application.

More information

Read articles on the principles underlying in-season nitrogen applications:
https://agric.wa.gov.au/n/3579

https://agric.wa.gov.au/n/3604

https://agric.wa.gov.au/n/3326

In some seasons, late application of nitrogen (post stem elongation) can increase tiller survival and longevity of leaf area, which in turn can result in increased grain yield through larger grain or, depending on timing of application, more grain per ear.

Photo credit: Paul Jones.

References

Lemon, J (2004) Grain protein management - lessons learnt on the south coast. In Proceedings of Agribusiness Crop Updates 2004 (Department of Agriculture and Food, WA) pp 22-23.

Palta, J Bowden, W and Asseng, S (2003) Timing of late applications of N fertiliser and season on grain yield and protein in wheat. In Proceedings of the 11th Australian Agronomy Conference, 2-6 February 2003, Geelong, Victoria. www.regional.org.au/au/asa/2003/p/5/palta.htm

Contact

Jeremy Lemon
Department of Agriculture and Food, WA
P: (08) 9892 8413
E: jeremy.lemon@agric.wa.gov.au

12.2 Pre-harvest sprouting

Key messages

- Pre-harvest sprouting of grain can affect grain quality and result in downgrades upon delivery.
- Wheat varieties differ in sprouting risk.
- Sprouting tolerance should be considered when making varietal choices.
- Pre-harvest sprouting is a particular problem for growers in coastal areas of WA such as Esperance, Albany and Geraldton.
- Predictions of increased summer rain as a result of climate change could lead to sprouting becoming a more widespread issue.

Significant rainfall during grain ripening and leading up to harvest can cause grain to germinate or sprout.

Sprouting degrades the quality of the starch component of the wheat grain, leading to downgrading of grain upon delivery.

Varietal differences with regard to sprouting damage are reflected in differing falling numbers (FN) upon grain delivery.

Varietal differences in sprouting tolerance are due to a combination of several traits with grain dormancy the most important. Sprouting damage in delivered grain is assessed using the falling numbers test.

Photo credit: Kevin Young.

More information

DAFWA: Seed quality

DAFWA: Frost risk – variety and sowing time.

GRDC Update Paper: Philip Barrett-Lennard, The impacts of early sowing and crop grazing on the grain yield and quality of a range of winter and spring cereal varieties.

Varietal differences with regard to sprouting damage are due to a combination of several traits, but grain dormancy (the ability to resist germinating when water is absorbed) is the most important. Other traits include seed coat dormancy, dormancy inhibitors released from the glumes when they become wet, rate of water absorption and a range of attributes that relate to the structure of the wheat head.

Historically the term 'sprouting tolerance' is associated with germination index (GI) because it has been regarded as the most important and easily measured trait. However, unfortunately GI does not always provide an accurate indication of what will happen in the field after a rainfall event. For example Eagle Rock⁽ᵖ⁾, which commonly suffers the least drop in FN after harvest rain has only an average GI because its tightly adhering glumes and nodding waxy head make water penetration difficult. By contrast Emu Rock⁽ᵖ⁾, which has a similar GI to Eagle Rock⁽ᵖ⁾ is very sensitive to harvest rain, with its FN dropping rapidly in comparison to other varieties.

12.2.1 Falling number index

To overcome the confusion surrounding the term sprouting tolerance, wheat varieties are instead rated for their ability to maintain FN after rainfall events leading up to harvest. The resultant falling number index encompasses not only GI but also other attributes, such as head structure, which collectively determine the likely response of FN to harvest rain.

On a 1–9 scale the higher the FN index the more likely a variety is to maintain FN (and the lower its susceptibility to sprouting leading up to harvest).

The highest FN index of currently available (2014) WA wheat varieties is six.

Note to Table 2

No variety is completely sprouting tolerant — any variety left wet enough for long enough will sprout.

*Table 2: Falling number ratings (1-9) of Australian wheat varieties**
(9 = most likely to maintain FN, 1 = least likely to maintain FN)

Variety	FN rating
Australian Hard (AH) wheat varieties	
Bonnie Rock⁽ᵖ⁾	4
Carnamah	2
Cascades	5
Cobra⁽ᵖ⁾	2
Eagle Rock⁽ᵖ⁾	6
Emu Rock⁽ᵖ⁾	2
Janz⁽ᵖ⁾	3
King Rock⁽ᵖ⁾	4
Mace⁽ᵖ⁾	5
Sapphire⁽ᵖ⁾	5
Tammarin Rock⁽ᵖ⁾	3
Yitpi⁽ᵖ⁾	5
Australian Premium White (APW) varieties	
Annuello⁽ᵖ⁾	5
Axe⁽ᵖ⁾	2
Corack⁽ᵖ⁾	4
Correll⁽ᵖ⁾	2
Endure⁽ᵖ⁾	4

Variety	FN rating
Envoy⁄	5
Espada⁄	2
Estoc⁄	6
Fang⁄	5
Australian Premium White (APW) varieties (cont.)	
Frame⁄	5
Gladius⁄	2
Harper⁄	5p
H45⁄	3
Halberd⁄	5
Katana⁄	2
Magenta⁄	3
Scout⁄	6
Spear⁄	5
Stiletto⁄	5
Trojan⁄	4p
Westonia	2
Wyalkatchem⁄	3
Zippy⁄	4
Australian Premium White- imidazolinone-tolerant (APW–imi) wheat varieties	
Clearfield Stl⁄	6
Grenade CL Plus⁄	4p
Justica CL Plus⁄	4p
Australian Standard White Noodle (ASWN)	
Arrino	2
Binnu⁄	5
Calingiri	5
Eradu⁄	2
Australian Standard White Noodle (ASWN) (cont.)	
Fortune⁄	2
Yandanooka⁄	2
Australian Soft (ASFT) wheat varieties	
Bullaring⁄	2
EGA 2248⁄	3
Kunjin⁄	2
Wedin⁄	2

Source: Department of Agriculture and Food, WA.

Resources

DAFWA Wheat grain quality: falling number and sprouting tolerance https://agric.wa.gov.au/n/3124

GRDC 2015 Wheat variety guide for WA www.grdc.com.au/WAWheatVarietyGuide

Contact

Christine Zaicou- Kunesch
Department of Agriculture and Food, WA
M: 0408 459 603
E: christine.zaicou-kunesch@agric.wa.gov.au

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

Nitrogen top ups

SFS00025 - Evaluation of late nitrogen applications to achieve yield potential (S: 15/08/2013 F: 30/04/2014)

Pre-harvest sprouting

CFF00003 - Elimination of pre-harvest sprouting in wheat (S: 01/07/2011 F: 30/06/2015)

UT00025 - Developing high throughput technologies for assessing pre-harvest sprouting (S: 01/06/2013 F: 05/02/2015)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC late season projects can be found at: www.grdc.com.au

SECTION 13

Harvest

13.1 Weed management

Key messages

- The seed of most southern Australian cropping weeds does not shatter before harvest enabling it to be removed from cropping systems during harvest.
- Chaff carts, windrow burning, chaff baling and the crushing and destroying of weed seeds before they exit the harvester are all proven methods for removing weed seeds from cropping systems at harvest.
- Each of the harvest weed seed control methods has been shown to reduce ryegrass emergence in the following autumn by about 50 per cent.
- Research shows that 75-85 per cent of annual ryegrass seeds and 85-95 per cent of wild radish seeds that enter the front of the header during the harvest operation can be collected using harvest weed seed control methods.
- Combined with effective herbicides, harvest weed seed control methods can keep weed numbers at fewer than one plant per square metre – enabling earlier sowing each season.

A major biological weakness of most southern Australian cropping weeds is that their seed does not shatter before harvest and a very large proportion (75-99 per cent) is retained above crop harvest height – providing the potential to remove the weed seed from cropping systems at harvest (Figure 1).

Note to Figure 1

While seed retention of annual ryegrass and wild radish remained high throughout the 28-day harvest period, seed retention for brome grass (41%) and wild oat (39%) was substantially lower after 28 days.

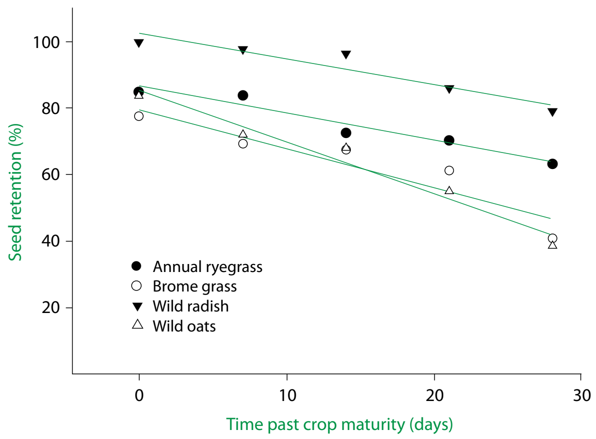


Figure 1: Proportion (%) of total seed of annual ryegrass, wild radish, brome grass, and wild oat at nine sites across the WA wheatbelt retained above harvest height (15cm) at wheat maturity (day zero) and at seven-day intervals for 28 days.

Source: Re-drawn from Walsh and Powles (2014).

Another weakness of southern Australian weeds is that their seed does not remain viable in the soil for very long and weed seedbanks therefore decline rapidly if not replenished with annual seed production. Combined with a pre-emergent herbicide, GRDC funded Department of Agriculture and Food, WA research has shown harvest weed seed systems to be highly effective at removing the final few weeds in cropping paddocks (Figure 2).

Despite starting with a larger seed bank, growers who implemented regular harvest weed seed control in the form of narrow windrow burning or chaff carts eroded their ryegrass population to very low levels in four years. By year eight, these growers had fully depleted ryegrass from their focus paddocks and since then have averaged fewer than 1.5 ryegrass plants/m^2 (Figure 2).

Note to Figure 2

While the herbicide-only growers were also very successful at eroding the ryegrass seed bank, such a heavy reliance on herbicides is likely to result in higher levels of herbicide resistance in these paddocks, making the few remaining plants expensive to contain.

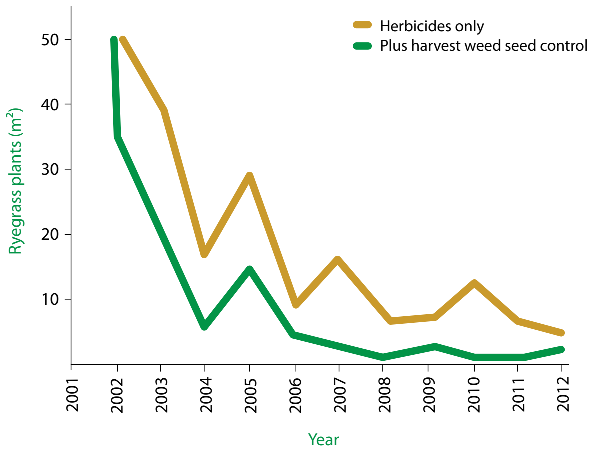


Figure 2: Impact of pre-emergent herbicides with and without narrow windrow burning and chaff carts on the ryegrass populations of 31 northern WA wheatbelt cropping paddocks over 13 years.

Source: Re-drawn from Newman (2013).

A conveyor belt adaptation for chaff carts captures a small amount of straw with the chaff, which significantly increases the burn time of the chaff dump.

Narrow windrow burning achieves a higher temperature burn and consistently kills more weed seeds than burning standing stubble.

The Harrington Seed Destructor removes up to 95 per cent of weed seed entering the harvester, eliminating the need for an autumn burn.

Up to 95 per cent of annual ryegrass sed entering the harvester can be collected using a baling system towed directly behind the harvester.

Photo credits: Australian Herbicide Resistance Initiative

13.1.1 Harvest weed seed control methods

A comparison of chaff carts, windrow burning and the Harrington Seed Destructor system across 12 WA wheatbelt sites found all three systems were similar in their weed-curbing capacity. Each method resulted in a 50 per cent reduction in autumn emergence of annual ryegrass populations (Walsh, 2012).

Table 1: Comparison of harvest weed seed control methods.

Harvest weed control methods	Pros	Cons	More information
Narrow windrow burning Chutes to rear of harvester concentrate harvested straw and chaff fraction into narrow windrows for subsequent autumn burning.	Simple, inexpensive. No loss of harvest efficiency. Windrows concentrate residues to provide higher burn temperature and weed seed kill. Narrow windrows estimated to expose less than 10 per cent of paddock to erosion. Capable of killing 99 per cent of annual ryegrass and wild radish seed in wheat, canola or lupin stubble windrows.	Involves burning. Time-consuming during autumn. Nutrients (particularly potassium) become concentrated on windrows so important to shift windrows each year to spread potassium across paddock.	www.weedsmart.org.au/online-workshop-portal/harvest-weed-seed-control/part-a-narrow-windrow-burning-2/
Chaff cart Chaff cart towed behind header during harvest collects weed-laden chaff fraction as it exits the harvester.	Minimises area of paddock burnt. Can provide valuable stockfeed. Can collect 75 to 85 per cent of annual ryegrass seeds, and 85 to 95 per cent of wild radish seeds that enter the front of the header during the harvest operation.	Capital cost. Reduces harvest efficiency. Autumn burn is time consuming. Chaff dumps can burn/smoulder for days.	www.weedsmart.org.au/online-workshop-portal/harvest-weed-seed-control/part-b-chaff-carts/
Baling A baler attached to the harvester collects all chaff and straw material and exports weed seeds.	No burning. Potential additional income from bales. Can remove up to 95 per cent of annual ryegrass seeds entering the harvester.	Capital cost. Soil nutrients and organic matter exported. Requires a market for straw bales.	www.weedsmart.org.au/bale-direct-system/
Harrington Seed Destructor (HSD) A unique weed-seed control system that is trailed behind the harvester and smashes the chaff and weed-seed fraction as it exits the harvester. Weed seed viability is destroyed and the crushed fraction returned to the paddock.	No burning. No post-harvest operations required to destroy/remove weed seeds. No nutrient/organic matter removal from cropping system. Can remove up to 95 per cent of weed seed entering the harvester.	Capital cost.	www.weedsmart.org.au/-Harrington-Seed-destructor

More information

For more information on herbicide resistance read: http://ahri.uwa.edu.au/susceptibility-testing/ and www.grdc.com.au/GRDC-FS-TestForHerbicideResistance

Download the 2014 herbicide test results from the Charles Sturt University: http://www.csu.edu.au/__data/assets/pdf_file/0004/1227793/2014-report.pdf

Videos

Watch a video on herbicide resistance testing: https://www.youtube.com/watch?v=aSNj-5p9tkk&feature=youtu.beloACpykKja0.

Testing seed for herbicide resistance

The most expensive herbicide is one that does not work.

Knowing which herbicides are still effective enables better weed management and saves money in wasted control efforts.

Herbicide resistance testing of seed is best done at harvest. All that is needed is an envelope labelled with the location from which the seed sample was collected.

The amount of seed required for ryegrass is about a coffee cup full of clean seed or an A4 envelope full of seed heads. For wild oats or wild radish, a comfortably full A4 envelope of seed heads or pods is ample.

Insufficient seed will reduce the number of herbicides that can be tested.

Paddocks or areas of interest (such as weed blow outs) need to be sampled separately. Use a similar technique to soil sampling to capture the variation across an area.

Put the clearly labelled seed sample envelopes inside another envelope for mailing. Do not use plastic bags, as the seed will go mouldy if there is any moisture in it.

Mail the samples to either of the testing services below.

Herbicide Resistance Testing
School of Agricultural and Wine Sciences
Charles Sturt University
Locked Bag 588
Wagga Wagga, NSW, 2678.
www.csu.edu.au/research/grahamcentre

OR

Plant Science Consulting
22 Linley Avenue
Prospect SA 5082
Phone: 0400 66 44 60
Email: plantscience@ozemail.com.au
www.plantscienceconsulting.com

References

Newman, P. (2013) Remaining weeds are hard to control. Proceedings 2013 WA Crop Updates.

Walsh, M. J. (2012) Harrington Seed Destructor - comparison with chaff carts and windrow burning systems. Proceedings 2012 WA Crop Updates.

Walsh, M. J. and Powles, S. B. (2014) High seed retention at maturity of annual weeds infesting crop fields highlights the potential for harvest weed seed control. Weed Technology, Vol. 28, No 3, July-September.

Contact

Peter Newman
Australian Herbicide Resistance Initiative
Phone: 08 9964 1170
Email: petern@planfarm.com.au

13.2 Managing a wet harvest

Key messages

- Harvesting in a timely manner and strategically managing grain moisture levels maintains optimal grain quality through to delivery.
- Access to grain drying and aeration facilities enables harvest to start and finish earlier and reduces the risk of exposure to weather-related damage during the harvest period.
- Weather damaged grain can be retained and dried as seed for the following crop provided there is no sign of embryo development – shoot and or roots.

To capture optimal grain quality harvest ideally needs to start as soon as the crop is mature. In reality, the start of harvest is dictated by a grower's ability to handle and potentially store high moisture grain.

Harvest can theoretically start as soon as the grain moisture falls below about 20 per cent moisture content, however receival standards dictate a grain moisture content of 12.5 per cent upon delivery.

As the time between crop maturity and harvest lengthens the risk of grain quality degradation and yield loss increases.

The ability to handle and manage high moisture grain at harvest enables an earlier start to harvest, which in turn reduces exposure to wet weather and increases the efficiency of the harvest operation (see Figure 3).

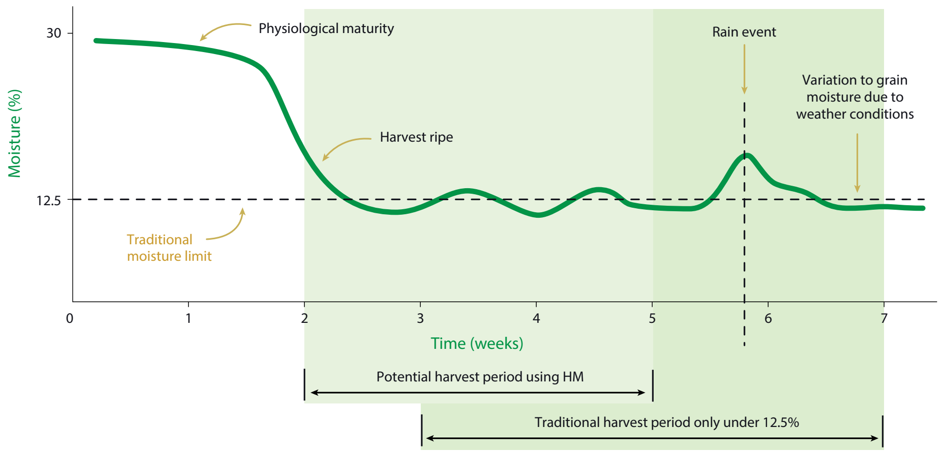


Figure 3: The impact of grain moisture on the harvest period. Source: SEPWA, Guide to High Moisture Harvesting.

13.2.1 Impacts of a delayed harvest

Every day a mature wheat crop remains in the paddock it is exposed to ongoing yield and quality loss, which in turn impact on returns (Figure 4).

Rain during the harvest period impacts on grain quality through the development of mould and fungi, darkening of the grain and the stimulation of germination (sprouting). Sprouting uses the grain's energy stores, reducing the bulk density, weight and ultimately yield. Yield losses of 10–50 per cent have been recorded in years with exceptional sprouting events.

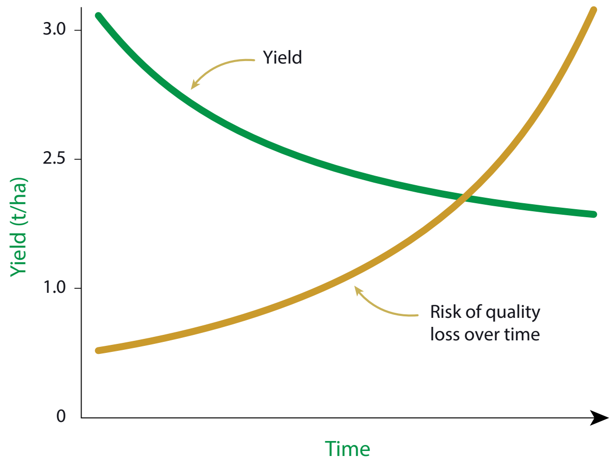


Figure 4: Impact of a delayed harvest on wheat yield and quality.

13.2.2 Managing high moisture grain

There are several ways to deal with high moisture grain at harvest. The key is to act quickly and effectively:

Blending: high moisture grain is mixed with lower moisture grain to create a sample with acceptable moisture content. Blending is a cost-effective way to manage grain batches that are only slightly above 12.5 per cent moisture content.

Aeration cooling: grain of moderate moisture content (up to 15 per cent), can be held for a short time under aeration cooling until drying equipment is available.

Aeration drying: large volumes of air force a drying front through the grain in storage and slowly remove moisture. Supplementary heating can be added. Aeration drying can be combined with blending and aeration cooling and can handle grain up to 18 per cent moisture content depending on the equipment. Aeration drying requires significant capital investment.

Continuous flow drying: grain is transferred through a dryer, which uses a high volume of heated air to pass through the continual flow of grain.

Batch drying: usually a transportable trailer drying 10–20 tonnes of grain at a time with a high volume of heated air, which passes through the grain and out perforated walls.

Money invested in high moisture management, on a per tonne basis for drying or delivery, or on a capital item like a grain dryer, needs to be considered in the context of the whole harvest program. Considering costs on a per tonne basis alone can be misleading.

The evaluation of a high moisture management cost on a per hectare basis is a more realistic method.

13.2.3 Harvester management for high moisture grain

Harvesting crops with higher moisture contents requires careful machinery set up and operation. High moisture crops are heavier and more pliable in cool, damp conditions and do not break up as easily during threshing.

High moisture crops tend to require slightly harder threshing and the machines grain sieves can experience heavier loads. Harvesting capacity can be impeded and fuel consumption can increase.

Green or damp straw puts an additional load on harvester knives and dry matter can build up under the knife fingers. Slowing the ground speed or lowering the cutter height can help.

The most common harvester adjustment in high moisture conditions is the reduction of ground speed and hence throughput capacity. This allows the crop to receive more threshing attention and the grain cleaning sieves are not placed under as much load.

Stripper fronts (purpose-built header fronts, which strip the crop head from the stalk rather than cutting it) can prove more effective in consistently damp conditions.

More information

The South East Premium Wheat Growers Association (SEPWA) has produced booklets called 'Dealing with a Difficult Harvest' and 'The WA Guide to High Moisture Harvest Management' see: www.sepwa.org.au

Aeration drying can be combined with blending and aeration cooling and can handle grain up to 18 per cent moisture content depending on the equipment.
Photo credit GRDC.

The ability to handle and manage high moisture grain at harvest enables an earlier start to harvest, which in turn reduces exposure to wet weather and increases the efficiency of the harvest operation.

Photo credit Brad Collis.

More information

For information on retaining seed refer to: www.grdc.com.au/GRDC-FS-RetainingSeed

More information on retaining weather damaged grain for seed can be found at: http://storedgrain.com.au/saving-weather-damaged-grain-for-seed-grdc-fact-sheet-january-2011/

More information on managing high moisture grain at harvest and evaluating the potential costs and benefits can be found at: http://storedgrain.com.au/dealing-with-high-moisture-grain/

Retaining weather-damaged grain as seed

Depending on the level of damage, some weather-damaged grain may successfully be viable as seed for the subsequent cropping season. Provided any damaged seed dries out before the embryo starts to grow this seed could still be viable for sowing.

Mild damage often is seen as a loose and wrinkled seed coat; severe damage can be identified through stained seed or signs of germination. It is essential to determine with the damage is cosmetic of the symptom of a seed-borne disease and whether it will impact on germination.

Test and grade any retained seed for germination, vigour and seed-borne disease. Knowing the germination percentage at harvest will help determine how much extra seed may be required at sowing.

Assessing germination during storage will indicate potential problems, while a germination test before sowing will enable sowing rates to be adjusted accordingly.

Harvest management

If retaining grain for seed, take care to harvest at a moisture content about one per cent below receival standard if no aeration drying facilities are on hand. If aeration drying is used, ensure any further grain damage is minimal.

Use harvester settings and handling processes that minimise any damage to the seed coat to maintain germination capacity and seed integrity.

Grain storage

Achieving and maintaining low temperature, humidity and grain moisture content for stored grain is critical if grain has been weather damaged. Damaged grain and retained for seed should not be stored for more than 12 months. Carry out a germination test on retained seed one to two months after storing to reassess its viability.

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

USA00010 – Mechanical weed seed termination at harvest
(S: 30/10/2010 F: 30/06/2015)

UWA00124 - Efficacy of the Harrington Seed Destructor in targeting weed seeds during the harvest of Australian grain crops (S: 01/10/2008 F: 30/06/2015)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC harvest projects can be found at: www.grdc.com.au

SECTION 14

Grain storage

14.1 Infrastructure

Key messages

- Investing in grain storage infrastructure requires careful planning and consideration to match grain storage needs with the range of available options.
- Consider the benefits and disadvantages of each option to ensure you choose the right one for your operation.
- Carry out a cost–benefit analysis before investing in storage infrastructure.Harvest is the ideal time to plan future storage requirements because it is at this time that grain storage issues and opportunities can be most easily identified.

On-farm grain storage systems can provide either short or long-term storage and be used to maximise harvest efficiency and extend marketing options.

Table 1 identifies the major on-farm grain storage options, their advantages and disadvantages.

Silos are the most common method of storing grain in Australia. Silos come in a variety of configurations, including flat-bottom or cone base, and both are available as gas-tight sealable or non-sealed, aerated and non-aerated.

Silos are the most common method of storing grain in Australia and come in a range of configurations including flat-bottom (left) or cone base (right) with both available as gas-tight sealable or non-sealed and aerated or non-aerated.

Photo credit: GRDC.

More information

DAFWA: Quality and agronomic traits/grades table, p21.

DAFWA: Market requirements, p37-38.

The balance of on-farm grain storage facilities can be split between grain storage bags and bunkers or sheds.

Grain-storage bags are increasing in popularity as a short-term storage solution to assist with harvest logistics. With careful management growers can also use silo bags to provide short-term marketing opportunities.

Where options are limited, well-prepared sheds can also be used to store grain during harvest; offering a similar storage time frame to grain storage bags.

Table 1: Advantages and disadvantages of grain storage options.

Storage type	Advantages	Disadvantages	More information
Gas-tight sealable silo	Gas-tight sealable status allows phosphine and controlled atmosphere options to control insects. Easily aerated with fans. Fabricated on-site or off-site and transported. Capacity from 15 tonnes up to 3000 tonnes. Up to 25 year plus service life. Simple in-loading and out-loading. Easily administered hygiene (cone base particularly). Can be used multiple times in-season.	Requires foundation to be constructed. Relatively high initial investment required. Seals must be regularly maintained. Access requires safety equipment and infrastructure. Requires an annual test to check gas-tight sealing.	http://storedgrain.com.au/managing-sealed-unsealed-storage/ http://storedgrain.com.au/stored-grain-silos-fumigation/ http://storedgrain.com.au/pressure-testing/ http://storedgrain.com.au/silo-pressure-test-demonstration/ http://storedgrain.com.au/national-standard-sealed-silos/
Non-sealed silo	Easily aerated with fans. 7–10% cheaper than sealed silos. Capacity from 15 tonnes up to 3000 tonnes. Up to 25 year plus service life. Can be used multiple times in-season.	Requires foundation to be constructed. Silo cannot be used for fumigation. Insect control options limited . Access requires safety equipment and infrastructure.	http://storedgrain.com.au/managing-sealed-unsealed-storage/
Grain storage bags	Low initial cost. Can be laid on a prepared pad in the paddock. Provide harvest logistics support. Can provide segregation options. Are all ground operated. Can accommodate high-yielding seasons.	Requires loader and unloader. Increased risk of damage beyond short-term storage (typically three months). Limited insect control options, fumigation only possible under specific protocols. Requires regular inspection and maintenance which needs to be budgeted for. Aeration of grain in bags currently limited to research trials only. Must be fenced off from livestock. Prone to attack by mice, birds, foxes etc. Limited wet weather access if stored in paddock. Single use only — need to dispose of bag after use.	http://storedgrain.com.au/successful-storage-in-grain-bags/ http://storedgrain.com.au/wp-content/uploads/2013/06/Insects-a-pest-in-harvest-bags.pdf

Storage type	Advantages	Disadvantages	More information
Grain storage sheds	Multi-purpose infrastructure. 30 year plus service life. Low cost per stored tonne. Aeration systems require specific design.	Risk of contamination from alternative purpose use. Difficult to seal for fumigation. Vermin control is difficult. Limited insect control options. Difficult to unload.	http://storedgrain.com.au/managing-sealed-unsealed-storage/
Underground storage	Inexpensive and simple. Provides ideal insect control by excluding air. Can maintain grain quality during long-term storage.	Poor site selection and management can affect grain quality.	https://www.agric.wa.gov.au/barley/underground-storage-grain

Source: Kondinin Group 2012 and DAFWA 2014.

14.1.1 Economics of grain storage

Many growers investing in on-farm grain storage have paid for it in one or two years because they strike the market at a valuable time.

However, to make a viable grain storage decision, it is important to compare the expected returns from grain storage vs expected returns from other farm business investments, such as more land, a chaser bin, a wider boomspray, a second truck or paying off debt.

Calculating the costs and benefits of on-farm storage will deliver a return-on investment figure that can then be compared with other investment choices.

To compare the benefits and costs in the same form, it is necessary to determine costs and benefits on a dollars-per-tonne ($/t) basis. It is also helpful to reality check each figure and ask if the figure entered is realistic. For example, grain market projections are fraught with difficulty and are best kept conservative. A more realistic approach is to use averages based on medium-term to long-term trends.

Grain storage bags are a short-term grain storage option that can help with harvest and marketing logistics.
Photo credit: GRDC.

More information

For the complete guide to carrying out a cost benefit analysis download the GRDC Economics of on-farm grain storage cost–benefit analysis, A grains industry guide: http://storedgrain.com.au/wp-content/uploads/2013/07/GRDC-GS-FACILITIES-Booklet-2013_Final.pdf

Read an article on the economics of grain storage: www.grdc.com.au/GC104-OnFarmStorageSums

For more information on the advantages and disadvantages of different storage systems see: www.grdc.com.au/GRDC-Booklet-GrainStorageFacilities

More information

[DAFWA: Underground storage.]

[GRDC Update Paper: On-farm grain storage in WA, Storage of seed and marketable grain, Ben White, GRDC Grain Storage Extension Team.]

[GRDC Stored Grain Hub: Grain bags.]

[GRDC Stored Grain Hub: Western Region, Stored grain pests identification.]

[GRDC Stored Grain Hub: What new grain protectants are available?]

[GRDC Stored Grain Hub: Overcoming phosphine resistant insects.]

[GRDC Stored Grain Hub: Aeration cooling.]

Resources

GRDC Stored grain information hub http://storedgrain.com.au/

Grain storage workshops: For information about grain storage workshops in your region go to: http://storedgrain.com.au/events/category/western-region/

Contact

Ben White
Kondinin Group
M 0407 941 923
E ben.white@kondinin.com.au

14.2 Grain storage pests

Key messages

- Grain for domestic human consumption (especially export grain) must not contain live insects.
- Hygiene, aeration and cooling are the three critical management tools for successful insect control in on-farm grain storages.
- Phosphine resistance in grain storage pests is widespread and a vigilant and diligent approach to fumigation is essential to maximise effective fumigation.

If stored grain is not properly managed it can become infested with stored grain pests. Grain for domestic human consumption, and especially grain for export, must not contain live insects.

Regular inspection of storage facilities will provide an early warning of insect infestation.

Protecting any grain stored from insect attack makes economic sense, because even feed grain can lose value though loss of protein or palatability, affecting livestock growth rates.

Seed grain is next year's investment and if insects are present they can destroy the germ of the grain.

The most common insect pests of stored cereal grains in Australia are:

- Weevils: (*Sitophilus* spp.) Rice weevil is the most common weevil in wheat in Australia.
- Lesser grain borer: (*Rhyzopertha dominica*)
- Rust-red flour beetle: (*Tribolium* spp.)
- Saw-toothed grain beetle: (*Oryzaephilus* spp.)
- Flat grain beetle: (*Cryptolestes* spp.)
- Indian meal moth: (*Plodia interpunctella*)
- Angoumois grain moth: (*Sitotroga cerealella*)

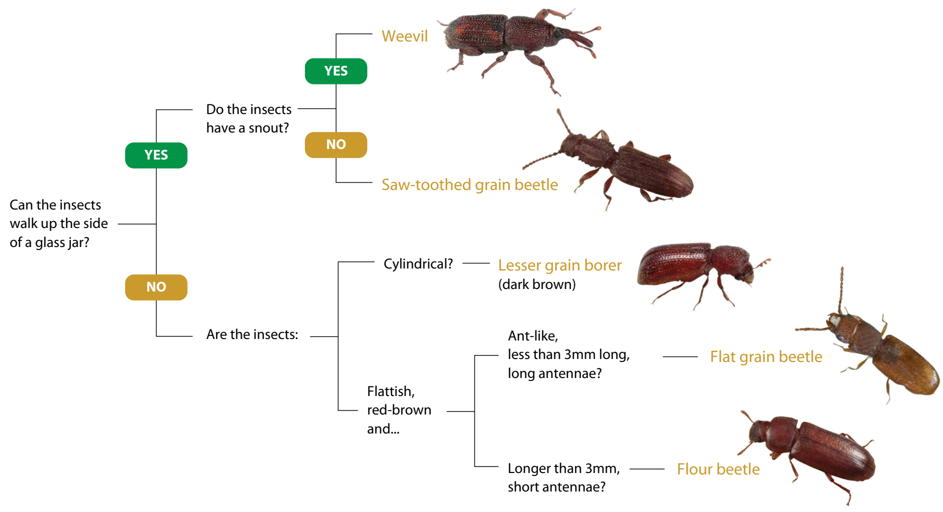


Figure 1: Identifying common pests of stored grain.

14.2.1 Managing stored grain pests

A combination of meticulous grain hygiene and well-managed aeration cooling generally overcomes 85 per cent of storage pest problems. Hygiene, aeration cooling and correct fumigation underpin both pest control and grain quality of stored grain.

14.2.2 Hygiene

The first grain harvested is often at the greatest risk of early insect infestation due to contamination of equipment.

Remove grain residues from empty storages and grain handling equipment, including harvesters, field bins, augers and silos to ensure an uncontaminated start for new-season grain. Clean equipment by blowing or hosing out residues and dust and then consider a structural treatment.

Remove and discard any grain left in hoppers and bags from the grain storage site so it does not provide a habitat for pests during the off-season.

14.2.3 Aeration cooling

Freshly harvested grain usually has a temperature around 30°C, which is ideal for storage pest breeding (see Table 1) and will reduce germination.

Studies have shown that rust-red flour beetles stop breeding at 20°C, lesser grain borer at 18°C and below 15°C all storage pests stop breeding.

Aim for grain temperatures of less than 23°C during summer and less than 15°C during winter using aeration fans in storage systems. Grain temperatures below 20°C significantly reduce mould growth and insect development.

More information

For more information on identifying key pests of stored grain read: http://storedgrain.com.au/western-region-grain-storage-pest-control-guide/ or GRDC Fact Sheet www.grdc.com.au/GRDC-FS-GrainStoragePestControl

For more information on hygiene read the GRDC Fact Sheet Hygiene and structural treatments for grain storage: http://storedgrain.com.au/grain-storage-fact-sheet-hygiene-structural-treatments-for-grain-storage/ or www.grdc.com.au/GRDC-FS-HygieneStructuralTreatments

For a comprehensive guide to managing stored grain pests read the GRDC Fact sheet (Western Region) Grain storage pest control guide: www.grdc.com.au/GRDC-FS-StoredGrainPestID

For a comprehensive guide to aerating to control grain storage pests read the GRDC Fact Sheet Aeration cooling for pest control: http://storedgrain.com.au/aeration-cooling-for-pest-control-grdc-fact-sheet-september-2010

Table 1: The effect of grain temperature and moisture on stored grain insect and mould development.

Grain temperature (°C)	Insect and mould development	Grain moisture content (%)
40-55	Seed damage occurs, reducing viability	
30-40	Mould and insects are prolific	>18
25-30	Mould and insects active	13-18
20-25	Mould development is limited	10-13
18-20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Source: GRDC Fact Sheet Western region Grain storage pest control guide www.grdc.com.au/GRDC-FS-StoredGrainPestID

14.2.4 Fumigation for insect control

Fumigating with phosphine is a common component of many integrated pest control strategies.

Using the right type of storage is the first and most important step towards an effective fumigation.

Only use fumigants, like phosphine, in a pressure-tested, sealed silo.

Research shows that fumigation of grain stores that are anything less than pressure sealed does not achieve a high enough concentration of fumigant for a long enough period to kill pests at all life cycle stages.

For effective phosphine fumigation, a minimum of
300 parts per million (ppm) gas concentration for seven days or 200ppm for 10 days is required.

14.2.5 Phosphine resistance

An almost total reliance on a single fumigant (phosphine) through the value chain places WA in a dangerous position with respect to resistance development.
An extensive phosphine resistance monitoring and management program was established in 1982.

Across WA grain insect samples are either submitted by CBH Group or collected by a network of Department of Agriculture and Food, WA field staff. The strains of insects are initially screened for phosphine resistance with the 30 minute ‘Reichmuth’ test. Follow-up testing is done using dosages designed to detect high resistance. If sufficient insects are available, an international standard FAO test is done to validate the rapid test.

During 2013–14, 409 insect populations or strains were tested with 848 phosphine resistance assays carried out. Of the 251 strains received for resistance testing, 60 per cent of these showed positive results (compared with 252 strains and 58 per cent during 2013).

More information

For more information on using fumigants in a pressure tested, sealed silo, read GRDC Fact Sheet Pressure testing sealable silos: http://storedgrain.com.au/pressure-testing/

For more information on fumigating with phosphine read the GRDC Fact Sheet Grain fumigation - a guide: http://storedgrain.com.au/fumigation-guide/

Videos

Watch a video on grain pest identification: http://storedgrain.com.au/grain-storage-insect-id/

Watch a video on using a mixture of sealed and unsealed grain storage options to manage insect pests before sale: http://storedgrain.com.au/mixed-sealed-unsealed-storage-strategy/

Watch a video on managing phosphine resistant grain pests: http://storedgrain.com.au/overcoming-phosphine-resistant-insects/

All resistant strains that survive the preliminary rapid test are cultured for strong resistance testing.

Control of strongly resistant insects can be achieved with label-rate phosphine fumigation in a gas-tight storage. Follow-up eradication involves regular insect trapping, sampling and resistance monitoring on an ongoing basis to ensure strongly resistant strains are completely controlled.

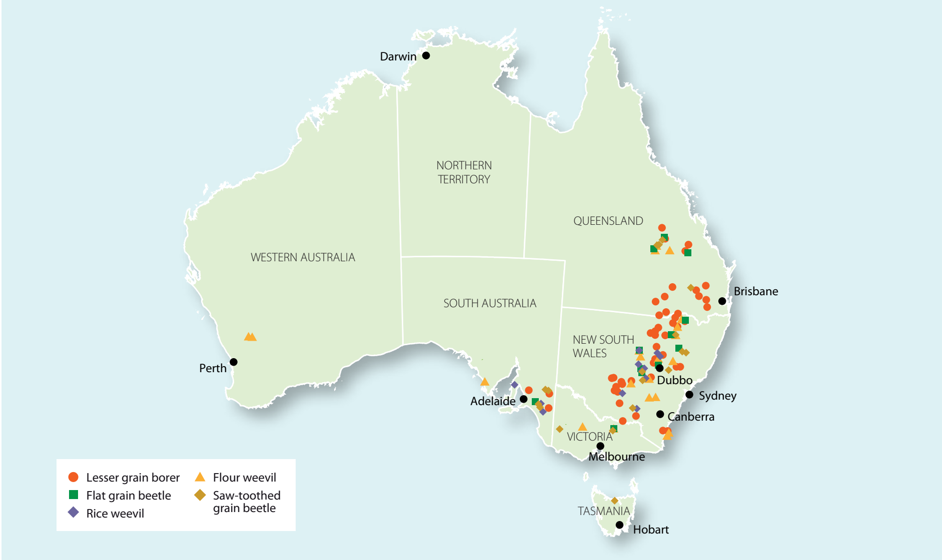


Figure 2: Phosphine resistance map 1986-2014.

Source: Department of Agriculture and Food, WA.

Resources

GRDC http://storedgrain.com.au/

Plant Health Australia for information on biosecurity and exotic pests http://phau.com.au

Grain storage workshops: For information about grain storage workshops in your region go to: http://storedgrain.com.au/events/category/western-region/

Contact

Rob Emery
Department of Agriculture and Food, WA
P (08) 9368 3247
E rob.emery@agric.wa.gov.au

GRDC supported projects

Below is a snapshot of relevant GRDC supported projects delivering benefits to Western Australian growers:

PAD00001 - Improving on-farm grain storage management practices through technical training and extension (S: 01/07/2012 F: 30/06/2015)

QUT00005 - New technology for stored grain pest management (S: 01/03/2012 F: 30/01/2015)

QUT00006 - New technology for stored grain pest management phase 2 (S: 01/06/2015 F: 30/05/2017)

UA00135 - Improved functionality of grain storage products (S: 01/01/2015 F: 30/06/2015)

WCA00005 – Wireless acoustic sensor for the detection, identification and monitoring of biological hazards in grain silos and storage systems (S: 30/06/2014 F:31/12/2015)

WJM00005 - Coordination of registration of grain storage chemicals and Codex attendance (S: 01/07/2011 F: 30/06/2016)

Key:
S = Start date of project
F = Finish date of project

More information about these and other GRDC grain storage projects can be found at: www.grdc.com.au

SECTION 15

Marketing

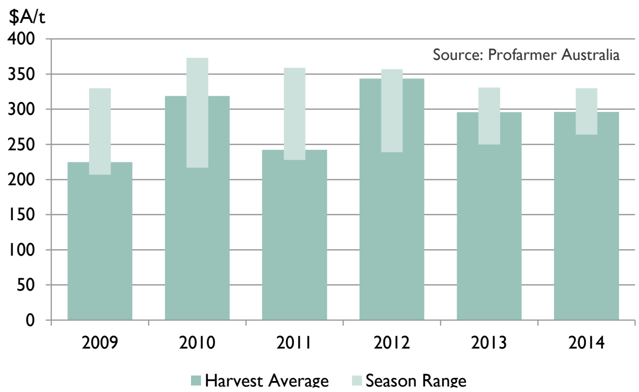
The final step in generating farm income is converting the tonnes of grain produced per hectare into dollars at the farm gate. This section provides best-in-class marketing guidelines for managing price variability to protect income and cash flow.

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 factors that are difficult to quantify, in order to establish the target price, and then working towards achieving that target price.

These factors include the amount of grain available to sell (production variability), the final cost of that production, 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 difficult to predict (Figure 1).

The skills that growers have developed to manage production variability and costs can be used to manage and overcome price uncertainty.



Note to figure: Kwinana APW2 wheat prices have varied A$60-$160/t over the past 6 years (25-60% variability). For a property producing 2,000 tonne of wheat this means $120,000-$320,000 difference in income depending on price management skill.

Figure 1: Annual price variation (season average and range) for Kwinana Australian Premium White 2 (APW2) wheat.

15.1.1 Be prepared

Being prepared and having a selling plan are essential for managing uncertainty. The steps involve forming a selling strategy, and having a plan for effective execution of sales. A selling strategy consists of when and how to sell.

When to sell

This requires an understanding of the farm's internal business factors including:

- production risk
- a target price based on cost of production and a desired profit margin
- business cash-flow requirements

How to sell?

This depends more on external market factors including:

- time of year, which determines the pricing method
- market access, which determines where to sell
- relative value, which determines what to sell

The key selling principles when considering sales during the growing season are described in Figure 2.

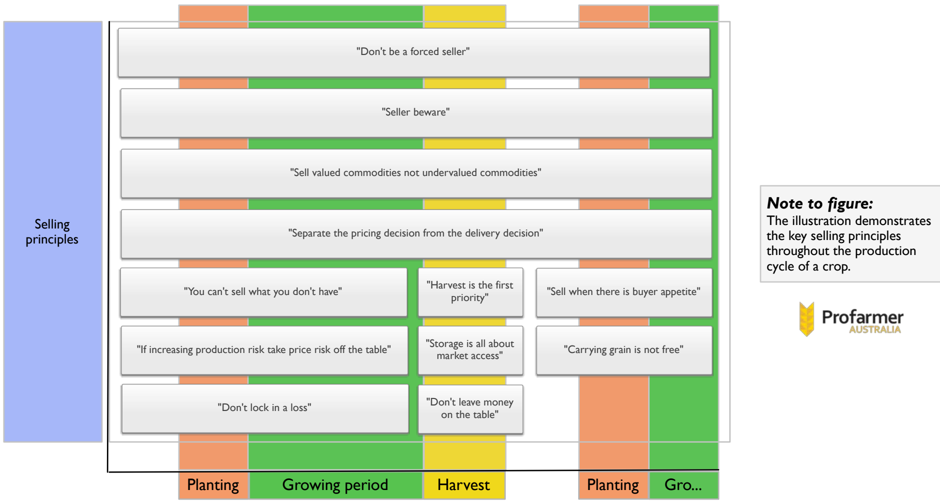


Figure 2: Grower commodity selling-principles timeline.

15.1.2 Establishing the business risk profile—when to sell

Establishing your business risk profile allows the development of target price ranges for each commodity and provides confidence to sell when the opportunity arises. Typical business circumstances of a cropping enterprise, and how the risks may be quantified during the production cycle, are described in Figure 3.

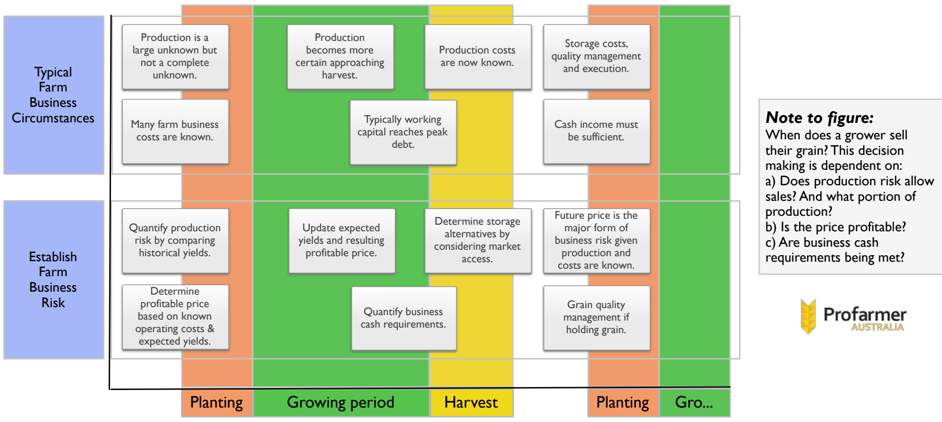


Figure 3: Typical business circumstances and risk.

Production risk profile of the farm

Production risk is the level of certainty around producing a crop and is influenced by location (climate and soil type), crop type, crop management, and time of the year.

Principle: 'You can't sell what you don't have.' Do not increase business risk by over-committing production.

Establish a production risk profile (Figure 4) by:

- collating historical average yields for each crop type and a below-average and above-average range
- assessing the likelihood of achieving average based on recent seasonal conditions and seasonal outlook.
- revising production outlooks as the season progresses

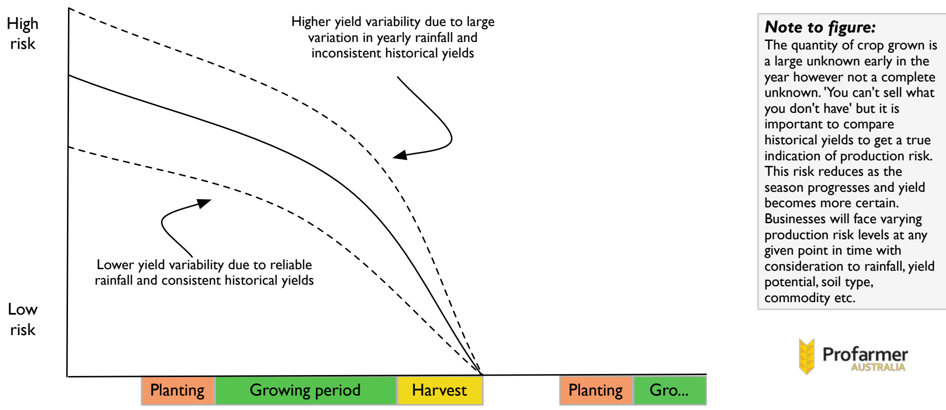


Figure 4: Typical production risk profile of a farm operation.

Farm costs in their entirety, variable and fixed costs (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.

Principle: 'Don't lock in a loss.' If committing production ahead of harvest, ensure the price is profitable.

Steps to calculate an estimated profitable price based on total cost of production and a range of yield scenarios are provided in Figure 5.

Estimating cost of production - Canola	
Planted Area	1,200 ha
Estimate Yield	1.45 t/ha
Estimated Production	1,740 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	$168,000
Herbicide and application	$84,000
Insect/fungicide and application	$36,000
Harvest costs	$48,000
Crop insurance	$18,000
Total fixed and variable costs	$742,000
Per Tonne Equivalent (Total costs + Estimated production)	$426 /t
Per tonne costs	
Levies	$3 /t
Cartage	$12 /t
Freight to Port	$22 /t
Total per tonne costs	$37 /t
Cost of production Port track equiv	$463.44
Target profit (ie 20%)	$93.00
Target price (port equiv)	**$556.44**

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 Klause "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 5: Steps to calculate an estimated profitable price for wheat.

The GRDC manual 'Farming the business' also provides a cost-of-production template and tips on skills requires for grain selling, as opposed to grain marketing. [1]

Income requirements

Understanding farm business cash-flow requirements and peak cash debt enables grain sales to be timed 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.

[1] M Krause (2014) Farming the business. Sowing for your future. GRDC, http://www.grdc.com.au/FarmingTheBusiness

A typical cash flow to grow a crop is illustrated in Figure 6. Costs are incurred upfront and during the growing season, with peak working capital debt incurred at or before harvest. This will vary depending on circumstances and enterprise mix. Figure 7 demonstrates how managing sales can change the farm's cash balance.

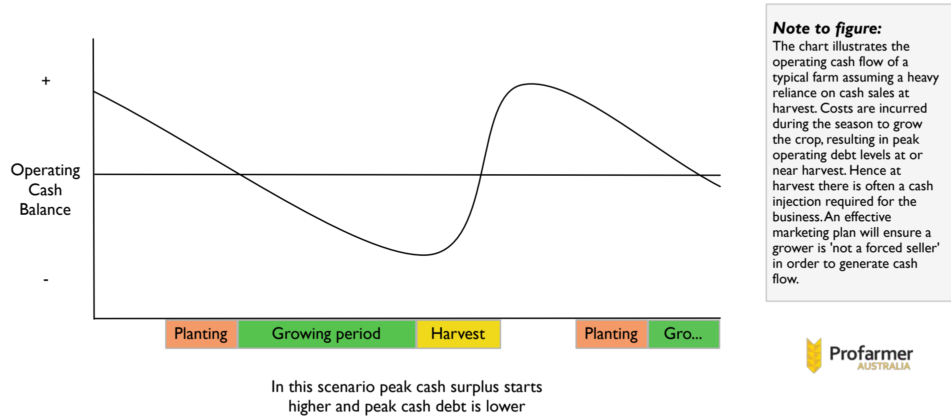


Figure 6: Typical farm operating cash balance, assuming harvest cash sales.

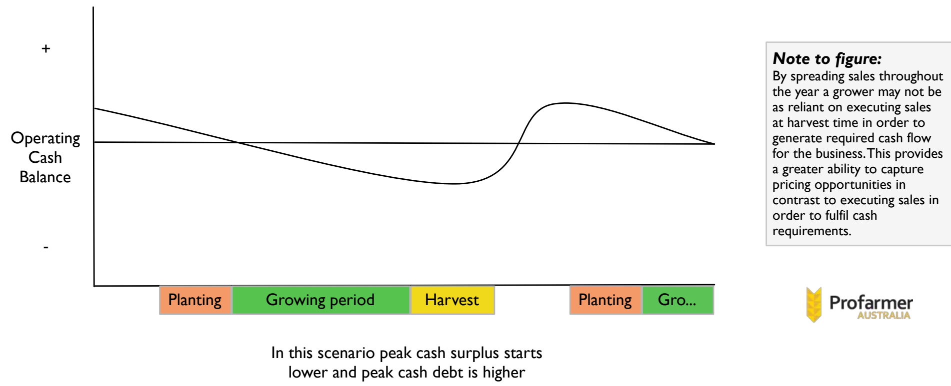


Figure 7: Typical farm operating cash balance, with cash sales spread throughout the year.

Summary

The when-to-sell steps above result in an estimated production tonnage and the risk associated with that tonnage, a target price range for each commodity, and the time of year when cash is most needed.

15.1.3 Managing your price—how to sell

This is the second part of the selling strategy.

Methods of price management

The pricing methods for products provide varying levels of price risk coverage (Table 1).

Table 1: Pricing methods and how they are used for various crops

	Description	Wheat	Barley	Canola	Sorghum	Maize	Faba beans	Chick peas
Fixed price products	Provides the most price certainty	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	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	Options on futures	Options on futures	none	none
Floating price products	Subject to both price upside and downside	Pools	Pools	Pools	Pools	Pools	Pools	Pools

Figure 8 below provides a summary of when different methods of price management are suited for the majority of farm businesses.

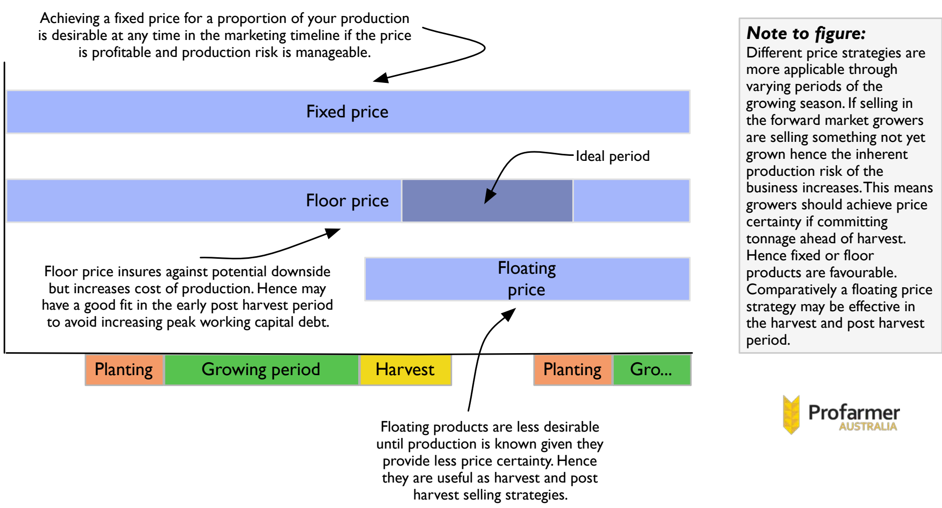


Figure 8: Price strategy timeline through the growing season.

Principle: 'If increasing production risk, take price risk off the table.' When committing 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 negotiable; hence, price management is not determined by delivery.

Fixed price

A fixed price is achieved via cash sales and/or selling a futures position (swaps) (Figure 9). It provides some certainty around expected revenue from a sale because the price is largely a known, except when there is a floating component in the price, for example, a multi-grade cash contract with floating spreads or a floating basis component on futures positions.

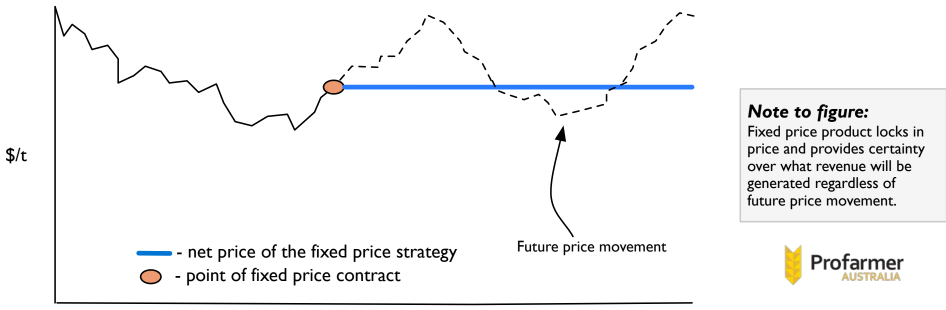


Figure 9: Fixed-price strategy.

Floor price

Floor-price strategies can be achieved by utilising 'options' on a relevant futures exchange (if one exists), or via a managed sales program product by a third party (i.e. a pool with a defined floor-price strategy). This pricing method protects against potential future downside while capturing any upside (Figure 10). The disadvantage is that the price 'insurance' has a cost, which adds to the farm business's cost of production.

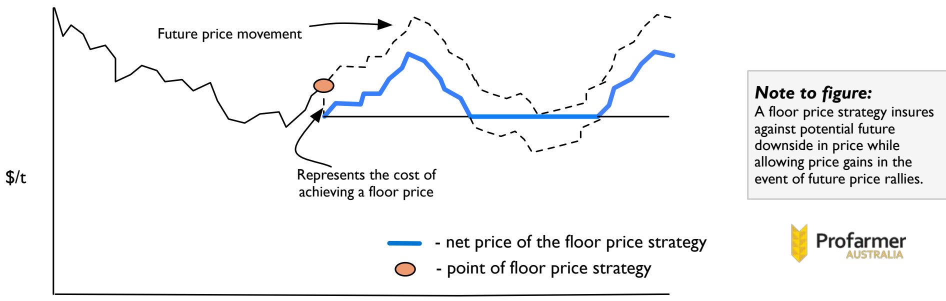


Figure 10: Floor-price strategy.

Floating price

Many of the pools or managed sales programs are a floating price where the net price received will move both up and down with the future movement in price (Figure 11). Floating-price products provide the least price certainty and are best suited for use at or after harvest rather than pre-harvest.

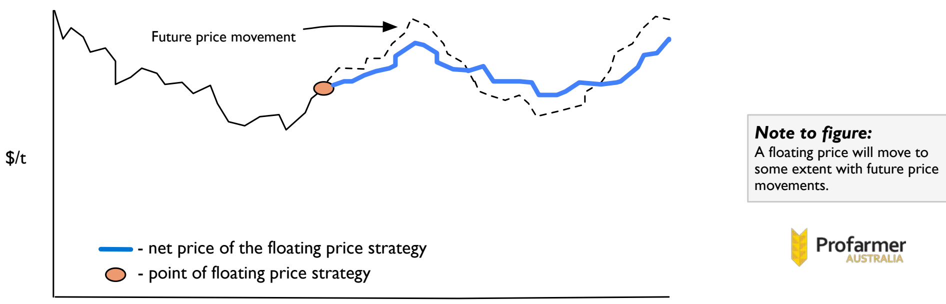


Figure 11: Floating-price strategy.

Summary

Fixed-price strategies include physical cash sales or futures products and provide the most price certainty; however, 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; however, they cost more.

Floating-price strategies provide minimal price certainty and they are best used after harvest.

15.1.4 Ensuring access to markets

Once the selling strategy is organised, the storage and delivery of commodities must be planned to ensure timely access to markets and execution of sales. At some point, growers need to deliver the commodity to market; hence, planning where to store the commodity is important in ensuring access to the market that is likely to yield the highest return (Figure 12).

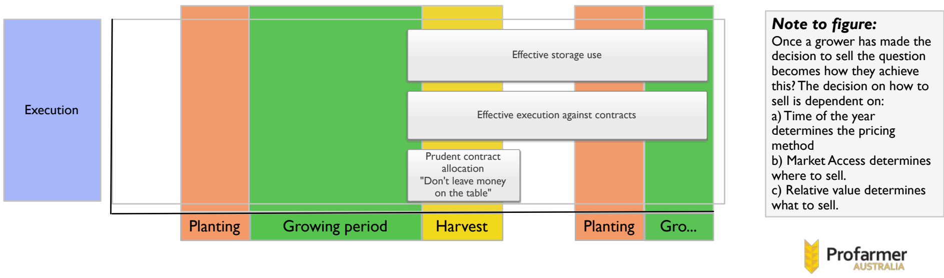


Figure 12: Effective storage decisions.

Storage and logistics

Return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access to maximise returns as well as harvest logistics.

Storage alternatives include variations around the bulk-handling system, private off-farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity (Figure 13).

Principle: 'Harvest is the first priority.' Getting the crop into the bin is most critical to business success during harvest; hence, selling should be planned to allow focus on harvest.

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-farm requires prudent quality management to ensure delivery at agreed specifications and can expose the business to high risk if this aspect is not well planned. Penalties for out-of-specification grain on arrival at a buyer's weighbridge can be expensive. The buyer has no obligation to accept delivery of an out-of-specification load. This means that the grower may have to suffer the cost of taking the load elsewhere, while also potentially finding a new buyer. Hence, there is potential for a distressed sale, which can be costly.

On-farm storage also requires prudent delivery management to ensure that commodities are received by the buyer on time 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 about on-farm storage alternatives and economics, refer to *GrowNotes* Wheat Western Region, Section 14. Grain storage.

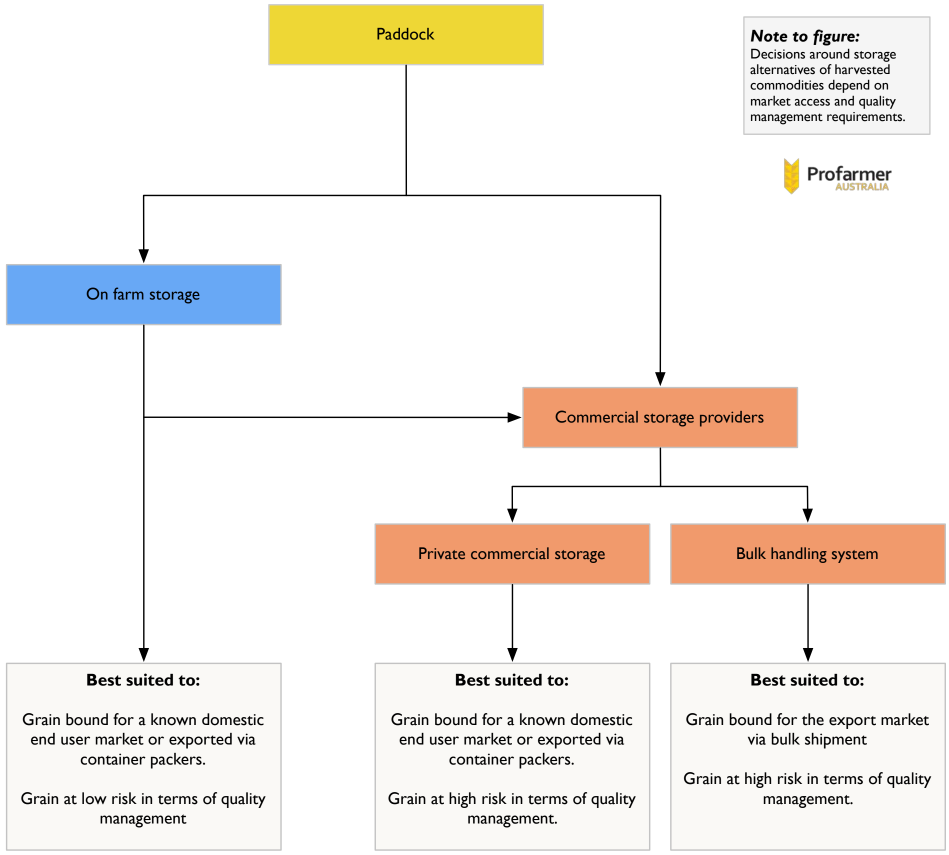


Figure 13: Grain storage decision making.

Cost of carrying grain

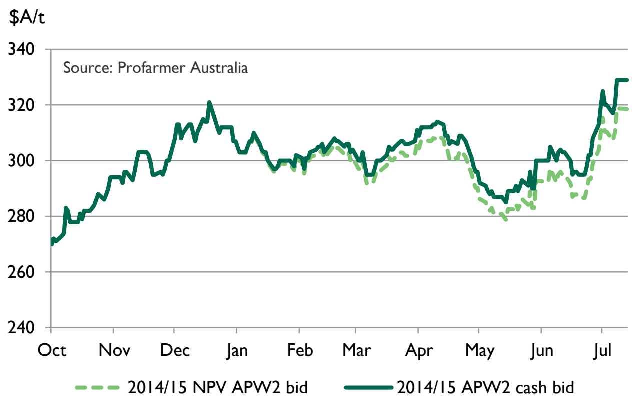
Storing grain to access sales opportunities post-harvest invokes a cost to "carry" grain. Price targets for carried grain need to account for the cost of carry.

Carry costs per month are typically $3–4/t, consisting 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 in cash or against 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 was offered at harvest. The cost of carry applies to storing grain on-farm because there is a cost of capital invested in the farm storage plus the interest component. A reasonable assumption is $3-4/t per month is for on-farm storage.

Principle: 'Carrying grain is not free.' The cost of carrying grain needs to be accounted for if holding grain and selling it after harvest is part of the selling strategy (see Figure 14).



Note to figure:
If selling a cash contract with deferred delivery, a carry charge can be negotiated into the contract. For example in the case of a March sale of APW2 wheat for March-June delivery on buyers call at $300/t + $3/t carry per month, if delivered in June would generate $309/t delivered.

Figure 14: Kwinana Australian Premium White 2 (APW2) wheat cash v. net present value (NPV).

Summary

Optimising farm-gate returns involves planning the appropriate storage strategy for each commodity to improve market access and cover carry costs in pricing decisions.

15.1.5 Executing tonnes into cash

Below are 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 includes:

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; and other market information pertinent to the particular commodity.
2. Professional services. Grain-selling professional service offerings 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 relationships. Return on investment for the farm business through improved farm-gate prices is obtained by accessing timely information, greater market knowledge and greater market access from the professional service.
3. Futures account and bank-swap facility. These accounts provide access to global futures markets. Hedging futures markets is not for everyone; however, strategies that utilise exchanges such as CBOT (Chicago Board of Trade) can add significant value.

For current financial members of Grain Trade Australia, including buyers, independent information providers, brokers, agents, and banks providing over-the-counter grain derivative products (swaps), go to: http://www.graintrade.org.au/membership.

For a list of commodity futures brokers, go to: http://www.asx.com.au/prices/find-a-futures-broker.htm.

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 15):

- Price. Future price is largely unpredictable; hence, devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.
- Quantity and quality. When entering a cash contract, you are committing to delivery of the nominated amount of grain at the quality specified. Hence, production and quality risk must be managed.
- Delivery terms. Timing of 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 of grain to be transferred ahead of payment; hence, counterparty risk must be managed.

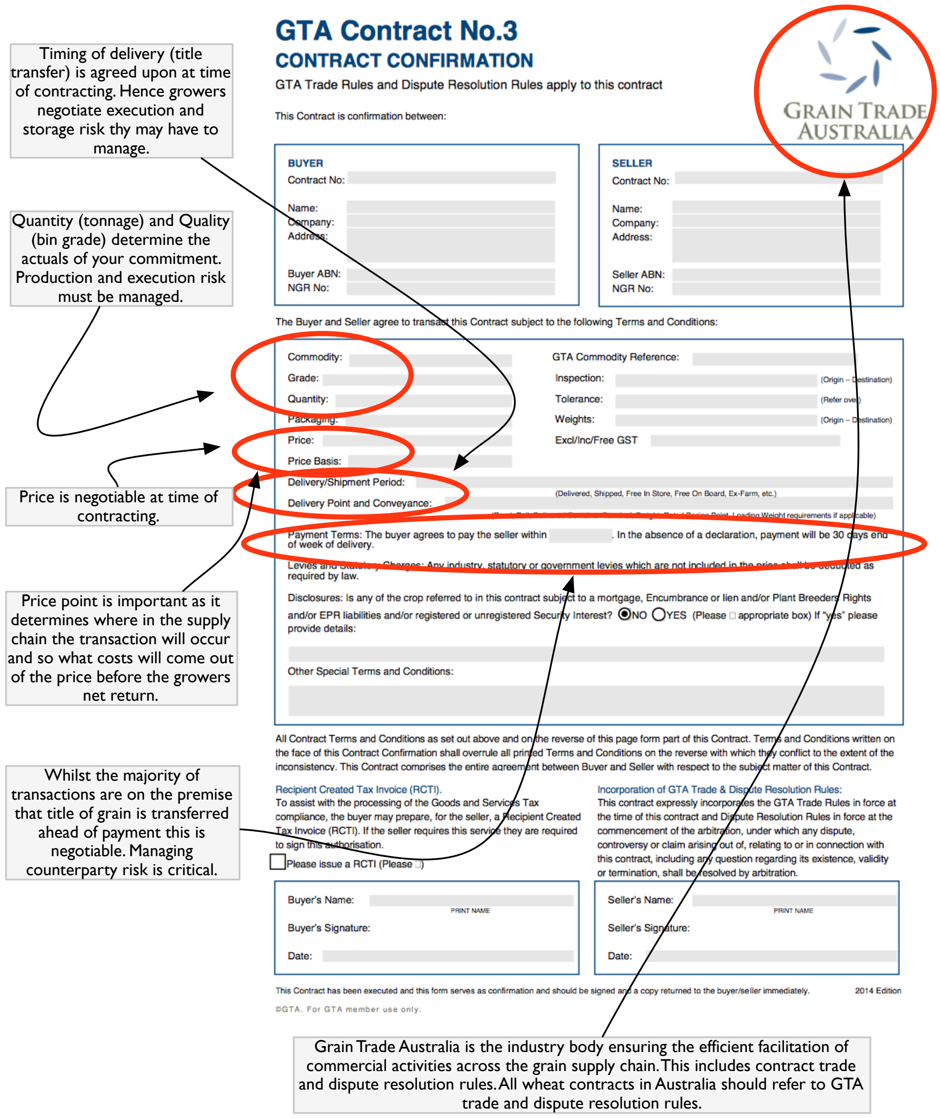


Figure 15: Typical cash contracting as per Grain Trade Australia standards.

The price point within a cash contract will depend on where the transfer of grain title will occur along the supply chain. Figure 16 shows the terminology used to describe pricing points along the grain supply chain and the associated costs to come out of each price before growers receive their net farm-gate return.

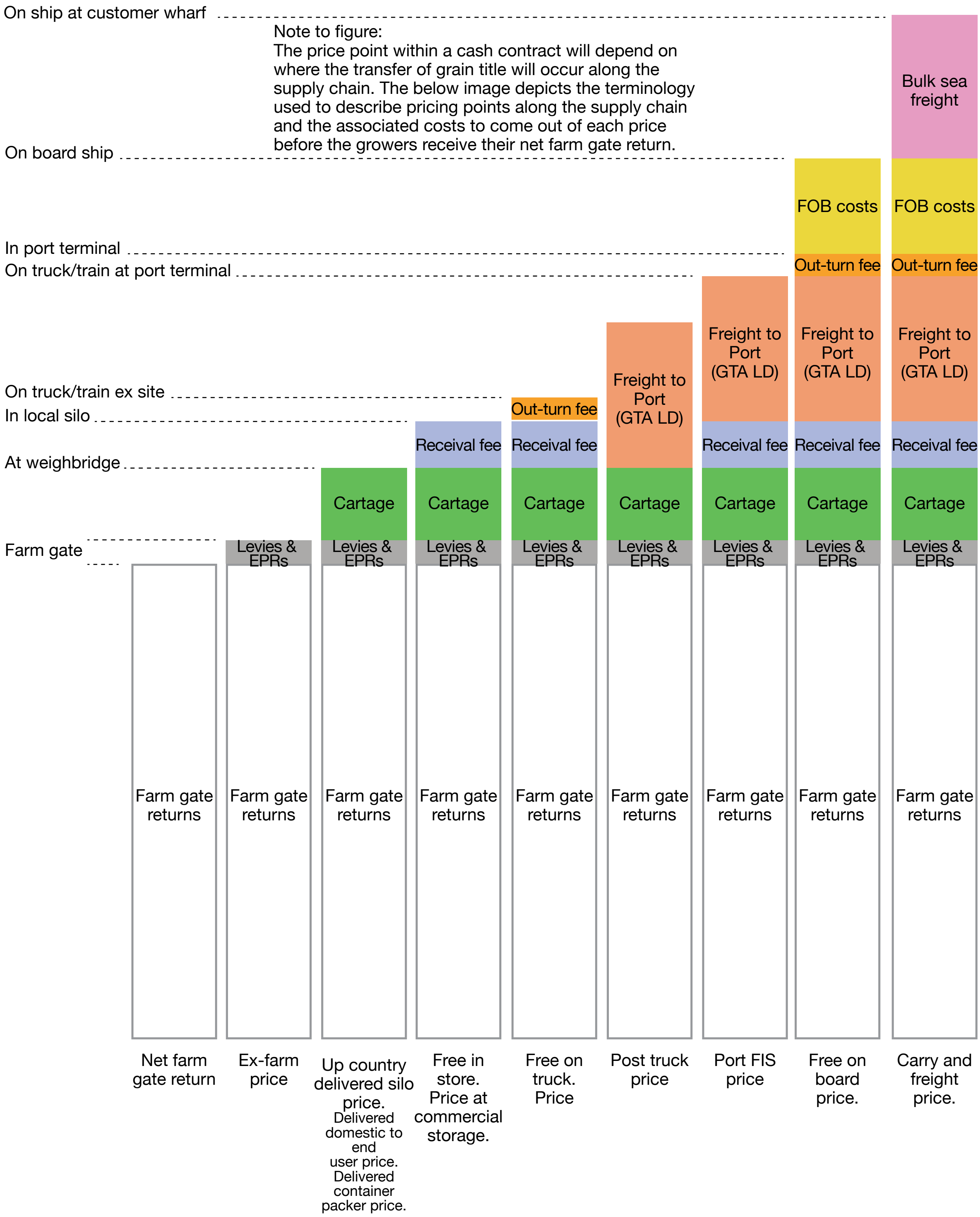


Figure 16: Costs and pricing points throughout the supply chain.

Cash sales generally occur through three methods:

1. 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 available for all commodities.
2. 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 transferring the grain online to the buyer. The availability of this depends on location and commodity.
3. 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 firm offer and firm bid match, the parcel transacts via a secure settlement facility where title of grain does not transfer from the grower until funds are received from the buyer. The availability of this 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.

More information

GTA Guide to taking out contracts

GTA Contracts and vendor declarations

GTA Trading standards

GrainTransact Resource Centre

GrainFlow Network

Emerald Grain customer and grower logins

Clear Grain Exchange terms and conditions

Clear Grain Exchange—getting started

Counterparty risk

Most sales involve transferring title of 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.' Selling for an extra $5/t is not a good deal if you do not get payment.

Counterparty risk management includes the following principles:

- Deal only with known and trusted counterparties.
- Conduct a credit check (banks will do this) before dealing with a buyer you are unsure of.
- Only sell a small amount of grain to unknown counterparties.
- Consider credit insurance or letter of credit from the buyer.
- Never deliver a second load of grain if payment has not been received for the first.
- Do not part with title of grain before payment or request a cash deposit of part of the value ahead of delivery. Payment terms are negotiable at time of contracting; alternatively, the Clear Grain Exchange provides secure settlement whereby the grower maintains title of grain until payment is received from the buyer, and then title and payment are settled simultaneously.

Above all, act commercially to ensure that the time invested in a selling strategy is not wasted by poor counterparty risk management. Achieving $5/t more and not receiving payment is a disastrous outcome.

More information

GTA Grain contracts—managing counterparty risk

Clear Grain Exchange title transfer model

GrainGrowers Guide to managing contract risk

Counterparty risk management: A producer perspective—Leo Delahunty

Relative commodity 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 of the highest relative value. This achieves price protection for the overall farm business revenue and enables more flexibility to a grower's selling program while achieving the business goals of reducing overall risk.

Principle: 'Sell valued commodities, not undervalued commodities.' If one commodity is priced strongly relative to another, focus sales there. Do not sell the cheaper commodity for a discount.

An example based on a wheat and barley production system is provided in Figure 17.

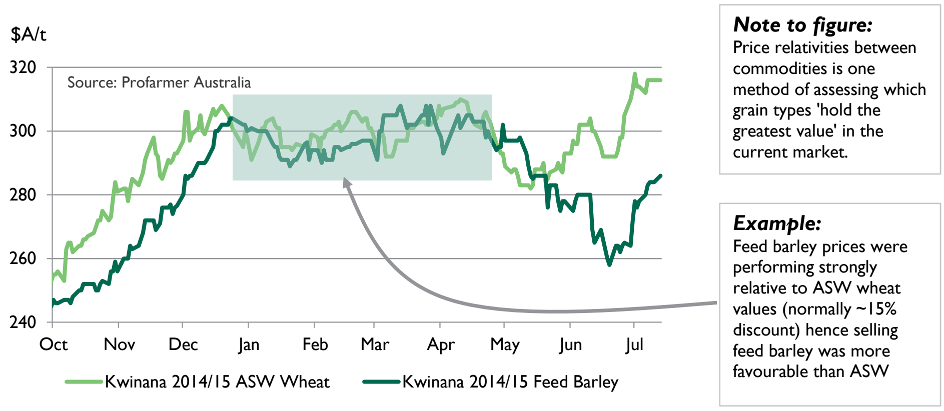


Figure 17: Kwinana Australian Standard White (ASW) wheat v. feed barley (AU$/t).

If the decision has been made to sell wheat, CBOT wheat may be the better alternative if the futures market is showing better value than the cash market (Figure 18).

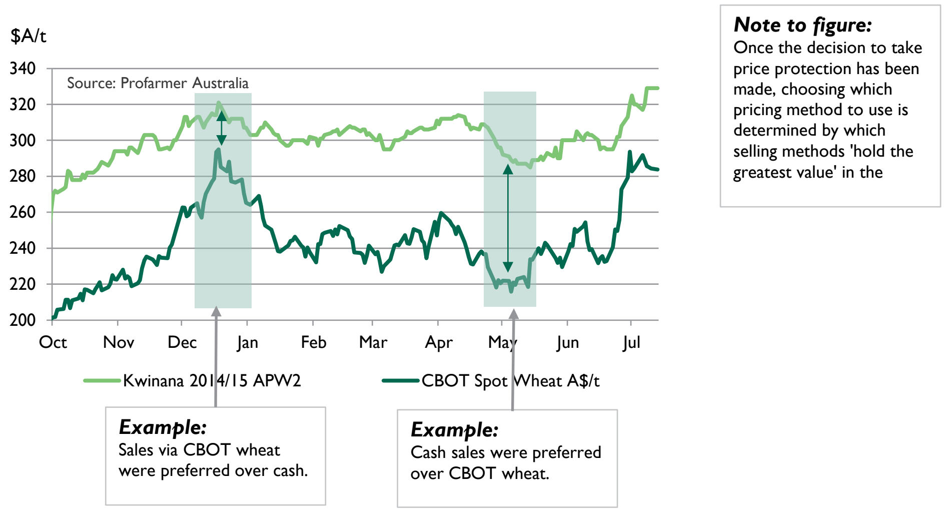


Figure 18: Kwinana Australian Premium White 2 (APW2) wheat v. Chicago Board of Trade (CBOT) wheat (AU$/t).

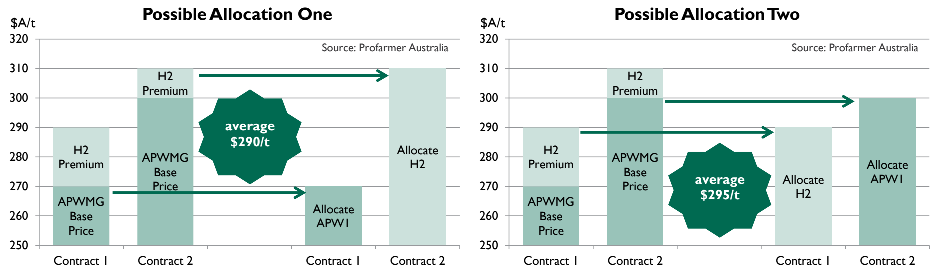
Contract allocation

Contract allocation means choosing which contracts to allocate your grain against at delivery time. Different contracts will have different characteristics (price, premiums–discounts, oil bonuses, etc.), and optimising your allocation reflects immediately on your bottom line (Figure 19).

Principle: 'Don't leave money on the table.' Contract allocation decisions do not take long, and can be worth thousands of dollars to your bottom line.

To achieve the best average wheat price, growers should:

- Allocate their lower grades of wheat to contracts with the lowest discounts.
- Allocate their higher grades of wheat to contracts with the highest premiums.



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 19: Examples of contract allocation of grain.

Read market signals

The appetite of buyers to purchase 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 as interested in buying the commodity.

Principle: 'Sell when there is buyer appetite.' When buyers are chasing grain, growers have more market power to demand a price when selling.

Buyer appetite can be monitored by:

1. The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate buyer appetite is strong. However, if there is one buyer at $5/t above the next best bid, it may mean cash prices are susceptible to falling $5/t if that buyer satisfies their buying appetite.
2. 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.

Sales execution revised

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 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 prevent selling at a discount

15.2 Western wheat—market dynamics and execution

Price determinants for Western Australian wheat

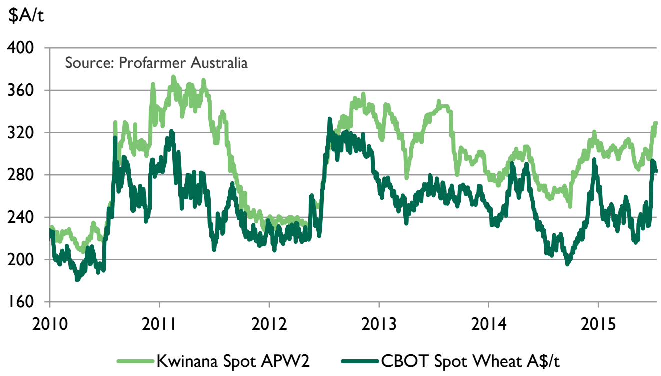
Australia is a relatively small player in terms of world grain production, contributing about 3.5% of global wheat production. However, in terms of world trade, Australia is a major player, exporting about 60–75% of the national wheat crop, which accounts for ~15% of global wheat trade.

Western Australia (WA) is Australia's largest wheat-export state, exporting ~90% of its wheat production each year to more than 45 countries.

Given this dynamic, WA farm-gate prices are heavily influenced by global price volatility. This makes offshore markets such as CBOT useful indicators of where Australian wheat prices will trade (Figure 20).

Figure 21 highlights some of the seasonal factors influencing global wheat prices throughout each year. Because of WA's export focus, the timing of harvest in major exporting and importing countries is a considerable influencer of prices.

Prices can be compared with historic values by consulting decile charts (Figure 22).



Note to figure:
Australian wheat prices tend to perform strongly between January and April due to the uncertainty over northern hemisphere production and off-shore exporter demand for Australian product. Hence, this is often a reasonable time to be selling old season grain and beginning a forward sales program.

Figure 20: Kwinana Australian Premium White 2 (APW2) wheat v. Chicago Board of Trade (CBOT) wheat (AU$/t).

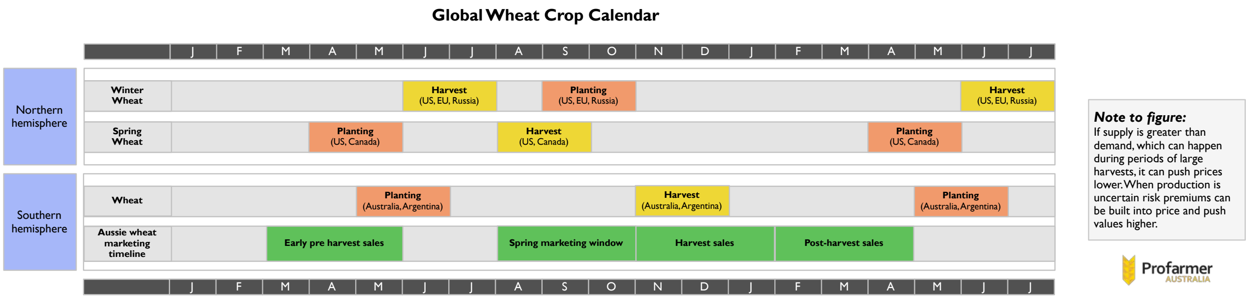
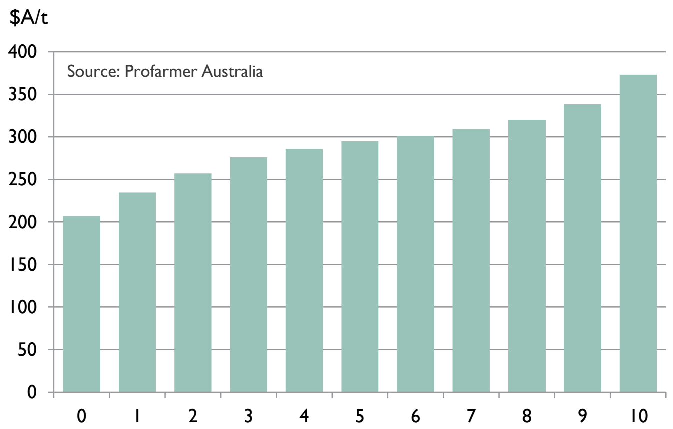


Figure 21: Seasonal factors influencing global canola prices.



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

Figure 22: Decile chart illustrating the price distribution for Kwinana Australian Premium White 2 (APW2) wheat.

Ensuring market access for WA wheat

The majority of wheat in WA is exported in bulk for human consumption (Figure 23); therefore, the bulk-handling system is often the most cost-effective pathway to get grain to offshore customers. The bulk storage provider should gain scale efficiencies when moving the bulk commodity grades such as APW1, ASW1, H2, H1, ANW1.

	Western Australia		National Total	
	Implied tonnes	% of production	Implied tonnes	% of production
Bulk	7.25 Mt	87%	16.72 Mt	65%
Container	0.75 Mt	9%	2.28 Mt	9%
Domestic Use	0.18 Mt	2%	6.67 Mt	25%

Source: Australian Crop Forecasters

Figure 23: Market destinations for wheat—Western Australian and national 5-year averages.

The majority of WA wheat will be stored and sold from within a bulk-handling system; however, private commercial and on-farm storage is a reasonable alternative for accessing container export and domestic end-user markets. The proportion of wheat exports in containers from WA has grown to ~9% and can provide price premiums for specific grades because a container can access niche offshore markets; this particularly applies to off-spec grades such as high protein–high screenings loads.

Although domestic consumers in WA demand a relatively small proportion of the crop, for growers who are well positioned to service these markets, they can sometimes return premiums over the bulk export market. Private commercial or on-farm storage can be a more effective method of accessing this market.

Supply-chain flow options are illustrated in Figure 24.

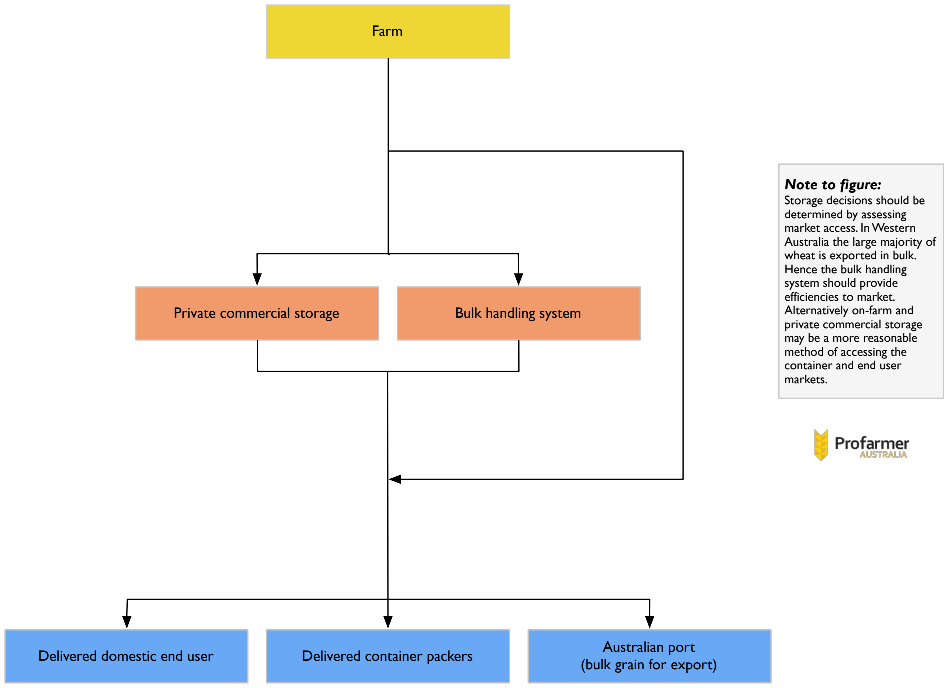


Figure 24: Australian supply-chain flow for wheat.

Executing tonnes into cash for WA wheat

Knowing where the WA wheat crop is likely to end up will help to refine a grower's selling and logistics decisions. Broadly, there are two customer types:

- Customer type A. These customers require consistent supply of reliable quality at regular intervals regardless of time of the year.
- Customer type B. These customers buy opportunistically based on price and are able to manage the quality inconsistency associated with switching suppliers more regularly.

The buyer behaviour drives the supply chain to operate at two levels: first, a consistent monthly tonnage to suit customer type A; and second, a surge capacity to suit customer type B. Consequently, appetite to accumulate WA wheat often peaks during and shortly after harvest as the surge demand kicks in to make the most of more abundant supply, as well as cost savings by shipping immediately post-harvest (Figure 25).

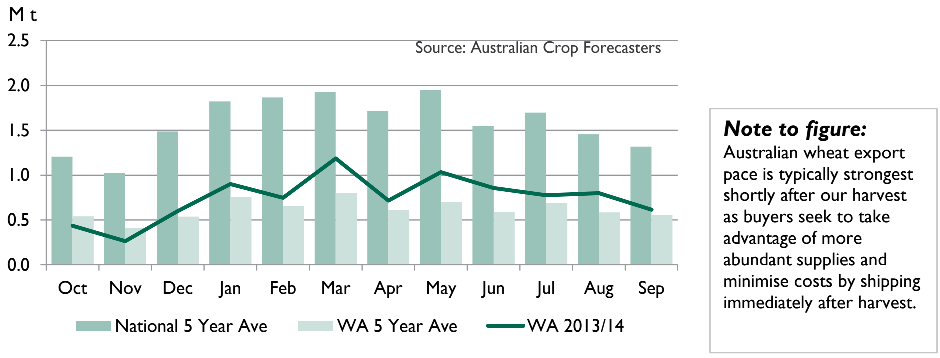


Figure 25: Monthly export pace of wheat.

What does this mean for a WA grower? Demand is generally strongest for WA wheat during the harvest period, when type A and type B customers are both active in the market; hence, the number of buyers bidding for wheat increases. Because of the extra bid liquidity at harvest, most grower selling strategies should encompass some harvest sales.

The key to executing harvest sales effectively by determining which grades to sell and which grades to hold (Figure 26). Some wheat grades, such as high-protein and niche-grade wheats (H1, H2, ANW1, ANW2) generally trade at stronger levels during harvest. This is because consumers of these grades require consistent quality, and often quantity, so they tend to accumulate their requirements pre-harvest and at harvest to ensure their supply while it is available. This appetite tends to push up the price premium for these grades over base APW1, making them a more attractive harvest sell. These grades are higher risk to be holding for post-harvest sales because once the buyers have their requirements covered, prices tend to move toward APW1 levels as buyers begin to drop out of the market.

Lower grades such as ASW1 and AGP1 tend to be more heavily discounted at harvest, with the grade spread closing up after harvest, making these wheats lower risk and more desirable to hold for post-harvest sales.

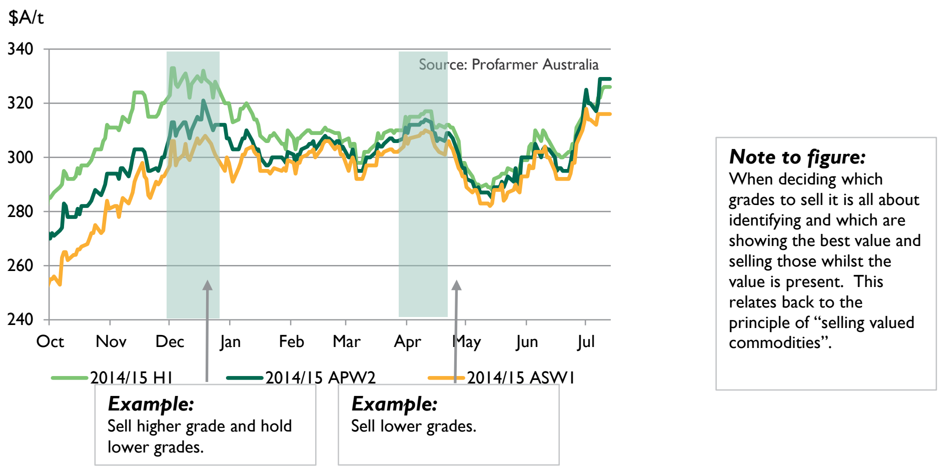


Figure 26: Monthly prices of Kwinana Australian Hard (H1) v. Australian Premium White (APW2, APW1).

Risk-management tools available for WA wheat

An Australian cash price has three components: futures, foreign exchange, and basis (Figure 27). Each component affects price. A higher futures and basis and a lower exchange rate will create a higher Australian grain price.

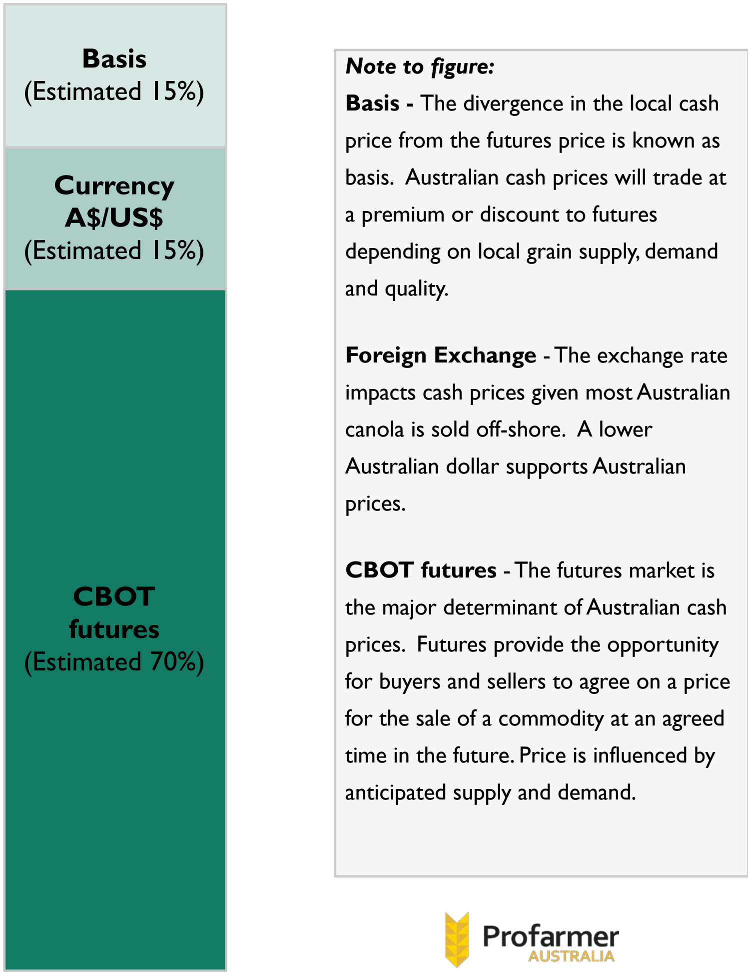


Figure 27: Components of pricing.

Table 2 outlines products available to manage WA wheat prices; the major difference in products is the ability to manage the individual components of price.

Table 2: Advantages and disadvantages of the products available to manage wheat prices

	Description	Advantages	Disadvantages
Spot cash contracts	Futures, foreign exchange, basis all locked at time of contracting	Simple to use. Locks in all components of price. Cash is received almost immediately (within payment terms).	Immediate grain delivery required. Sales after harvest require storage which incur costs. Locks away three pricing components at the same time. Risk of counterparty default between transfer and payment.
Forward cash contracts	Futures, foreign exchange, basis all locked at time of contracting	Simple to use. Locks in all components of price (no uncovered price risk). No storage costs. Cash income is a known ahead of harvest	Often inflexible and difficult to exit. Locks away the three pricing components at the same time. Future delivery is required resulting in production risk. Counterparty default risk must be managed.
Futures contracts	Futures, foreign exchange, basis are able to be managed individually	Liquid markets enable easy entry and exit from the marketplace. Locks in only some components of price, hence more flexible than cash contracts. Price determined by the market, and is completely transparent. No counterparty risk due to daily clearing of the contracts.	Requires constant management and monitoring. Margin calls occur with market movements creating cash-flow implications. Grain is required to offset the futures position, hence production risk exists. Cash prices may not move inline with futures, hence some price risk. You still have to sell the underlying physical grain.
Over-the-counter bank swaps on futures contracts	Futures, foreign exchange, basis are able to be managed individually	Based off an underlying futures market so reasonable price transparency. Liquid markets enable easy entry and exit from the marketplace. Locks in only some components of price, hence more flexible than cash contracts. Counter party risk is with the Bank, hence it is low. The bank will manage some of the complexity on behalf of the grower, including day to day margin calls.	Costs vary between $5-10/t at the providers discretion. Requires constant management and monitoring. Grain is required to offset the futures position, hence production risk exists. Cash prices may not move inline with futures, hence some price risk. You still have to sell the underlying physical grain.
Options on futures contracts	Futures, foreign exchange, basis are able to be managed individually	No counterparty risk due to daily clearing of the contracts. No margin calls. Protects against negative price moves but can provide some exposure to positive moves if they eventuate. Liquid markets enable easy entry and exit from the marketplace. Price risk can be reduced without increasing production risk. Price determined by the market, and is completely transparent.	Options can be costly and require payment upfront. The value of options erode overtime as expiry approaches - depreciating asset. Perceived to be complicated by growers. Move in option value may not completely offset move in cash markets. You still have to sell the underlying physical grain.

For more information and worked examples on how each pricing component affects wheat grain price, refer to the GRDC publication: [Grain market lingo—what does it all mean?]

SECTION 16

Key Contacts

Manager Regional Grower Services – West

Roger States

Before joining the GRDC earlier this year Roger had been working for 7 years with Sipcam Pacific Australia in product development and sales. He has also worked for Summit Agro Australia as well as Elders as an agronomist. He has extensive knowledge of farming systems and networks across the Western Region.

Suite 4, Petroleum House
12 Brodie Hall Drive
Technology Park
Bentley WA 6102
M 0427 565 780
E roger.states@grdc.com.au

Western Regional Panel

Panel Chairman

Peter Roberts

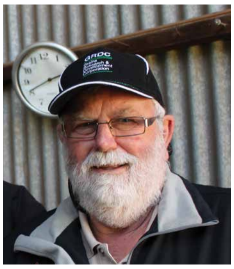
Peter Roberts, who farms at Dunn Rock, in the Esperance Port Zone, has been a member of the GRDC Western Panel since 2008 and was appointed Chairman in April 2011.

A key focus for Peter as Panel Chairman is for the panel to have a strong level of engagement with the WA grains industry. Peter was Chairman of the South East Premium Wheat Growers Association for three years before joining the GRDC's Western Panel. Other organisations he has been involved with in recent years include the Grains Industry of WA, Barley Council and Barley Australia.

M 0428 389 060
E kpeterroberts@gmail.com

Deputy Panel Chairman

Dr Mike Ewing



Mike has had a long career in agricultural research in Western Australia, having started his career in 1972 as an agronomist and advisor for the then WA Department of Agriculture in Geraldton.

He is a former CEO of the Cooperative Research Centre (CRC) for Legumes in Mediterranean Agriculture and was Deputy Director of the Salinity CRC before taking on the position of Research Director for the Future Farm Industries CRC. After relinquishing this role, Mike joined the GRDC Western Panel in 2011. He retired from his role at the Department of Agriculture and Food WA at the end of 2013.

M 0409 116 750
E mike.ewing25@gmail.com

Panel Members

John Even

John farms on a mixed sheep and grain farm between Goomalling and Calingiri, 135 kilometres north-east of Perth.

He took up full-time farming in 2009 following a 20-year career as an accountant with Byfields, serving mainly grain growers in the central Wheatbelt of WA.

John, who has a Bachelor of Commerce from Murdoch University, joined the GRDC Western Panel in 2011.

E johneven@bigpond.com

Dr William (Bill) Ryan

Bill has accumulated extensive research and corporate experience during a long career in Australian agriculture.

With a degree in Agricultural Science and PhD in animal science from the University of Western Australia, his career includes overseeing the complete restructure and refinancing of the Kondinin Group, of which he was Chief Executive Officer from 2002 to 2008, seven years with the Heytesbury Group and 21 years with the then WA Department of Agriculture, focused in research.

Bill joined the GRDC Western Panel in 2011 and also chairs the Agricultural Produce Commission.

M 0409 791 997
E wryan@iinet.net.au

Paul Kelly

Mingenew farmer Paul Kelly, who joined the GRDC western panel in 2011, has many years of experience as a primary producer and grower representative on numerous organisations. His family came to the Mingenew area in 1950 and Paul has farmed in his own right for more than 35 years with his wife and daughters.

He has completed the Australian Institute of Company Directors course, as well as an export management course.

M 0427 275 022
E paulsuekelly@westnet.com.au

Susan Hall

Originally from a farm at Quairading, Susan has worked in recent years as the project leader of the Grower Group Alliance which connects grower groups, research organisations and agribusiness in WA. One of her main priorities as a panel member is capacity building – understanding the obstacles stopping the grains industry from achieving improved grower profitability, and addressing them.

Susan joined the Western Panel in 2012, the same year that she completed a Master of Business Administration (MBA) at the University of Western Australia.

Susan is the Acting Chair of the Australian Grains Institute (WA) and sits on the Grains Industry WA (GIWA) executive.

M 0400 889 036
E susanhall@iinet.net.au

Shauna Stone

Shauna is a full-time farmer at Quairading in WA's central Wheatbelt, with her involvement in running the farm having increased as her three children grew up.

The farm, which comprises owned, share farmed and leased land, has been 100 per cent cropped since the Stone family sold their last line of commercial sheep in 2007.

Shauna brings communication and leadership skills to the Western Panel, in addition to practical skills as a producer and a sound knowledge of cropping systems. She joined the Western Panel in 2011.

T 08 9645 5218
E shauna@wn.com.au

Chris Wilkins

Based in Badgingarra, Chris is an agronomic and agribusiness advisor who joined the GRDC Western Panel in July, 2013.

He has 22 years of experience in WA's agricultural industry, including offering farm business, agronomy, farming systems and crop protection advice through his Vision Agribusiness Services company for the past 15 years.

Chris is also a director of one of the State's leading agricultural consultancy businesses, Synergy Consulting WA, the Deputy Chairman of the Council of Grain Grower Organisations Ltd (COGGO) and a member of WA Agriculture Minister Ken Baston's Ministerial Agricultural Advisory Council.

M 0427 940 925
E cwilkins@synergyco.com.au

Darrin Lee

Darrin is managing partner of a family farming business located 15km north-east of Mingenew in WA's Northern Agricultural Region.

The business is predominantly focused on grain growing, including production of wheat, barley, canola, and both albus lupin and narrow-leafed lupin. It also produces wool and prime lambs.

He has added value to his albus lupin production through an Australian 'paddock to plate' joint venture initiative. He started farming in 1998 after nearly 15 years in the banking and finance industry, mainly in agribusiness.

Darrin is represented on the CBH Group's Growers Advisory Council and is a Mingenew Irwin Group board member.

M 0427 281 021
E blighleefarms@bigpond.com.au

Brondwen MacLean

Brondwen was appointed to the Western Panel in October 2013 and is GRDC executive manager for research programs. She has primary accountability for managing all aspects of the GRDC's nationally coordinated R&D investment portfolio and aims to ensure that these investments generate the best possible return for Australian grain growers. Prior to her current appointment, Brondwen was senior manager, breeding programs, and theme coordinator for Theme 6, Building Skills and Capacity.

T 02 6166 4500
E brondwen.maclean@grdc.com.au

Gemma Walker

Gemma has extensive experience in broadacre cropping and livestock systems gained through managing the tri-state Mallee Sustainable Farming and her hands-on involvement in her family farm near Munglinup in WA's Esperance region.

She is the national vice chairwoman of Partners in Grain, which she also chaired for two years. Gemma holds a Bachelor of Agribusiness (Hons) and has furthered her education through opportunities such as the Northern Mallee Leaders Program.

M 0428 751 095
E hamiltondowns@hotmail.com

Panel Support Officer

Dr Julia Easton

Julia Easton has lived in Perth for over 30 years, and married into a farming family from the South Stirlings. She has a PhD in Plant Biology from Edith Cowan University and a BSc (Hons) Environmental Biology from Curtin University of Technology.

Julia joined GRDC as the Regional Coordinator West (including Panel Support) in August 2013. She has worked as a researcher on GRDC grants at the Centre for Legumes in Mediterranean Agriculture at UWA in pre-breeding of chickpea, field pea and lupins (2003-2008). More recently (2007-2013), Julia worked as the Research Manager for Future Farm Industries CRC and managed research projects funded by GRDC. She has excellent intellectual property as well as contracts management skills plus a good working knowledge of plant based research in Western Australia.

M 0403 311 395
E GRDCWesternPanel@gmail.com

SECTION 17

References

A: Introduction

Kingwell, R. Anderton, L. Islam, N. Xayavong, V. Feldman, D. and Speijers, J. (2013) A decadal assessment of farm performance: any learnings? Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Section 1: Wheat developmental stages

Anderson, W. and Garlinge, J. (Eds.) (2000) The Wheat Book: Principles and Practice (2nd Edition). Perth, Western Australia: Western Australian Department of Agriculture.

GRDC (2005) Cereal Growth Stages – the link to crop management. Canberra, Australia: Grains Research and Development Corporation.

White, J. and Edwards, J. (Eds.) (2007) Wheat Growth and Development. New South Wales: NSW Department of Primary Industries.

Section 2: Water use efficiency

Anderson, W. and Garlinge, J. (Eds.) (2000) The Wheat Book: Principles and Practice (2nd Edition). Perth, Western Australia: Western Australian Department of Agriculture.

French, R. and Schultz, J. (1984) Water use efficiency of wheat in a Mediterranean-type environment. I. The relationship between yield, water use and climate. Australian Journal of Agricultural Research 35, 743-764.

Hall, D. Galloway, P. Lemon, J. Curtis, B. van Burgel, A. Kong, K. and Metz, M. (2014) The Agronomy Jigsaw: finding the pieces that maximise water use efficiency. Bulletin 4850. Perth, Western Australia: Department of Agriculture and Food, WA.

Hooper, P. (2010) Strategic applications of nitrogen fertiliser to increase the yield and nitrogen use efficiency of wheat. MSc Thesis. Adelaide: The University of Adelaide.

Oliver, Y. Wong, M. Robertson, M. Andrew, J. (2014) Response of crop yield to soil acidity and lime: diagnosing acid constraints and case studies. Australia: CSIRO.

Oliver, Y. Robertson, M. Stone, P. Whitbread, A. (2009) Improving estimates of water-limited yield of wheat by accounting for soil type and within-season rainfall. Crop and Pasture Science 60, 1137–1146.

Sadras, V. and McDonald, G. (2012) Water use efficiency of grain crops in Australia: principles, benchmarks and management. Canberra: Grains Research and Development Corporation.

Tennant, D. (2000) Crop Water Use. In Anderson, W. and Garlinge, J. (Eds.) (2000) The Wheat Book: Principles and Practice (pp. 57-67) (2nd Edition) Perth, Western Australia: Western Australian Department of Agriculture.

Section 3: Disease

Beard, C. (2013) Potassium deficiency can make wheat more vulnerable to septorium nodorum blotch and yellow spot. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Beard, C. and Smith, A. (2012) Interaction of nitrogen and fungicide applications for managing yellow spot and stagonospora nodorum in wheat-on-wheat cropping. In Proceedings of the 2012 Agribusiness Crop Updates, Perth, WA, pp. 26-29.

Beard, C. and Smith, A. (2012) Early fungicide application can be profitable for managing yellow spot and stagonospora nodorum in wheat-on-wheat cropping. In Proceedings of the 2012 Agribusiness Crop Updates, Perth, WA, pp. 30-33.

Galloway, J Payne, P and Salam, M (2013) Environment affects maturation of yellow spot on wheat stubble. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Salam, K. Thomas, G. Beard, C. Loughman, R. MacLeod, W. and Salam, M. (2013) A meta-analysis of 30 years of DAFWA field trials on fungicide management of yellow spot - septoria nodorum blotch disease complex of wheat in Western Australia. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Root Disease: rhizoctonia

Huberli, D. Connor, M. Miyan, S. MacLeod, W. Bogacki, P. and McKay, A. (2013) Integrated disease management options to control rhizoctonia bare-patch in cereals. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Huberli D. Connor M. Miyan S. MacLeod W. Bogacki P. Desbiolles J. Correll R. Gupta V. Battaglia R. McKee K. May L. Forsyth L. Roget D. and McKay, A. (2014) Liquid banding of fungicide increases yields of cereals in paddocks with rhizoctonia bare-patch. In Proceedings 2014 North Mallee Farm Improvement Group Crop Updates, Salmon Gums, WA.

Root Disease: pythium

MacLeod, B. Vanstone, V. Khangura, R. and Beard, C. (2008) Root disease under intensive cereal production systems. Bulletin 4732. Department of Agriculture and Food, WA.

More information

GRDC Ground Cover supplement: http://www.grdc.com.au/GCS111

Section 5: Nutrition

Phosphorous

Wong, M. Weaver, D. and Bell, R. (2013) Use soil test to inform change from phosphorus build-up to maintenance for more profits. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Sulfur

Anderson, W. and Garlinge, J. (Eds.) (2000) The Wheat Book: Principles and Practice (2nd Edition). Perth, Western Australia: Western Australian Department of Agriculture.

Section 6: Integrated weed management

Borger, C. Hashem, A. and Wilkins, N. (2003). The double knockdown effect on annual ryegrass. In A. Douglas (Ed.) Crop Updates 2003 Weeds, Perth, pp. 25–26.

Borger, C. Hashem, A. and Wilkins, N. (2004). Double knockdown herbicides – preserving glyphosate. In A. Douglas (Ed.) Crop Updates 2004 Weeds, Perth, pp. 34–35.

Borger, C. Hashem, A. Powles, P. (2014) Manipulating crop row orientation and crop density to suppress annual ryegrass. Paper presented at the 2014 Agribusiness Crop Updates, Perth, WA.

Code, G. Walsh, M. and Reeves, T. (1987) Effect of depth and duration of burial of wild radish seed on seed viability and seedling emergence. In Proceedings of the Weed Seed Biology Workshop, Orange, New South Wales, pp. 136–1 38.

Newman, P. (2013) Remaining weeds are hard to control. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Newman, P (2014) Aim for the narrowest possible row spacing. Paper presented at the 2014 Agribusiness Crop Updates, Perth, WA.

Peltzer, S. and Matson, P. (2002) How fast do the seedbanks of five annual cropping weeds deplete in the absence of weed seed input?

Thompson, G. and Alderman, R. (2014) Spray resistant radish early for best efficacy and yield. Paper presented at the 2014 Agribusiness Crop Updates, Perth, WA.

Walsh, M. (2012) Harrington Seed Destructor - comparison with chaff carts and windrow burning systems. In Proceedings of the 2012 Agribusiness Crop Updates, Perth, WA, pp. 294-97.

Walsh, M. and Powles, S. (2014) High seed retention at maturity of annual weeds infesting crop fields highlights the potential for harvest weed seed control. Weed Technology, Vol. 28, No 3, July-September.

Resources

GRDC Integrated Weed Management hub: www.grdc.com.au/Resources/IWMhub

WeedSmart website: www.weedsmart.org.au

Australian Herbicide Resistance Initiative: www.ahri.uwa.edu.au

Australian Glyphosate Sustainability Working Group: www.glyphosateresistance.org.au

Department of Agriculture and Food e-weed newsletter: www.agric.wa.gov.au/newsletters/eweed

Giving a Rats newsletter: www.agronomo.com.au/giving-a-rats/

Section 7: Pre-sowing

Lawes, R. (2010) Using industry information to obtain insight into the use of crop rotations in the Western Australian wheat belt and quantifying their effect on wheat yields. In Proceedings of the 15th Australian Agronomy Conference 15-18 November Lincoln, New Zealand.

Lawes, R. Renton, M. (2010) The Land Use Sequence Optimiser (LUSO): a theoretical framework for analysing crop sequences in response to nitrogen, disease and weed populations. Crop & Pasture Science 61, 835–843.

MacLeod, W. MacNish, G. Thorn, C. (1993) Manipulation of pasture pastures with herbicides to control take-all. Aust. J. Agric. Res. 44,1235.

McConnell, G. and O'Hare, N. (2013) Break crop economics for the Kwinana East Regional Solutions Cropping Network. GRDC report prepared by Planfarm Pty Ltd.

Robertson, M. Lawes, R. Bathgate, A. Byrne, F. White, P. Sands, R. (2010) Determinants of the proportion of break crops on Western Australian broadacre farms. Crop & Pasture Science 61, 203-213.

Seymour, M. Kirkegaard, J. Peoples, M. White, P. French, R. (2012) Break-crop benefits to wheat in Western Australia - insights from over three decades of research. Crop & Pasture Science 63, 1-16.

Summer weeds

Hunt JR and Kirkegaard JA (2011). Re-evaluating the contribution of summer fallow rain to wheat yield in southern Australia. Crop and Pasture Science 62: 915-929.

Ward, P. Oliver, Y. and Hollamby, N. (2013) What to do with a wet summer: summer weeds, soil water and subsequent crop yield. Presented at the 2013 regional Liebe Group Crop Updates, Dalwallinu.

Soil acidity

Cregan, P. Hirth, J. Conyers, M. (1989) Amelioration of soil acidity by liming and other amendments. In 'Soil Acidity and Plant Growth'. (Ed. A. D. Robson) pp. 205-264. (Academic Press: Sydney).

Gazey, C. Davies, S. and Master, R. (2014) Soil acidity; a guide for WA farmers and consultants. Bulletin 4858 (Second edition). Department of Agriculture and Food, Western Australia.

Gazey, C. Oliver, Y. Fisher, J. Andrew, J. and Carr, S. (2014) 20 years of soil acidity RD& E in Western Australia—what have we learnt? Paper presented at the 2014 Agribusiness Crop Updates, Perth, WA.

Gazey, C. Andrew, J. and Griffin, E. (2013) 'Soil acidity' In Report card on sustainable natural resource use in agriculture. Perth, WA: Department of Agriculture and Food, Western Australia.

Scanlan, C. Brennan, R. Sarre, G. (2014) Shifting investment from nutrients to lime and cultivation on acid soils: is an immediate payback possible? Paper presented at the 2014 Agribusiness Crop Updates, Perth, WA.

Non-wetting soils

Bakker, D. Bowden, B. Poulish, G. Hulse, K. Davies, S. Scanlan, C. (2014) Managing non-wetting and crop nutrition of forest gravels. Paper presented at the 2014 Agribusiness Crop Updates, Perth, WA.

Blackwell, P. Hagan, J. Davies, S. Bakker, D. Hall, D. Roper, M. Ward, P. Matthews, A. (2014) Smart no-till furrow sowing to optimise whole-farm profit on non-wetting soil. Paper presented at the 2014 Agribusiness Crop Updates, Perth, WA.

Davies S, Blackwell P, Bakker D, Scanlan C, Roper M, Ward P (2012) Developing and assessing agronomic strategies for water repellent soils. In Proceedings of the 2012 Agribusiness Crop Updates, Perth, WA, pp. 71-77.

Roper, M. Ward, P. Keulen, A. Hill, J. (2013) Under no- tillage and stubble retention, soil water content and crop growth are poorly related to soil water repellency. Soil & Tillage Research 126: 143-150.

Soil compaction

Blackwell, P. and Davies, S. (2013) Controlled traffic farming: value to low rainfall croppers, especially using deep tillage. 2013 Liebe Local Research and Development Results pp. 141-147.

Blackwell, P. Hagan, J. Davies, S. Riethmuller, G. Bakker, D. Hall, D. Knight, Q. Lemon, J. Yokwe, S. and Isbister, B. (2013) Pathways to more grain farming profit by CTF. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Crabtree, W. (1989) Cereal grain yield responses to deep ripping on duplex soils. Australian Journal of Experimental Agriculture, vol. 29, pp. 691–694.

Davies, S. Gazey, C. Gilkes, R. Evans, D. and Liaghati, T. (2006) What lies beneath? Understanding constraints to productivity below the soil surface. Paper presented at the 2006 Regional Crop Updates, Geraldton: Department of Agriculture and Food, Western Australia.

Davies, D. and Lacey, A. (2011) Subsurface compaction - a guide for WA farmers and consultants. Bulletin 4818. Department of Agriculture and Food, Western Australia.

Jarvis, R. (2000) 'Deep tillage', In: Anderson, W and Garlinge, J (Eds.) The Wheat Book: Principles and Practice, pp. 185–187, Bulletin 4443, Department of Agriculture, Western Australia.

Kingwell, R. and Fuchsbichler, A. (2011) The whole-farm benefits of controlled traffic farming: an Australian appraisal. Agricultural Systems 104: pp. 513–521.

More information

GRDC Fact Sheet on deep ripping: www.grdc.com.au/uploads/documents/GRDC_DeepRipping_6pp_.pdf

GRDC Fact Sheet on controlled traffic: www.grdc.com.au/GRDC-FS-ControlledTraffic

Stubble management

Newman, P. (2012) Nutrient removal – the hidden cost of chaff carts and windrow burning. In Proceedings 2012 Agribusiness Crop Updates, Perth, WA pp.194–197.

Walsh, M. and Newman, P. (2007) Burning narrow windrows for weed seed destruction. Field Crops Research 104: 24–40.

Walsh, M. and Powles, S. (2007) Management strategies for herbicide-resistant weed populations in Australian dryland crop production systems. Weed Technology, 21(2), 332-338.

Resources

Australian Herbicide Resistance Initiative: www.ahri.uwa.edu.au

GRDC Integrated Weed Management hub: www.grdc.com.au/Resources/IWMhub

WeedSmart website: www.weedsmart.org.au

Section 8: Pre-sowing

Dalgliesh, N. (2009) Soil water in cropping systems: concepts and language. Presentation to the Grains Research and Development Corporation National Water-Use Efficiency Initiative meeting held in Canberra in July, 2009.

Oliver, Y. and Roth, C. (2014) Measuring and managing soil water – who is doing what in WA. Paper presented at 2014 Crop Updates, Perth, WA.

Oliver, Y. Robertson, M. Lawes, R. (2012) Bridging the Yield Gap: diagnosing poor performing patches from paddock to farm scale. Proceedings of the 16th Australian Agronomy Conference, 14-18th October, 2012 Armidale, New South Wales.

Oliver, Y. Wong, M. Robertson, R. Wittwer, K. (2006) PAWC determines spatial variability in grain yield and nitrogen requirement by interacting with rainfall on northern WA sandplain. In Proceedings of the 13th Australian Agronomy Conference, 10-14 September 2006, Perth, Western Australia.

Variety choice

Young, K. (2013) Wheat 2012 NVT trial results and key agronomy issues. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Zaicou-Kunesch, C. D'Antuono, M. Reeves, K. Choosing the right wheat variety for the system (part A) Paper presented at 2014 Crop Updates, Perth, WA.

Zaicou-Kunesch, C Choosing the right wheat variety for the system (part B) Paper presented at 2014 Crop Updates, Perth, WA.

Knockdown herbicides

Borger, C. Hashem, A. and Wilkins, N. (2003). The double knockdown effect on annual ryegrass. In A. Douglas (Ed.) Proceedings Crop Updates 2003 Weeds, Perth, pp. 25–26.

Borger, C. Hashem, A. and Wilkins, N. (2004). Double knockdown herbicides – preserving glyphosate. In A. Douglas (Ed.) Crop Updates 2004 Weeds, Perth, pp. 34–35.

Borger, C. Riethmuller, G. Ashworth, M. Minkey, D. Hashem, A. and Powles, S. (2013) Increased carrier volume improves pre-emergence control of rigid ryegrass (Lolium rigidum) in zero-tillage seeding systems. Weed Technology 2013 27:649–655.

Kleemann, S. Preston, C. and Gill, G. (2014) Influence of seeding system disturbance on pre-plant incorporated herbicide control of rigid ryegrass (Lolium rigidum) in wheat in Southern Australia. Weed Technology 28:323–331.

Newman, P. and Adam, G. (2005) Knockdowns for large wild radish, single and double. In Proceedings of the 2005 Crop Updates, Weeds Updates, Perth, WA pp.19-20.

Yu, Q. Cairns, A. Powles, S. (2007) Glyphosate, paraquat and ACCase multiple herbicide resistance evolved in a Lolium rigidum biotype. Planta. 2007 Jan; 225(2):499-513.

Resources

GRDC Integrated Weed Management hub: www.grdc.com.au/Resources/IWMhub

WeedSmart website: www.weedsmart.org.au

Australian Herbicide Resistance Initiative: www.ahri.uwa.edu.au

Australian Glyphosate Sustainability Working Group: www.glyphosateresistance.org.au/database/index.php

Department of Agriculture and Food e-weed newsletter: www.agric.wa.gov.au/newsletters/eweed

Giving a Rats newsletter: www.agronomo.com.au/giving-a-rats/

Soil nutrient testing

More Information

GRDC Fact Sheet: Soil testing for crop nutrition: Western region: www.grdc.com.au/GRDC-FS-SoilTestingW

GRDC Fact Sheet: Phosphorus management: Western region: www.grdc.com.au/GRDC-FS-PhosphorusManagement

GRDC Fact Sheet: Micronutrients and trace elements: www.grdc.com.au/Resources/Factsheets/2013/11/Micronutrients-and-trace-elements

GRDC Supplement: More Profit from Crop Nutrition: www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS108

Better Fertiliser Decisions for Cropping: www.bfdc.com.au

DAFWA workshops: Get to know your soils deeper: contact soils.forum@agric.wa.gov.au or call +61 0(8) 9690 2081.

Nematode management

More information

DAFWA How to diagnose root lesion nematode: www.youtube.com/watch?v=ttFltE-B4qA

GRDC GroundCover TV: www.grdc.com.au/GCTV6-RootLesionNematode

GRDC GroundCover Root and Crown Disease Supplement: www.grdc.com.au/GCS111

Mouse control

GRDC Mouse management factsheet, Western region: www.grdc.com.au/GRDC-FS-MouseManagement2012//

Snail and slug control

More information

GRDC Snail management factsheet, Southern and Western region: www.grdc.com.au/GRDC-FS-SnailManagement

GRDC Snail Identification and Control Back Pocket Guide: www.grdc.com.au/Resources/Publications/2011/03/Snail-Identification-and-Control-The-Back-Pocket-Guide

GRDC Bash 'em, Burn 'em, Bait 'em: Integrated snail management in crops and pastures: www.grdc.com.au/GRDC-Snails-BashBurnBait

Section 9: Sowing

Plant establishment

Cornish, P. and Hindmarsh, S. (1988) Seed size influences the coleoptile length of wheat. Australian Journal of Experimental Agriculture 28(4) 521 – 523.

French, R. (2014) Wheat variety response to dry sowing and seeding depth. Paper presented at the 2014 Crop Updates, Perth, Western Australia.

Riethmuller, G. (2004) Row spacing and stubble effect on wheat yield and ryegrass seed set. In Proceedings Agribusiness Crop Updates - Cereals. Perth, WA. pp. 20-21.

Riethmuller, G. (1990) Machinery for improved crop establishment in Western Australia. In Proceedings 'Agricultural Engineering Conference 1990' pp. 40-45 (Institute of Engineers: Australia).

Scott, B. Martin, P. Riethmuller, G. (2013). Graham Centre Monograph No. 3: Row spacing of winter crops in broad scale agriculture in southern Australia. Eds. T Nugent and C Nicholls. NSW Department of Primary Industries, Orange.

Dry sowing

Celenza, L. McNee, M. Minkey, D. Fletcher, A. Weeks, C. (2013) Adoption and management practices of dry seeding across the W.A. wheatbelt. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

French, R. (2014) Wheat variety response to dry sowing and seeding depth. Paper presented at the 2014 Agribusiness Crop Updates, Perth, WA.

French, R. and Schultz, J. (1984) Water use efficiency of wheat in a Mediterranean-type environment. I. The relationship between yield, water use and climate. Australian Journal of Agricultural Research 35, 743-764.

Minkey, D. and Ashworth, M. (2012) Weed management in dry seeded wheat. In Proceedings 2012 Crop Updates, Perth, Western Australia pp. 182-85.

Sharma, D. and Abrecht, D. (2013) Wheat variety selection for managing exposure of dry sown crops to frost and heat damage at flowering. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Robertson, M. Weeks, C. O'Conner, M. Abrecht, D. Grima, R. Newman, P. (2011) Pros and cons of dry seeding to counter variable season breaks. In Proceedings 2011 Crop Updates, Perth, Western Australia (Eds. J Paterson and C Nicholls) pp 208-11.

Section 10: Early season

Post emergent herbicides

Cook, A. (1998) Reducing seed production using late post-emergence applications of selective herbicides to manage wild oats (Avena spp.) populations. MSc Thesis, University of New England, New South Wales.

Hughes, P. (2004) Spray right – reduce drift. Queensland Dept. of Primary Industries and Fisheries extension note.

McNamara, D. (1976) Wild oat density and the duration of wild oat competition as it influences wheat growth and yield. Australian Journal of Experimental Agriculture and Animal Husbandry 16: 403–406.

Resources

GRDC Integrated Weed Management hub: www.grdc.com.au/Resources/IWMhub

Giving a Rats newsletter: www.agronomo.com.au/giving-a-rats/

Department of Agriculture and Food e-weed newsletter: www.agric.wa.gov.au/newsletters/eweed

Department of Agriculture and Food, WA MyCrop tool: https://agric.wa.gov.au/n/1976

GRDC Ground Cover Supplement: www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS105/How-will-you-spray-your-weeds-this-year

Crop grazing

Curtin, S. and Whisson, B. (2014) Delaying wheat flowering time through grazing to avoid frost damage (Part 1: Time of cutting). Paper presented at 2014 Agribusiness Crop Updates, Perth, Western Australia.

Barrett-Lennard, P. Quinlan, R. Taylor, S. Warren, G. Handley, M. and Pearce, R. (2013) Grazing crops in a dry year. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Section 11: Mid season

Frost identification

Cereal Growth Stages - the link to crop management (2005) Grains Research and Development Corporation, Canberra.

Section 12: Late season

Nitrogen top ups

Lemon, J. (2004) Grain protein management - lessons learnt on the south coast. In Proceedings of Agribusiness Crop Updates 2004 (Cereals) pp. 22-23. Department of Agriculture and Food, WA.

Palta, J. Bowden, W. and Asseng, S. (2003) Timing of late applications of N fertiliser and season on grain yield and protein in wheat. In Proceedings of the 11th Australian Agronomy Conference, 2-6 February 2003, Geelong, Victoria.

Pre-harvest sprouting

More information

DAFWA Wheat grain quality: falling number and sprouting tolerance: https://agric.wa.gov.au/n/3124

GRDC 2015 Wheat variety guide for WA: www.grdc.com.au/WAWheatVarietyGuide

Section 13: Harvest

Weed management

Newman, P. (2013) Remaining weeds are hard to control. Paper presented at the 2013 Agribusiness Crop Updates, Perth, WA.

Walsh, M. (2012) Harrington Seed Destructor - comparison with chaff carts and windrow burning systems. In Proceedings of the 2012 Agribusiness Crop Updates, Perth, WA, pp. 294-97.

Walsh, M. and Powles, S. (2014) High seed retention at maturity of annual weeds infesting crop fields highlights the potential for harvest weed seed control. Weed Technology, Vol. 28, No 3, July-September.

Section 14: Grain storage

Infrastructure

Resources

GRDC Stored grain information hub: http://storedgrain.com.au/

Grain storage workshops: http://storedgrain.com.au/events/category/western-region/

Grain storage pests

Resources

GRDC: http://storedgrain.com.au/

Plant Health Australia: http://phau.com.au

Grain storage workshops: http://storedgrain.com.au/events/category/western-region/

Section 15: Marketing

M Krause (2014) Farming the business. Sowing for your future. GRDC, http://www.grdc.com.au/FarmingTheBusiness