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GRDC GROWNOTES™

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

WHEAT

SECTION 1

PLANNING / PADDOCK PREPARATION

PADDOCK SELECTION | PADDOCK ROTATION AND HISTORY | FALLOW WEED CONTROL | FALLOW CHEMICAL PLANT-BACK PERIODS | SEEDBED REQUIREMENTS | SOIL MOISTURE | YIELD AND TARGETS | DISEASE STATUS OF THE PADDOCK | NEMATODE STATUS OF THE PADDOCK | INSECT AND PEST STATUS OF PADDOCK

SECTION 1

Planning/Paddock preparation

Profitable growing of winter crops demands higher production per unit area while aiming to maintain a low cost per unit of production. This can only be achieved by increasing grain yields through economic adoption of new or improved technology. The aim is not only higher total production, but also greater productivity from the resources invested in crop production, along with total sustainability of the farm business.

Check out what other Southern Region growers are doing at http://grdc.com.au/Media-Centre/Over-the-Fence/Over-The-Fence-Videos/Over-the-Fence-Southern-Region and keep up to date with the latest news at http://grdc.com.au/Media-Centre/Ground-Cover, http://grdc.com.au/Media-Centre/GRDC-Podcasts/Driving-Agronomy-Podcasts and http://www.grdc.com.au/Media-Centre/GroundCover-TV.

1.1 Paddock selection

Pulses, oilseeds, oats and barley offer breaks crops for many wheat diseases, and indeed, differing genetic backgrounds of wheat varieties sometimes allow wheat to be sown in consecutive years. Incorporation of disease resistances and tolerances into wheat has also virtually eliminated some diseases, such as cereal cyst nematode, and allowed more frequent sowing of wheat.

Choice of paddock to sow wheat is therefore based on a range of issues. Economics, production risk from disease or weed pressures, herbicide residues, seasonal forecasts, stored soil water, and achieving a balance of risk with other crop types are some of the considerations. [1]

Profitable wheat yields result from good management, of which variety choice is only one component. Managing soil moisture, disease, weed and nutrients are also important.

Paddock selection and rotation, combined with use of disease-resistant varieties, are the best actions to minimise disease (Figure 1). [2]

[1] Agriculture Victoria (2012) Growing wheat. DEDJTR Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat

[2] NSW DPI District Agronomists (20082007) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

Figure 1: Paddock selection and rotation combined with use of disease-resistant varieties are the best actions to minimise disease. (Photo: Penny Heuston)

More information

[GRDC Update Papers: Management of yellow spot in wheat: decide before you sow]

[GRDC Resources: IWM Hub. Section 2 — Agronomy to enhance weed management]

1.1.1 Paddock topography

Topographical characteristics can determine crop and pasture options (Figure 2). Crops and varieties prone to lodging should be avoided in uneven paddocks. Waterlogged conditions also reduce root growth and can predispose the plant to root rots. [3] Choose varieties with higher tolerance to wet conditions.

Figure 2: Topographical characteristics can determine crop options. (Photo: Penny Heuston)

3 J Ransom (2011) Impacts of flooding/waterlogging on crop development. North Dakota State University Crop & Pest Report (, 26 May 2011), http://www.ag.ndsu.edu/cpr/plant-science/impacts-of-flooding-waterlogging-on-crop-development-5-26-11

1.1.2 Soil type

Soil characteristics (surface and subsurface) such as pH, sodicity, salinity, acidity, texture, drainage characteristics and compaction will affect variety selection. See the National Variety Trials (NVT) guides for details of recommended varieties and planting times for individual districts within the Southern Region. For more detail, see GrowNotes Wheat South. Section 2. Pre-planting.

More information

http://www.ag.ndsu.edu/cpr/plant-science/impacts-of-flooding-waterlogging-on-crop-development-5-26-11 - no link?NDSU: Impacts of flooding/waterlogging on crop development

1.1.3 Subsoil moisture

Growing a crop always incurs financial risk due to upfront expenditure on inputs, labour and fuel. Low levels of available soil moisture at sowing can significantly increase financial risks. Paddocks with retained stubble can retain moisture for longer, extending the time for planting after small rainfall events. Levels of starting available soil moisture should also affect crop variety choice. Varieties with greater canopy size, such as late-maturing and/or very vegetative varieties, will generally require higher soil moisture levels to perform well.

1.1.4 Paddock nutrition

Fertiliser can be a major upfront investment. Fertiliser rates to meet crop requirements may be modified if residual fertiliser from the last season remains. Soil tests, paddock history, past crop performance and fertiliser test strips can help to determine the most appropriate decision. Paddocks often have multiple nutrition deficiencies or variations in nutritional requirements, even with a similar cropping history.

1.1.5 Herbicide history

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonylurea, triazines, etc.) may be an issue in some paddocks. Remember that plant-back periods begin after significant rainfall occurs. For more information, see under heading below 'Fallow chemical plant-back periods' and download the NSW DPI publication Weed control in winter crops.

1.1.6 Weed burden

A high weed burden will influence the likelihood of cropping success. The species present or likely to occur based on previous years should influence crop species choice to ensure that effective in-crop control measures are available.

More information

NSW DPI: Weed control in winter crops

GRDC Ground Cover: Weeds don't like the competition

Strategic and integrated weed management over a rotation can greatly increase the likelihood of controlling weeds across all crops. Paddocks being planted to wheat in the first year of rotation should for instance have a vigilant strategy for the control and prevention of seed set of key broadleaf weeds prior to a rotation to canola or legume crops.

The use of pre-emergent herbicides as appropriate should be considered as well as cultural control methods such as species choice and row width.

1.1.7 Disease carryover

Crop sequencing and rotation are important components of long-term farming systems and contribute to the management of soil nitrogen status, weeds, pests and diseases.

More information

GRDC Update Papers: Diseases shared by different crops and issues for crop sequencing

In the paddock, considerations include soil moisture levels before planting, current and desired stubble cover, and history of herbicide use and history of diseases.

Crop sequencing is only a part of the integrated management of diseases. Other practices include maintaining sufficient distance from last year's paddock of the same crop or from a paddock with residue infected with a pathogen of the intended crop; the use of high-quality, fungicide-treated seed; planting within the planting window, variety selection, and in-crop fungicide treatments. [4]

[4] M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Papers, 13 September 2011, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/09/Diseases-shared-by-different-crops-and-issues-for-crop-sequencing

The previous crop will influence levels of both soil- and residue-borne diseases. Important diseases to consider include take-all, crown rot, yellow leaf spot, stripe rust, cereal cyst nematode, and wheat streak mosaic virus. Transmission from neighbouring paddocks and volunteers are key concerns with some diseases. Controlling the 'green bridge' of over-summering cereals and weeds is an important strategy.

1.1.8 Pests

Pests such as redlegged earth mites, blue oat mites, nematodes and, in some seasons, cutworms pose a risk in some paddocks. Risk should be assessed based on paddock history (including recent control) and crop susceptibility. Controlling weeds in summer fallows and around paddocks can also minimise some of these pests.

More information

APVMA: Public Chemical Registration Information System search

For information on in-furrow treatment options see GrowNotes Wheat South Section 3. Planting.

See also GrowNotes Wheat South Section 7. Insect control.

Further information is available from the Australian Pesticides and Veterinary Medicines Authority Public Chemical Registration Information System (APVMA PubCRIS database) and winter crop variety sowing guide websites.

1.1.9 Fallow management

Paddocks with well-managed fallow periods significantly lower the risk of poor crop and financial performance.

Timely weed control can reduce moisture and nutrition loss, prevent an increase in the seedbank, and decrease the risk of disease carryover. Absence (or restriction) of grazing periods maintains soil friability and groundcover. Prolonged grazing periods may create crop emergence problems through induced surface compaction. [5] (See *under heading Fallow weed control below.*)

The green bridge provides a between-season host for insects and diseases (particularly rusts); these pose a threat to future crops and can be expensive to control later in the season.

More information

GRDC Fact Sheets: The essential crop management tool—green bridge control is essential to pest and disease management

NSW DPI: Paddock selection after drought

Key points for control of the green bridge:

- Outright kill of the weeds and volunteers is the only certain way to stop them from hosting diseases and insects.
- Diseases and insects can quickly spread from the green bridge, jeopardising crops and current control methods, including the effectiveness of chemicals and genetic breeding for resistance.
- Effective control of pest and disease risks requires neighbours to work together to eradicate weeds and crop volunteers simultaneously.
- Weed growth during summer and autumn depletes soil moisture and nutrients that would otherwise be available to following crops and can have an allelopathic effect. [6]

The GRDC produces an annual Paddock Diary for downloading, which includes information and record-keeping templates.

Diary headings include:

- Your paddocks list
- Paddock operations and paddock observations
- Growth stages
- Pests, diseases and weeds

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5 N Border, K Hertel, P Barker (2007) Paddock selection after drought. NSW Department of Primary Industries, February 2007, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/126100/paddock-selection-after-drought.pdf

6 GRDC (2009) Green bridge—The essential crop management tool —green bridge control is integral to pest and disease management. Green Bridge Fact Sheet, GRDC Fact Sheet, http://www.grdc.com.au/uploads/documents/GRDC_GreenBridge_FS_6pp.pdf

- Rust risk
- The Australian Cereal Rust Control Program
- Groups (modes of action)
- Herbicide resistance
- How will you spray this year?
- Spray application
- Surface temperature inversions and spraying
- Delta T and droplet survival
- Spray calibration
- Nozzle selection and calculation
- Sprayer checks and calibration
- Pesticide application
- Water-use efficiency (WUE)
- Planting rate
- Rainfall records
- Calendars
- Public holidays and school terms
- Names and addresses
- Weights and measures
- Conversions formulae
- Useful conversions

More information

GRDC Ground Cover: Paddock Diary 2015

More information

Ag Excellence Alliance: Cover cropping benefits from the Mallee

Research paper: Warm season cropping in the southern cropping zone of Australia

Farm Weekly: Cover cropping demo grows

Nuffield Farming Scholars: David Cook

Aust Cover Crop: David Cook, Nuffield Scholar

Weekly Times: New tillage radish to revolutionise cropping

Victorian No-till Farmers Association

Fallow moisture

A growing crop has two sources of water: the water stored in the soil during the fallow, and the water that falls as rain while the crop is growing. Growers have some control over the stored soil water; measure soil water before planting the crop. Long-range forecasts and tools such as the SOI can indicate the likelihood of the season being wet or dry; however, they cannot guarantee that rain will fall when needed. [7]

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

1.2 Paddock rotation and history

Paddock choice can determine the amount of disease, weed and nutrient pressure on the crop. Increasing interest in crop sequencing is providing more financial and agronomic data to help growers to choose crops and paddocks each year.

1.2.1 Benefits of cereals as a rotation crop

Cereals present the opportunity for effective utilisation of residual N. They also offer good options for broadleaf control and are non-hosts for many pulse crop and oilseed diseases. A major benefit of winter cereal crops is the high levels of groundcover they provide for management of soil loss in following fallows and some subsequent pulse crops.

1.2.2 Disadvantages of cereals

Growing cereals in continuous production is no longer a common practice because of the rising incidence of:

- difficult-to-control and herbicide-resistant weeds, particularly grass weeds
- disease build-up, e.g. crown rot, tan (yellow) spot, nematodes
- nitrogen (N) depletion and declining soil fertility

Crop rotation is a key strategy for managing Australian farming systems, and improvements in legume and oilseed varieties and their management have facilitated this shift.

In many of Australia's grain-growing regions, broadleaf crop options have been seen as riskier and less profitable than cereals. This perception has been driven, in part, by fluctuating prices and input costs associated with the broadleaf crop in the year of production, and difficulties in marketing. However, when the profitability of the entire rotation is assessed, it is often more profitable to include broadleaf crops in the crop sequence.

A broadleaf crop is often included in the crop sequence to counteract limitations in the cereal phase (weeds, disease, N), so the broadleaf crop's financial impact may be considerably better if considered across the crop sequence. [8]

Leading growers and advisers advocate sustainable crop sequences as a valuable strategy for southern farming systems. Many growers are sacrificing cereal yield and protein by not adopting current research findings on the use of correct sequences. [9]

Modern conservation cropping systems sometimes involve successive wheat, no-till crops, which can suffer 5–15% yield penalties from unidentified biological constraints in the rhizosphere. However, evidence from field and laboratory studies shows that some wheat varieties perform better in these conditions, owing to differences in the chemistry of root exudates or residues, which influence rhizobacterial populations. Varietal differences also interact with soil type, season and agronomic management (sowing time, row placement).

CSIRO researchers have developed hypotheses that may explain these effects. They aim to establish which selected wheat varieties perform better in intensive wheat rotations and to improve industry understanding of the mechanisms involved. These steps are necessary to capitalise on the significant increase in productivity for the grains

More information

GRDC Ground Cover: Returns from break crops can challenge wheat

GRDC Fact Sheets: Choosing rotation crops. Short-term profits, long-term payback

GRDC: Improving productivity by rotating wheat varieties in wheat on wheat systems

GRDC Update Papers: Drivers of profit and success—use of technology on the farm

GRDC: Integrated disease management for cereal and broadleaf crops in southern NSW and northern Victoria

GRDC Update Papers: Crop and pasture sequences sustain wheat productivity

GRDC Update Papers: Crop sequencing—what are the key issues to making profitable and sustainable decisions?

CSU: Crop sequences: using broadleaf crops to improve wheat grain production and profitability

FAO: What is the best cropping sequence for the farm?

Research paper: Break crops pay in the Victorian Mallee

GRDC Online Farm Trials: Barley and wheat disease management using foliar and fertiliser fungicides

GRDC Ground Cover: Crop sequencing supplement

8 M Peoples (2012) Returns from break crops can challenge wheat. GRDC Ground Cover Issue 98, 27 April 2012, http://www.grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-98-Supplement-Crop-Sequencing/Returns-from-break-crops-can-challenge-wheat

9 GRDC (2011) Choosing rotation crops—Short-term profits, long-term payback. GRDC Fact Sheet Northern Region. Choosing Rotation Crops Fact Sheet, GRDC, March 2011, http://www.grdc.com.au/~/media/9219D55FFB4241DC9856D6B4C2D60569.pdf

industry that would arise from breeding and/or agronomic strategies to overcome the productivity constraints in intensive cereal systems. [10]

1.2.3 Long-fallow disorder

Soils naturally contain beneficial fungi that help the crop to access nutrients such as phosphorus (P) and zinc (Zn). The combination of the fungus and crop root is known as arbuscular mycorrhiza(e) (AM) (Figure 3). Many different species of fungi can have this association with the roots of crops. Many that are associated with crops also form structures called vesicles in the roots.

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

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

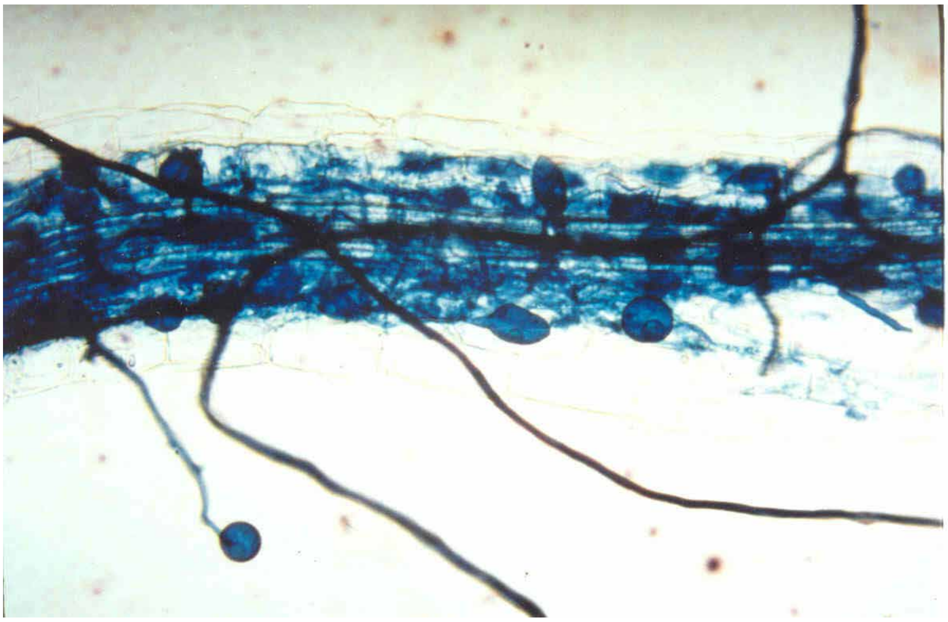

Figure 3: Arbuscular mycorrhizae pictured in a wheat root. (Photo: DAF Qld)

Benefits of good levels of AM are:

- improved uptake of P and Zn
- improved crop growth
- improved N_2 fixation
- greater drought tolerance
- improved soil structure
- greater disease tolerance

More information

Research paper: Effect of agronomic management on gross margins from crop sequences in the high rainfall zone of south western Victoria

http://www.agronomy2015.com.au/papers/agronomy2015final00155.pdf

Research paper: Effects of row spacing and row placement on grain yield in a sorghum/wheat sequence under high rainfall

More information

GRDC Online Farm Trials: Sick crops in the southern Mallee in 1995

Research paper: Increasing mycorrhizal colonisation does not improve growth and nutrition of wheat on Vertosols in south-eastern Australia

Research paper: Rotation, sequence and phase. Research on crop and pasture systems

Farming Ahead: Mycorrhizal fungi enhance crop nutrient uptake

Research paper: Is there a role for arbuscular mycorrhizal fungi in production agriculture?

[10] J Kirkegaard (2008) Improving productivity by rotating wheat varieties in wheat on wheat systems. GRDC Research & Development Project CSP00115, http://www.grdc.com.au/Research-and-Development/Meeting-market-requirements/CSP00115

In general, the benefits of AM are greater at lower soil P levels because AM increase a plant's ability to access this nutrient. Crops with higher P dependency benefit more from AM (Table 1). [11]

Table 1: Dependency of various crop species on mycorrhizae (value decreases as the phosphorus level of the soil increases)

Mycorrhizal dependency	Potential yield loss without mycorrhizae (%)	Crops
Very high	>90	Linseed
High	60–80	Sunflowers, mungbeans, pigeon peas, maize, chickpeas
Medium	40–60	Sudan grass, sorghum, soybeans
Low	10–30	Wheat, barley, triticale
Very low	0–10	Panicum, canary grass
Nil	0	Canola, lupins

More information

GRDC Fact Sheets: Summer fallow spraying

GRDC Update Papers: Achieving good pre-emergent spray results

GRDC Update Papers: Summer weeds reduce moisture and nitrogen

GRDC Update Papers: Impact of crop residues on summer fallow weeds

GRDC: Manual summer fallow weed management

1.3 Fallow weed control

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

Benefits of fallow weed control are significant:

- Conservation of summer rain and fallow moisture (this can include moisture stored from last winter or the summer before in a long fallow) is integral to cropping, particularly so as the climate moves towards summer-dominant rainfall.
- Modelling studies show that the highest return on investment in summer weed control is for lighter soils or in situations where soil water that would support continued weed growth is present. [12]

1.3.1 Double-knock strategies

Double-knock refers to the sequential application of two different weed-control tactics applied in such a way that the second tactic controls any survivors of the first. Most commonly used for pre-sowing weed control, this method can also be applied in-crop. [13]

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

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

Critical factors for successful double-knock approaches are for the first application to be on small weeds and to ensure good coverage and adequate water volumes, particularly when using products containing paraquat. For a double knock with herbicides to be successful both applications should be at label rate for control.

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

[12] GRDC (2012) Summer fallow—Make summer weed control a priority. GRDCWestern Region Summer Fallow Management Fact Sheet GRDC, January 2012., http://www.grdc.com.au/~/media/91deacef2dd843f6bbf9fab09bfe0d65.pdf

[13] C Borger, V Stewart, A Storrie. DAFWA. Herbicides—knockdown herbicides for fallow and pre-sowing control. Department of Agriculture and Food, Western Australia, https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C1

More information

[GRDC: Weed Webinars]

[GRDC: Integrated Weed Management Hub]

Double-knock strategies are not fail-proof and are rarely effective for salvage weed-control situations unless environmental conditions are exceptionally favourable.

1.4 Fallow chemical plant-back periods

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

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical or carryover in the soil may break down rapidly to half the original amount, what remains can persist for long periods. This is the case with sulfonylureas (SUs, e.g. chlorsulfuron). Residual persistence and half-lives of common herbicides are shown in the Table 2. Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the SUs. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the 'Protection of crops, etc.' heading in the 'General Instructions' section of the label. [14]

Table 2: Residual persistence of common pre-emergent herbicides and noted residual persistence from broadacre trials and paddock experiences [15]

Sources: CDS Tomlinson (ed,) (2009) The pesticide manual. 15th edn. British Crop Protection Council, Farnham, UK. Extoxnet: http://extoxnet.orst.edu/. California Dept Pesticide Regulation Environmental Fate Reviews, http://www.cdpr.ca.gov/

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19	High. Persists longer in high pH soils. Weed control commonly drops off within 6 weeks
Glean® (chlorsulfuron)	28–42	High. Persists longer in high pH soils. Weed control longer than Logran®
Diuron	90 (range: 1 month–1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Long-lasting activity observed on grass weeds such as black/stink grass (*Eragrostis* spp.) and to a lesser extent broadleaf weeds such as fleabane
Atrazine	60–100, up to 1 year if dry	High. Long-lasting (>3 months) activity observed on broadleaf weeds such as fleabane
Simazine	60 (range: 28–149)	Med./high. 1 year of residual in high pH soils. Long-lasting (>3 months) activity observed on broadleaf weeds such as fleabane
Terbyne® (terbuthylazine)	6.5–139	High. Long-lasting (>6 months) activity observed on broadleaf weeds such as fleabane and sow thistle
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Long-lasting activity observed on grass weeds such as black/stink grass
Stomp® (pendimethalin)	40	Medium. 3–4 months of residual
Avadex® Xtra (triallate)	56–77	Medium. 3–4 months of residual
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall event. Long-lasting (> 6 months) activity observed on broadleaf weeds such as fleabane and sow thistle
Boxer Gold® (prosulfocarb)	12–49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall event
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than trifluralin and Boxer Gold®; however, weed control persists longer than Boxer Gold®

More information

[Australian Pesticides and Veterinary Medicines Authority]

[NSW DPI: Using pre-emergent herbicides in conservation farming systems]

[NSW DPI: Weed control winter crops]

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

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

1.4.1 How do herbicides break down?

Herbicides break down via either chemical or microbial degradation. Chemical degradation occurs spontaneously, the speed depending on the soil type (clay or sand, acid or alkaline), moisture and temperature. Microbial degradation depends on a population of suitable microbes living in the soil to consume the herbicide as a food source.

Both processes are enhanced by heat and moisture. However, they are both impeded by herbicides binding to the soil, and this depends upon the make-up of the soil (i.e. pH, clay or sand, and other compounds such as organic matter or iron).

For these reasons, degradation of each herbicide should be considered separately and growers need to understand the soil type for each paddock and climate when interpreting re-cropping periods on the product label.

1.4.2 How can I avoid damage from residual herbicides?

Select an appropriate herbicide for the weed population present. Make sure you consider what the re-cropping limitations may do to future rotation options. Read the herbicide label.

Users of chemicals are required to keep good records, including weather conditions. In the case of unexpected damage, good records can be invaluable, particularly spray dates, rates, batch numbers, rainfall, soil type(s) and pH.

If chemical residues could be present, choose the least susceptible crop (refer to product labels). Optimise growing conditions to reduce the risk of compounding the problem with other stresses such as herbicide spray damage, disease and nutrient deficiency. These stresses make a crop more susceptible to herbicide residues.

Be wary of compounding a residue problem by planting a herbicide-resistant crop and spraying with more of the same herbicide group. You may avoid the problem with residues in the short term however be further locked out for future crops.

Group B. The sulfonylureas

Sulfonylureas persist longer in alkaline soils (pH >7), where they rely on microbial degradation.

Residual life within the SU family varies widely, with chlorsulfuron persisting for ≥2 years and not suitable for highly alkaline soils. Triasulfuron persists for 1–2 years and metsulfuron generally for <1 year.

Legumes and oilseeds are most vulnerable to SUs, particularly lentils and medics. However, barley can also be sensitive to some SUs. Check the label.

Group B. The triazolopyrimidines (sulfonamides)

There is still debate about the ideal conditions for degradation of these herbicides. However, research in the alkaline soils of the Victorian Wimmera and Mallee, and the Eyre Peninsula in South Australia, has shown that sulfonamides are less likely to persist than SUs in alkaline soils. Plant-back periods should be increased in shallow soils.

Group B. The imidazolinones (IMIs)

The imidazolinones are very different from the SUs because the main driver of persistence is soil type, not soil pH. They tend to be more of a problem on acid soils, but carryover does occur on alkaline soils. Research has shown that in sandy soils, such as on the Eyre Peninsula, they can break down very rapidly (within 15 months in alkaline soils), but in the heavy clay soils in Victoria they can persist for several years. Breakdown is by soil microbes. Oilseeds are most at risk. Widespread use of IMI-tolerant canola and wheat in recent years has increased the incidence of residues.

Group C. The triazines

Usage of triazines has increased to counter Group A resistance in ryegrass and because of high rates used on triazine-tolerant canola. Atrazine persists longer in soil than simazine. Both generally persist longer in high pH soils, and cereals are particularly susceptible to damage. Recent research in the USA indicates that breakdown rates tend to increase when triazines are used regularly, because the number of microbes able to degrade the herbicide can increase. This may mean that breakdown can take an unexpectedly long time in soils that have not been exposed to triazines for some years.

Group D. Trifluralin

Trifluralin tends not to leach through the soil but it can be moved into the seedbed during cultivation or ridging. Trifluralin binds strongly to stubble and organic matter and is more likely to be a problem in paddocks with stubble retention. Be particularly careful with wheat, oats and lentils. Barley is more tolerant. Use knife-points to throw soil away from seed and sow deep.

Group H. The isoxazoles

Persistence in acid soils (pH <7) has not been fully tested, but research suggests that isoxazole persistence is expected to be longer than the label recommendations for legume crops and pastures. Isoxazoles will also persist longer in clay soils and those with low organic matter. Cultivation is recommended prior to re-cropping.

Group I. The phenoxies

Clopyralid and aminopyralid can be more risky on heavy soils and in conservation cropping, where they can accumulate on stubble. Even low rates can cause crop damage up to 2 years after application. They cause twisting and cupping, particularly for crops suffering from moisture stress.

2,4-D used for fallow weed control in late summer may cause a problem with autumn-sown crops. There have been recent changes to the 2,4-D label, and not all products can be used for fallow weed control; check the label. The label recommends not to sow sensitive crops, especially canola, until after a significant rainfall event. Oilseeds and legumes are very susceptible to injury from 2,4-D.

Group K. Pyroxasulfone

Pyroxasulfone relies on microbial degradation, which is favoured by in-season rainfall. Label plant-backs are important, particularly for oats, durum wheat and canola. Residues will lead to crop stunting. [16]

More information

Research paper: Pasture plant-back periods following application of simazine to control Vulpia spp.

GRDC Online Farm Trials: Residual herbicides. Group B & C carry-over

1.4.3 Genetic controls

The Clearfield® Production System is designed to deliver extended weed control and increased yield potential and crop quality. [17] It matches selected seed varieties with Intervix®, a custom-designed herbicide that can only be used on Clearfield® varieties. Refer to the herbicide label for weed species that can be controlled.

More information

BASF: Clearfield Production System

1.5 Seedbed requirements

Wheat seed needs good soil contact for germination (Figure 4). This can be assisted with press-wheels, coil packers or rollers. Soil type determines which implement will produce the ideal seedbed.

If germination rate and vigour are good, 70–90% of seeds sown will produce a plant. Depth of sowing, disease, crusting, moisture and other stress in the seedbed all reduce

Video

Stubble height and crop emergence

16 http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

17 Crop Care (2011) Clearfield best management practice. Crop Care Australasia Pty Ltd, http://www.cropcare.com.au/Assets/501/1/2011ClearfieldBMPWeb.pdf

the number of plants establishing. Field establishment is unlikely to be above 90%, and may be as low as 60% if seedbed conditions are unfavourable.

Seedbed preparation is also important to emergence. A cloddy seedbed may reduce emergence because the clods allow light to penetrate below the soil surface. The coleoptile senses the light and stops growing while still below the surface. [18]

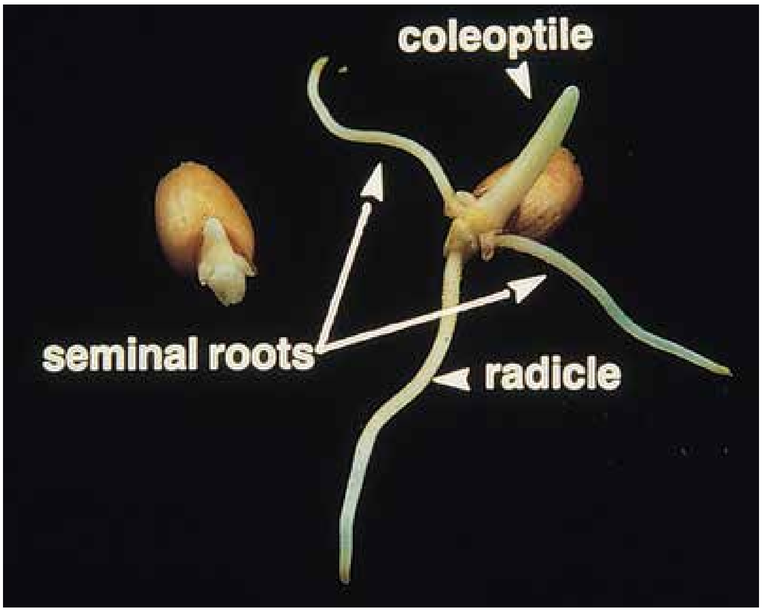

Figure 4: Germinated wheat seed. (Photo: David L. Hansen, University of Minnesota)

1.5.1 Deep sowing

For successful crop establishment, seed needs to be placed into soil with enough seedbed moisture for germination to occur, or into dry soil in anticipation of rainfall to increase soil moisture levels such that germination may occur.

Where soil profiles have high levels of plant-available water in the root-zone coupled with a dry seedbed, 'moisture seeking' may be required. The seed is placed deeper in the soil than is generally recommended, with the aim of ensuring timely crop establishment. This practice generally involves the use of tynes to open a furrow to a depth of >7.5 cm, into which the seed is then placed, followed by a press-wheel to close moist soil around the seed. Moisture seeking is reported to increase cropping frequency and improve timeliness of crop establishment.

1.5.2 Coleoptile length

Most wheat varieties currently grown in Australia contain a reduced-height gene that results in shorter plants and shorter coleoptiles than standard-height varieties. A positive correlation has been found between coleoptile length and crop establishment, which implies that widely grown, semi-dwarf varieties have reduced establishment compared with standard-height varieties when sown deep.

More information

GRDC Update Papers: Riverine Plains Inc. research update

Corangamite CMA: Brown Book—how to optimise your soils to enhance productivity

GRDC Update Papers: Using crop competition for weed control in barley and wheat

Research paper: Variations in wheat yields behind windbreaks in southern Queensland

Research paper: Small grains seedbed preparation and residue management

More information

GRDC Update Papers: Wheat variety response to dry sowing and seeding depth

GRDC Update Papers: Row spacing and deep sowing

Research paper: Effect of sowing depth on the establishment of several commercial wheat varieties

Riverine Plains: Sowing date—getting the best from our varieties and optimising whole-farm wheat yield

More information

NSW DPI: Coleoptile length of wheat varieties

[18] NSW DPI District Agronomists (2008) Wheat growth and development. PROCROP Series, NSW Department of Primary Industries 2007, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

More information

GRDC Update Papers: New technology for measuring and advising on soil water

GRDC: Making the most of a wet summer in the Southern Region

GRDC Update Papers: Dune discharge seepage areas in the South Australian landscape

GRDC Update Papers: Dryland water-use efficiency—what is it and how to improve it

More information

GRDC: Estimating plant-available water capacity

GRDC Update Papers: Moisture probes—application and usefulness in crop decision making

GRDC Update Papers: Managing seasonal variability with soil moisture monitoring devices

1.6 Soil moisture

1.6.1 Dryland

Water availability is a key limiting factor for wheat production in the grainbelt of Australia. Varieties with improved adaptation to water-limited conditions are actively sought and studies have been carried out to identify the physiological basis of the adaptive traits underpinning this advantage. Experiments were undertaken in field environments representing the range of moisture availability conditions commonly encountered by winter crops grown on deep Vertosol soils. [19]

Technologies to support decision-making

Several technologies will provide a level of information useful in decision-support without excessive investment.

Devices for soil monitoring

In-situ devices that have relatively small zones of measurement and rely on good soil–sensor contact to measure soil water are at a disadvantage in shrink–swell soils where soil movement and cracking are typical.

This is more important in dryland than irrigated systems because seasonal soil-water levels vary from above field capacity through to wilting point or lower. The potentially high levels of error associated with cracking and soil movement and high levels of inherent soil variability mean that increased device replication would be necessary to achieve confidence in results. This comes at an increased capital cost.

Some devices (capacitance sensors, time-domain reflectometers) also have an upper measurement limit over which they are unable to measure soil water accurately. This may be a problem on high-clay soils where moisture content at drained upper limit is likely to be >50% volumetric, the common limit for these devices.

By comparison, the use of a portable electromagnetic induction (EMI) device to measure bulk electrical conductivity and calculate soil water has a number of advantages. The EMI is quick, allowing for greater replication, measures the soil moisture of a large volume of soil (to 150 cm depth), is not affected by cracking or soil movement, and does not require installation of an access tube, thus making it available for use on multiple paddocks. However, it is unsuitable for use in saline soils and does not apportion soil water to particular layers within the soil profile. [20]

The EM38

Despite the extensive range of monitoring instruments now available, measuring paddock soil moisture remains a challenge. Among the suite of instruments on offer, one that is increasingly being used by researchers and agronomists is the EM38 (Geonics Ltd, Ontario, Canada). This EMI instrument is proving to have significant potential for determining soil properties useful in precision agriculture and environmental monitoring.

It is now commonly used to provide rapid and reliable information on properties such as soil salinity and sodicity, which can then be used to identify soil management zones. Both relate well to crop yield. It is also used widely in agronomic and environmental applications to monitor soil water within the root-zone. The EM38 provides an efficient means to monitor crop water use and plant-available water (PAW) in the soil profile throughout the growing season so that informed management decisions can be made, such as the application, timing and conservation of irrigation water and fertiliser. EM38

[19] JT Christopher, AM Manschadi, GL Hammer, AK Borrell (2008) Developmental and physiological traits associated with high yield and stay-green phenotype in wheat. *Australian Journal of Agricultural Research* 59, 354–364., http://www.publish.csiro.au/paper/AR07193.htm

[20] N Dalgliesh, N Huth (2013) New technology for measuring and advising on soil water. GRDC Update Papers Goondiwindi, 5 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/New-technology-for-measuring-and-advising-on-soil-water

datasets have also proved valuable to test and validate water balance models that are used to extrapolate to other seasons, management scenarios and locations.

The EM38 is an easy-to-use, geophysical surveying instrument that provides a rapid measure of soil electrical conductivity. Soil calibrations or qualitative assessments can be used to convert this to estimates of soil water in the root-zone. This information is vital to farm-management decisions based on accurate knowledge of soil PAW. [21]

More information

GRDC Update Papers: A 'how to' for getting soil water from your EM38 field measurements

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/A-how-to-for-getting-soil-water-from-your-EM38-field-measurements

Calibration of monitoring devices

Electronic monitoring tools require calibration to convert the device output signal into information easily understood by the user, e.g. millivolts to volumetric soil water or PAW. This process requires the development of a relationship between sensor output and physically measured soil moisture content at moisture levels from dry to wet. The resulting calibration is then used to convert the device output signal to gravimetric or volumetric water content.

To calculate the availability of soil moisture for crop use (mm available water) requires further processing of the data and knowledge of a soil's PAW capacity (PAWC). A suitable characteristic may be identified from the APSoil database or SoilMapp, or electronic sensor output may be used to identify the soil's water-content operating range, to make reasonable assumptions on values for drained upper limit and crop lower limit. An alternative is Soil Water Express, a tool that uses the soil's texture, salinity and bulk density to predict PAWC and convert electronic sensor output to meaningful soil-water information (mm available water). [22]

Modelling of soil water

Simulation of the water balance should be considered as an alternative to field-based soil-water monitoring. Considering the error surrounding in-field measurement and issues with installation of sensing devices, there is a reasonable argument that the modelling of the water balance, when initialised with accurate PAWC and daily climate information, is likely to be as accurate as direct measurement.

More information

GRDC Update Papers: New technology for measuring and advising on soil water

APSIM (Agricultural Production Systems Simulator) and Yield Prophet® successfully predict soil water and they should be considered for both fallow and cropping situations. CliMate is a good choice for managing fallow water. [23]

Subsoil constraints

More information

GRDC Update Papers: Subsoil constraints: impacts of crop type, variety and agronomy on crop performance

Soils with high levels of chloride and/or sodium in their subsurface layers are often referred to as having subsoil constraints. There is growing evidence that these constraints affect wheat yields by increasing the lower limit of a crop's available soil water and thus reducing the soil's PAWC.[24]

Effect of strategic tillage

Research showed that one-time tillage with a chisel plough or an offset disc in long-term- no-tillage helped to control winter weeds, and slightly improved grain yields and profitability, while retaining many of the soil-quality benefits of no-till farming systems.

Tillage reduced soil moisture at most sites; however, this decrease in soil moisture did not adversely affect productivity. This could be due to good rainfall received after tillage, prior to seeding in these years.

21 J Foley (2013) A 'how to' for getting soil water from your EM38 field measurements. GRDC Update Papers Goondiwindi, 5 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/A-how-to-for-getting-soil-water-from-your-EM38-field-measurements

22 L Burk, N Dalgliesh (2012) Soil Water Express—a system to generate approximate soil water characterisations and current soil water estimates from minimal input data. 16th Australian Agronomy Conference 2012, http://www.regional.org.au/au/asa/2012/soil-water-management/8164_dalgleishn.htm

23 N Dalgliesh, N Huth (2013) New technology for measuring and advising on soil water. GRDC Update Papers Goondiwindi, 5 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/New-technology-for-measuring-and-advising-on-soil-water

24 Z Hochman *et al.* (2007) Simulating the effects of saline and sodic subsoils on wheat crops growing on Vertosols. *Australian Journal of Agricultural Research* 58, 802–810., http://www.publish.csiro.au/paper/AR06365.htm

More information

[GRDC Update Papers: The strategic use of tillage in conservation farming]

[GRDC Fact Sheets: Is there room for strategic tillage in a no-till system?]

[GRDC Update Papers: Tillage impact in long-term no-till]

Video

[Strategic tillage]

Rainfall between the tillage and sowing or immediately after sowing is necessary to replenish soil water lost from the seed-zone. This suggests the importance of timing of tillage and of considering the seasonal forecast. Future research will determine the best timing for strategic tillage in no-till systems. [25] Note that these results are from one season and research is ongoing, so any impacts are likely to vary with subsequent seasonal conditions (Figure 5).

Figure 5: Strategic tillage trials are under way at sites across eastern Australia. (Photo: Yash Dang)

1.6.2 Irrigation

Wheat responds well to irrigation. Critical periods for water are at tillering and flowering. Water requirements (in-crop) after starting with a full profile are ~3 ML/ha. The WUE for wheat ranges between 10 and 20 kg/mm soil water.ha. As an example, if the expected yield output is 15 kg/mm and the yield target is 4.5 t/ha, the water required would be ~300 mm or 3 ML irrigation water/ha (assuming no in-crop rainfall and a full moisture profile).

Consider near-infrared plant tissue testing in-crop to determine side-dressing rates of N to obtain optimum yield and protein levels. [26]

Growing irrigated wheat in southern New South Wales and northern Victoria is more than simply adding water to dryland varieties. Higher yields require increased monitoring and correct management practices to avoid yield penalties:

- Growing 8 t/ha of irrigated wheat requires more monitoring and management than 5 t/ha.
- Variety selection is integral to success for high grain-yield potential.
- Nitrogen supply at sowing should be 100–120 kg/ha, (this will include the amount already in the soil profile).

More information

[GRDC Update Papers: Finley irrigated wheat, canola and faba bean systems results 2014]

[GRDC Fact Sheets: Irrigated wheat in the Murrumbidgee, Murray. Lifting yields from 5 t/ha to 8 t/ha or more]

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

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/08/Sowing-date-heat-stress-and-frost-risk-in-irrigated-wheat-crops

[25] Y Dang, V Rincon-Florez, C Ng, S Argent, M Bell, R Dalal, P Moody, P Schenk et al. (2013) Tillage impact in long term no-till. GRDC Update Papers, 27 Feb. 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Tillage-impact-in-long-term-no-till

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

More information

GRDC Update Papers: Leading farmers have closed the yield gap

GRDC Update Papers: Managing resources and risk for 8 tonne cereal crops

DAF Qld: Wheat—planting information

DAF Qld: Managing water resources

GRDC Update Papers: Irrigation and automation—a look to the future

- To prevent lodging, avoid shoot numbers >800/m^2 at the first-node stage (Zadoks growth stage 31) through precise seed-rate calculation and placement. Use varieties with a lodging rating closer to 1 than 9.
- Maintain three green leaves per shoot at flowering through use of N topdressing, timely irrigations, and foliar fungicides for stripe rust and other diseases.
- Use a layout that allows irrigation and drainage in under 12 h. [27]

1.7 Yield and targets

Australia's climate, and in particular rainfall, is among the most variable on Earth; consequently, crop yields vary from season to season. In order to remain profitable, crop producers must manage their agronomy, crop inputs, marketing and finance to match each season's yield potential. [28]

Before planting, identify the target yield required to be profitable (Figure 6):

- Do a simple calculation to see how much water you need to achieve this yield.
- Know how much soil water you have (treat this water like money in the bank).
- Think about how much risk your farm can take.
- Consider how this crop fits into your cropping plan—will the longer term benefits to the system outweigh any short-term losses?
- Avoiding a failed crop saves money now and saves stored water for future crops. [29]

More information

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

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Yield-Prophet-What-difference-can-it-make-to-crop-decision-making

.http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Managing-data-on-the-modern-farm

Figure 6: Before planting, identify the target yield. (Photo: Yash Dang)

Soil tests are available to assist in the assessment of paddock nutrient status.

27 GRDC (2014) Lifting yields from 5t/ha to 8t/ha … or more. Irrigated Wheat in the Murrumbidgee, Murray Fact Sheet, GRDC, 30 April 2014, http://www.grdc.com.au/GRDC-FS-IrrigatedWheatNSWVic

28 T McClelland (2012) Yield- Prophet®—What difference can it make to crop decision making? GRDC Update Papers, 6 February 2012, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Yield-Prophet-What-difference-can-it-make-to-crop-decision-making

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

Adequate phosphorus (P) is essential for the early growth of wheat (Table 3). Most Victorian soils are low in available P, and it is critical that some P and much of the crop requirement will need to be supplied through the application of fertilisers at sowing time. Paddock history of P application and crop yields in conjunction with soil test results and economics of application will determine the rates required.

The rule of thumb is a requirement for 3 kg/ha of available P for each tonne of wheat anticipated. The application may then be adjusted in the light of soil test results.

Table 3: Adequate soil phosphorous ranges for different soil types

Soil test reading (Colwell P)	Soil type
20–30 mg/kg	Sand
25–35 mg/kg	Loam
30–40 mg/kg	Clay

Nitrogen (N) availability is equally important. Besides its role in plant growth, the availability of soil N at grainfill, along with soil moisture, is the key determinant of grain protein. The farmer has a high degree of control over N build-up and availability through the choice of crop sequences, use of long fallow and tillage methods. The availability of N in the soil is affected by many factors: soil organic matter, paddock history including fallowing, soil type, moisture content, time of year and tillage methods. High yields are a drain on soil N. Conversely, low yield and summer rain to mineralise N can mobilise soil N for the next crop. Soil tests for N should be done as close as possible to sowing time and at the same time each year.

Cropping advisors are a good source of support in determining fertiliser application strategies. [30]

1.7.1 Yield Prophet®

Scientists have aimed to support farmers' capacity to achieve yield potential by developing APSIM. APSIM is a farming systems model that simulates the effects of environmental variables and management decisions on crop yield, profits and ecological outcomes.

Yield Prophet® is an online crop-production model designed to present grain growers and consultants with real-time information about their crops. This tool provides growers with integrated production risk advice and monitoring of decision-support relevant to farm management.

Yield Prophet® delivers information from APSIM to farmers (and consultants) to aid their decision-making. Yield Prophet® has had some acceptance and adoption amongst innovative farmers and has made valuable impacts in terms of assisting farmers to manage climate variability at a paddock level.

Operated as a web interface for APSIM, Yield Prophet® generates crop simulations and reports. By matching crop inputs with potential yield in a given season, Yield Prophet® subscribers may avoid over- or under-investing in their crop. This is achieved primarily by conducting scenario analyses in which the effects of alternative management options on crop yield and potential profitability can be assessed and applied, and can thereby influence decision-making. The simulations provide a framework for farmers and advisers to:

- forecast yield
- manage climate and soil water risk
- make informed decisions about N and irrigation applications
- match inputs with the yield potential of their crop
- assess the effect of changed sowing dates or varieties
- assess the possible effects of climate change

30 http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat

More information

[GRDC Update Papers: Yield Prophet—what difference can it make to crop decision making?]

[Soil Quality Pty Ltd: Calculators—wheat yield potential calculator]

How does it work?

Yield Prophet® generates crop simulations that combine the essential components of growing a crop including:

- a soil test sampled prior to planting
- a soil classification selected from the Yield Prophet® library of ~1000 soils, chosen as representative of the production area
- historical and active climate data taken from the nearest Bureau of Meteorology weather station
- paddock-specific rainfall data recorded by the user (optional)
- individual crop details

1.7.2 Seasonal outlook

Growers and advisers now have a readily available online tool. CropMate was developed by NSW Department of Primary Industries and can be used in pre-season planning to analyse average temperature, rainfall and evaporation. It provides seasonal forecasts and information about influences on climate, such as the impact of Southern Oscillation Index (SOI) on rainfall. The CropMate decision tool provides estimates of soil water and soil N, and frost and heat risk, as well as gross margin analyses of the various cropping options (Figure 7).

Download CropMate from the App Store on iTunes at: https://itunes.apple.com/au/app/cropmate-varietychooser/id476014848?mt=8

Figure 7: Screen shot of CropMate app. (Photo: NSW DPI)

For tips on understanding the drivers of weather and climate, including the SOI, visit the Climate Kelpie website. Case studies of farmers across Australia recruited as 'Climate Champions' as part of the Managing Climate Variability Climate Champion Program can also be accessed at the Climate Kelpie website.

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

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

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

More information

GRDC Update Papers: Practical production risk management—matching inputs with seasonal outlook

Climate Kelpie: Climate Champion Program

GRDC Update Papers: Seasonal climate outlook improvements—changes from historical to real-time data

Australian CliMate

GRDC: Managing frost risk—a guide for southern Australian grains

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

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

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

As outputs, text and two graphical presentations are used to show the current season in the context of the average and all years. Departures from the average are shown in a fire-risk chart as the departure from the average in units of standard deviation. [31]

The Bureau of Meteorology has moved from a statistics-based to a physics-based (dynamical) model for its seasonal climate outlooks. The new system has better overall skill, is reliable, allows for incremental improvements in skill over time, and provides a framework for new outlook services including multi-week or monthly outlooks and the forecasting of additional climate variables. [32]

1.7.3 Water-use efficiency

Water-use efficiency is the measure of a cropping system's capacity to convert water into plant biomass or grain. It includes the use of water stored in the soil and rainfall during the growing season. It relies on:

- the soil's ability to capture and store water
- the crop's ability to access water stored in the soil and rainfall during the season
- the crop's ability to convert water into biomass
- the crop's ability to convert biomass into grain

More information

GRDC Update Papers: Dryland water-use efficiency—what is it and how to improve it

GRDC Update Papers: Opportunities with liquid systems

GRDC Fact Sheets: Water use efficiency. Converting rainfall to grain. Northern Region

Water-use efficiency can be considered at several levels:

- Fallow efficiency is the efficiency with which rainfall during a fallow period is stored for use by the following crop.
- Crop WUE is the efficiency with which an individual crop converts water transpired (or used) to grain.
- Systems WUE is the efficiency with which rainfall is converted to grain over multiple crop and fallow.

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

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

Ways to increase yield

In environments where yield is limited by water availability, there are four ways of increasing yield: [33]

1. Increase the amount of water available to a crop (e.g. good summer weed control, stubble retention, long fallow, sowing early to increase rooting depth).
2. Increase the proportion of water that is transpired by crops rather than lost to evaporation or weeds (e.g. early sowing, early N, vigorous crops and varieties, narrow row spacing, high plant densities, stubble retention, good weed management).
3. Increase the efficiency with which crops exchange water for carbon dioxide to grow dry matter, i.e. transpiration efficiency (e.g. early sowing, good nutrition, varieties with high transpiration efficiency such as Spitfire⁽ᵇ, Scout⁽ᵇ, Drysdale⁽ᵇ, Gregory⁽ᵇ).
4. Increase the total proportion of dry matter that is grain, i.e. improve the harvest index (e.g. early-flowering varieties, delayed N, wider row spacing, low plant densities, minimising losses to disease, varieties with high harvest index such as H45⁽ᵇ, Hindmarsh⁽ᵇ, Wyalkatchem⁽ᵇ, Espada⁽ᵇ).

More information

[GRDC Update Papers: How much water is lost from northern crop systems by soil evaporation]

The French–Schultz approach

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

In this model, potential crop yield is estimated as:

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

where crop water supply is an estimate of water available to the crop, i.e. soil water at planting plus in-crop rainfall minus soil water remaining at harvest. Typical estimates of WUE and soil evaporation are listed in Table 4.

We use a target WUE of 18 kg/ha/mm for wheat. From our benchmarking in 2014 of 149 wheat paddocks, 11% achieved this target, 46% achieved between 13 and 17 kg/ha/mm.

A practical WUE equation for farmers to use developed by James Hunt (CSIRO) is:

WUE = (yield x 1000) / available rainfall

Where avail rain = (25% Nov-Mar rain) + (GSR) – 60 mm evap

Agronomist's view

The French–Schultz model has been useful in giving growers performance benchmarks. Where yields fall well below these benchmarks, it may indicate something wrong with the crop's agronomy or a major limitation in the environment. There could be hidden problems in the soil such as root diseases, or soil constraints affecting yields. Alternatively, apparent underperformance could be simply due to seasonal rainfall distribution patterns, which are beyond the grower's control. [34]

[33] JB Passioura, JF Angus (2010) Improving productivity of crops in water-limited environments. (Ed. DL Sparks) Advances in Agronomy, Vol. 106, pp. 37–75, Academic Press, http://www.sciencedirect.com/science/article/pii/S0065211310060025

[34] *GRDC (2009) Water use efficiency—convertingConverting rainfall to grain. GRDC Fact Sheet Northern Region. Water Use Efficiency Fact Sheet, GRDC,* http://www.grdc.com.au/~/media/607AD22DC6934BE79DEAA05DFBE00999.pdf

More information

https://publications.csiro.au/rpr/download?pid=csiro:EP156113&dsid=DS2

Table 4: Typical parameters that could be used in the French–Schultz equation

Crop	Water-use efficiency (kg/ha.mm)	Soil evaporation (mm)
Wheat	18	100
Chickpea	12	100

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

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

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

More information

GRDC Update Papers: Farming systems design and water use efficiency—challenging the French–Schultz model

Researchers have analysed some of the consequences of the shift from winter to summer rainfall between southern and northern regions in terms of implications for management and breeding. They advise caution on the use of simple rules of thumb (French–Schultz) for benchmarking WUE, and discuss the importance of more integrative and dynamic modelling approaches to explore alternatives to increase WUE at the single-crop and whole-farming-systems level, i.e. $/ha.mm. [35]

1.7.4 Nitrogen-use efficiency

Soil type, rainfall intensity and the timing of fertiliser application largely determine N losses from dryland cropping soils.

Insufficient rainfall after surface application of N fertilisers can result in losses from the soil through volatilisation. The gas lost in this case is ammonia. Direct measurements of ammonia losses have found that they are generally <15% of the N applied, even less with in-crop situations. An exception occurred with the application of ammonium sulphate to soils with free lime at the surface, where losses were >25% of the N applied. Recovery of N applied in-crop requires sufficient in-crop rainfall for plant uptake from otherwise dry surface soil. [36]

A balance of nutrients is essential for profitable yields. Fertiliser is commonly needed to add the essential nutrients P and N. Lack of other essential plant nutrients may also limit production in some situations.

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

1.8 Disease status of the paddock

1.8.1 Soil testing for disease

PreDicta B (B = broadacre) is a DNA-based soil testing service to identify which soilborne pathogens pose a significant risk to broadacre crops prior to seeding.

It has been developed for cropping regions in southern Australia and includes tests for:

- cereal cyst nematode

[35] D Rodriguez (2008) Farming systems design and water use efficiency (WUE). Challenging the French & Schultz WUE model. GRDC Update Papers, 13 June 2008, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2008/06/Farming-systems-design-and-water-use-efficiency-WUE-Challenging-the-French-Schultz-Wue-model

[36] G Schwenke, P Grace, M Bell (2013) Nitrogen use efficiency. GRDC Update Papers 16 July 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Nitrogen-use-efficiency

- take-all (*Gaeumannomyces graminis var. tritici* and *G. graminis var. avenae*)
- Rhizoctonia bare patch (*Rhizoctonia solani* AG8)
- crown rot (*Fusarium pseudograminearum*)
- root-lesion nematode (*Pratylenchus neglectus* and *P. thornei*)
- stem nematode (*Ditylenchus dipsaci*)

Southern region grain producers can access PreDicta B via agronomists accredited by the South Australian Research and Development Institute (SARDI) to interpret the results and provide advice on management options to reduce the risk of yield loss.

PreDicta B samples are processed weekly from February to mid-May (prior to crops being sown) to assist with planning the cropping program.

The service is not intended for in-crop diagnosis, which is best achieved by sending samples of affected plants to your local plant pathology laboratory.

More information

SARDI: Predicta B

1.8.2 Effects of cropping history

Continuous cereal cropping increases the risk of diseases including crown rot and tan spot. All winter cereals and many grassy weeds host crown rot, and it can survive for many years in infected plant residues. Infection can occur when plants come in close contact with those residues. [37]

Stubble burning is not recommended as a control for crown rot, and cultivation can increase the incidence of seed–stubble contact. Inter-row sowing is a recommended strategy.

High cereal intensity and inclusion of durum wheat in cropping programs are factors that increase levels of crown rot. [38]

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

- durum wheat in the past 1–3 years
- winter cereal or a high grass burden from last season—crown rot fungus survives in winter cereal residues, dense stubble cover or where dry conditions have made residue decomposition slow
- break crops, which can influence crown rot in cereals by manipulating the amount of nitrogen (N) and moisture left in the soil profile
- paddocks that have high levels of N at sowing and/or low stored soil moisture at depth [39]
- wheat varieties grown in previous years [40,41]

More information

GRDC Fact Sheets: Grain protectants prevent pests

[37] GRDC (2012) Crown rot—about the crown rot disease. GRDC Hot Topics, 10 July 2012, http://www.grdc.com.au/Media-Centre/Hot-Topics/Crown-Rot

[38] GRDC (2012) Crown rot—about the crown rot disease. GRDC Hot Topics, 10 July 2012, http://www.grdc.com.au/Media-Centre/Hot-Topics/Crown-Rot

[39] GRDC (2009) Understanding the disease underpins effective management. Southern and Western Region. Crown rot in cereals. GRDCCereals Fact Sheet, GRDC, May 2009, https://www.grdc.com.au/~/media/AF642FA0A889465089D2B6C59E5CA22E.pdf

[40] R Brill, S Simpfendorfer (2013) Resistance of eighteen wheat varieties to the root lesion nematode Pratylenchus thornei—Trangie 2011. In: NSW DPI Northern Grains Region Trial Results Autumn 2013, pp. 129–131, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf

[41] R Brill, S Simpfendorfer (2013) Resistance of eighteen wheat varieties to the root lesion nematode *Pratylenchus thornei*—Trangie 2011. In: NSW DPI Northern Grains Region Trial Results Autumn 2013, pp. 129–131, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf

1.9 Nematode status of the paddock

1.9.1 Nematode testing of soil

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

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

It is important to know which species are present because some crop-management options are species-specific. If a particular species is present in high numbers, immediate decisions must be made to avoid losses in the next crop to be grown. With low numbers, it is important to take decisions to safeguard future crops. Learning that a paddock is free of these nematodes is valuable information because steps may be taken to avoid future contamination of that field. [42]

Testing of soil samples taken before a crop is sown provides valuable information.

More information

Agriculture Victoria: Collecting soil and plant samples for nematode analysis

1.9.2 Effects of cropping history on nematode status

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

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

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

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

The main tool for managing nematodes is growing resistant crops. In the case of crops such as wheat or chickpeas, choose the most tolerant variety available and rotate with resistant crops to keep nematode numbers at low levels. Information on the responses of crop varieties to root-lesion nematodes is regularly updated in grower planting guides. Note that crops and varieties have different levels of tolerance and resistance to *Pratylenchus thornei* and *P. neglectus* (see Table 5). [43]

Table 5: Susceptibility and resistance of various crops to root-lesion nematodes [44]

RLN species	Susceptible	Intermediate	Resistant
Pratylenchus thornei	Wheat, chickpeas, faba beans, barley, mungbeans, navy beans, soybeans, cowpeas	Canola, mustard, triticale, durum wheat, maize, sunflowers	Canary seed, lablab, linseed, oats, sorghum, millet, cotton, pigeon peas
Pratylenchus neglectus	Wheat, canola, chickpeas, mustard, sorghum (grain), sorghum (forage)	Barley, oats, canary seed, durum wheat, maize, navy beans	Linseed, field peas, faba beans, triticale, mungbeans, soybeans

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

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

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

For more information, download GRDC Tips and Tactics—Root-lesion nematodes and see GrowNotes Wheat South Section 8. Nematodes.

1.10 Insect and pest status of paddock

1.10.1 Sampling of soil for insects

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

- cockroaches
- crickets
- earwigs
- black scarab beetles
- cutworms
- false wireworm
- true wireworm

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

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

More information

DAFWA: Identifying soil beetle pests

Soil insect control measures are normally applied at sowing. Different insects require different control measures; therefore, the species of soil insects must be identified before planting.

Soil sampling by spade

1. Take a number of spade samples from random locations across the field.
2. Check that all spade samples are deep enough to take in the moist soil layer (this is essential).
3. Hand-sort samples to determine type and number of soil insects.

Germinating-seed bait technique

Immediately following planting rain:

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

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

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

More information

GRDC Update Papers: Surveillance and forecasts for mouse outbreaks in Australian cropping systems

GRDC Ground Cover: Mouse management a numbers game

GRDC Fact Sheets: Mouse control—Western Region

GRDC Hot Topics: Snail control before seeding

VNTFA: Slugs

Video

Mouse management

Detecting soil-dwelling insects

Soil insects are often difficult to detect; they hide under trash or in the soil. Immature insects such as false wireworm larvae are usually found at the moist–dry soil interface.

For current chemical control options, see the websites of Pest Genie Australia or APVMA. [45]

1.10.2 Mouse management

During years of high mouse activity, young winter crops can be severely damaged. Growers need to monitor crops closely and determine whether zinc phosphide baiting should be carried out to reduce damage to summer crops and protect newly sown winter crops. Growers are reminded that there is a 2-week withholding period for zinc phosphide baits prior to harvest. Talk to your neighbours and coordinate a baiting program to reduce reinvasion. [46]

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

[46] J Farrell, PR Brown (2014) Mouse plague prediction models: relevant forecasts for growers in Queensland. GRDC Update Papers, 5 March 2014, http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Mouse-plague-prediction-models-relevant-forecasts-for-growers-in-Queensland