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GRDC GROWNOTES™

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GRAINS RESEARCH & DEVELOPMENT CORPORATION

BARLEY

SECTION 1

PLANNING AND PADDOCK PREPARATION

AGRONOMY TIPS AT A GLANCE | PADDOCK SELECTION | PADDOCK ROTATION AND HISTORY | BENEFITS OF BARLEY AS A ROTATION CROP | DISADVANTAGES OF CEREALS AS A ROTATION CROP | FALLOW WEED CONTROL | FALLOW CHEMICAL PLANT-BACK EFFECTS | SEEDBED REQUIREMENTS | SOIL MOISTURE | YIELD AND TARGETS | DISEASE STATUS OF PADDOCK | NEMATODE STATUS OF PADDOCK | INSECT STATUS OF PADDOCK | MOUSE MANAGEMENT

SECTION 1

Planning/Paddock preparation

More information

Barley Agronomy for the Southern Region 2010-2013

Barley agronomy in southern NSW

Salinity tolerance of barley expressing an Arabidopsis vacuolar pyrophosphatase gene

1.1 Agronomy tips at a glance

- Plant barley as early as possible in its recommended window.
- Plant into good moisture conditions.
- Aim for a plant population of 100–150 plants/m.
- Use good quality treated planting seed.
- Use soil testing and fertilise to achieve protein of 10–11% (dry basis).
- Malting barley requires only ~40% of the nitrogen (N) needed to grow prime hard wheat.
- Good levels of phosphorus (P) are also important.
- Harvest as soon as possible. [1]

1.2 Paddock selection

Paddock selection is critical for reliable malting barley production. When selecting paddocks to grow barley, consider the following:

- Nitrogen (N) status appropriate for expected yield level
- soil pH($CaCl_2$) not <5.0 or soil aluminium not >5%
- avoid soils prone to waterlogging
- rotation—ideally sow after a root-disease break crop
- avoid barley on barley
- barley may be sown after wheat if disease or seed contamination is not a problem
- avoid varietal contamination

Southern grains region research results suggest paddocks with pre-sowing soil nitrate-N levels >150 kg/ha are unsuitable for malting barley production. Paddocks with pre-sowing nitrate-N between 100 and 150 kg/ha were at increased risk of not achieving barley of malting quality compared with those with <100 kg/ha. [2]

Informed paddock selection, suitable crop rotation and the planting of disease-resistant varieties are the best tools to minimise disease. A table of disease ratings for current varieties can be found in the NSW DPI 'Winter crop variety sowing guide' and Department of Agriculture, Fisheries and Forestry Queensland (DAFF) 'Barley—planting and disease guide 2013 for Queensland and northern New South Wales'. [3]

1 DAFF (2011)Barley malting, feed varieties and sowing times. Department of Agriculture, Fisheries and Forestry Queensland. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/malting,-feed-varieties-and-sowing-times

2 L Lenaghan, T Fay, M. Evans (2001) Paddock selection is critical for reliable malt barley production, Department of Natural Resources and Environment, Victoria. http://www.regional.org.au/au/asa/2001/4/b/lenaghan.htm

3 NSW DPI Agronomists (2007) Wheat growth and development. NSW Department of Primary Industries. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/449367/Procrop-wheat-growth-and-development.pdf

Paddock selection is an important consideration for crown rot management in particular, and cereal growers should select paddocks with a low risk of the disease. Determine paddock risk by visually assessing crown rot and root-lesion nematode (RLN) (see section below) levels in a prior cereal crop, paying attention to basal browning, and/or by having soil samples analysed at a testing laboratory.

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 stubble 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 N and moisture left in the soil profile
- paddocks that have high N at sowing and/or low stored soil moisture at depth [4]

1.3 Paddock rotation and history

Crop sequencing is a key part of a long-term approach to tackling weed, disease and moisture challenges in northern grains region farming systems. Nitrogen-fixing summer and winter pulses are gaining increasing popularity as cereal breaks.

GRDC-supported research aims to increase the profitability of minor rotation crops such as faba beans by improving pest and disease resistance.

Development of new varieties is boosting yields of potential rotation crops and disease resistance, and the potential fit of sorghum as part of the rotation in western areas is the subject of further research. [5]

It is important to consider the impact of preceding crops that build up RLN species, *Pratylenchus thornei* and *P. neglectus.*

A tolerant crop yields well when large populations of RLN are present (the opposite is an intolerant crop). A resistant crop does not allow RLN to reproduce and increase in number (the opposite is a susceptible crop).

Table 1: Susceptibility and resistance of various crops to root-lesion nematodes [6]

RLN species	Susceptible	Intermediate	Resistant
Pratylenchus thornei	Wheat, chickpea, faba bean, barley, mungbean, navy bean, soybean, cowpea	Canola, mustard, triticale, durum wheat, maize, sunflower	Canary seed, lablab, linseed, oats, sorghum, millet, cotton, pigeon pea
Pratylenchus neglectus	Wheat, canola, chickpea, mustard, sorghum (grain), sorghum (forage)	Barley, oat, canary seed, durum wheat, maize, navy bean	Linseed, field pea, faba bean, triticale, mungbean, soybean

1.3.1 Long fallow disorder

Soils naturally contain beneficial fungi that help crops to access nutrients such as P and zinc (Zn). The combination of the fungus and crop root is known as arbuscular mycorrhiza(e) (AM). 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.

4 M Evans, G Hollaway, S Simpfendorfer (2009) Crown rot—cereals. GRDC Fact Sheet, May 2009. http://www.grdc.com.au/Resources/Factsheets/2009/05/Crown-Rot-in-Cereals-Fact-Sheet-Southern-Western-Regions

5 R Daniel, S Simpfendorfer, L Serafin, G Cumming, R Routley, (2011) Choosing Rotation Crops: Short-term profits, long-term payback. GRDC Fact Sheet March 2011. http://www.grdc.com.au/~/media/9219D55FFB4241DC9856D6B4C2D60569.pdf

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

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 fallow periods. As cropping programs restart after dry years, an unexpected yield drop is likely due to reduce AM levels, making it difficult for the crop to access nutrients.

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

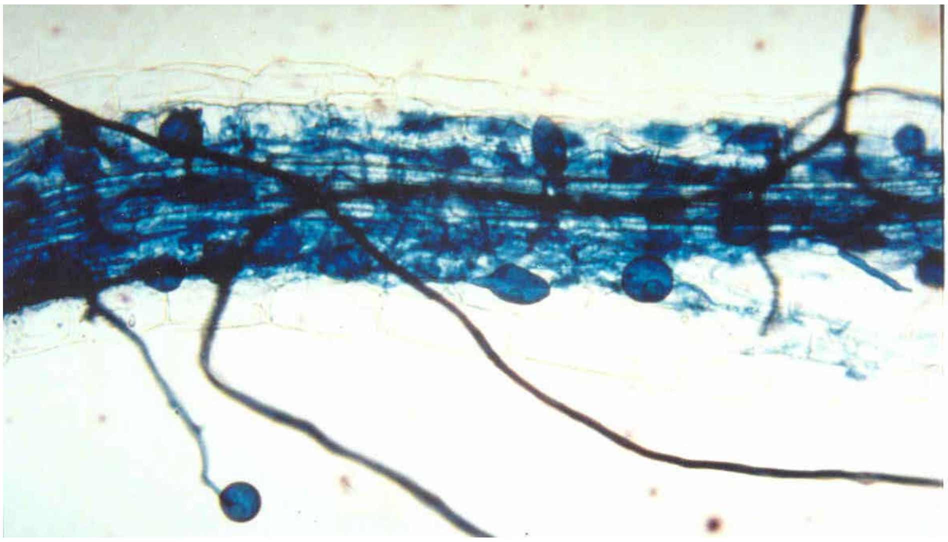

Figure 1: AM pictured in a wheat root. (Photo: QDAFF)

Benefits of good AM levels are:

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

In general, the benefits of AM are greater at lower soil P levels because AM increase a plant's ability to access this nutrient. Crops with higher dependency benefit more from AM.[7]

Table 2: The 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	Sunflower, mungbean, pigeonpea, maize, chickpea
Medium	40–60	Sudan grass, sorghum, soybean
Low	10–30	Wheat, barley, triticale
Very low	0–10	Panicum, canary grass
Nil	0	Canola, lupins

[7] DAFF (2010) Nutrition—VAM and long fallow disorder. Department of Agriculture, Fisheries and Forestry, Queensland. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/nutrition-vam

1.4 Benefits of barley as a rotation crop

Barley is a good rotation crop for breaking disease and weed cycles, and providing high stubble levels. [8] It fits well into the northern farming systems as a winter cereal crop.

Advantages of barley include:

- less susceptible to frost than wheat
- lower N fertiliser requirements than wheat
- matures faster and can be harvested earlier than wheat.
- vigorous plant growth and high water-use efficiency (WUE)—an excellent choice for double-cropping from a summer crop back to a winter rotation
- vigorous early growth—establishes ground cover which smothers weeds and produces early grazing
- produces more dry matter than wheat, leaving very good stubble cover and valuable straw for livestock feeding
- a good choice for silage, hay or early grazing—can regrow to produce a good grain crop when grazed before stem elongation
- a good break crop due to differences in foliar disease responses compared with wheat
- has varieties which produce good early biomass and can act as an effective weed competitor
- has varieties which are very erect and can be used as an effective cover crop for undersowing pastures

Growers should soil-test and record paddock rotations to determine adequate crop nutrition. A 4 tonne (t) per ha barley crop at 11.5% protein uses about 144 units of N and some P. [9]

1.5 Disadvantages of cereals as a rotation crop

Growing cereals in continuous production is a practice largely of the past in the northern grains region due to 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 depletion and declining soil fertility

Crop rotation is a key strategy for managing northern farming systems and improvements in legume and oilseed varieties and 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 financial profitability of the entire rotation is assessed, is it more profitable to include broadleaf crops.

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 could be considerably better if it was considered across the crop sequence. [10]

[8] DAFF (2012) Barley planting, nutrition and harvesting. Department of Agriculture, Fisheries and Forestry Queensland. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

[9] DAFF (2013) Barley planting and disease guide. Department of Agriculture, Fisheries and Forestry Queensland. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

[10] M Peoples (2012) Returns-from-break-crops-can-challenge-wheat. Crop Sequencing Supplement, GRDC Ground Cover Issue 98, 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

Leading growers and advisers advocate sustainable rotations as a valuable strategy for northern farming systems. In a survey of leading growers it was reported that those adopting farming systems based on best management practices allocated about 25% of their winter cropping area to chickpea or other broadleaf crops.

Their major motivation for introducing a non-cereal was to break the crown rot cycle and, consequently, improve profitability. The growers reported in the survey that wheat crops following a rotation crop averaged up to 1 t/ha extra yield as well as an additional 1% grain protein. In addition, the growers reported savings in N and weed-control inputs.

Many growers are sacrificing cereal yield and protein by not adopting current research findings on the use of rotations. [11]

1.6 Fallow weed control

Controlling summer weeds is the most effective way to conserve soil moisture during the summer fallow period. Aim to control weeds as early as possible. Paddocks generally have multiple weed species present at the same time, making weed-control decisions more difficult and often involving a compromise of control via assessment of the prevalence of key weed species. Knowing your paddock is imperative to good fallow weed control. While GRDC and other sources provide general information on common problem weeds, growers are advised to contact their agronomists for individual paddock advice.

Benefits of fallow weed control include conservation of summer rain and fallow moisture, which is integral to winter cropping in the Northern Region, particularly as the climate moves towards summer-dominant rainfall. Remember this can include moisture stored from the previous winter or the summer before in a long fallow. [12]

Return on investment from the control of summer weeds is commonly calculated at $6.00 for every $1.00 invested.

1.6.1 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 tactic. Most commonly used for pre-sowing weed control, this concept can also be applied in-crop. [13]

Consider the species present, interval timing and water rate. For information on double-knock tactics, download the GRDC Herbicide Application Fact Sheet: 'Effective double knock herbicide applications northern region'.

Double-knock herbicide strategies are useful tools for managing difficult-to-control weeds but there is not a one-size-fits-all treatment.

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

Critical factors for successful double-knock approaches are to apply the first application on small weeds and ensure good coverage and adequate water volumes, particularly when using products containing paraquat. Double-knock strategies are certainly

[11] R Daniel, S Simpfendorfer, L Serafin, G Cumming, R Routley (2011) Choosing rotation crops: Short-term profits, long-term payback. GRDC Fact Sheet March 2011. http://www.grdc.com.au/~/media/9219D55FFB4241DC9856D6B4C2D60569.pdf

[12] GRDC (2012) Summer fallow management. GRDC Fact Sheet, January 2012. https://www.grdc.com.au/Resources/Publications/2014/05/Summer-fallow-weed-management

[13] C Borger, V Stewart, A Storrie Double knockdown or 'double knock', Agriculture WA.

not bullet-proof and are rarely effective for salvage weed control situations unless environmental conditions are exceptionally favourable.

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

1. Glyphosate-resistant and tolerant weeds are a major threat to our reduced tillage cropping systems.
2. Although residual herbicides will limit re-cropping options and will not provide complete control, they are a key part of successful fallow management.
3. Double-knock herbicide strategies are useful tools but the herbicide choices and optimal timings will vary by weed species.
4. Other weed management tactics, e.g. crop competition, should be incorporated to assist herbicide control.
5. Cultivation may need to be considered as an option to avoid seed-bank salvage.

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

1. ABYG (*Echinochloa colona*)
2. Flaxleaf fleabane (*Conyza bonariensis*)
3. Feathertop Rhodes grass (FRG) (*Chloris virgata*)
4. Windmill grass (*Chloris truncata*) [14]

More information

http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Weeds-and-resistance-considerations-for-awnless-barnyard-grass-Chloris-spp-and-fleabane-management

Awnless barnyard grass

Figure 2: Awnless barnyard grass. (Photo: Rachel Bowman)

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

1. Multiple emergence flushes (cohorts) each season
2. Easily moisture stressed, leading to inconsistent knockdown control

[14] R Daniel (2013) Weeds and resistance—considerations for awnless barnyard grass, *Chloris* spp. and fleabane management, Northern Grower Alliance. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Weeds-and-resistance-considerations-for-awnless-barnyard-grass-Chloris-spp-and-fleabane-management

3. Glyphosate-resistant barnyard grass populations are more frequently found

Key points

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

Resistance levels

Prior to summer 2011–12, there were 21 cases of glyphosate-resistant ABYG. Collaborative survey work was conducted by NSW DPI, DAFF and NGA in summer 2011–12 with a targeted follow-up in 2012–13. Agronomists from the Liverpool Plains to the Darling Downs and west to areas including Mungindi collected ABYG samples that were tested at the Tamworth Agricultural Institute with Glyphosate CT at 1.6 L/ha at a mid-tillering growth stage. Total application volume was 100 L/ha.

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

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

Residual herbicides (fallow and in-crop)

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

Double-knock control

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

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

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

Flaxleaf fleabane

Figure 3: Flaxleaf fleabane. (Photo: QDAFF)

There are three main species of fleabane in Australia: *Conyza bonariensis* (flaxleaf fleabane), *C. Canadensis* (Canadian fleabane) and *C. albida* (tall fleabane). There are two varieties of *C. canadensis*, var. *canadensis* and var. *pusilla*. Of the three species, flaxleaf fleabane is the most common across Australia. [15]

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

One of the key issues with fleabane is that knock-down control of large plants in the summer fallow is variable and can be expensive due to reduced control rates.

Key points

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

15 MI Widderick, H Wu, Fleabane, Agriculture WA

Resistance levels

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

Residual herbicides (fallow and in-crop)

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

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

Knockdown herbicides (fallow and in-crop)

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

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

Double-knock control

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

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

Feathertop Rhodes grass

Figure 4: Feathertop Rhodes grass. (Photo: Rachel Bowman)

Feathertop Rhodes grass has emerged as an important weed management issue in southern Queensland and northern NSW since ~2008. It is another small-seeded weed species that germinates on, or close to, the soil surface. It has rapid early growth rates and can become moisture-stressed quickly. Although FTR is well established in central Queensland, it is still largely an emerging threat further south. Try to aggressively treat the patches to avoid whole-of-paddock blow-outs.

Key points

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

Residual herbicides (fallow and in-crop)

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

Double-knock control

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

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

- Group A herbicides generally have narrower windows of weed growth stage for successful use than herbicides such as glyphosate i.e. Group A herbicides will generally give unsatisfactory results on flowering and/or moisture-stressed FTR.
- Not all Group A herbicides are effective on FTR.

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

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

Windmill grass

Figure 5: Windmill grass. (Photo: Maurie Street)

While FTR has been a grass weed threat coming from Queensland and heading south, windmill grass is more of an issue in central NSW and is spreading north. Windmill grass is a perennial, native species found throughout northern NSW and southern Queensland. The key cropping threat appears to be from the selection of glyphosate-resistant populations, with control of the tussock stage providing most management challenges.

Key points

- Glyphosate alone or glyphosate followed by paraquat gives generally poor results.
- Preliminary data suggest that residual chemistry may provide some benefit.
- A double-knock of quizalofop-p-ethyl (e.g. Targa) followed by paraquat can be used in NSW.
- Cultivation is quite effective in controlling windmill grass as the plant is relatively shallow rooted.

Resistance levels

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

Residual herbicides (fallow and in-crop)

Preliminary trial work has shown a range of residual herbicides with useful levels of efficacy against windmill grass. These herbicides have potential for both fallow and in-crop situations. Currently there are no products registered for residual control of windmill grass.

Double-knock control

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

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

Timing of the second application for windmill grass is still being refined but application at ~7–14 days generally provides the most consistent control. Application of paraquat at shorter intervals can be successful when the Group A herbicide is translocated rapidly through the plant, but has resulted in more variable control in field trials and has been clearly antagonistic when the interval is one day or less. Good control can often be obtained up to 21 days after the initial application. [16]

1.7 Fallow chemical plant-back effects

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

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down to half the original amount rapidly, what remains can be persistent for long periods, e.g. sulfonylureas (chlorsulfuron). Where known, this is shown in Table 3. Herbicides with long residuals can affect subsequent crops, especially if, like the sulfonylureas, they are effective at low rates. 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.'[17]

16 R Daniel (2013) Weeds and resistance—considerations for awnless barnyard grass, *Chloris* spp and fleabane management Northern Grower Alliance, 2013. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Weeds-and-resistance-considerations-for-awnless-barnyard-grass-Chloris-spp-and-fleabane-management

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

Table 3: Residual persistence of common pre-emergent herbicides, and noted residual persistence in broad acre trials and paddock experiences [18]

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 to 1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Has had observed long-lasting activity 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. Has had observed long lasting (>3 months) activity on broadleaf weeds such as fleabane
Simazine	60 (range 28–149)	Med./high. 1 year residual in high pH soils. Has had observed long lasting (>3 months) activity on broadleaf weeds such as fleabane
Terbyne® (terbulthylazine)	6.5–139	High. Has had observed long lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Has had observed long lasting activity on grass weeds such as black/stink grass (*Eragrostis* spp.)
Stomp® (pendimethalin)	40	Medium. 3–4 months residual
Avadex® Xtra (triallate)	56–77	Medium. 3–4 months residual
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall event. Has had observed long lasting (> 6 months) activity 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

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, www.cdpr.ca.gov/

For more information, visit www.apvma.gov.au.

1.8 Seedbed requirements

Barley seed needs good soil contact for germination. This was traditionally achieved by producing a fine seedbed by multiple cultivations. Good seed–soil contact can now be achieved by the use of press wheels or rollers. Soil type and soil moisture influence the choice of covering device.

Between 70% and 90% of seeds sown produce a plant. Inappropriate sowing depth, disease, crusting, moisture deficiency and other stresses all reduce the numbers of plants that become established. Field establishment rates can be 60% or lower if seedbed conditions are unfavourable.

Seedbed preparation is also important to emergence. A cloddy seedbed can reduce emergence rates, as the clods reduce seed–soil contact, stop some seedlings reaching the surface, and allow light to penetrate below the soil surface.

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

The coleoptile senses the light and stops growing, and a leaf is produced while still below the surface. Cloddy soils also dry out more quickly. [19]

1.9 Soil moisture

The APSIM-Barley module simulates the growth and development of a barley crop in a daily time-step on an area basis (per square meter, not single plant). Barley growth and development in this module respond to weather (radiation, temperature), soil water and soil N. The barley module returns information on its soil water and N uptake to the soil water and N modules on a daily basis for reset of these systems. Information on crop cover is also provided to the water balance module for calculation of evaporation rates and run-off. Barley root residues are passed from barley to the surface residue and soil N modules respectively at harvest of the barley crop. [20]

For more information, visit http://www.apsim.info/Documentation/Model,CropandSoil/CropModuleDocumentation/Barley.aspx

1.9.1 Dryland

Soil water can be effectively monitored to assist managers in crop decision support. However, using currently available technologies it is unrealistic to think that highly accurate estimates of plant-available water will be possible given the inherent variability of northern cropping soils and currently available sensor technologies. [21]

Technologies to support decision-making

Given the vagaries of the system, there are a number of technologies which will provide a level of information useful in decision support without excessively high levels of investment. Read about them at http://www.grdc.com.au/GRDC-Booklet-PlantAvailableWater

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 where seasonal soil water levels vary from above field capacity through to wilting point or lower. Consequently, the potentially high levels of error associated with cracking and soil movement and high levels of inherent soil variability mean increased device replication would be necessary to achieve confidence in results. This however comes at an increased capital cost. Some devices (capacitance, *time-domain reflectometer*) also have an upper measurement limit over which they are unable to accurately measure soil water. This may be an issue 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. 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. The downsides are that it is unsuitable for use in saline soils and does not apportion soil water to particular layers within the soil profile. [22]

[19] Industry & Investment NSW Agronomists (2010), Barley growth & development, PROCROP Series, Industry & Investment NSW. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/516180/Procrop-barley-growth-and-development.pdf

[20] Crop Module Documentation: Barely, Agricultural Production Systems Simulator (APSIM) http://www.apsim.info/Documentation/Model,CropandSoil/CropModuleDocumentation/Barley.aspx

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

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

New thoughts on soil moisture monitoring

Despite an extensive range of monitoring instruments now available to us, measuring paddock soil moisture is still a considerable challenge. Among the suite of instruments currently available, one that stands out and is increasingly being used by researchers and agronomists is the EM38 (Geonics Ltd., Ontario, Canada). This electromagnetic induction instrument is proving to have significant application 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 soil management zones, both of which relate well to crop yield. It is also used in a wide number of agronomic and environmental applications to monitor soil water within the root-zone. It 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 e.g. the application, timing and conservation of irrigation water and fertiliser. EM38 data-sets have also proved valuable to test and validate water balance models which are used to extrapolate to other seasons, management scenarios and locations.

EM38s is an easy-to-use geophysical surveying instrument that provides a rapid measure of soil electrical conductivity (EC). 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. [23]

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 device output signal to gravimetric or volumetric water content.

To calculate the availability of soil moisture for crop use (in mm of available water) requires the 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 used to identify the soil's water-content operating range and reasonable assumptions made on values for drained upper limit and crop lower limit. An alternative is to use Soil Water Express (Burk and Dalgliesh 2012), a tool which uses the soil's texture, salinity and bulk density to predict PAWC and to convert electronic sensor output to meaningful soil water information (mm of available water).

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 surrounding 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. APSIM and Yield Prophet successfully predict soil water and should be considered for both fallow and cropping situations. CliMate is a logical choice for managing fallow water (Freebairn 2012). [24]

Subsoil constraints

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 affect

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

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

More information

[Assessment of sub-soil salinity and sodicity constraints to barley and faba bean production]

yields by increasing the lower limit of a crop's available soil water and thus reducing the soil's PAWC.[25]

Effect of strategic tillage

Research shows one-time tillage with chisel or offset disc in long-term no-till helped 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 between tillage and seeding and during the growing season. The occurrence of rain between tillage and sowing or immediately after sowing is necessary to replenish soil water lost from the seed-zone. This suggests importance of timing of tillage and taking the seasonal forecast into consideration. Future research will determine best timing for strategic tillage in no-till. [26]

1.9.2 Irrigation

Barley has not been a traditional irrigation crop due to its susceptibility to waterlogging on older irrigation layouts and the lack of suitable varieties for the cooler and wetter environment of the southern irrigation areas. However, barley has a number of good agronomic attributes for these regions compared with other cereals. It has a shorter growing season so it requires less water to finish and can fit into a double-cropping program, e.g. barley and soybeans. There is normally good local and export demand for malting and feed-grade barley. There are no stripe rust issues in barley; it provides good weed suppression and generally has lower input costs.

These attributes, combined with the features of recently developed varieties, have led to increasing interest in barley as an irrigated crop.

Management of the crop can be flexible. Variety choice, seeding rate and fertiliser rates are determined according to how the crop will be watered, that is:

- rainfed and residual irrigation water
- restricted watering (e.g. one spring irrigation)
- fully irrigated with the aim of achieving maximum yield and targeting malting quality [27]

Barley has a high water-use-efficiency rating. The plant can extract moisture from below 80 cm and, given a good starting moisture profile, high-yielding crops can be grown on limited irrigation. Yields of 7.3 t/ha and higher have been recorded. Growers should target yields of 5-6 t/ha and protein content of 10.1% (dry) or 11.5% (wet basis) to maximise yield and quality. Requirements for water depend on winter rainfall and irrigation systems, but one of the crucial times to apply water for achieving malting quality is grain-fill. Adequate moisture during tillering and early jointing is important for maximising potential yield. [28] High water use efficiency also makes it a more reliable cereal in lower rainfall regions.

1.10 Yield and targets

1.10.1 Variety yield comparisons

[25] 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://era.daf.qld.gov.au/1336/

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

[27] K O'Keeffe, N Fettell (2010) Barley varieties & sowing rates for irrigation. Industry & Investment NSW, 2010. http://irec.org.au/farmer_f/pdf_182/Barley%20proves%20valuable%20for%20irrigation%20rotations.pdf

[28] DAFF (2012) Barley planting, nutrition and harvesting. Department of Agriculture, Fisheries and Forestry Queensland 2012. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/barley/planting-nutrition-harvesting

See the National Variety Trial website, www.nvtonline.com.au, to compare the performance of current barley varieties across the northern region.

1.10.2 Seasonal outlook

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

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

Queensland Alliance for Agriculture and Food Innovation produces regular seasonal outlooks for winter-crop producers in Queensland. These high-value reports are written in an easy-to-read style and are free. Download the 'Seasonal Crop Outlook—wheat, October 2013'.

http://www.qaafi.uq.edu.au/seasonal-crop-outlook-wheat

http://www.qaafi.uq.edu.au/content/Documents/crop-outlook/wheat/2013-10-wheat-outlook.pdf

For tips on understanding weather and climate drivers including the SOI, visit the Climate Kelpie website at http://www.climatekelpie.com.au/understand-climate/weather-and-climate-drivers/queensland#ElNino.

Case studies of 37 farmers across Australia recruited as Climate Champions as part of the Managing Climate Variability R&D Program can be accessed at http://www.climatekelpie.com.au/ask-a-farmer/climate-champion-program.

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, as well as El Nino/Southern Oscillation status. It is designed for decision -makers like 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 to the average and all years.

Season's progress? efficiently explores the readily available weather data and compares the current season with the long -term average and graphically presents the spread of experience from previous seasons.

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

- 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?

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

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. [29]

The Bureau of Meteorology has recently moved from a statistics-based to a physics-based (dynamical) model for its seasonal climate outlooks. The new system has better overall skill, is reliable, allows for incremental improvements in skill over time and provides a framework for new outlook services including multi-week/monthly outlooks and the forecasting of additional climate variables. [30]

1.10.3 Fallow moisture

For a growing crop, there are 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. You have some control over the stored soil water; you can measure how much you have before you plant the crop. However, rainfall is out of your control. Long-range forecasts and tools such as the SOI can indicate the likelihood of the season being wet or dry, but they cannot guarantee rain will fall when you need it. [31]

HowWet?

HowWet? uses records from a nearby weather station to estimate how much plant available water (PAW) has accumulated in the soil and the amount of organic nitrogen that has been converted to an available nitrate during a fallow.

Howwet? tracks soil moisture, evaporation, run-off and drainage on a daily time step. Accumulation of available N in the soil is calculated based on surface soil moisture, temperature and soil organic carbon.

HowWet?:

- estimates how much rain has been stored as plant-available soil water during the most recent fallow period;
- estimates how much N has been mineralised as nitrate-N in soil; and
- and provides a comparison with previous seasons.

This information aids in the decision of what crop to plant and how much nitrogen fertiliser to apply.

Barley is grown in regions where stored soil water and nitrate at planting are important in crop management decisions. This is of particular importance to northern Australian grain growers with clay soils where stored soil water at planting can constitute a large part of a crop's water supply.

Questions this tool answers:

- How much longer should I fallow? If the soil is near full, maybe the fallow can be shortened.
- Given my soil type and local rainfall to date, what is the relative soil moisture and nitrate N accumulation over the fallow period compared to most years? Relative changes are more reliable than absolute values.
- Based on estimates of soil water and nitrate-N accumulation over the fallow, what adjustments are needed to the N supply? [32]

Inputs

29 Australian Climate: www.australianclimate.net.au

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

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

32 How Wet/N? http://www.australianclimate.net.au/About/HowWetN

- A selected soil type and weather station
- An estimate of soil cover and starting soil moisture
- The stand-alone version of HowOften? uses rainfall data input by the user

Outputs

- A graph showing plant-available soil water for the current year and all other years and a table summarising the recent fallow water balance
- A graph showing nitrate accumulation for the current year and all other years

Reliability

HowWet? uses a standard water-balance algorithms from Howleaky? and a simplified nitrate mineralisation based on the original version of HowWet? Further calibration is needed before accepting with confidence in absolute value estimates.

Soil descriptions are based on generic soil types with standard organic carbon and C/N ratios and as such should be regarded as indicative only and best used as a measure of relative water accumulation and nitrate mineralisation.

For more information, visit http://www.australianclimate.net.au/About/HowWetN.

1.10.4 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 both the use of water stored in the soil and rainfall during the growing season.

Water use efficiency 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 (harvest index)

Water is the principal limiting factor in rain-fed cropping systems in northern Australia. The objective of rain-fed cropping systems is to maximise the proportion of rainfall that crops use and minimise water lost through run-off, drainage and evaporation from the soil surface and to weeds.

Rainfall is more summer-dominant in the northern region, and both summer and winter crops are grown. However, rainfall is highly variable and can range during each cropping season, from little or no rain to major rain events that result in waterlogging or flooding.

Storing water in fallows between crops is the most effective tool growers have to manage the risk of rainfall variability, as in-season rainfall alone—in either summer or winter—is rarely enough to produce a profitable crop, especially given high levels of plant transpiration and evaporation.

Fortunately, many cropping soils in the northern region have the capacity to store large amounts of water during the fallow. [33]

Fallow efficiency: the efficiency with which rainfall during a fallow period is stored for use by the following crop.

$$\text{Fallow efficiency (\%)} = \frac{\text{change in plant available water during the fallow} \times 100}{\text{fallow rainfall (mm)}}$$

Crop water use efficiency: the efficiency with which an individual crop converts water transpired (or used) to grain.

$$\text{Crop WUE (kg/ha/mm)} = \frac{\text{grain yield (kg/ha)}}{\text{crop water supply (mm)} - \text{soil evaporation}}$$

[33] GRDC (2009) Water use efficiency—converting rainfall to grain. Northern Region. GRDC Fact Sheet 2009. http://www.grdc.com.au/uploads/documents/GRDC_Water%20Use%20Efficiency%20.North%20version%20231009.pdf

Systems water use efficiency: the efficiency with which rainfall is converted to grain over multiple crop and fallow phases.

$$\text{SWUE (kg grain/mm rainfall)} = \frac{\text{total grain yield (kg)}}{\text{total rainfall (mm)}}$$

Ways to increase yield

In environments such as western NSW where yield is limited by water availability, there are four ways of increasing yield (Passioura and Angus 2010);

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 nitrogen, 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, that is, transpiration efficiency (e.g. early sowing, good nutrition, high transpiration efficiency varieties such as Spitfire⚬, Scout⚬, Drysdale⚬, Gregory⚬).
4. Increase the total proportion of dry matter that is grain i.e. improve harvest index (e.g. early flowering varieties, delayed nitrogen, wider row spacing, low plant densities, minimising losses to disease, high HI varieties such as H45⚬, Hindmarsh⚬, Wyalkatchem⚬, Espada⚬).

The last three of these all improve WUE. [34]

Knowledge of evaporation for the northern growing region soils is limited yet it is the largest part of the water balance. Since 2010 Queensland Department of Natural Resources and Mines (DNRM) researchers have been measuring evaporation directly for a range of soils using lysimetry techniques. They found most, but not all, soils evaporate at a similar rate. There are significant interactions between soil water, climate and rainfall that influence this rate of evaporation. This data has been used to test current modelling assumptions, better parameterise models, and is now directly contributing to improving predictions of the soil water balance component of models such as APSIM, APSIM-SWIM, HowLeaky, and HowWet (via CLiMate), by providing more realistic responses for our soils and climates. For more information, visit http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/How-much-water-is-lost-from-northern-crop-systems-by-soil-evaporation[35]

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.

In the highly variable rainfall environment in the northern region, estimating in-crop rainfall, soil evaporation and soil water remaining at harvest is difficult. However, this model may still provide a guide to crop yield potential.

34 J Hunt, R Brill, Strategies-for-improving-wateruse-efficiency-in-western-regions-through-increasing-harvest-index, GRDC Update, 2012. https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Strategies-for-improving-wateruse-efficiency-in-western-regions-through-increasing-harvest-index

35 GRDC (2014), How much water is lost from northern crop systems by soil evaporation. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/How-much-water-is-lost-from-northern-crop-systems-by-soil-evaporation

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. [36]

Table 4: Typical parameters that could be used in this equation

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

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

Table 5: Effect of soil water threshold for planting on systems water use efficiency (SWUE) and other system performance parameters

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

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

Challenging the French–Schultz model

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

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

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

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

[36] GRDC (2009) Water use efficiency—converting rainfall to grain. Northern Region. GRDC Fact Sheet 2009. http://www.grdc.com.au/uploads/documents/GRDC_Water%20Use%20Efficiency%20.North%20version%20231009.pdf

management and breeding. They make a note of caution on the use of simple rules of thumb (French–Schultz) for benchmarking WUE, and discuss the importance of more integrative and dynamic modelling approaches to explore alternatives to increase WUE at the single crop and whole farming systems level i.e. $/ha.mm.

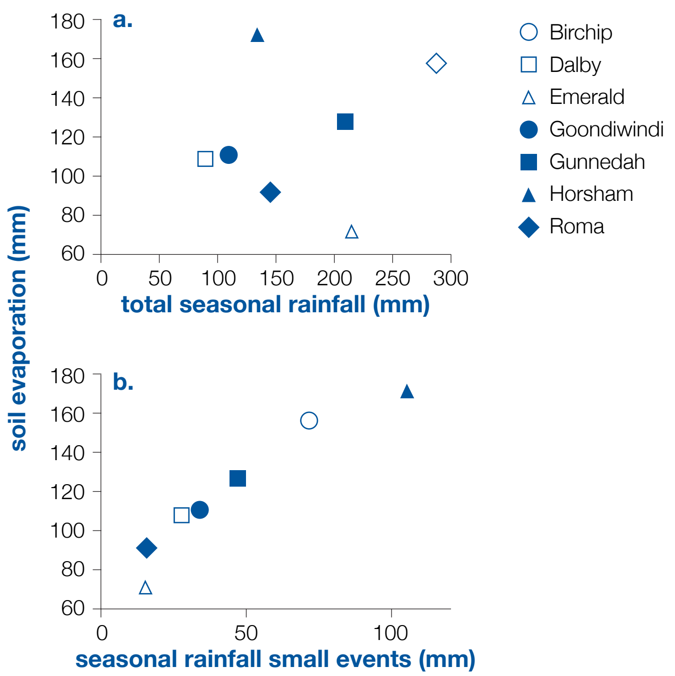

Figure 6: Simulated soil evaporation is (a) unrelated to seasonal rainfall and (b) closely related to rainfall in small events (i.e. ≤5 mm).

More information

http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/BFDC-Interrogator

1.10.5 Nitrogen-use efficiency

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

In cracking clay soils of the northern grains region, saturated soil conditions between fertiliser application and crop growth can lead to significant N losses from the soil through denitrification. The gases lost in this case are nitric oxide, nitrous oxide and di-nitrogen (N_2). Isotope studies in the northern region have found these losses can be > 30% of the N applied. Direct measurements of nitrous oxide highlight the rapidity of loss in this process.

Insufficient rainfall after surface application of nitrogen fertilisers can result in N losses from the soil through volatilisation. The gas lost in this case is ammonia. Direct measurements of ammonia loss have found these losses were generally <15% of the N applied, even less in in-crop situations. An exception was the application of ammonium sulfate 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. [37]

A balance of nutrients is essential for profitable yields. Fertiliser is commonly needed to add the essential nutrients phosphorus and nitrogen. The lack of other essential plant nutrients may also limit production in some situations.

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

37 G Schwenke, P Grace, M Bell (2013) Nitrogen use efficiency. GRDC Update, 2013. https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Nitrogen-use-efficiency

An online fertiliser cost comparison calculator is available via CropMate™. Download CropMate from the App Store on iTunes at https://itunes.apple.com/au/app/cropmate-varietychooser/id476014848?mt=8.

1.10.6 Double-crop options

A mounting body of research shows that integrated weed management (IWM) approaches incorporating strategic crop sequences and rotations, herbicides and other tactics provide effective weed control within holistic production systems.

Similarly, it has long been recognised that introduction of legumes and ley phases into cropping sequences are an important means by which long-term improvements in soil fertility can be achieved. GRDC-funded research is under way to quantify the benefits in central Queensland. [38]

1.11 Disease status of paddock

Diseases remain a major threat to barley production in Australia but are generally well controlled at present. The current average annual loss from barley diseases was estimated to be AU$252 million, including $34 million in the northern region. This compares with a potential average loss nationally of $192 million from a single disease, spot form of net blotch, which is reduced to $43 million by current controls.

On average, the current national average losses from diseases are $66.49/ha. The losses represent $81.53/ha in the northern region. [39]

1.11.1 Soil testing for disease

PreDicta B (B = broadacre) is a DNA-based soil testing service to identify which soil-borne 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
- take-all (*Gaeumannomyces graminis var. tritici (Ggt*) and *G. graminis var. avenae (Gga))*
- rhizoctonia barepatch (*Rhizoctonia solani AG8*)
- RLN (*Pratylenchus neglectus* and *P. thornei*)
- stem nematode (*Ditylenchus dipsaci*)

Northern region grain producers can access PreDicta B via Crown Analytical Services or agronomists accredited by 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.

PreDicta B is not intended for in-crop diagnosis. This is best achieved by sending samples of affected plants to your local plant pathology laboratory.

For more information, visit http://www.crownanalytical.com.au or http://www.sardi.sa.gov.au/products__and__services/entomology/diagnostic_services/predicta_b.

1.11.2 Cropping history effects

Continuous cereal cropping increases the risk of diseases including crown rot. This fungal disease is hosted by all winter cereals and many grassy weeds and can survive for many years in infected plant residues. Infection can occur when plants come in close contact with those residues.

[38] R Sequeira, GRDC Grower Solutions for Central Queensland, GRDC, 2010. http://www.grdc.com.au/Research-and-Development/DAQ00170

[39] GM Murray, JP Brennan (2009), The Current and-Potential-Costs-from-Diseases-of-Barley-in-Australia, GRDC, 2009. http://www.grdc.com.au/uploads/documents/GRDC_Disease_Loss_Barley_Report_240809.pdf

High cereal intensity and inclusion of durum wheat in cropping programs are factors which increase crown rot levels. [40]

1.12 Nematode status of paddock

In the northern grain region, the predominant RLN, *Pratylenchus thornei,* costs the wheat industry AU$38 million [41] annually, and including the secondary species, *P. neglectus*, RLN are found in three-quarters of fields tested. [42]

1.12.1 Nematode testing of soil

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

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

It is important to know what species are present because crops and varieties have different tolerance and resistance to different species of nematodes.

If a particular species is present in high numbers it is important to make immediate decisions to avoid losses in the next crop to be grown. When low numbers are present, it is important to take decisions to safeguard future crops. Learning that a paddock is free of these nematodes is valuable information because it may be possible to take steps to avoid future contamination of that field. [43]

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

Link to SARDI PreDictaB testing service: http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b

1.12.2 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 greater than 50% can occur in some wheat varieties and up to 20% yield loss 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 root-lesion nematodes per kilogram soil anywhere in the soil profile has the potential to reduce the grain yield of intolerant varieties.[44]

A tolerant crop yields well when high populations of RLN are present (opposite is intolerance). A resistant crop does not allow RLN to reproduce and increase in number (opposite is susceptibility).[45]

[40] Hot-Topics: Crown-Rot, GRDC, 2012. http://www.grdc.com.au/Media-Centre/Hot-Topics/Crown-Rot

[41] GM Murray, JP Brennan (2009) The Current and Potential Costs from Diseases of Wheat in Australia, GRDC, 2009. http://grdc.com.au/uploads/documents/GRDC_WheatDiseaseLoss_Report_final.pdf

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

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

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

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

Growing resistant crops is the main tool for managing nematodes. In the case of crops such as wheat or chickpea, choose the most tolerant variety available and rotate with resistant crops to keep nematode numbers at low levels. Information on the responses of crop varieties to RLN are regularly updated in grower and DAFF planting guides. It is worth noting that crops and varieties have varying levels of tolerance and resistance to *Pratylenchus thornei* and *P. neglectus* (See Table 1). [46]

Summer crops have an important role in management of RLN. Research shows when *P. thornei* is present in high populations two or more resistant crops in sequence are needed to reduce populations to low enough levels to avoid yield loss in the following intolerant, susceptible cereal crops. [47]

For more information on nematode management, see Section 8: Nematodes.

1.13 Insect status of paddock

1.13.1 Insect sampling of soil

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

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

Soil sampling by spade

1. Take a number of spade samples from random locations across the field.

[46] Queensland Primary Industries and Fisheries (2009) Root lesion nematodes—management of root-lesion nematodes in the northern grain region. Queensland Government. http://soilquality.org.au/factsheets/root-lesion-nematode-in-queensland

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

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

Germinating seed bait technique

Immediately following planting rain:

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

Trials have shown that there is no difference in the type of seed used when it comes to attracting soil-dwelling insects. However, using 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.

Recognising soil insects

Visit the QDAFF Photo gallery or for more information, see *Section 7: Insect Control*.

Detecting soil-dwelling insects

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

For current chemical control options see Pest Genie or APVMA. [48]

1.14 Mouse management

During years of high mouse activity young winter crops can be severely damaged. Growers need to monitor crops closely and determine if 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 two week withholding period for zinc phosphide baits prior to harvest. Talk to your neighbours and coordinate a baiting program to reduce reinvasion.[49]

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

49 Mouse plague prediction models: relevant forecasts for growers in Queensland http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Mouse-plague-prediction-models-relevant-forecasts-for-growers-in-Queensland