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GRDC GROWNOTES™

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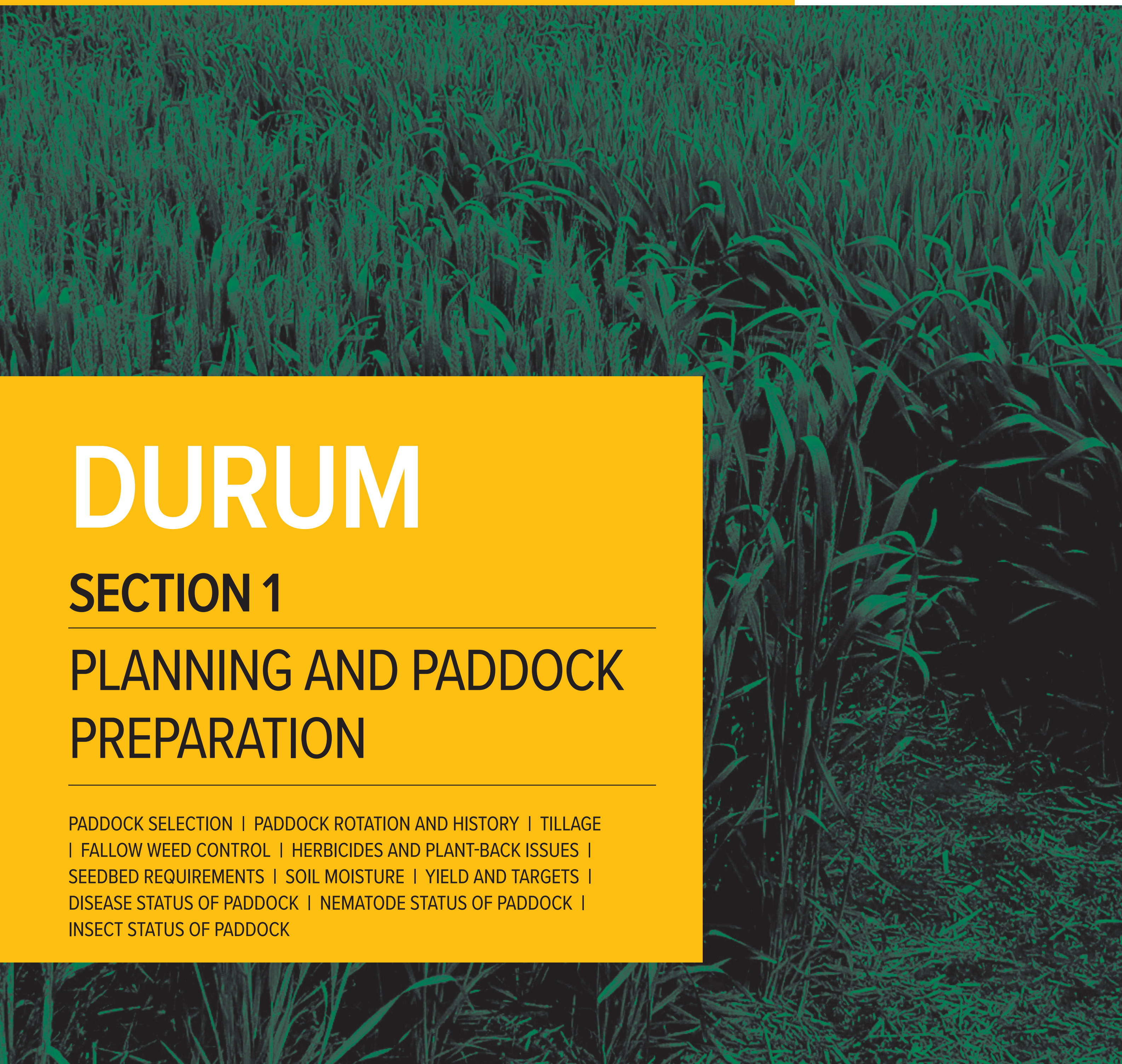

DURUM

SECTION 1

PLANNING AND PADDOCK PREPARATION

PADDOCK SELECTION | PADDOCK ROTATION AND HISTORY | TILLAGE | FALLOW WEED CONTROL | HERBICIDES AND PLANT-BACK ISSUES | SEEDBED REQUIREMENTS | SOIL MOISTURE | YIELD AND TARGETS | DISEASE STATUS OF PADDOCK | NEMATODE STATUS OF PADDOCK | INSECT STATUS OF PADDOCK

Planning/Paddock preparation

Key messages:

- Durum should be grown in fertile paddocks, preferably with good stored moisture.
- Avoid sowing into paddocks with high pre-existing levels of crown rot fungus (*Fusarium pseudograminearum*).
- Crop rotations using pulses, canola, sorghum, sunflowers and pasture legumes are recommended to help disease and weed control. Legume break crops are ideal due to their ability to fix substantial amounts of nitrogen.
- Limited and strategically timed tillage could help control weeds and disease in minimum tillage systems.
- High nitrogen is essential to maximise the potential of durum to reach its minimum protein level of 13%.
- Testing paddocks for and controlling disease, nematodes and insects is essential to manage risks and maximise yield.

1.1 Paddock selection

Durum should not be grown in paddocks at high risk of grass weed competition.

Choice of paddock to sow cereals is 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]

Successful crop establishment is the key to maximising crop yield potential. Focus on paddock selection, the use of good quality seed, optimising seeding rate, depth and spacing, and matching varieties to seeding date and length of growing season.

Durum wheat grows best on soils with good water holding capacity (generally clay and clay-loams). [2] Select paddocks that are fertile and store good levels of plant available water, receive reliable in-crop rainfall or have access to supplementary irrigation. Durum wheat should only be grown where a reliable harvest of high protein (13%+), plump, hard, vitreous grain can be produced. The highest grade of durum (ADR1) must have a minimum protein level of 13% and ADR2 must be at least 11.5%. Careful management of soil nitrogen (N) is essential to achieve this (Photo 1). [3]

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

2 A Mayfield, H van Rees (1994) Durum wheat. In The Southern Mallee and Northern Wimmera Crop and Pasture Manual, http://www.farmtrials.com.au/trial/13301

3 R Hare (2006) Agronomy of the durum wheats Kamilaroi⟨Þ, Yallaroi⟨Þ, Wollaroi⟨Þ and EGA Bellaroi⟨Þ. Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

Photo 1: *Trials run over several years and sites highlight that the newer durum lines, such as Saintlyⴔ (pictured) do not require extra nitrogen for growth but require more nitrogen to achieve 13% protein. (Source: DAFQ)*

Photo: Emma Leonard, Source: GRDC

Durum wheats should not be sown into paddocks known to carry high levels of crown rot inoculum. A suitable rotation should be practiced to reduce inoculum levels. Ground preparation is the same as that for bread wheat. Adequate weed control should eliminate all weeds and volunteer plants of bread wheat, barley or other crop species. [4]

Paddock topography

Topographical characteristics can determine crop and pasture options. Crops and varieties prone to lodging should be avoided in uneven paddocks. Some durum varieties such as Saintly can be prone to lodging, so topography is an important factor in paddock selection (Photo 2). Waterlogged conditions make harvest difficult and also reduce root growth and can predispose the plant to root rots. The topographic variations typical of large agricultural paddocks can have a substantial impact on dynamics of soil mineral N as well as on performance of crops. Spatial variations in soil organic matter, soil microbial biomass, natural drainage, plant growth, and water and nutrient redistribution caused by topography are the main factors controlling the dynamics of soil mineral N. Along with weather, landscape topographic patterns accounted for most of the variations in plant available N.

There are potential environmental and economic benefits of site-specific topography-driven crop management. Management decisions regarding where to plant crops can vary depending on the management goals and complexity of the terrain. [5]

4 DAFQ (2012) Durum wheat in Queensland. Department of Agriculture and Fisheries Queensland, June 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/durum-wheat

5 Ladoni, M., Kravchenko, A. N., & Robertson, G. P. (2015). Topography Mediates the Influence of Cover Crops on Soil Nitrate Levels in Row Crop Agricultural Systems. *PloS one*, *10*(11), e0143358.

Photo 2: *Topography is an important consideration in paddock selection for durum.*

Photo: Arthur Mostead, Source: GRDC

1.1.1 Soil

Soil pH

Optimum soil pH for durum wheat growth is between 5.5 and 7.5. [6] Soils with low pH often have high levels of aluminium in the soil solution. Durum wheat, is reportedly more sensitive to aluminum (Al) toxicity in acid soils than hexaploid wheat, *Triticum aestivum* L. [7]

- Soil pH is a measure of the concentration of hydrogen ions in the soil solution.
- Low pH values (< 5.5) indicate acidic soils and high pH values (> 8.0) indicate alkaline soils.
- Soil pH between 5.5 and 8 is not usually a constraint to crop or pasture production.
- In Southern Australia more than 60% of agricultural soils are alkaline.
- Outside of the optimal soil pH range, microelement toxicity and deficiency damages crops.

Hydrogen ion concentration in the soil is called pH and is influenced by chemical reactions between soil components and water. Soil pH is affected by the varied combinations of positively charged ions (sodium, potassium, magnesium, calcium, aluminum, manganese and iron) and negatively charged ions (sulfate, chloride, bicarbonate and carbonate). Soil pH directly affects the concentration of major nutrients and the forms of microelements available for plant uptake and can result in deficiencies or toxicities (Figure 1).

6 Brink, M., & Belay, G. (2006). Cereals and pulses. PROTA, Wageningen, Pays Bas

7 Foy, C. D. (1996). Tolerance of durum wheat lines to an acid, aluminum- toxic subsoil. *Journal of plant nutrition*, *19*(10-11), 1381-1394

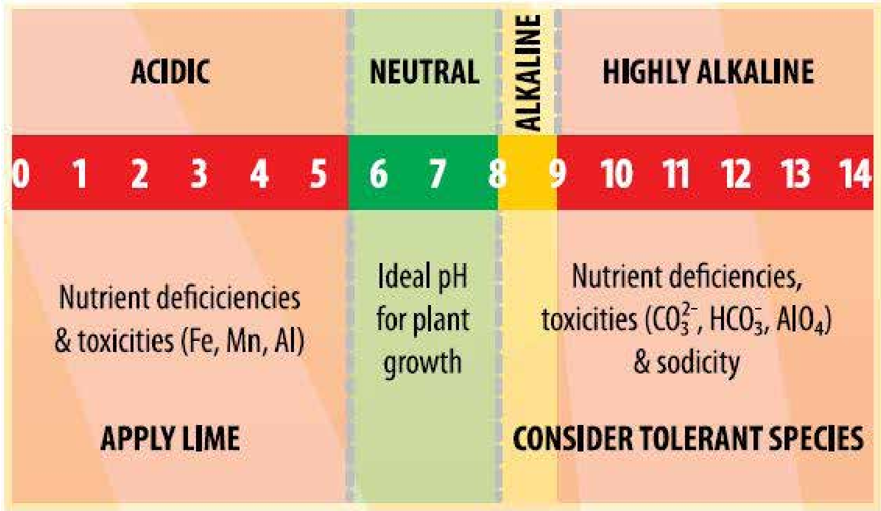

Figure 1: *Effect of soil pH(1:5 soil:water) availability, plant growth and management options. Classification of soils on the basis of pH (1:5 soil:water) the implications for plant growth and some management options.*

Source: Soilquality.org)[8]

What influences location of acid and alkaline soils in southern Australia?

Alkaline soils are found in arid/semi-arid regions, because little leaching and high evaporation causes ions to concentrate in the soil.

Acid soils occur in areas of southern Australia with high rainfall where basic ions (sodium, potassium, magnesium and calcium) have been removed by leaching. Nitrate leaching also contributes to significant soil acidification under high rainfall. Very frequent legume cropping can reduce pH in non-calcareous soils. Soils high in sulfur may become very acidic due to the dominance of certain chemical (oxidation-reduction) reactions.

Measurement of soil pH

Soil sampling and measurement of pH helps to determine the practices necessary to manage land with low or high pH. Sampling strategies need to take into account the variation across a paddock and down the soil profile (see section below).

Soil pH can be measured by a simple device called an ion electrode inserted into a mixture of one part soil to five parts water. Scientists dealing with acid soils with pH less than 5 prefer to measure soil pH using soil in calcium chloride solution. This is not suitable for soils with a pH greater than 5 because some of the ions in these soils (mainly bicarbonate and carbonate) become bound to the calcium and are removed from solution, which then causes an inaccurate pH reading. Soils with pH greater than 5 should be measured in water.

Managing soil pH

Alkaline soils

Treating alkaline soils through the addition of acidifying agents is not generally a feasible option due to the large buffering capacity of soils and uneconomic amounts of acidifying agent (e.g. sulfuric acid, elemental sulfur or pyrites) required.

Gypsum will reduce sodicity and this can reduce alkaline pH to some extent. Growing legumes in crop rotation may help in sustaining any pH reduction.

In high pH soils, using alkalinity tolerant species/varieties of crops and pasture can reduce the impact of high pH.

8 Soilquality.org. Soil pH—South Australia, http://www.soilquality.org.au/factsheets/soil-ph-south-australia

Acid soils

Acid soils can be economically managed by the addition of agricultural lime, usually crushed limestone. Sufficient lime should be added to raise the pH to above 5.5. The amount of lime required to ameliorate acid soils will vary, mainly depending on the quality of the lime, soil type and how acidic the soil has become.

Soils prone to becoming acidic will need liming every few years. Seek advice on an appropriate liming regime from your local agricultural advisor. [9]

Liming

The signs of soil acidity are more subtle than the clearly visible symptoms of salinity and soil erosion. Cereal growers may predict that their soil is acidic when acid sensitive crops fail to establish, or crop production is lower than expected, particularly in dry years. In pasture paddocks poor establishment or lack of persistence of acid sensitive pastures such as lucerne, and to a lesser degree phalaris, is an indication that the soil may be acidic.

More definitive indications of acidic soil are:

- stunted or shallow root growth in crops and pastures;
- poor nodulation in legumes or ineffective nodules; and
- manganese toxicity symptoms in susceptible plants.

A soil test is the most reliable way to assess if soils are acidic. Where soils are at risk of becoming acidic the future impact of soil acidity can be reduced, but not eliminated, by slowing the rate of acidification.

To slow the rate of acidification:

- minimise leaching of nitrate nitrogen
- use less acidifying fertilisers
- reduce the effect of removal of product
- prevent erosion of the surface soil

Application of finely crushed limestone, or other liming material, is the only practical way to neutralise soil acidity. Limestone is most effective if sufficient is applied to raise the pHCa to 5.5 and it is well incorporated into the soil. Where acidity occurs deeper than the plough layer, the limestone will only neutralise subsurface soil acidity if the pHCa of the surface soil is maintained above 5.5. [10]

The economic benefits of lime

The benefits of lime prove to be not only economically significant but the consequence of improved soil quality and increased nutrient uptake makes cropping more sustainable. However, a liming scheme does not result in overnight success. The amelioration of acidified soils is a lengthy process but it is worthwhile in the retention of a healthy, vibrant and sustainable soil. The longer the beneficial effects of lime persist, the more the investment in liming becomes economically favourable. Subsoil constraints such as acidity result in decreased rates of root elongation and limit the plant's ability to access water and nutrients. Subsoil acidity is caused by the excess application of acidic substances such as ammonium fertilisers. Surface liming is a common practice for ameliorating topsoil acidity in the relatively short-term, but is generally slow in ameliorating subsoil acidity. When acidity is increased, important nutrients such as nitrogen (N) and phosphorus (P) are less available to plants, while nutrients only needed in trace amounts such as aluminium (Al) and manganese (Mn) are increased. This can lead to Al and Mn toxicity resulting in a dramatic decline of plant growth. Lime substantially reduces the level of exchangeable Al and exchangeable Mn while raising soil pH by about 1.0 unit. Liming soils can remove the toxicities of Al and Mn and, dependent on the extent of acidity and species, plants

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9 Soilquality.org. Soil pH—South Australia, http://www.soilquality.org.au/factsheets/soil-ph-south-australia

10 B Upjohn, G Fenton, M Conyers (2005) Soil acidity and liming. Agfact AC. 19. 3rd edition. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/167209/soil-acidity-liming.pdf

VIDEOS

WATCH : GCTV8: Liming Acids Soils.

may differ in their response to soil amelioration with lime. [11] A pH level of 5.5 and 8 is often seen as the optimum value for the growth of the plants.

Liming schemes are an appropriate solution to this problem and ensure the longevity of soils that may be succumbing to acidity. The long-term residual benefits of limestone have been shown to extend for beyond 8–10 years and indicate that liming should be profitable in the long term. [12]

Subsoil moisture

Low levels of soil moisture at sowing can significantly increase financial risks. Paddocks with ground cover can retain moisture for longer, extending the time for planting after small rainfall events. Levels of starting soil water should also affect 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.

Paddock nutrition

Fertiliser is a major cost. Fertiliser rates to meet crop requirements may be modified if residual fertiliser from the last season remains. Paddock history, past crop performance, fertiliser test strips and soil tests can help to determine the most appropriate decision. It is not uncommon for paddocks to have multiple nutrition deficiencies, or variations in nutritional requirements, even with a similar cropping history.

See Section 5: Nutrition and fertiliser, for more information.

Weed burden and herbicide history

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.

Strategic and integrated weed management over a rotation can greatly increase the likelihood of controlling weeds across all crops. Paddocks being planted to durum 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.

Paddocks planted to durum wheat should have a vigilant strategy for control of grass weeds in the preceding canola or pulse crops. Identify your 'cleanest' paddocks and consider the use of pre-emergent herbicides. Risk may be reduced through the combination of pre-sowing weed knockdown, late-sown (early-maturing) crops/varieties and pre-harvest desiccation in crops where registration is current. Weed management involves strategic herbicide applications in combination with other, non-chemical management options. Weed management in year one will affect the crop in year two.

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

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines, etc.) may be an issue in some paddocks and particularly low rainfall years (Photo 3). Remember that plant-back periods begin after rainfall occurs.

11 D Brooke, DR Coventry, TG Reeves, DK Jarvis (1989) Plant and Soil, 115, 1-6

12 M Quin (2015) Central West Farming Systems Inc., http://cwfs.org.au/2015/12/08/the-economic-benefits-of-lime/

Photo 3: *Effects of Group B herbicide residues on growth in barley and wheat.*

Source: DAFWA

See Section 6: Weed control for more information.

Disease carryover

Crop sequencing is an important component of long-term farming systems and contributes to the management of soil nitrogen (N) status, weeds, pests and diseases. Broad scale decisions on the sequence of crops include commodity prices, the short- and medium-term weather outlook, and the level of acceptable risk. In the paddock, considerations include soil moisture levels before planting, current and desired stubble cover, history of herbicide use, history of diseases, and the population level(s) of root-lesion nematodes. Crop sequences also affect the incidence and severity of major diseases of summer crops, especially those diseases that have several summer, and in some instances winter, crop hosts.

Crop sequencing is only a part of the integrated management of disease. 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. [13]

The previous crop will influence levels of both soil- and residue-borne diseases. Important diseases to consider include crown rot, take-all, yellow leaf spot, stripe rust, Barley Yellow Dwarf Virus (BYDV), Septoria blotch 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.

13 M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Papers 13 September 2011, http://elibrary.grdc.com.au/ark%21%2133517/vhnf54t/a9ft5hf

Pests

Pests such as redlegged earth mites, blue oat mites, nematodes and, in some seasons, cutworms, aphids and armyworm may pose a risk in some paddocks. Aphids may also be vectors for transmission of diseases such as BYDV, particularly in higher rainfall environments. 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. [14]

See Section 7: Insect control for more information.

1.2 Paddock rotation and history

Crop rotations have an important role in managing water, disease, weed and nutrient cycles. [15] Rotations with non-cereal species, including pulses, canola, pasture legumes (especially lucerne), sorghum and sunflowers, are essential in order to:

- Manage root disease, especially crown rot
- provide for the biological fixation of N gas through legumes
- control weeds and contaminant crop species, and aid in herbicide group rotation.

Durum should be the first cereal crop after a non-cereal species. Avoid successive durum crops. [16] One advantage of using durum as part of a crop rotation is its relative resistance to the root lesion nematode *Pratylenchus thornei*, compared with other winter cereal crops. Durum crops in rotation will reduce the nematode count in the soil. But conversely, durum will more rapidly build up crown rot inoculum which can negatively affect subsequent winter cereal crops (Photo 4).

To achieve the high protein levels (desirable at least 13%) for durum, soil N management requires careful planning. Grain as low as 10% (DR3 quality grain) is accepted by marketers and end-users as blending can be done.

Ideally durum should be planted into a rotation following a grain or pasture legume phase. Alternatively the paddock's cropping history in conjunction with soil tests can be used to calculate a N budget. It is important to soil test for N to the effective rooting depth of the crop. N fertiliser is an expensive input for farming systems and it pays dividends to get the levels correct. Depending on location, requirements for other nutrients should also be met, including phosphorus, sulfur and—on highly alkaline soils— zinc. A robust crop rotation must be planned over a number of seasons if successful crops of durum wheat are to be produced. [17]

VIDEOS

WATCH: Over the Fence: The sweet benefits of legume rotations

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

15 NSW DPI (2009) Setting up for high quality durum. Agriculture Today. NSW Department of Primary Industries, March 2009, http://www.dpi.nsw.gov.au/content/archive/agriculture-today-stories/ag-today-archives/march-2009/setting-up-for-high-quality-durum

16 R Hare (2006) Agronomy of the durum wheats Kamilaroi⟨D⟩, Yallaroi⟨D⟩, Wollaroi⟨D⟩ and EGA Bellaroi⟨D⟩. Primefacts 140, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/63646/Agronomy-of-the-durum-wheats---Primefact-140-final.pdf

17 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

Photo 4: *Durum showing crown rot damage. Rotations with non-cereal species, are important for reducing crown rot in durum crops.*

Source: GRDC

Crops such as wheat and barley leave behind relatively large quantities of stubble that will persist for some time. Pulse crops such as chickpea and field peas produce less stubble and because of their high N content they break down faster.

Crop rotations should aim to maintain stubble cover as much as possible. For this reason, crops producing low stubble cover should be followed by crops that will restore ground cover.

Crown rot causes significant losses in durum and survives from year to year in stubble residue. Crop rotation to non-host crops, such as pulses and oilseeds, reduces crown rot levels in paddocks by allowing time for the stubble to breakdown and disease levels to fall. A good crop rotation can increase the diversity of herbicides and weed control tactics that can be used throughout the whole rotation which aids the management of herbicide resistance. [18]

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.

Disadvantages of cereals as a rotation crop

Growing cereals in continuous production is not a recommende practice 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 (N) depletion and declining soil fertility

18 NSW DPI (2009) Setting up for high quality durum. Agriculture Today. NSW Department of Primary Industries, March 2009, http://www.dpi.nsw.gov.au/content/archive/agriculture-today-stories/ag-today-archives/march-2009/setting-up-for-high-quality-durum

1.3 Tillage

Key points:

- Conservation farming involves reduced tillage, stubble retention and good rotations. This underpins sustainable grain production systems worldwide.
- Current advice on soil tillage management contains apparent contradictions. Some flexibility may be required in the application of conservation farming practices.
- No-till has revolutionised cropping, but has resulted in an increased reliance on herbicides, leading to herbicide-resistant weeds.
- A lack of tillage can cause nutrient stratification and favour diseases such as crown rot, *Rhizoctonia* and *Pseudomonas*.
- Conventional tillage can suppress plant parasitic nematode populations, lower the number of snails and slugs prior to canola crops and lower mice numbers in affected fields.
- From an overall systems perspective, limited and strategically timed tillage could have a tactical role as part of a productive, sustainable system. [19]

The practice of reduced tillage and stubble retention started 40 years ago following the development of the first knockdown herbicides. These practices meant a change from conventional cultivation, which at the time consisted of stubble burning and several passes with tines or discs to control weeds and produce a seedbed (Photo 5). Reduced cultivation and retained stubble led to improved soil structure and less soil erosion, and the environmental value of conservation cropping became more widely recognised. Many farmers adopted minimum tillage, which consisted of a single cultivation before sowing, generally with a tined implement, followed by seeding with a combine. Conventional cultivation, involving multiple passes, had largely disappeared by the mid-1980s. [20]

Photo 5: *The impact of tillage varies with the tillage implement used: inversion tillage using a mouldboard plough, as pictured here, results in greater impacts than using a chisel or disc plough.*

Source: Grains Research and Development Corporation

No-till is attractive to farmers because it reduces production costs relative to conventional tillage. However, some producers are reluctant to adopt this practice because it can have contrasting consequences on grain yield depending on weather conditions and other factors.

19 GRDC (2014) Strategic tillage fact sheet. Grains Research and Development Corporation, July 2014, www.grdc.com.au/GRDC-FS-StrategicTillage

20 J Midwood, Paul Birbeck. Managing heavy stubble loads and crop residue. In Managing stubble, Grains Research and Development Corporation, pp. 4–25

No-till improves moisture retention and soil structure, but can also contribute to increased incidence of soil and stubble-borne diseases, herbicide-resistant hard-to-kill weeds and stratification of immobile nutrients near the soil surface.[21]

Photo 6: *Strategic tillage can provide control for herbicide-resistant weeds and those that continue to shed seed throughout the year. Here it has been used for control of barnyard grass in fallow.*

Source: Grains Research and Development Corporation

1.4 Fallow weed control

Fallow management is not a major practice in the southern cropping region. Choosing paddocks with low levels of grass weeds (primarily herbicide resistant ryegrass and brome grass) is important due to durum's lower competitiveness and limited in-crop weed control options. [22]

Good weed control can be achieved effectively by:

- controlling weeds in preceding crops and fallow
- rotating crops and herbicides
- growing competitive durum crops
- the judicious use of herbicides.

Controlling weeds in both preceding crops and winter fallows is important for subsequent durum crop quality (Photo 7).

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 both important for good control of fallow weeds. For advice on individual paddocks growers should contact their local agronomist.

21 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. Grains Research and Development Corporation, February 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Tillage-impact-in-long-term-no-till

22 Tony Craddock (2016). Personal Communication.

Photo 7: *Fallow paddock. Weed control in fallow paddocks is important for subsequent durum crop yield and quality.*

Source: Tim Scrivener

For more information, see Section 6: Weed control

1.4.1 The green bridge

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 (Photo 8).

Photo 8: *Broad-leafed weeds and grasses form a green bridge between successive crops.*

Source: DAFWA

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.

MORE INFORMATION

Green bridge management fact sheet

- 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 neighbouring properties 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. [23]

1.4.2 Stubble retention

Key points:

- Retaining stubble has several advantages to soil fertility and productivity.
- Retaining stubble can decrease erosion and increase soil water content.
- Benefits of stubble retention are enhanced by reduced tillage and leguminous crop rotations.

Historically, stubble has been burnt in southern Australia because it creates easier passage for seeding equipment, enhances seedling establishment of crops, and improves control of some soil-borne diseases and herbicide resistant weeds. However, the practice of burning stubble has recently declined due to concerns about soil erosion, loss of soil organic matter and air pollution. However, stubble is increasingly being retained which has several advantages of soil fertility and productivity (Photo 9).

VIDEOS

WATCH: GCTV5: Managing summer fallow.

WATCH : Managing Stubble.

Photo 9: *Management of retained stubble is important for healthy crop rotations.*

Source: GRDC

Summer rainfall and warmer conditions promote decomposition of stubble.

MORE INFORMATION

Developments in stubble retention

Other benefits of stubble retention

Retaining stubbles returns nutrients to the soil, the amounts depend on the quality and quantity of stubble. Wheaten stubble from a high yielding crop may return up to 25 kg of available nitrogen per hectare to the soil. The addition of organic matter with retained stubbles supports soil life, and can improve soil structure, infiltration

23 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

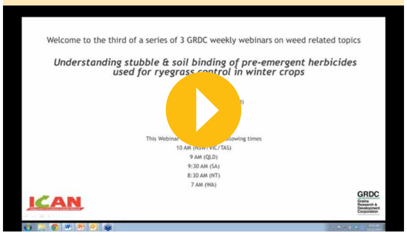
VIDEOS

WATCH: Stubble height part 1 and part 2.

WATCH : Southern farm groups cutting through stubble issues.

WATCH : Over the Fence south: Jim Cronin.

WATCH : Stubble and soil binding of pre-emergent herbicides for annual ryegrass control in winter crops.



and water holding capacity. These benefits are greater when integrated with no till practices.[24]

1.5 Herbicides and plant-back issues

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop. Herbicide plant-back restrictions should be taken into account when spraying fallow weeds prior to sowing. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods. Some herbicides can remain active in the soil for weeks, months or years. This can be an advantage as it ensures good long-term weed control. However, if the herbicide stays in the soil longer than intended it may damage sensitive crop or pasture species sown in subsequent years.

Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the 'Protection of crops etc.' heading in the 'General instructions' section of the label. [25]

It is important to note that product labels do not use consistent terminology or put warnings in the same place so you need to read the entire label carefully. A real problem for growers is the difficulty in identifying herbicide residues before they cause a problem. Currently, we are limited to predicting carryover based on information provided on the product labels about soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, or if the testing is possible it is too expensive to be part of routine farming practice. Once the crop has emerged, diagnosis is difficult because the symptoms of residual herbicide damage can often be confused with and/or make the crop vulnerable to other stresses, such as nutrient deficiency or disease. [26]

Table 1 lists common herbicides with some residual activity that may be of risk to durum crops.

Table 1: *Herbicides that pose a potential risk to durum crops. Current at publication of this GrowNote.*

Herbicide group	Active constituent
Group B: Imidazolinones	imazamox, imazapic, imazapyr, imazethapyr
Group B: Triazolopyrimidines (sulfonamides) (Lower risk)	flumetsulam, florasulam, metosulam, pyroxsulam
Group C: Triazines	atrazine, simazine
Group C: Triazinones	metribuzin
Group C: Ureas	diuron
Group H: Pyrazoles	pyrasulfotole
Group H: Isoxazoles	isoxaflutole
Group K: Chloroacetamides	dimethenamid, metholachlor
Group K: Isoxazoline	pyroxasulfone NOTE: Important to note that durum is more sensitive to this Active constituent than bread wheat.

Source: Agriculture Victoria

24 Soilquality.org. Benefits of retaining stubble – NSW. http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

25 DPI NSW. (2008). Herbicide residues in soil and water. http://www.smarttrain.com.au/__data/assets/pdf_file/0008/351863/Herbicide-Residues-in-Soil-and-Water.pdf

26 DEDJTR (2013) Avoiding crop damage from residual herbicides, Department of Economic Development, Jobs, Transport and Resource, August 2013, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

Most herbicide residues are broken down by microbial activity in the soil. The soil microbes require warm, moist soil to survive and "feed" on the chemical. Degradation of chemical residue is slower when soils are dry or cold. Soil type and pH also have an influence on the rate at which chemicals degrade. [27]

Note that label plant-backs are important particularly for durum wheat as it can be more sensitive to residues of some herbicides than bread wheat. Residues can lead to crop stunting and delayed growth and poor establishment. [28]

Conditions required for breakdown

Warm, moist soils are required to breakdown most herbicides through the processes of microbial activity. For the soil microbes to be most active they need good moisture and an optimum soil temperature range of 18°C to 30°C. Extreme temperatures above or below this range can adversely affect soil microbial activity and slow herbicide breakdown. Very dry soil also reduces breakdown. To make matters worse where the soil profile is very dry it requires a lot of rain to maintain topsoil moisture for the microbes to be active for any length of time.

In those areas that do not experience conditions which will allow breakdown of residues until just prior to sowing, it is best to avoid planting a crop that is sensitive to the residues potentially present on the paddock, and opt for a crop that will not be affected by the suspected residues.

If dry areas do get rain and the temperatures become milder, then they are likely to need substantial rain (more than the label requirement) to wet the sub-soil, so the topsoil can remain moist for a week or more. This allows the microbes to be active in the top-soil where most of the herbicide residues will be found. [29]

Plant-back periods for fallow herbicides in the Southern Region

Herbicide plant-back restrictions should be taken into account when spraying fallow weeds prior to sowing winter crops in the Southern region. Many herbicide labels place time and/or rainfall restrictions on sowing certain crops and pastures after application, due to potential seedling damage. Crops such as canola, pulses and legume pastures are the most sensitive to herbicide residues, but cereal crops and especially durum wheat can also be affected.

When treating fallow weeds, especially in late summer or autumn, consideration must be given to the planned crop or pasture for the coming year. In some cases, the crop or pasture for the following year may also have an influence on herbicide choice.

Most herbicide residues are broken down by microbial activity in the soil. The soil microbes require warm, moist soil to survive and "feed" on the chemical. Degradation of chemical residue is slower when soils are dry or cold. Soil type and pH also have an influence on the rate at which chemicals degrade.

The following points are especially relevant:

- Phenoxy herbicides such as 2,4D Ester, 2,4D Amine and Dicamba, require 15 mm of rainfall to commence the plant-back period when applied to dry soil.
- Group B herbicides such as Ally, Logran and Glean break down more slowly as soil pH increases. Recently applied lime can increase the soil surface pH to a point where the plant-back period is significantly extended.
- Lontrel, Grazon and Tordon products break down very slowly under cold or dry conditions, which can significantly extend the plant-back period.

27 RMS (2016) Plant-back periods for fallow herbicides in southern NSW. Rural Management Strategies Agricultural Consultants, April 2016, http://www.rmsag.com.au/2016/plant-back-periods-for-fallow-herbicides-in-southern-nsw/

28 DEDJTR (2013) Avoiding crop damage from residual herbicides, Department of Economic Development, Jobs, Transport and Resource, August 2013, http://www.depi.vic.gov.au/agriculture-and-food/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

29 Dow AgroSciences. Rotational crop plant-back intervals for southern Australia. http://msdssearch.dow.com/PublishedLiteratureDAS/dh_0931/0901b80380931d5a.pdf?filepath=au&fromPage=GetDoc

Keeping accurate records of all herbicide treatments and planning crop sequences well in advance can reduce the chance of crop damage resulting from herbicide residues (Table 2). [30]

Table 2: *The below table provides indicative plant-back intervals for a selection of relevant herbicides.*

Product	Rate	Plant-back period	Wheat	Barley	Oats	Canola	Legume Pasture	Pulse Crops
2,4-D 680*	0–510 ml/ha	(days)	1	1	1	14	7	7
	510–1,150 ml/ha		3	3	3	21	7	14
	1,150–1,590 ml/ha		7	7	7	28	10	21
Amicide Advance 700*	0 – 500 ml/ha	(days)	1	1	1	14	7	7
	500 - 980 ml/ha		3	3	3	21	7	14
	980–1500 ml/ha		7	7	7	28	10	21
Kamba*	200 ml/ha	(days)	1	1	1	7	7	7
	280 ml/ha		7	7	7	10	14	14
	560 ml/ha		14	14	14	14	21	21
Hammer 400 EC					No	Residual	Effects	
Nail 240 EC					No	Residual	Effects	
Goal					No	Residual	Effects	
Striker					No	Residual	Effects	
Sharpen	26 g/ha	(weeks)	-	-	-	16	-	-
Lontrel	300 ml/ha	(weeks)	1	1	1	1	36	36
Garlon 600		(weeks)	1	1	NS	NS	NS	NS
Ally		(weeks)	2	6	36	36	36	36
Logran #		(months)	-	-	-	12	12	12
Glean		(months)	-	9	6	12	12	12
Grazon Extra /Grazon DS		(months)	9	9	NS	9	24	24
Tordon 75D, Tordon 242		(months)	2	2	NS	4	9	6
Tordon Fallow Boss		(months)	9	9	NS	12	20	20

Table key:
* 15 mm rainfall required to commence plant-back period
Period may extend where soil pH is greater than 7
\# Assumes 300 mm rainfall between chemical application and sowing
NS Not Specified

Source: RMS

MORE INFORMATION

Herbicide residues in soils – are they an issue?

Weed control in winter crops.

For more information on herbicide residues, see Section 6: Weed control.

1.6 Seedbed requirements

One of the first ways to achieve high yields in durum wheat is to seed the crop into a clean seedbed to reduce competition for moisture and nutrients.

Wheat seed needs good soil contact for germination. This can be assisted with press wheels, coil packers or rollers. Soil type determines the implement that produces the ideal seedbed. Between 70 and 90% of seeds sown produce a plant if vigour and germination are high. Depth of sowing, disease, crusting, moisture and other stress in the seedbed all reduce the number of plants establishing. Field establishment is unlikely to be more than 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, as the clods allow light to penetrate below the soil surface.

30 RMS (2016) Plant-back periods for fallow herbicides in Southern-NSW, http://www.rmsag.com.au/2016/plant-back-periods-for-fallow-herbicides-in-southern-nsw/

The coleoptile senses the light and stops growing while still below the surface. For successful crop establishment, seed needs to be placed into soil with enough seedbed moisture for germination to occur, or into dry soil with the anticipation of rainfall to increase soil moisture levels such that germination may occur. [31]

Ground preparation is the same as for bread wheat. Adequate cultivation and/or spraying should eliminate all volunteer plants of bread wheat, barley and other crop/weed species. [32]

A good seedbed should be weed, disease and insect free. It should provide good seed/soil contact and be moist and warm. To aid in erosion control use implements that will preserve the previous crop residue. Substituting herbicides for cultivation and seeding without pre-seeding tillage (minimum to zero till) are other practical considerations. Under dry or firm soil conditions, seed with seeding implements that minimize soil disturbance, such as air drills with disc or narrow openers, to prevent soil drying.

When shallow seeding, the previous crop's residue will have a greater tendency to interfere with good seed-to-soil contact. Even spreading of the previous crop residue is essential for quick emergence. Make sure seed-to-soil contact occurs. When seeding on summer fallow, take extra care to obtain a firm seedbed to facilitate shallow seed placement into moist soil and to prevent soil erosion by wind.

If irrigating, pre-irrigation is favoured over "irrigating up" after sowing, as seeds can swell and burst. Sowing after pre-irrigation should be as soon as soil conditions allow. For an April 1st pre-irrigation, this delay may range from one week on light soils to 3–4 weeks on some heavy clay soils.

Following the initial irrigation, subsequent irrigations should be at a cumulative evaporation less rainfall interval (E-R) of 75 mm on grey soils and 50 mm on red soils.

Pre-irrigation completed by April 1st is a safe option in most years. Later irrigations can cause problems by making the ground too wet for both sowing and grazing.

If not pre-irrigated, then the crop should be sown following sufficient rainfall to wet the soil to 100 mm depth. [33]

There are several approaches that can be used to achieve a good seedbed preparation. The deciding factor in choosing an approach is how the various techniques manage harvest residues.

The seedbed lays the foundations for crop establishment. However, there are different techniques that can be used to create a seedbed. The technique used depends on many different factors, e.g. harvest residues, the equipment available, soil type, climate, labour requirement, etc (Figure 2).

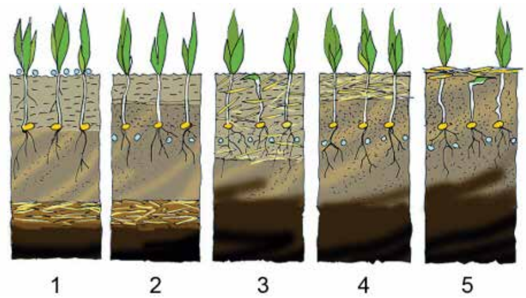


Figure 2: *Diagram demonstrating the results of different seedbed preparation options.*

Source: Vaderstad

31 NSW DPI (2008) Wheat growth and development (Eds J White, J Edwards). New South Wales Department of Primary Industries, February 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/516185/Procrop-wheat-growth-and-development.pdf

32 R Hare (2006) Agronomy of the durum wheats Kamilaroi(D), Yallaroi(D), Wollaroi(D) and EGA Bellaroi(D). Primefacts 140. NSW Department of Primary Industries, April 2006, http://www.dpi.nsw.gov.au/content/agriculture/broadacre/winter-crops/winter-cereals/agronomy-durum-wheats

33 Agriculture Victoria. Managing winter cereals, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/irrigated-pastures/managing-winter-cereals

The seedbed and sowing using different techniques:

1. Conventional technique: ploughing in of straw, cultivation to sowing depth with a tyne/disc cultivator, conventional drilling, fertiliser spreading.
2. Mouldboard ploughing: Ploughing in of straw.
3. Minimal tillage: tillage of straw by cultivator.
4. Shallow tillage: shallow burial of straw at the surface.
5. Direct drilling: The straw remains on the surface.

Ploughing warms up the soil and buries plant residues so that they do not obstruct sowing. However, ploughing disrupts the soil structure and increases oxidation of the organic material. Without ploughing, the organic material and the soil structure are retained, but the straw can cause problems with sowing and can transmit diseases. [34]

1.6.1 Seedbed soil structure decline

Key Points

- Hard-setting or crusting soils are usually indicators of poor soil structure.
- A “massive” soil has significantly reduced pore space resulting in poor infiltration and low water holding capacity.
- Bulk density is a good indicator of soil structure.
- Increasing organic matter and decreasing traffic and stock can improve soil structure.
- Gypsum can help in alleviating problems with hard-setting or crusting.

Background

Surface soil structure decline generally results in one of two things: hard-setting or crusting (Photo 10). A surface crust is typically less than 10 mm thick and when dry can normally be lifted off the loose soil below. Crusting forces the seedling to exert more energy to break through to the surface thus weakening it. A surface crust can also form a barrier, reducing water infiltration.

Soil structure breakdown caused by rapid wetting can lead to hard-setting. Once wet, the unstable soil structure, collapses, and then shrinks as it dries. This leads to a “massive” soil layer with little or no cracks and greatly reduced pore space. This hard-set “massive” structure is associated with poor infiltration, low water holding capacity and a high soil strength. In many instances, this causes patchy establishment and poor crop and pasture growth.

Photo 10: *Soil crusting (left) and cloddy seedbed (right) associated with high concentrations of exchangeable sodium.*

Source: Soilquality.org

34 Vaderstad. Seedbed Preparation, http://www.vaderstad.com/knowhow/seed-beds/seedbed-creation

Management to improve seedbed soil structure

To decrease the level of crusting or hard-setting in soils, it is necessary to stabilise soil structure. For example, amelioration of a hard-setting grey clay was found to be most effective using management practices that increased soil organic matter and reduced trafficking, thereby improving soil structure. Removing or reducing stock when the soil is saturated also helps avoid compaction, smearing and "pugging" of the soil surface.

Another option for stabilising soil structure in soils prone to hard-setting or crusting is through the addition of gypsum on dispersive soils. This effectively displaces sodium, and causes clay particles to bind together, helping to create stable soil aggregates. A resulting reduction in the exchangeable sodium percentage (ESP) and increase in the calcium/magnesium ratio may be observed. Addition of lime also adds calcium to the soil, but is generally only used for soils with a low pH. [35]

1.7 Soil moisture

Soil characteristics (surface and subsurface) such as pH, sodicity, salinity, acidity, texture, drainage and compaction will affect variety selection. See your local variety guide for details of recommended varieties and planting times. There is significant variation in soil type across the southern region.

1.7.1 Dryland

Soil moisture

Low levels of soil moisture at sowing can significantly increase financial risks. Water is often the limiting factor in crop production and crop rotation can help maximise water intake by soil. Surface cover (stubble) is essential for this process. While around 20% of rain is stored during fallows, small changes in soil management can improve this apparent low efficiency and have large impacts on profit. Water stored can be improved through weed control, soil cover and reduced compaction. This can be achieved through reduced tillage, controlled traffic and planting crops before the soil fills. Paddocks with ground cover can retain moisture for longer, extending the time for planting after small rainfall events. Stubble retention combined with reduced or zero tillage almost universally results in better water storage. Better water storage results in better yields, especially in dry years. [36] After drought, it is important to restore ground cover as soon as possible to get the water cycle working again. [37]

Soil salinity

A saline soil is one that contains sufficient soluble salts (most commonly sodium chloride [NaCl]) to adversely affect the growth of most plants. Salinity reduces a plant's ability to extract water from the soil and can cause toxicities from specific ions. Salt tolerance in the genus *Triticum* is associated with low accumulation of sodium (Na+) in leaves. Durum and other tetraploid wheats generally have high accumulation of Na+ relative to bread wheat, and are salt-sensitive.

Salinity that effects crop growth is associated with water tables and susceptibility to waterlogging in south-east South Australia (SA), whilst most cropped soils in Victoria and SA have the potential to experience transient salinity associated with excess rainfall occurring in sodic soils. The economic effect of salinity in agriculture is considerable, being estimated at $1.5 billion annually for the whole of Australia. An exception is in the higher rainfall environment of southern Victoria where salinity is not considered a major factor effecting productivity of grain crops. [38]

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35 Soilquality.org. Seedbed soil structure decline, www.soilquality.org.au/factsheets/seedbed-soil-structure-decline

36 D Freebairn (2016) Improving fallow efficiency. GRDC Update Papers. Grains Research and Development Corporation, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Improving-fallow-efficiency

37 NSW DPI (2009) Setting up for high quality durum. Agriculture Today. NSW Department of Primary Industries, March 2009, http://www.dpi.nsw.gov.au/content/archive/agriculture-today-stories/ag-today-archives/march-2009/setting-up-for-high-quality-durum

38 Crop Pro (2003) Physical and chemical soil constraints of wheat crops in southern Australia.

Signs of salinity in the paddock:

- crop symptoms including reduced yield, and burnt leaf tips and/or margins (Photo 11)
- salt-tolerant plant species thriving while others show poor growth
- dieback of trees
- waterlogged soil (separate from rain or flood events)
- bare patches of soil
- wet, dark, greasy patches
- salt crusts on the soil surface when it is dry
- stock congregating and licking surface salt
- very clear water in dams and waterways. [39]

Photo 11: *Cereal plant with salinity symptoms.*

Source: Department of Agriculture and Food Western Australia

Genetics: building salt tolerance

CSIRO scientists developed a salt-tolerant, premium-priced durum wheat that yields 25% more grain than the parent variety in previously unsuitable saline soil. [40] Research revealed that an ancient Persian durum wheat has the ability to exclude salt from its roots. Elite lines derived from crosses between Tamaroi(D and the sodium-excluding ancestors were grown in saline and non-saline soils for the first time in the 2004 season. The Durum Breeding Australia project (NSW Department of Primary Industries and the University of Adelaide) and researchers at CSIRO Plant Industry Canberra identified two major genes that confer the salt tolerance, and a molecular marker has been found for one. There is ongoing research to find a marker for the other. The research is being conducted through the AUSGRAINZ joint venture between CSIRO and New Zealand Crop and Food Research (GRDC Research Codes: CSP344, CSP298, CSP00058). [41]

39 S. Alt (2016). Salinity – New South Wales. Soil Quality Fact Sheets, http://www.soilquality.org.au/factsheets/salinity-nsw

40 University of Adelaide (2012) World breakthrough on salt-tolerant wheat. University of Adelaide, March 2012, https://www.adelaide.edu.au/news/news51221.html

41 GRDC (2005) Tracking Water Use Efficiency. GRDC Groundcover Issue 54. Grains Research and Development Corporation, February 2005, http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-54/Tracking-wateruse-efficiency

IN FOCUS

Impact of ancestral wheat sodium exclusion genes Nax1 and Nax2 on grain yield of durum wheat on saline soils. [42]

Nax1 and Nax2 are two genetic loci that control the removal of Na+ from the xylem and thereby help to exclude Na+ from leaves of plants in saline soil. They originate in the wheat ancestral relative *Triticum monococcum* L. and are not present in modern durum or bread wheat. The Nax1 and Nax2 loci carry TmHKT1;4-A2 and TmHKT1;5-A, respectively, which are the candidate genes for these functions. This paper describes the development of near-isogenic breeding lines suitable for assessing the impact of the Nax loci and their performance in controlled environment and fields of varying salinity. In young plants grown in 150 mM NaCl, Nax1 reduced the leaf Na+ concentration by three-fold, Nax2 by two-fold and both Nax1 and Nax2 together by four-fold. In 250 mM NaCl, Nax1 promoted leaf longevity and greater photosynthesis and stomatal conductance. In the uppermost leaf, the Na+-excluding effect of the Nax loci was much stronger. In the field, Na+ in the flag leaf was reduced 100-fold by Nax1 and four-fold by Nax2; however, Nax1 lines yielded 5–10% less than recurrent parent (cv. Tamaroi⒟) in saline soil. In contrast, Nax2 lines had no yield penalty and at high salinity they yielded close to 25% more than Tamaroi⒟, indicating this material is suitable for breeding commercial durum wheat with improved yield on saline soils.

Subsoil

Subsoils are typically defined as below the plough layer, although some references imply below the A1 horizon or soil profile greater than 10 cm. The nature and impact of particular subsoil constraints (SSCs) in the southern region is strongly related to soil type and soil pH, particularly Vertosols, Calcarosols, Tenosols and Sodosols with alkaline subsoils, and acidic Chromosols and Sodosols. Crop types differ in their relative tolerance to different subsoil constraints, and the relative impact that constraints have on grain yield is heavily dependent on soil (especially subsoil) moisture. The general nature of subsoil physicochemical properties is relatively uniform across all the neutral-alkaline soils in the low to medium rainfall regions of SA and Victoria and the southern Mallee. However, an unexpected trend towards lower boron concentrations has been identified in SA.

Field research conducted under dry seasonal conditions in the low rainfall environments of the Eyre Peninsula and Victorian Mallee and the medium rainfall environment of the southern Wimmera indicate there are few, if any, subsoil amelioration strategies that will reliably increase grain yields and profitability of cropping. All these regions were characterised by sodic, high-clay, neutral-alkaline soils and experimentation was conducted under extremely dry (Decile 1 to 4) seasonal conditions.

In contrast there is evidence (obtained via simulation modelling and controlled environment trials) that under better seasonal conditions some of these subsoil amelioration strategies could significantly improve grain yields. Similarly, in environments with sand-over-clay soils (in both low and medium rainfall regions) there were consistent yield responses to deep ripping/nutrient placement. The current

42 RA James, C Blake, AB Zwart, RA Hare, AJ Rathjen, R Munns (2012). Impact of ancestral wheat sodium exclusion genes Nax1 and Nax2 on grain yield of durum wheat on saline soils. Functional Plant Biology, 39(7), 609–618, http://www.publish.csiro.au/paper/FP12121.htm

financial viability of this strategy was questionable, however, and further work is required to develop more cost-effective strategies. [43]

GPS mapping and empirical modelling techniques have been used to determine the relationships between the wheat and soil factors. Areas within the field with lower soil profile available water capacities, caused by a combination of coarser soil texture and lower organic carbon content, probably contributed to water stress during grain-fill, which interacted with soil N to give higher protein levels. These areas of the field had lower yields and smaller 1000-kernel weights. Protein quality was not compromised by increasing protein concentrations which resulted from water stress. [44]

Genetic solutions to subsoil constraints

The potential contribution of genetic variation to improving crop production on hostile subsoils has been assessed. Closely-related genotypes of bread and durum wheat, barley and lentil with differing tolerances to boron (B) and/or Na+ were compared by growing the different lines in intact soil cores of two Calcarosol profiles with differing levels of subsoil physicochemical constraints ('hostile'/'benign') from the southern Mallee.

Grain yields were significantly reduced on the hostile soil compared with the benign soil, with durum wheat yielding 31% less on the hostile soil. Durum wheat (genotype with greater Na+ tolerance) did not show significant yield advantage compared to the respective 'non-tolerant' parent line when grown on the hostile soil. This work suggests there is little benefit in lines with tolerance for a single specific subsoil constraint where there are multiple potential constraints. In contrast, lentils possessing tolerance to both high Na+ and B show considerable promise for improving yields on these soils. This experiment also highlighted the potential benefit of pyramiding tolerances to specific SSCs. [45]

1.7.2 Irrigation

Durum can be grown successfully under irrigated conditions using both surface and overhead irrigation systems. [46] Both water and N management are crucial if high yielding crops of high quality grain are to be achieved (Figure 3). [47]

Although irrigation of wheat generally leads to an increase in biomass and grain yield, it can have negative effects on grain quality. Usually the kernels become larger with irrigation (depending on the duration and frequency) than under rain-fed farming, and this causes a dilution of grain protein and yellow pigment and an increase in yellow berry (lower percentage of hard vitreous kernels [HVK]), which is associated with lower semolina extraction. This can be corrected by increasing N application at sowing, and especially by splitting application between stem elongation and heading. [48] More N translates into more grain protein, thereby reducing yellow berry incidence, which is inversely related to grain protein content. [49] N fertilisation generally increases grain protein content, gluten content, HVK, carotenoids and the dough strength (as assessed by sodium dodecyl sulfate (SDS) sedimentation) if soil available N is deficient. [50]

43 GRDC (2008) Improving the profitability of cropping on hostile subsoils – DAV00049. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DAV00049

44 CM Stewart, AB McBratney, JH Skerritt (2002) Site-specific durum wheat quality and its relationship to soil properties in a single field in northern New South Wales. Precision Agriculture, 3(2), 155–168, DOI: 10.1023/A:1013871519665

45 GRDC (2008) Improving the profitability of cropping on hostile subsoils – DAV00049. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DAV00049

46 Rharrabti et al. (2001), Reynolds et al. (2002), Karam *et al*. (2009), and Mohammadi *et al*. (2011).

47 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

48 CA Grant, N Di Fonzo, M Pisante (2012) Agronomy of durum wheat production. In Durum wheat chemistry and technology. 2nd edn (Eds M Sissons, J Abecassis, B Marchylo, M Carcea) pp. 37–55. (AACC International: St. Paul, MN, USA)

49 M Sissons, J Abecassis, B Marchylo, R Cubadda (2012) Methods used to assess and predict quality of durum wheat, semolina and pasta. In Durum wheat chemistry and technology. 2nd edn (Eds M Sissons, J Abecassis, B Marchylo, M Carcea) pp. 213–234. (AACC International: St. Paul, MN, USA)

50 L Ercoli, L Lulli, M Mariotti, A Masoni, I Arduini (2008) Post-anthesis dry matter and nitrogen dynamics in durum wheat as affected by nitrogen supply and soil water availability. European Journal of Agronomy, 28, 138–147. http://dx.doi.org/10.1016/j.eja.2007.06.002

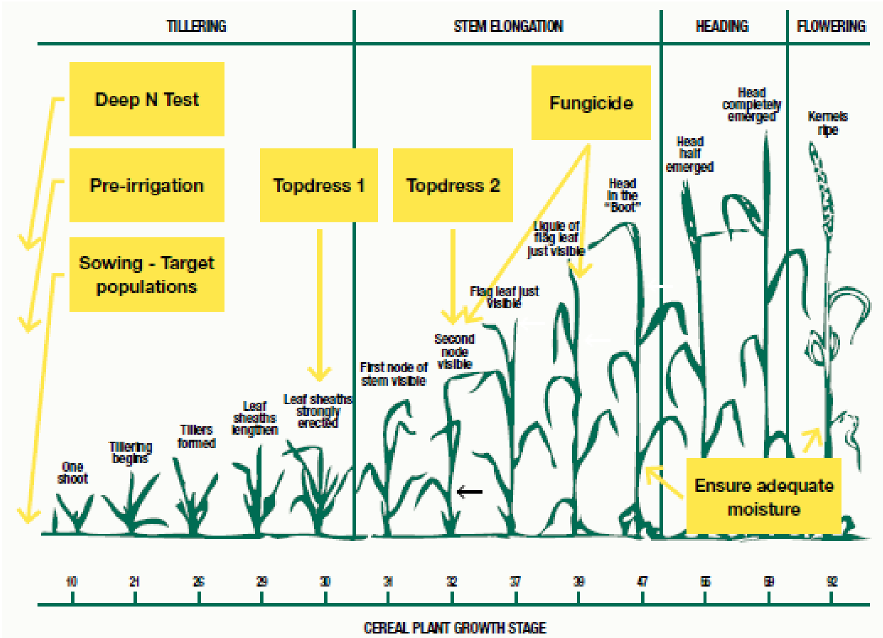

Figure 3: *Irrigated wheat management practices by growth stage. If sowing early, it is vital the crop is not moisture stressed at head emergence or during the first 10 days after flowering—these are the critical stages for determining grain number and size. Other key management practices include timing of nitrogen application.*

Source: Grains Research and Development Corporation

In field trials conducted under irrigated conditions, durum varieties Arrivato(D and Bellaroi(D yielded well and appear well suited to the high-yielding irrigation environment. Late topdressing of N was evaluated on Arrivato(D at Griffith (on-farm test strips) and demonstrated the difficulty in reaching required quality at 8 t/ha or more. [51]

MORE INFORMATION

[Irrigated wheat in the Murrumbidgee and Murray Factsheet.]

51 GRDC (2005) Wheat variety evaluation for irrigation in the southern region – CSP342. Grains Research and Development Corporation, http://finalreports.grdc.com.au/CSP342

IN FOCUS

Durum wheat quality in high-input irrigation systems in south-eastern Australia. [52]

Durum wheat is primarily grown under non-irrigated conditions. To help extend the production base of durum wheat in Australia, field trials have been conducted on seven registered durum varieties across four seasons and six sites in locations where irrigation was supplied during crop growth. This was done to determine if the quality of the grain produced met the requirements for good milling and pasta-making quality and to understand the genotype, environment and their interaction in affecting yield and technological quality of the grain and derived pasta.

High grain yields and grain protein were obtained, producing large grain weights, low screenings and low percentage of HVK. Yellow colour of semolina and pasta was reduced marginally but dough and other pasta technological characteristics were similar to typical dryland durum production, with some exceptions.

High-yielding durum production can be achieved with irrigation and with appropriate N applications; 13% protein, the level required by pasta industry standards, is also achievable. The highest yielding variety was Hypernoⓓ, followed by EGA Bellaroiⓓ, whereas Jandaroiⓓ was the lowest yielding. However, Hypernoⓓ is more predisposed to lodging, and the varieties EGA Bellaroiⓓ and Arrivatoⓓ had the best lodging scores (but with a poor yellow score). Excellent grain size is a feature of irrigated wheat, but the downside was the low HVK, with EGA Bellaroiⓓ performing the best but still not attaining ADR1 grade. Yellowness of the semolina and pasta was lower than obtained in typical dryland production, with the best varieties being EGA Bellaroiⓓ, Hypernoⓓ and Caparoiⓓ. Pasta quality from irrigated durum was similar to typical dryland durum, having acceptable cooking and texture properties except for a reduction in pasta yellowness. Significant genotype, location and genotype × location effects for all of the technological characteristics were quantified. Breeding selection under irrigation might be a useful strategy to improve semolina yield, protein content, grain yield, and semolina and pasta colour, because irrigation and suitable N provide more stable conditions for varietal selection.

1.8 Yield and targets

Yield potential (as opposed to achieved yield) is determined in the growth phase before anthesis, during the formation and growth of the ear. Yield potential can best be thought of in terms of the number of grains per unit area and the size (weight) of each grain. There are several critical times during crop development where grain number and size are determined. The first step in establishing yield potential is that of crop establishment; i.e. how many plants per square metre, as this directly affects the number of heads per square metre a crop can produce. [53]

52 M Sissons, B Ovenden, D Adorada, A Milgate (2014). Durum wheat quality in high-input irrigation systems in south-eastern Australia. Crop and Pasture Science, 65(5), 411–422, http://dx.doi.org/10.1071/CP13431

53 N Poole, J Hunt (2014) Advancing the management of crop canopies. Grains Research and Development Corporation, January 2014, http://www.grdc.com.au/CanopyManagementGuide

Management factors to build a crop structure for achieving high yields:

1. Soil conditions allowing good root structure development.
2. Variety with stem and straw strength.
3. Sowing at the correct sowing window.
4. Flowering during a period to avoid potential low and high temperature stress.
5. Restricting tillering to attain 600 to 800 shoots per square metre.
6. Limited early growth with less than 70% ground cover at early stem elongation.
7. Avoiding water stress during stem elongation to maintain highest yield potential.
8. More than three green leaves per shoot at flowering to maintain the highest yield potential. [54]

A study monitored eight commercial durum crops to identify the factors limiting durum wheat yields and the levels for target yields. Low plant population (42–91 plants/m^2) resulting from poor seed quality (60–95% germination), combined with insufficient nitrate supply (3–27 kg N/ha at harvest at four of five sites), appeared to be major factors limiting durum yields in the monitored crops (range 4.3–5.3 t/ha). Disease management was also likely to be a contributing factor, as crown rot levels in the wheat paddocks were <5% following sorghum and 15–30% following wheat. [55]

Accurate, early estimations of grain yield and crop loss are important skills in grain production. Extensive personal experience is essential for estimating yields at early stages of growth. As crops near maturity, it becomes easier to estimate yields with greater accuracy. A simple but accurate formula for estimating cereal grain yield is based on the number of heads per 500 mm of drill row, the number of grains per head and the size of the grain.

MORE INFORMATION

Estimating crop yields

Formula for estimating grain yield:

$$\frac{\text{Average number of grains per head} \times \text{Average number of heads per 500 mm of row}}{\text{Known constant (K)}} = \text{tonnes/hectare}$$

Yield Prophet®

Scientists have aimed to support farmers' capacity to achieve yield potential by developing the Agricultural Production Systems Simulator (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 delivers information from APSIM to farmers (and consultants) to aid their decision-making. Yield Prophet has enjoyed a measure of acceptance and adoption amongst innovative farmers and has made valuable impacts in terms of assisting farmers to manage climate variability at a paddock level.

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 decision-support relevant to farm management.

Operated as a web interface for APSIM, Yield Prophet generates crop simulations and reports to assist decision-making. By matching crop inputs with potential yield in a given season, Yield Prophet subscribers may avoid over or under-investing in their crop.

54 GRDC (2005) Wheat variety evaluation for irrigation in the southern region – CSP342. Grains Research and Development Corporation, http://finalreports.grdc.com.au/CSP342

55 GJ Butler, PT Hayman, DF Herridge, T Christian (2001) Working with farmers to benchmark high-yielding durum wheat on the Liverpool Plains. 10th Australian Agronomy Conference, 31 January 2001, Hobart, Tasmania, http://www.regional.org.au/au/asa/2001/4/b/butler.htm

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

Farmers and consultants use Yield Prophet to match crop inputs with potential yield in a given season. 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.

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 (BOM) weather station
- paddock-specific rainfall data recorded by the user (optional)
- individual crop details
- fertiliser and irrigation applications during the growing season

MORE INFORMATION

Yield Prophet

1.8.1 Seasonal outlook and crop modelling tools

Though weather patterns can be unpredictable, it is important to stay up-to-date with seasonal forecasts. Growers and advisers now have a readily available online tool. CropMate (Figure 9) 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 N, frost and heat risk, as well as gross margin analyses of the various cropping options.

Download CropMate from the iTunes store.

Figure 4: *Screen shot of the CropMate app.*

Source: NSW Department of Primary Industries

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 Nino-SOI status. It is designed for decision makers such as farmers whose businesses rely on the weather. One of the CliMate tools, 'Season's progress?', uses long-term (1949 to present) weather recods to assess progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and with all years. It explores readily-available weather data, compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons.

Download CliMate from the iTunes store or visit the CliMate website.

1.8.2 Fallow moisture

Fallow periods are not common practice in the southern durum cropping region, however, this information may be of use to some growers. For a growing crop there are two sources of water: first, the water stored in the soil during the fallow; and second, the water that falls as rain while the crop is growing. Growers have some control over the stored soil water, in that the amount of stored water can be measured 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 you need it. [56]

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

HowWet?

HowWet? is a program that 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 N 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 PAW during the most recent fallow period
- estimates the N mineralised as nitrate-N in soil
- provides a comparison with previous seasons.

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

1.8.3 Water Use Efficiency

Greater yield per unit rainfall is one of the most important challenges in dryland agriculture. Water Use Efficiency (WUE) is the ratio of grain yield to crop water use, and a measure of a cropping system's capacity to convert water into plant biomass or grain. It includes the use of water stored in the soil and rainfall during the growing season.

WUE relies on:

- the 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 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.

While the French and Schultz method for calculating water use efficiency has known limitations, it remains a sound tool provided its limitations are understood and the right parameters are used. More recent research has shown that size of rainfall events, rather than total rain, drives soil evaporation. Known limitations include it does not account for timing of rainfall. The critical window around flowering is particularly important for grain set and shortage of water in this window causes large reductions in yield and water use efficiency. The notion of a single parameter representing maximum yield per unit water use and a single parameter representing soil evaporation is a simplification. Both parameters have large season-to-season variation. [57]

Ways to increase yield

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

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).

57 V Sandras and G McDonald (2011) Water use efficiency of grain crops in Australia: principles, benchmarks and management. Grains Research and Development Corporation. http://www.pir.sa.gov.au/__data/assets/pdf_file/0003/238413/SARDI-Water-Use-Efficiency-Grain-Crops-Australia.pdf

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).
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). [58]

WUE provides a simple means of assessing whether yield is limited by water supply or other factors. Yields of commercial dryland crops in south-eastern Australia are often limited by water. Transpiration efficiency (TE), the ratio of yield to transpiration, is relatively stable for well-managed crops, but the amount of water used is strongly affected by crop management. [59]

Calculating WUE:

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.

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

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

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

Providing optimum N fertiliser or suppressing root diseases with break crops has been found to increase water use by 23 mm and yields by 378 kg/ha, equivalent to 10% of the control yields. In the study, additional soil water was extracted to levels of water potential as low as -5 MPa. A possible means of increasing yield potential of dryland crops is to manage transpiration so that relatively more water is used during the vegetative phase when vapor pressure deficit is low, and hence TE is high. However, based on budgets of soil water and soluble carbohydrates stored in the vegetative organs and available for re-translocation, this option provides lower TE than conserving soil water for transpiration until grain filling when assimilates are directed to grain. Increasing the proportion of water transpired during the vegetative phase with N fertiliser can lead to particularly inefficient water use because increasing N status generally reduces the soluble carbohydrate reserves available for re-translocation to grain. [60]

Plant breeders in the Durum Breeding Australia project and researchers at CSIRO Plant Industry Canberra are developing water-use efficient and salt-tolerant durum wheats to increase durum yields in current production areas as well as new environments. Researchers are improving WUE by trying to combine several traits: high transpiration efficiency, long coleoptiles and early vigour. They have found, using 50 years of climate data and computer simulation, that combining high transpiration efficiency and early vigour is likely to make durum wheat much more suitable for growing in both southern and northern cropping areas. Elite durum varieties have

58 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

59 JF Angus, AF Van Herwaarden (2001) Increasing water use and Water Use Efficiency in dryland wheat. Agronomy Journal, 93(2), 290–298, https://dl.sciencesocieties.org/publications/aj/abstracts/93/2/290

60 JF Angus, AF Van Herwaarden (2001) Increasing water use and Water Use Efficiency in dryland wheat. Agronomy Journal, 93(2), 290–298, https://dl.sciencesocieties.org/publications/aj/abstracts/93/2/290

low transpiration efficiency, but the research team has found a highly transpiration-efficient durum to cross with them. This will give the plants a WUE trait similar to that of the new bread wheats Drysdale⒫ and Rees⒫. The team is also introducing alternative dwarfing genes from European durum wheats into commercial varieties. These genes restrict plant height, but allow the expression of long coleoptiles (about 15 cm compared with 9 cm for Tamaroi⒫). Longer coleoptiles provide insurance that the shoot will reach the soil surface, even when deep sowing is required because of receding topsoil moisture, or when there is uneven sowing depth due to stubble or direct drilling. [61]

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.

> *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. [62]

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

61 GRDC (2005) Tracking Water Use Efficiency. GRDC Groundcover Issue 54. Grains Research and Development Corporation, February 2005, http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-54/Tracking-wateruse-efficiency

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

integrative and dynamic modelling approaches to explore alternatives to increase WUE at the single-crop and whole-farming-systems level, i.e. $/ha.mm. [63]

1.8.4 Nitrogen Use Efficiency

Key points:

- Improving Nitrogen Use Efficiency (NUE) begins with identifying and measuring meaningful NUE indices and comparing them with known benchmarks, and contrasting N management tactics.
- Potential causes of inefficiency can be grouped into categories. Identification of the most likely groups is useful in directing more targeted measurement and helping identify possible strategies for improvement.
- As a result of seasonal effects, NUE improvement is an iterative process. Therefore, consistency in investigation strategy and good record keeping is essential. [64]

Nitrogen Use Efficiency (NUE) aims to quantify the amount of N fertiliser applied that is available to the crop. Achieving 13% protein in the new durum lines remains a major production challenge. As yields increase, protein levels are more than likely to decline within nitrogen-limited environments. [65] Improvements in NUE may be one method of improving the frequency in which growers achieve 13% protein. In benchmarking trials this value ranged from 25-95% in the benchmarked crops, which varies dramatically from the figure of 50% commonly used for N budgeting purposes. The major reason for the variation is the level of N that is tied up by trash, and the amount released by mineralisation. In the crops benchmarked, crops following cotton tended to have lower NUE, as the cotton trash that is incorporated into the soil requires large amounts of N to feed the microbes that break the trash down. In addition, there is minimal short-term, in-crop mineralisation. Crops following maize or fallow, however, had very little N tied up, and released much more N through mineralisation, and therefore had higher NUE. The amount of N removed was calculated by N in grain (kg/ha) = yield (t/ha) x 1.75 x protein (%), and crop N requirement = N in grain (kg/ha) x N uptake efficiency factor. So, if the starting soil N, the yield and the protein percentage is known, the N uptake efficiency factor can be estimated. [66]

1.8.5 Double crop option

Double cropping is growing a winter and summer crop following one another. Successful double cropping relies on careful planning of rotations, herbicide use and minimal hold-ups between harvesting and sowing. Durum has no or little evaluation in this system but would be expected to perform similarly to hard wheat, however variety choice and avoiding extremes of temperature at flowering will be critical for success with durum varieties.

There has been little adoption of double cropping in northern Victoria. Issues such as stubble management, conflict of harvest and sowing times between winter and summer crops, and difficulty in determining the best rotation of winter and summer crop options have been identified as barriers to adoption. Double cropping in northern Victoria could provide irrigation farmers with an opportunity to capitalise on their investment in irrigation infrastructure and improve their profitability and Water Use Efficiency.

A best practice management guide outlines nine key checks that must be undertaken to maximise the results of double cropping in northern Victoria. These are:

63 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

64 C Dowling C (2014) The fundamentals of increasing Nitrogen Use Efficiency, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/The-fundamentals-of-increasing-nitrogen-use-efficiency-NUE

65 GRDC (2012) Durum expansion in SA through improved Agronomy – DGA00001. Grains Research and Development Corporation, http://finalreports.grdc.com.au/DGA00001

66 B Haskins, M Sissons (2011) Growing wheat after cotton—durum benchmarking 2009. GRDC Update Papers. Grains Research and Development Corporation, August 2011,

1. **Field layout, water delivery and drainage**: double cropping layouts need to be irrigated quickly and drained without delay. Use as a priority the paddocks with efficient channel delivery systems and reuse systems that allow drainage and eliminate farm runoff.
2. **Weed, pest and disease control**: use fallow, hay/silage and break crops to control weeds, pests and diseases. Determine weed densities and use integrated weed management to reduce the likelihood of herbicide resistance and limit yield loss.
3. **Opportunity cost of water**: determine the production costs of growing the crop. In low water allocation years, compare the market price of temporary trade water with the return on potential crop production. Use the opportunity cost *v.* commodity price matrix to determine best gross margin return for 1 ML of water.
4. **Sowing time:** a double cropping program can commence in either the summer or winter crop phase. The critical issue with crop sowing is timeliness—sowing on time to maximise yield potential, and to ensure harvest is complete before the optimal sowing window of the next crop phase.
5. **Soil moisture at sowing**: ensure there is adequate soil moisture for crop establishment and crop growth during the season. Determine subsoil moisture levels after the previous crop and pre-irrigate if required.
6. **Crop establishment**: achieve a uniform plant population using equipment necessary for good plant establishment. Some summer crops require the use of a precision planter. It is critical to the desired plant density for summer crops otherwise the economics of irrigation can be poor.
7. **Nutrition**: determine the soil nutrient status of paddocks by soil testing. Apply nutrients to the crop according to potential yield and product nutrient requirements.
8. **Irrigation**: double cropping is limited by water availability so efficient application is critical. Use soil moisture monitoring equipment to assist in determining root zone moisture levels. Use crop growth stage and weather patterns in conjunction with soil moisture levels to schedule irrigation.
9. **Timeliness of operations**: if necessary, use contractors with appropriate equipment to sow into potentially heavy stubble loads and for precision sowing to achieve optimum plant density. Contractors may also be required to harvest the crop in a timely manner so the next crop can be sown. [67]

The GRDC correct crop sequencing project will investigate rotations and techniques to provide results that will allow irrigators to be confident in investing their time and resources into double cropping. Research into double cropping funded by GRDC commenced with the winter 2014 season. It is a joint project between the Victorian Irrigated Cropping Council Inc (ICC) and NSW DPI. Each organisation has a different focus, with NSW DPI looking at rotations and ICC examining herbicide residues and techniques to reduce the intervals between the summer and winter crops.

1.9 Disease status of paddock

Disease management of paddocks is essential for maximising yield. Research by the South Australian Research and Development Institute (SARDI) and GRDC is combining DNA technology with precision agriculture (PA) zoning techniques to provide grain growers with better risk assessment of soil-borne diseases before sowing crops.

The main findings so far are:

- Soil-borne pathogen levels usually vary between PA zones within a paddock, even when zones are created using simple PA layers (for example, EM38 maps, elevation maps).
- Robust sampling methods for soil tests are critical: the current recommendation is to collect 45 cores targeted where practical along the rows of the previous

67 D Boyd (2009) Double cropping in northern Victoria. A best management practice guide. Grains Research and Development Corporation, August 2009, http://www.dairyfertility.com.au/hgf/110405%20-%20Double%20Cropping%20in%20Northern%20Victoria.pdf

cereal crop. Target sampling within PA zones gives more useful information than samples taken across the whole paddock. [68]

1.9.1 Common diseases found

Crown rot and Fusarium head blight

Durum is very susceptible to crown rot and also sensitive to closely related Fusarium head blight (FHB), both of which can be present in paddocks prior to planting, although FHB is rarely found in the Southern Region.

The crown rot fungus enters the plant through the roots, disrupting plant water supply and hence grain yield. Moisture stress will exacerbate these conditions, resulting in the appearance of 'whiteheads' in the crop, which produce small shriveled grain. It is therefore recommended that durum crops not be grown following susceptible crops, which are carriers of *Fusarium sp*. [69]

Paddocks should contain very little crown rot inoculum. Ground known to carry high levels of crown rot inoculum should be sown to an alternative crop such as broadleaf crops (e.g. chickpea, faba bean, mungbean, canola, sunflower) over a period of two years before replanting durum. The sowing of a durum crop following bread wheat is not recommended, as inoculum will be increased by both susceptible species.

Though maize is not often grown in Southern regions, it is not advisable to plant maize in the rotation prior to durum, as maize is a susceptible host of the FHB fungus. Inoculum carried by the maize trash may pass the disease to the following durum crop if suitable weather conditions for infection, such as an extended wet period, prevail during and following flowering. [70]

To determine whether a paddock is at risk, visually assess crown rot and FHB levels in a prior cereal crop, check for stem browning or have soil/stubble samples analysed at a testing laboratory.

Effect 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. [71] Stubble burning is not recommended as a control for crown rot, and cultivation can increase 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 crown rot levels.

Histories likely to result in high crown rot risk include:

- Durum wheat in the past one to three 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.
- Low rainfall during the last break from cereals.
- Paddocks with low stored soil moisture at grain fill will help to minimise yield loss.

See Section 9: Diseases for more information on crown rot.

68 GRDC (2007) Spotlight on diseases. GRDC Groundcover Issue 58. Grains Research and Development Corporation, August 2007, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-58-Precision-Agriculture-Supplement/Spotlight-on-diseases

69 J Kneipp (2008) Durum wheat production. NSW Department of Primary Industries, November 2008, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/280855/Durum-wheat-production-report.pdf

70 R Hare (2006) Agronomy of the durum wheats Kamilaroi⒟, Yallaroi⒟, Wollaroi⒟ and EGA Bellaroi⒟. Primefacts 140, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/63646/Agronomy-of-the-durum-wheats---Primefact-140-final.pdf

71 GRDC (2012) Crown rot. Grains Research and Development Corporation, July 2012, http://www.grdc.com.au/Media-Centre/Hot-Topics/Crown-Rot

1.9.2 Testing for disease

Soil sampling

Cereal root diseases cost grain growers in excess of $200 million a year in lost production. Much of this can be prevented.

PreDicta B (B = broadacre) is a DNA-based soil testing service that identifies which soil-borne pathogens pose a significant risk to broadacre crops prior to seeding. The test has been developed for cropping regions in southern Australia.

PreDicta B includes tests for:

- Cereal cyst nematode (*Heterodera avenae*).
- Take-all (*Gaeumannomyces graminis* var tritici (Ggt) and *G. graminis* var avenae (Gga)).
- *Rhizoctonia* barepatch (*Rhizoctonia solani* AG8).
- Crown rot (*Fusarium pseudograminearum* and *F. culmorum*).
- Root lesion nematode (*Pratylenchus neglectus* and *P. thornei*).
- Stem nematode (*Ditylenchus dipsaci*).

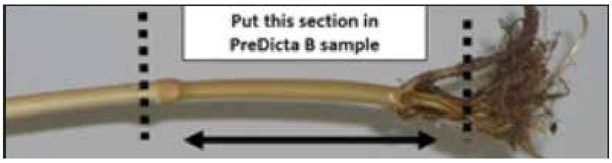

Photo 12: *Cereal stubble should be included in PreDicta B samples, if present, along with soil cores. Each piece of stubble should be from the base of the plant and include the crown to the first node (discard material from above the first node.*

Source: Grains Research and Development Corporation

MORE INFORMATION

PreDicta B Sampling strategy

You can access PreDicta B diagnostic testing services through a SARDI accredited agronomist. They will interpret the results and give you advice on management options to reduce your risk of yield loss. PreDicta B samples (Photo 12) are processed weekly between February to mid-May (prior to crops being sown) every year. These timeframes help assist you with your cropping program. PreDicta B is not intended for in-crop diagnosis—that is best achieved by sending samples of affected plants to your local plant pathology laboratory. [72]

Stubble assessment

Crown rot is a stubble-borne disease and for a plant to become infected it must come into contact with inoculum from previous winter cereal crops. Cultivation can spread the crown rot inoculum, increasing the chance of infection in the following cereal crop. [73] Knowing the initial inoculum levels in your stubble is critical in successfully managing crown rot. It is very important for crown rot testing to be carried out on stubble (Photo 13). It allows for growers and consultants to determine if there is crown rot present in a paddock and if so, how severe it is. An informed decision can then be made regarding crop choice and farming system. [74]

72 PIRSA (2015) Predicta B. Primary Industries and Regions South Australia, February 2010, http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b

73 GRDC (2014) Managing crown rot. Grains Research and Development Corporation, June 2014, https://grdc.com.au/Media-Centre/Hot-Topics/Managing-crown-rot

74 Crown Analytical Services. Crown Analytical Services – home, https://sites.google.com/site/crownanalyticalservices/home

Photo 13: *Stubble infected with crown rot fungus. Notice the pink discolouration in and around the crown and under leaf sheaths.*

Source: SARDI

Sampling method

Using the sampling pack from Crown Analytical Services:

- Randomly select 10 plants per site at five sites in a W pattern across the paddock.
- At each site gently pull out, or dig, 10 plant stubble butts within about a 2 m radius. Shake off any excess soil but be careful not to damage the crown or bottom nodes.
- Trim stubble to a length of about 25 cm so that it will fit in the stubble bag.
- Place the stubble (50 plants) into the sample bag with the information sheet.
- Send samples back to Crown Analytical Services. [75]

1.10 Nematode status of paddock

Key points:

- Root-lesion nematodes (RLN) are species of *Pratylenchus* nematodes that feed on the roots of crops and can cause yield loss.
- The main RLN species in the southern region are *Pratylenchus neglectus* and *P. thornei*.

75 Crown Analytical Services. Crown Analytical Services – protocol, https://sites.google.com/site/crownanalyticalservices/home/testing-process

- The *Pratylenchus* species present in the soil will affect choice of management practices, in particular rotations.
- RLN have a wide host range and can multiply on cereals, oilseeds, pulses and pastures as well as on broadleaf and grass weeds. [76]
- Durum wheat is also varyingly susceptible to cereal eelworm and cereal cyst nematode (CCN)

RLNs are tiny microscopic worms, about half a millimetre in length, that feed and reproduce in plant roots. This can lead to large yield losses in intolerant cereal and pulse crops. Nematodes invade the roots of growing plants. When nematode numbers are high, this can cause damage to the roots and affect nutrient and moisture uptake.

Populations of nematodes of 2000 nematodes per kilogram of soil is the threshold for yield loss in intolerant crops. At these levels or greater, growers need to choose a tolerant crop variety or rotate to a resistant crop according to the identified nematode species. [77]

RLN exacerbate the effects of crown rot, reducing the ability of the crop to extract soil water to deal with crown rot infection. [78]

1.10.1 Nematode testing

It is important to correctly identify the species of nematodes present due to differences in the susceptibility of break crops and varieties to different RLN. [79] Digging up plants and washing the roots can show black and brown-coloured root lesions, indicating tissue death. Whole sections of the root system may be dead. When nematode numbers are high, roots are often thin with little branching. It can be very difficult to distinguish between damage from nematodes and fungal root diseases like *Rhizoctonia* or take-all. To test a paddock for the presence of nematodes it is important to follow recommended procedures. See section 1.9.2 above for information of soil sampling with PreDicta B. This includes taking a minimum number of soil samples from different locations in the paddock as well as at different soil depths. [80]

CCN

Soil sampling guidelines for RLN include:

- Using a soil corer or trowel to collect a soil sample to a depth of 0–10 cm.
- Taking samples in the crop rows, close to root systems.
- Sampling from 12 to 20 locations towards the margins of poor crop growth areas, taking a 500 g sample at each location.
- Sealing the soil in a plastic bag. [81]

Plant sampling guidelines for RLN include:

- Collecting plants from several locations at the margins of the impacted area, making sure to keep the root system intact.
- Sending a separate sample collected from a healthy area of the paddock for comparison.

76 GRDC (2016) Tips and tactics: Root-lesion nematodes. Northern region. Grains Research and Development Corporation, February 2015, http://www.grdc.com.au/TT-RootLesionNematodes

77 NSW DPI Understanding root lesion nematodes—a hidden problem. NSW Department of Primary Industries.

78 GRDC (2014) Managing crown rot. Grains Research and Development Corporation, June 2014, https://grdc.com.au/Media-Centre/Hot-Topics/Managing-crown-rot

79 M Williams (2016) Managing root lesion nematodes pre-sowing. Grains Research and Development Corporation, March 2016, https://grdc.com.au/Media-Centre/Media-News/West/2016/03/Managing-root-lesion-nematodes-presowing

80 NSW DPI Understanding root lesion nematodes—a hidden problem. NSW Department of Primary Industries.

81 M Williams (2016) Managing root lesion nematodes pre-sowing. Grains Research and Development Corporation, March 2016, https://grdc.com.au/Media-Centre/Media-News/West/2016/03/Managing-root-lesion-nematodes-presowing

- Including notes about paddock symptoms when sending in a sample for testing. [82]

1.10.2 Effects of cropping history on nematode status

Nematodes survive in the soil between crops and different tillage practices will affect their survival rates. Research has shown that nematode numbers may build up rapidly in wheat crops and decline slowly during fallow periods. When the soil is dry and no living roots are available, nematodes become dormant and may survive in the root tissue of old crops. RLN were able to survive in low numbers for eight years without a crop and build up to damaging numbers in the first wheat crop. After two wheat crops followed by 30 months without a host crop, RLN were still at levels that would reduce yield of intolerant wheat varieties. [83]

Planting resistant crops, is an effective management tool for reducing *P. thornei* populations. [84]

See Section 8: Nematode Control for more information.

1.11 Insect status of paddock

Damaging pests such as lucerne flea and wireworm can be particularly destructive in durum crops. Deciding the best way to sample for a particular pest depends on where in the crop the pest feeds and shelters, and the effects of weather on its behaviour. The stage of crop development and the insect being monitored, will determine which sampling method is most suitable. For example, pests in seedling crops generally cannot be collected by sweeping because the crop is too short.

Pest outbreaks occur often in response to natural conditions, but sometimes in response to management practices. Minimum tillage and stubble retention have resulted in greater diversity of invertebrate species seen in crops. Cultural control methods such as burning, rolling or cultivating stubbles are sometimes needed to complement chemical and biological controls. [85]

For more information, see Section 7, Insect control.

Beneficials

Beneficial insects and other invertebrates ("beneficials") offer a variety of ecosystem services that are essential within agricultural environments and it is important to conserve and promote them as far as is practical within the constraints of controlling for major crop pests. For example, many beneficial species act as pollinators or are important for soil health and nutrient cycling. Some beneficial invertebrates can also take the form of "natural enemies" of pest species and play a major role in the suppression of pest populations within our cropping systems. [86]

How to promote beneficials:

- Learn about beneficial insects and what they can do to help control your pests.
- Modify chemical use to preserve beneficial insects. Reduce use of broad-spectrum and other highly disruptive sprays, and spray only when economic thresholds are reached.
- Use targeted spray controls that are effective against the pest species, but limit the impact on beneficial insects (e.g. Bt sprays).
- Incorporate beneficial insect counts into crop monitoring program.

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82 M Williams (2016) Managing root lesion nematodes pre-sowing. Grains Research and Development Corporation, March 2016, https://grdc.com.au/Media-Centre/Media-News/West/2016/03/Managing-root-lesion-nematodes-presowing

83 NSW DPI Understanding root lesion nematodes—a hidden problem. NSW Department of Primary Industries.

84 USQ (2015) Count your nematodes before planting wheat after mungbeans. University of Southern Queensland, March 2015, http://www.usq.edu.au/news-events/news/2015/03/kirsty-owen-mungbeans

85 P Bowden, P Umina, G McDonald (2014) Emerging insect pests. Grains Research and Development Corporation, July 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests

86 R Waugh (2011) Don't forget the good guys—recognising and identifying beneficial insects in your paddock. Grains Research and Development Corporation, September 2011, http://elibrary.grdc.com.au/ark%21%2133517/vhnf54t/nax0b3j

- Investigate ways of encouraging beneficial insects, e.g. maintain host vegetation, release commercially available beneficial insects (e.g. to target whiteflys, mites, aphids and thrips), provide supplementary sources of nectar and pollen.
- Manipulate the behavior of beneficial insects with attractants or with plant structure or arrangement.
- Be prepared to tolerate some "below threshold" insect pest activity to allow for the persistence of beneficial insects. [87]

1.11.1 Insect sampling

Sampling methods should be applied in a consistent manner between paddocks and sampling occasions. Any differences can then be confidently attributed to changes in the insect populations, and not different sampling techniques.

fSoil sampling

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

Use a standard spade and take a minimum of one spade full of soil at 10 sites within the paddock. If pest numbers exceed the threshold in one sample, take another spade full within 5 m. [88]

The SARDI Entomology Unit provides an insect identification and advisory service. The service identifies insects to the highest taxonomic level for species where this is possible and can also give farmers biological information and guidelines for control. [89]

Insect ID: The Ute Guide

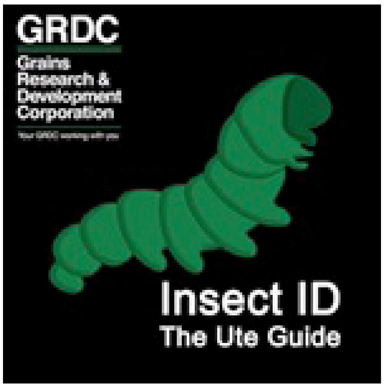

Figure 5: *GRDC's Ute Guide for insect identification is available as an app.*

Source: Grains Research and Development Corporation

The Insect ID Ute Guide is a comprehensive reference guide for insect pests commonly affecting broadacre crops and growers across Australia, and includes the beneficial insects that may help to control them. Photos have been provided for multiple life-cycle stages, and each insect is described in detail, with information on the crops they attack, how they can be monitored and other pests that they may be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [90]

App features:

- region selection
- predictive search by common and scientific names

87 R Waugh (2011) Don't forget the good guys—recognising and identifying beneficial insects in your paddock. Grains Research and Development Corporation, September 2011, http://elibrary.grdc.com.au/ark%21%2133517/vhnf54t/nax0b3j

88 DNRE (2000) Sampling methods for insects and mites. Department of Natural Resources & Environment Victoria, http://ipmguidelinesforgrains.com.au/insectopedia/introduction/sampling.htm

89 PIRSA (2015) Insect diagnostic service. Primary Industries and Regions SA, June 2015, http://pir.sa.gov.au/research/research_specialties/sustainable_systems/entomology/insect_diagnostic_service

90 GRDC. Apps. Grains Research and Development Corporation, https://grdc.com.au/Resources/Apps

- compare photos of insects side by side with insects in the app
- identify beneficial predators and parasites of insect pests
- opt to download content updates in-app to ensure you're aware of the latest pests affecting crops for each region
- ensure awareness of international bio-security pests.

Insect ID, The Ute Guide is available on Android and iPhone.

1.11.2 Effect of cropping history

It is important to consider paddock history when planning for pest management. Resident pests can be easier to predict by using paddock history and agronomic and weather data to determine the likely presence (and numbers) of certain pests within a paddock. This will point towards the likely pest issues and allow growers to implement preventive options. [91] Reduced tillage and increased stubble retention have changed the cropping landscape with respect to soil moisture retention, groundcover and soil biology and this has also affected the abundance and types of invertebrate species being seen in crops. These systems increase invertebrate biodiversity but also create more favourable conditions for many pests such as slugs, earwigs, weevils, beetles and many caterpillars. In turn they have also influenced beneficial species such as carabid and lady beetles, hoverflies and parasitic wasps. [92]

See Section 7: Insect control for more information

91 R Jennings (2015) Growers chase pest-control answers. Grains Research and Development Corporation, June 2015, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Growers-chase-pest-control-answers

92 P Bowden, P Umina, G McDonald (2014) Emerging insect pests. Grains Research and Development Corporation, July 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests