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TRITICALE

SECTION 1

PLANNING / PADDOCK PREPARATION

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

Planning/Paddock preparation

Key messages

- Triticale is suited to all soil types but has a significant yield advantage over wheat and barley when grown in a number of problem-soil situations.
- Of all the cereals available to farmers, triticale has the best adaptation to waterlogged soils and those with high pH (alkaline).
- Triticale is also tolerant of low pH (acid) soils, grows well on sodic soils, and tolerates soils high in boron.
- Triticale can out-produce other winter cereals on lighter soils with lower fertility. It has a more vigorous root system than wheat, barley or oats, binding light soils and extracting more nutrients from the soil.
- Incorporate crop rotation in farming systems: triticale can provide valuable benefits to a sequence.
- Ensure that paddocks are weed free before planting seed.
- Before planting, test soils for diseases and nematodes, and sample paddock soil for insects.

1.1 Paddock selection

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

1.1.1 Topography

Topographical characteristics can determine crop and pasture options. Crops and varieties prone to lodging should be avoided in uneven paddocks. Waterlogged conditions also reduce root growth and can predispose plants to root rots. Triticale is less prone to waterlogging than other cereals, and can be a good option for areas where water may sit.

The topographical variations typical of large agricultural paddocks can have a substantial impact on dynamics of soil mineral nitrogen (N) as well as on the performance of crops. 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 management of cover crops.. Decisions regarding where to plant crops can vary depending on the management goals and complexity of the terrain. For example, cover crops seem to be particularly advantageous on eroded, unfertile slopes where legumes bring the needed N inputs, while all cover crops contribute to erosion control and carbon (C) sequestration there. [2] For example, on a farm in Victoria (Figure 1), the farmer manages crops and grazing based on topography and soil characteristics. Between the rising country and the river flats is the intermediate country, which covers 33% of the farm. This is used mainly for grazing with a carrying capacity of 15–18 dry-sheep equivalents (DSE) per hectare. Also, some 60–70

1 Agriculture Victoria (2012) Growing wheat. Note AG0458. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-wheat

2 M Ladoni, AN Kravchenko, GP Robertson (2015) Topography mediates the influence of cover crops on soil nitrate levels in row crop agricultural systems. PLOS ONE, 10 (11), DOI doi:10.1371/journal.pone.0143358.

hectares are cropped for farm grain reserves. In the intermediate zone, Endeavour(|) triticale is sown and grazed every second year in late April. [3]

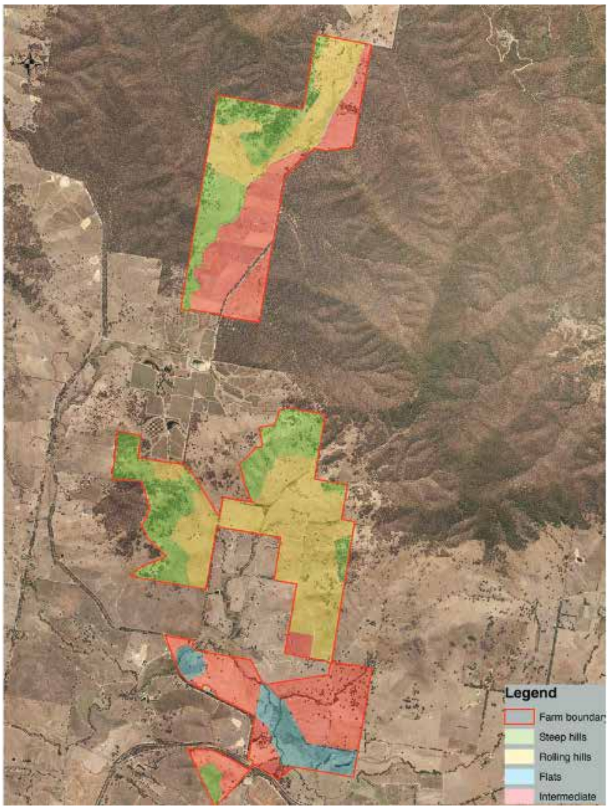

Figure 1: *Production zones in a farm facing the challenges of highly variable topography.*

Source: EverGraze

MORE INFORMATION

Dividing up the farm for flexibility and profit

1.1.2 Soil

Surface and subsurface soil characteristics such as soil pH, sodicity, salinity, acidity, texture, drainage characteristics and compaction will affect variety selection.

Of all the cereals available to farmers, triticale has the best adaptation to waterlogged soils and those of high pH (alkaline soils). Triticale is also tolerant of low pH (acid) soils, grows well on sodic soils and tolerates soils high in boron. In nutrient-deficient soils, triticale appears to respond better to applied fertilisers than other cereals do. Triticale has the capacity to survive utilising trace elements in soils which would be considered nutrient-deficient for any other type of crop. [4]

Triticale is suited to all soil types, but has a significant yield advantage over wheat and barley when grown in a number of problem-soil situations including:

- Acidic soils (pH less than 4.5 $CaCl_2$) which are high in aluminium (greater than 10% of the total cations) e.g. in southern NSW, north-eastern Vic and WA.
- Alkaline soils, e.g. in SA.
- Waterlogged conditions. [5]

National Variety Trials (NVT) experiments in South Australia on alkaline soils at Pinaroo, Streaky Bay and Minnipa have indicated good yields compared with other

3 G Saul (n.d.) Dividing up the farm for flexibility and profit. Ever Graze, http://www.evergraze.com.au/wp-content/uploads/2014/08/CS_Elmhurst-Greene.pdf

4 Agriculture Victoria (2012) Growing triticale. Note AG0497. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

5 Waratah Seed Co. (2010) Triticale: planting guide. Waratah Seed Co., http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

cereals, even in dry years. Farmers' experience on dry, rocky soils in South Australia has shown a 25% yield advantage for triticale compared with wheat. In these difficult conditions, the variety Rufus has proved most valuable. [6]

Triticale will grow on similar soils to wheat and barley, and is also adapted to soils that are too acid for the other cereals. It is relatively boron-tolerant and is tolerant to high-aluminium soils. On alkaline soils where other cereals are affected by manganese, zinc or copper deficiency, triticale is less affected.

Triticale can out-produce other winter cereals on lighter, lower fertility soils. It has more vigorous root system than wheat, barley or oats, and this allows it to bind light soils and extract more nutrients from the soil. [7]

Triticale and wheat are similar crops, but triticale represents a valuable alternative to wheat due to its greater biomass production and grain yield in Mediterranean-type growing conditions, such as in parts of southern Australia. [8]

IN FOCUS

The impact of different soil moisture and soil compaction on the growth of triticale root systems

The effects of different soil moisture (i.e. soil drought and waterlogging) and soil compaction (1.33 g/cm^{-3} and 1.50 g/cm^{-3}) on the growth and morphological traits of the root system were studied in four breeding forms and seven cultivars of triticale. Morphological changes, including the restriction of root extension, expansion and proliferation of laterals roots, occur in plants grown in different soil moisture and in compacted soil.

The results demonstrated a relatively broad variation in the habit of the triticale root system (Photo 1). Plants grown in compacted soil and in soild with low or high water content showed a smaller number and less dry matter of lateral branching than plants grown in control conditions. The harmful effects of compacted soil and drought conditions on the growth of roots was greater when compared with that of plants exposed to waterlogging. The observed effects of all treatments were more distinct in drought-sensitive strains. The drought-resistant forms were more characterised by extensive rooting and by smaller alterations in the root morphology under the stress conditions compared with drought-sensitive ones (Photo 1). Results confirm that the breeding forms with a high drought susceptibility (CHD-12 and CHD-173) were found to be also more sensitive to periodic soil-water excess. A more efficient water use and a lower shoot to root (S:R) ratio were found to be major reasons for the greater resistance to stress of the breeding forms CHD-220 and CHD-247. The reasons for the different response of the examined breeding forms and cultivars to drought or waterlogging may be a more economical water balance and more favourable relations between the shoot and root dimensions in the drought-resistant forms and cultivars. [9]

6 J Roake, R Trethowan, R Jessop, M Fittler (2009) Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

7 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, http://www.farmtrials.com.au/trial/13801

8 S Bassu, S Asseng, F Giunta, R Motzo (2013) Optimizing triticale sowing densities across the Mediterranean Basin. Field Crops Research, 144, 167–178.

9 S Grzesiak, MT Grzesiak, W Filek, T Hura, J Stabryła (2002) The impact of different soil moisture and soil compaction on the growth of triticale root system. Acta Physiologiae Plantarum, 24 (3), 331–342.

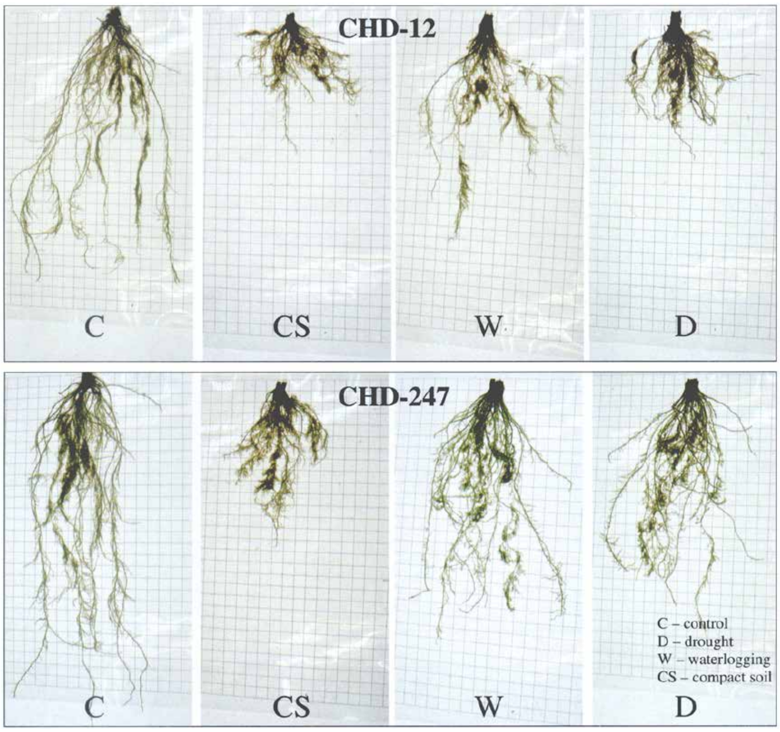

Photo 1: *Effects of compacted soil (CS), waterlogging (W) and soil drought (D) on root growth of drought-resistant (CHD-247) and drought-sensitive (CHD-12) triticale seedlings that are three weeks old.*

Soil compaction has been found to limit triticale growth. Severe soil compaction decreases leaf number, leaf area and dry matter of shoots and roots, while increasing the shoot-to-root dry matter ratio. In addition, high level of soil compaction strongly affects the length of seminal and seminal adventitious roots, and the number and length of lateral roots developed on the seminal root. Severely compacted soil also negatively impacts photosynthesis, gas exchange, transpiration rate and stomatal conductance. [10]

Soil pH

Key points:

- Triticale can grow on acidic soils (pH less than 4.5 $CaCl_2$) and alkaline soils.
- 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 South Australia more than 60% of agricultural soils are alkaline.
- Outside of the optimal soil pH range, microelement toxicity damages crops.

As a general rule, triticale's are suited to all soil types, but typically have a yield advantage over wheat and barley on light acidic soils higher in exchangeable

10 MT Grzesiak (2009) Impact of soil compaction on root architecture, leaf water status, gas exchange and growth of maize and triticale seedlings. Plant Root, 3, 10–16.

aluminium. In these soils, Canobolas⚲ and Bogong⚲ would be the two preferred varieties. [11]

Hydrogen ion concentration in the soil, called pH, and is influenced by chemical reactions between soil components and water (Figure 2). Soil pH is affected by the varied combinations of positively charged ions (sodium, potassium, magnesium, calcium, aluminium, 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.

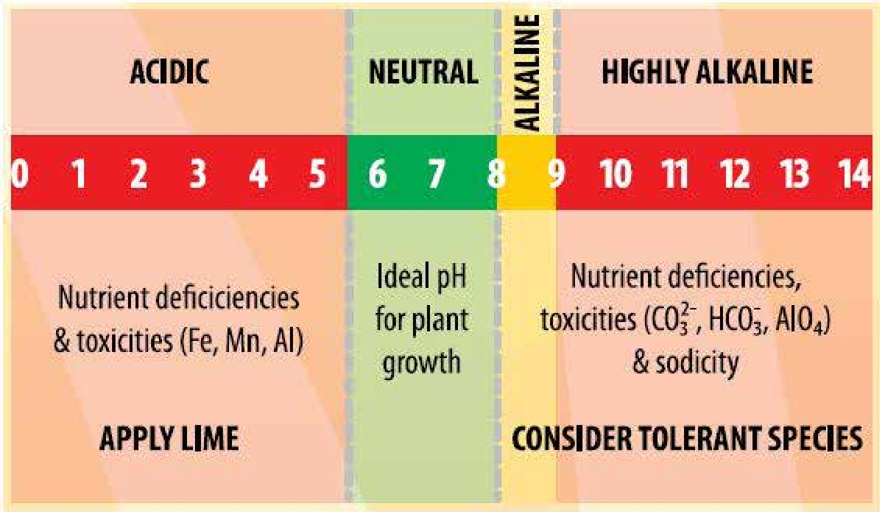

Figure 2: *Classification of soils on the basis of pH, showing the implications for plant growth and some management options.*

Source: Soilquality.org

What influences location of acidic and alkaline soils in Southern Australia

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.

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

Measurement of soil pH

Soil sampling and the measurement of pH helps to determine the practices necessary to manage land with low or high pH [12]. 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, which is 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.

11 Viterra (2010) Bogong and Canobolas triticale SA, Vic, NSW. Factsheet. Viterra, http://www.hartbrosseeds.com.au/f.ashx/Bogong-Canobolas-Factsheet.pdf

12 Soilquality.org (2011) Soil pH - SA. Soilquality.org, http://www.soilquality.org.au/factsheets/soil-ph-south-austral

VIDEOS

WATCH: GCTV8: Liming Acids Soils

Managing soil pH

Acid soils

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

Soils prone to becoming acidic will need liming every few years. Seek advice on an appropriate regime from your local agricultural advisor. [13]

Alkaline soils

In South Australia more than 60% of agricultural soils are alkaline. Treating alkaline soils by 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 pH reduction.

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

1.1.3 Sampling soil quality

Key points:

- The approach taken will be defined by the purpose of the investigation, variability in the area sampled, and the analysis and accuracy required.
- For many soil quality parameters, sampling is typically done to 10 cm, although 30 cm is required for carbon accounting purposes; stratification below 10 cm is recommended (e.g. 10–20, 20–30 cm).
- The sampling strategy should either integrate or describe the variation within the sampling area.
- Samples should be air-dried or kept below 4°C prior to analysis. For biological measurements, it is best to analyse as soon as possible.

Before deciding how to sample the soil, be clear about the purpose of your sampling. Different sampling approaches may be required depending on what you are sampling for, the soil type, the management unit (e.g. paddock), soil spatial variability (changes in soil type, dunes–swales, etc.), the accuracy required of the result, and the value placed on the information provided (Photo 2). Before starting, define very clearly the question you are asking of your soil samples. Consult a professional soil scientist, agronomist or your analytical laboratory to be sure that your soil samples are taken at the right time, from the right depth, in the right place and in the appropriate number, and are stored in such way that the required analysis is not compromised. If quantitative soil analyses (kg/ha) are required, soil bulk density must also be measured, and this requires considerable care. [14]

13 Soilquality.org. Soil pH: South Australia. Soilquaity,org, http://www.soilquality.org.au/factsheets/soil-ph-south-austral

14 M Unkovich. Soil sampling for soil quality—South Australia. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/soil-sampling-for-soil-quality-south-australia

Photo 2: *To be meaningful, soil sampling needs to take into account spatial variation in soil condition. Differences in soil type, nutrient status and other soil properties may be exhibited within a paddock.*

Source: Soil Quality Pty Ltd).

Sampling strategy

Soil properties and fertility often vary considerably, even over short distances, necessitating a sampling strategy that either integrates this variation by creating a composite sample (sampling across) or describes it by including replicate samples (sampling within). Describing the variation requires a defined sampling within each different soil patch and analysing replicate samples separately. Such an approach might be required where there are consistent zones within a field such as under controlled-traffic systems, perennial row or tree crops, or raised bed systems. More often, the variation within the field is integrated into a single sample by creating a composite. Examples of these are illustrated in Figure 3.

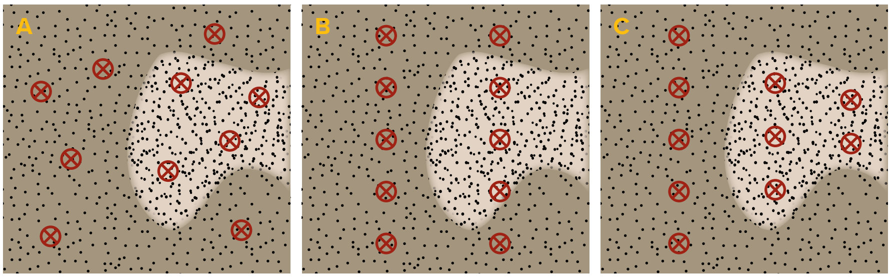

Figure 3: *Sampling strategies used to create a composite sample that integrates variation across different soil types (A & B), and a strategy to describe variation by sampling zones and analysing samples separately (C). Panel A: haphazard samples strategically located to approximate the relative representation of different soil types. Panel B: samples taken along transects intersecting different soil types. Panel C: equal numbers of samples from each zone.*

Source: Soil Quality Pty Ltd

Sampling equipment

Manual sampling is often used where sampling is only required to 10 cm and bulk density is not required. Small pogo-type samplers enable quick sampling for qualitative determinations such as nutrient concentrations or disease presence. To avoid contamination, ensure that your sampling equipment is cleaned before starting.

For greater depths, mechanical (hydraulic) samplers are usually required for most soil types. If using these for soil carbon sampling, take care not to contaminate samples with lubricating oil.

Sampling depth

Sampling for soil fertility or biological activity assessment is typically done to 10 cm depth because this is where most of the organic matter and nutrient cycling occurs. However, for mobile nutrients such as nitrate or K, deeper sampling may be required on sandier soils. Sampling to the rooting depth of a crop of interest might be useful for analysis of these nutrients or when studying water availability; otherwise, it is generally too onerous. When assessing soil carbon stocks for accounting or budgeting purposes, a sampling depth of 30 cm is required to conform to standard accounting procedures. When sampling below 10 cm, soil samples are usually stratified by depth increments (e.g. 10, 20, 30 cm), depending on the objectives. When characterising a soil for the first time, sampling corresponding to the different soil-layer depths (horizons) is often useful. Plant litter on the soil surface is not usually included in soil samples, whereas plant root material is usually included, although generally sieved out prior to analysis.

Sample handling

Samples can be stored in polyethylene bags but should generally be dried or kept cool prior to analysis. Air-drying (<40°C) is usually sufficient and storage <4°C usually arrests most biological activity. Dried samples can be broken up if clods are present, and any stones removed. If the amount of material collected is too great to manage and ship, it can be reduced in size by careful quartering, ensuring no discrimination against particular particle sizes. Samples are typically put through a 2-mm sieve prior to analysis. [15]

1.1.4 Biological inputs

Key points:

- When evaluating a biological input for grain production, it may be useful to consider whether the input will alleviate yield constraints.
- The major yield constraints in the Southern Region are high soil density, sodicity and acidity.
- The biological inputs with the most potential to help alleviate these yield constraints are manure, compost, vermicompost, biochar and some bio-stimulants.

MORE INFORMATION

Biological inputs – Southern grain growing region

Yield constraints in the Southern Region

The Southern Region has soils with generally low fertility and many have subsoil constraints such as high soil density, salinity, sodicity, acidity and toxic levels of some elements. However, due to the diversity of soils in this region, some areas have very productive soils. Crop-production systems in the region are varied and they include many mixed-farming enterprises that have significant livestock and cropping activities.

Yield potential in the region depends on seasonal rainfall, especially in autumn and spring, with less dependence on stored soil moisture than in the Northern Region. [16]

1.1.5 Paddock selection for forage cereals

Selecting a paddock for forage cereal production will depend on how the forage will be used on the dairy farm. If it is to provide additional grazing, choose a well-drained paddock that can resist pugging damage from dairy cows. A paddock that has higher fertility and is well drained should be chosen to provide maximum dry-matter production.

15 M Unkovich. Soilquality.org. Soil sampling for soil quality—South Australia. Fact Sheet, Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/soil-sampling-for-soil-quality-south-australia

16 J Carson. Soilquality.org. Biological inputs—Southern grain-growing region. Fact Sheet, Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/biological-inputs-southern-grain-growing-region

It is best to select a paddock that has a low level of pasture grasses to avoid the risk of cereal-disease transmission. Annual pasture grasses can be hosts for such diseases as take-all, *Rhizoctonia* root rot, *Fusarium* blight and *Pythium* root rot. In traditional cereal-growing areas, pasture grasses can be removed from the paddock in the year prior to cereal establishment by using herbicides to 'winter clean' the pasture or by green manuring to prepare the seedbed. However, in dryland dairying areas, a summer forage crop (e.g. brassica, maize, sorghum, millet) or spring sown 'hunter and herb' mix will help to reduce grasses.

Tough grasses such as bent grass, couches and kikuyu must be controlled before the autumn sowing of cereals. These grasses will compete with the cereal for nutrients and moisture, both in autumn at establishment and in the following spring. [17]

1.1.6 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 the choice of crop variety to ensure that effective in-crop control measures are available.

Strategic and integrated weed management over a rotation can greatly increase the likelihood of being able to control weeds across all crops. For example, a grower planting paddocks to wheat in the first year of a rotation should have a vigilant strategy for the control and prevention of seedset of key broadleaf weeds prior to a rotation to canola or legume crops.

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

Part of the management of herbicide resistance includes the rotation of herbicide groups. Therefore, consider the history of herbicide use in each paddock. Herbicide residues (e.g. sulfonylurea, triazines) may be a problem in some paddocks. Remember that plant-back periods begin after significant rainfall occurs.

For more information, see Section 6: Weed Control.

1.1.7 Fallow moisture and management

Paddocks that have been well managed during fallow periods significantly lower the risk of poor crop and financial performance. A growing crop has two sources of water: the water stored in the soil during the fallow, and rainfall while the crop is growing. Growers have some control over the stored soil water, so it should be measured before planting. Long-range forecasts and tools such as the Southern Oscillation Index (SOI) indicate the likelihood of the season being wet or dry, and are a useful adjunct in deciding what to plant. Timely weed control can reduce moisture and nutrition loss, prevent an increase in the seedbank, and decrease the risk of disease being carried over. Absence (or restriction) of grazing maintains soil friability and groundcover. Prolonged grazing periods may create crop emergence problems through induced surface compaction. [18]

1.2 Paddock rotation and history

Paddock choice can determine the amount of disease, weed and nutrient pressure on the crop. Increasing interest in crop sequencing is providing more financial and agronomic data to help growers to choose crops and paddocks each year. Crop rotation is a key strategy for managing Australian farming systems, and improvements in legume and oilseed varieties and their management have facilitated this shift. Leading growers and advisers advocate sustainable crop sequences as a valuable strategy for southern farming systems. Many growers are sacrificing cereal yield and protein by not adopting current research findings on the use of the best sequences.

17 Agriculture Victoria (2008) Establishing forage cereals. Note AG1269. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/forage-cereals/establishing-forage-cereals

18 N Border, K Hertel, P Barker (2007) Paddock selection after drought. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/content/agriculture/emergency/drought/drought-publication-archive/paddock-selection-after-drought

In many of Australia's grain-growing regions, broadleaf crop options have been seen as riskier and less profitable than cereals. This perception has been driven, in part, by fluctuating prices and input costs associated with the broadleaf crop in the year of production, and difficulties in marketing. However, when the profitability of the entire rotation is assessed, it is often more profitable to include broadleaf crops in the sequence. [19]

1.2.1 Triticale as a rotation crop

Besides its use as a feed grain, triticale can be used as a forage crop for ruminants and as a cover crop.

When added to a rotation, triticale may increase yields of other crops in the rotation, reduce costs, improve rgw distribution of labour and equipment use, provide better cash flow, and reduce weather risk. Additionally, the production of triticale may provide environmental benefits such as erosion control and improved nutrient cycling. [20]

Triticale yields more than its wheat and rye ancestors in two types of marginal conditions: in highlands where acid soils, phosphorus deficiency and foliar diseases are dominant; and in the arid and semi-arid zones where drought affects crop production. [21]

Traits observed that suggest higher yields in triticale than in wheat include greater early vigour, a longer phase of spike formation with same duration to flowering, reduced tillering, increased remobilisation of carbohydrates to the grain, early vigorous root growth, and higher transpiration-use efficiency. [22]

Trials in the UK suggest that triticale gives a greater yield advantage than wheat when it is in the second cereal position in a rotation. The researchers suggest that the greater yield of triticale was due to its greater resistance to take-all. [23] However, there are some disadvantages to growing triticale (Table 1).

19 GRDC (2011) Choosing rotation crops: short-term profits, long-term payback. Factsheet. GRDC, http://www.grdc.com.au/~/media/9219D55FFB4241DC9856D6B4C2D60569.pdf

20 LR Gibson, C Nance, DL Karlen (2005) Nitrogen management of winter triticale. Iowa University, http://farms.ag.iastate.edu/sites/default/files/NitrogenManagement.pdf

21 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

22 S Bassu, S Asseng, F Giunta, R Motzo (2013) Optimizing triticale sowing densities across the Mediterranean Basin. Field Crops Research, 144, 167–178.

23 S Clarke, S Roques, R Weightman, D Kindred (2016). Understanding triticale, AHDB Cereals and Oilseeds, https://cereals.ahdb.org.uk/media/897536/pr556-understanding-triticale.pdf

Table 1: *Advantages and disadvantages of triticale.*

Advantages	Disadvantages
Triticale is a hardy, relatively low input cereal crop with good disease resistance, particularly to rusts. It is as high a quality feed grain as wheat.	It is prone shattering. There is a spot about a quarter to a third of the way down from the tip on the rachis that is very weak. [26]
It is a tall crop bred for strong straw strength which can be useful in rocky paddocks or circumstances where crops have been known to lodge.	Stripe rust may be a problem in triticale (although there are now options to treat seed to provide seedling protection against stripe rust).
Triticale is more durable than wheat when grazed; which means it will remain healthier, and stand up to weeds, diseases and cold weather better than wheat.	Triticale grain is softer than wheat and barley grain. Soft grain is more prone to attack from weevils and other grain-storage insects. [27]
Many growers use triticale as a disease break in their rotations and value the benefits of triticale for its contribution to soil conservation. It assists in maintaining soil health helping to reduce nematodes such as *Pratylenchus neglectus* and *P. thornei* (root lesion nematodes) and *Heterodera avenae* (cereal cyst nematode), and a number of fungi and bacteria. It is also resistant to Barley yellow dwarf virus, mildew and rusts, which may cause significant yield reductions in wheat, barley and oats. The extensive root system of triticale binds sandy soils, and the fibrous stubble reduces wind and water erosion. [24] Roots of triticale in nematode-infested soil have been found to contain fewer nematodes than other cereals. Triticale is thus a useful rotational crop for areas infested with the root lesion nematode. [25]	It can be difficult to find a market for triticale.

Benefits of cereals as a rotation crop

Cereals present the opportunity to utilise residual N effectively. They also offer good options for broadleaf control, and also do not host many pulse crop and oilseed diseases. A major benefit of winter cereal crops is the high levels of groundcover they provide, helping the grower manage soil loss in following fallows and some subsequent pulse crops.

Disadvantages of cereals as a rotation crop

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

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

24 KV Cooper, RS Jessop, NL Darvey (2004) Triticale in Australia. In M Mergoum, H Gómez-Macpherson (eds), Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, ftp://ftp.fao.org/docrep/fao/009/y5553e/y5553e02.pdf

25 V Vanstone, M Farsi, T Rathjen, K Cooper (1996) Resistance of triticale to root lesion nematode in South Australia. In Triticale: Today and Tomorrow Springer Netherlands, pp. 557–560.

26 N Herdrich. Triticale for eastern Washington dryland area. Alternative crops. Washington State University

27 Agriculture Victoria (2012) Growing triticale. Note AG0497. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

1.2.2 Break cropping

Farmers use their soil intensively. There are pressures to grow more crop, in volume or value, to maintain profits. However, it is still important to grow cover crops. Cover (or break) crops include grasses such as triticale and oats, and legumes such as cowpeas and vetch. They may be ploughed in as 'green manure' crops, or they may be mulched, slashed or sprayed ('brown-manured') then sown into.

For more information, see Section 2: Pre-planting.

Although cover crops do not normally produce income, they are important because they protect the soil and give other benefits (Table 2). Bare soil is easily damaged, so it is best to protect it by maintaining plant cover. [28]

The main crops used for cover cropping, such as oats, triticale, brown (or Indian) mustard (*B. juncea*) and forage rape, host nematodes and many of them enable rapid multiplication of nematodes. Much of the practice being adopted on-farm in Australia involves the use of crops that can provide green-manure benefits, but in most cases, these crops host and multiply nematodes, and there is little information about their impacts on other soilborne fungi. [29]

Table 2: *Advantages and disadvantages of including cover crops in growing rotations.*

Advantages of cover cropping	Disadvantages of cover cropping
Protecting the soil: much less soil erosion and less surface crusting	**Loss of land for cash crops:** if an issue, do not grow the cover crops to maturity and grow only occasionally
Maintaining fertility: by maintaining organic matter levels in the soil, and adding N (if a legume)	**Cost of seed and sowing:** unavoidable but small. Costs usually associated with growing (e.g. watering) are generally avoidable
Weed control: a healthy cover crop keeps a paddock free of weeds	**Can become a weed**: usually not a problem in vegetable production
Disease control: by providing a break crop that helps to reduce disease, nematode and, perhaps, pest levels. For vegetable production, grasses rather than legumes tend to have most benefit	**Bulky crops**: can temporarily tie-up N and perhaps increase disease and have other effects. Trash can also get in the way
Biological tillage: less cultivation needed because cover crops loosen the soil	
Improved paddock access: in areas of medium–high rainfall, cover crops can dry out a soil profile and promote timely farm operations	

Source: NSW DPI

VIDEOS

WATCH: The importance of crop rotation.

28 A Senn (2007) Protect your land—use cover crops. NSW Department of Primary Industries, http://archive.dpi.nsw.gov.au/content/agriculture/horticulture/protect

29 Good Fruit and Vegetables (2014) Cover cropping practices multiplying nematodes. AgTrader.com.au, http://www.goodfruitandvegetables.com.au/story/3554224/cover-crop-practices-multiplying-nematodes/

1.2.3 Long-fallow disorder

Soils naturally contain beneficial fungi that help the crop to access nutrients such as phosphorus (P) and zinc (Zn) by forming structural associations with the crop root, known as arbuscular mycorrhizae (AM). Many different species of fungi can have this association with the roots of crops, and many of these form structures called vesicles in the roots. The severe reduction or lack of AM shows up as long-fallow disorder—the failure of crops to thrive despite adequate moisture. Ongoing drought in the 1990s and 2000s has highlighted long-fallow disorder, where AM fungi have died out through lack of host plant roots during long fallow periods. As cropping programs restart after dry years, a yield drop is likely because of reduced levels of AM fungi and hence reduced development of AM, making it difficult for the crop to access nutrients. Long-fallow disorder is usually typified by poor crop growth. Plants appear to remain in their seedling stages for weeks and development is very slow.

Benefits of AM formation are:

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

In general, the benefits of AM are greater at lower soil P levels because AM increase a plant's ability to access this nutrient. Crops species vary in their dependency on AM for growth (Table 3). [30]

Table 3: *The dependency of various crop species on mycorrhizae, with values decreasing as the phosphorus level in the soil increases.*

Mycorrhiza dependency	Potential yield loss without mycorrhiza (%)	Crop
Very high	Greater than 90	Linseed
High	60–80	Sunflower, mungbeans, pigeon peas, maize, chickpeas
Medium	40–60	Sudan, sorghum, soybeans
Low	10–30	Wheat, barley, triticale
Very low	0–10	Panicum, canary
Nil	0	Canola, lupins

Source: DAF Qld

1.3 Fallow weed control

Paddocks with well-managed fallow periods significantly lower the risk of poor crop and financial performance. The best form of weed control is rotation. If spraying, the ideal time for control is when weeds are small (Photo 3).

When sowing dual-purpose varieties early, choose a paddock with low weed numbers and control weeds before the first grazing. Strategic grazing can be used to help manage weeds. Always check grazing withholding periods before you apply post-emergent herbicides when planning to graze the crop. [31]

30 DAF Qld (2010) Nutrition: VAM and long fallow disorder. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/nutrition-management/nutrition-vam

31 Waratah Seed Co. (2010) Triticale: planting guide. Waratah Seed Co., http://www.porkcrc.com.au/1A-102_Triticale_Guide_Final_Fact_Sheets.pdf

Photo 3: *Spraying weeds when small is the key to effective long fallow.*

Source: AGRONOMO

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. Knowledge of the paddock's characteristics and history, and early control of weeds, is important for good control (Photo 4). Information is provided below for the most common problem weeds; however, for advice on individual paddocks contact your local agronomist.

Benefits of fallow weed control are significant:

- Conservation of summer rain and fallow moisture (this can include moisture stored from last winter or the summer in a long fallow) is integral to winter cropping, particularly in low-rainfall cropping areas and in regions where the climate moves towards summer-dominant rainfall.
- Modelling studies show that the highest return on investment in summer weed control is for lighter soils or in situations where soil water that would support continued weed growth is present. [32]

IN FOCUS

Summer fallow weed control and residue management impacts on winter crop yield through soil water and N accumulation in a winter-dominant low rainfall region of southern Australia.

The majority of rain used by winter grain crops in the Mallee region of Victoria falls during the cooler months of the year (April–October). However, rain falling during the summer fallow period (November–March) and stored as soil moisture contributes to grain yield. Strategies to better capture and store summer fallow rain include:

1. retention of crop residues on the soil surface to improve water infiltration and to minimise evaporation; and
2. chemical or mechanical control of summer fallow weeds to reduce transpiration and available nutrient uptake.

32 GRDC (2012) Summer fallow—make summer weed control a priority. GRDC Fact Sheet January 2012, https://grdc.com.au/~/media/91deacef2dd843f6bbf9fab09bfe0d65.pdf

Despite the widespread adoption of no-till farming systems in the region, few published studies have considered the benefits of residue management during the summer fallow relative to weed control, and fewer quantify the impacts of summer fallow weeds or identify the mechanisms by which they influence subsequent crop yield. Over 3 years (2009–11), identical experiments on adjacent sand and clay soil types at Hopetoun in the southern Mallee were conducted to quantify the effects of residue management (standing, removed, or slashed) and summer fallow weed control (chemical control) compared with cultivation on accumulation of soil water and N and subsequent crop yield. The presence of residue (2.4–5.8 t/ha) had no effect on soil-water accumulation and a small negative effect on grain yield on the clay soil in 2011. Controlling summer weeds (*Heliotropium europaeum* (heliotrope) and volunteer crop species) increased soil-water accumulation (mean 45 mm) and mineral N (mean 45 kg/ha) before sowing on both soil types in two years of the experiment with significant amounts of summer fallow rain (2010 and 2011). Control of summer weeds increased grain yield of canola by 0.6 t/ha in 2010 and of wheat by 1.4 t/ha in 2011. Using the data from these experiments to parameterise the APSIM model, simulation of selected treatments with historical climate data (1958–2011) showed that an extra 40 mm of stored soil water resulted in an average additional 0.4 t/ha yield, most of which was achieved in dry growing seasons. An additional 40 kg N/ha increased yield in wetter growing seasons only (mean 0.4 t/ha on both soil types).

The combination of extra water and N that was found experimentally to result from control of summer fallow weeds increased subsequent crop yield in all season types (mean 0.7 t/ha on sand, 0.9 t/ha on clay). The co-limitation of yield by water and N in the Mallee environment means that yield increases due to summer weed control (and thus returns on investment) are very reliable. [33]

1.3.1 The green bridge

The green bridge provides a between-season host for insects and diseases (particularly rusts), which pose a threat to subsequent crops and can be expensive to control later in the season (Photo 4) [34].

33 JR Hunt, C Browne, TM McBeath, K Verburg, S Craig, AM Whitbread (2013) Summer fallow weed control and residue management impacts on winter crop yield though soil water and N accumulation in a winter-dominant, low rainfall region of southern Australia. *Crop & Pasture Science* 64, 922–934, http://www.publish.csiro.au/CP/CP13237

34 DAFWA (2016) Control of green bridge for pest and disease management. DAFWA, https://www.agric.wa.gov.au/grains/control-green-bridge-pest-and-disease-management

MORE INFORMATION

GRDC factsheet, The essential crop management tool: green bridge control is integral to pest and disease management

Summer fallow weed management: A reference manual for grain growers and advisers in the southern and western grains regions of Australia

VIDEOS

WATCH: GCTV5: Managing summer fallow

WATCH: Over the Fence south: Summer weed control saves moisture for winter crops

Photo 4: *Broad-leafed weeds and grasses form a green bridge in paddock.*

Source: DAFWA

Key points for control of the green bridge:

- An outright kill of the weeds and volunteers is the only certain way to stop them from hosting diseases and insects.
- Diseases and insects can quickly spread from the green bridge, jeopardising crops and current control methods, including the effectiveness of chemicals and genetic breeding for resistance.
- Effective control of pest and disease risks requires neighbours to work together to eradicate weeds and crop volunteers simultaneously.
- Weed growth during summer and autumn depletes soil moisture and nutrients that would otherwise be available to following crops and can have an allelopathic effect. [35]

1.3.2 Management strategies

How farming country is managed in the months or years before sowing can be more important in lifting water-use efficiency (WUE) than in-crop management is. Of particularly high impact are strategies that increase soil capture and storage of fallow rainfall to improve crop reliability and yield.

Practices such as controlled-traffic farming and long term no-till seek to change soil structure to improve infiltration rates and thereby increase plants' access to stored water. This occurs when compaction zones are removed.

Shorter-term management decisions can have an equal or even greater impact on how much plant-available water (PAW) is stored at sowing. These include decisions such as crop sequence and rotation that dictate the length of the fallow and amount of stubble cover, how effectively fallow weeds are managed, stubble management, and decisions about whether to till at critical times.

Although many factors influence how much PAW is stored in a fallow period, good weed management consistently has the greatest impact. [36]

35 GRDC (2009) The essential crop management tool: green bridge control is integral to pest and disease management. Factsheet, GRDC, http://www.grdc.com.au/uploads/documents/GRDC_GreenBridge_FS_6pp.pdf

36 GRDC (2014).Summer fallow weed management. GRDC, https://grdc.com.au/Resources/Publications/2014/05/Summer-fallow-weed-management

1.3.3 Stubble retention

Key points:

- Triticale stubble is coarser than either wheat or barley stubble. [37]
- Retaining stubble has several advantages for soil fertility and productivity.
- Retaining stubble can decrease erosion and increase soil-water content.
- The benefits of stubble retention are enhanced by reduced tillage and leguminous crop rotations.

Historically, stubble has been burnt in southern Australia because doing so results in easier passage for seeding equipment, enhances seedling establishment, and improves the 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. Stubble retention has several advantages for soil fertility and productivity (see Photo 5).

Photo 5: *Triticale sown into stubble.*

Source: T Kaspar in MCCC

Summer rainfall and warmer conditions promote the decomposition of stubble.

Reducing erosion risk

One of the main benefits of stubble retention is reduced soil erosion. Retaining stubble decreases erosion by lowering wind speed at the soil surface and by decreasing run-off. At least 50% ground cover is required to reduce erosion; this is generally considered to be achieved by 1 t/ha of cereal stubble, 2 t/ha of lupin stubble or 3 t/ha of canola stubble. A study at Wagga Wagga, NSW, demonstrated that stubble retention reduced soil losses by almost two-thirds compared to burnt paddocks. It also increased infiltration of rainfall.

Increasing soil water content

A major advantage of retaining stubble is that it increases soil-water content by decreasing run-off and increasing infiltration (Figure 4). The actual benefits realised depend on the timing and intensity of rainfall as well as the quantity and orientation of the stubble. Rains in late summer–early autumn have more chance of improving the germination and establishment of the next crop. In addition, increased infiltration of water over summer can result in greater nitrogen mineralisation and availability for the subsequent crop.

37 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, http://www.farmtrials.com.au/trial/13801

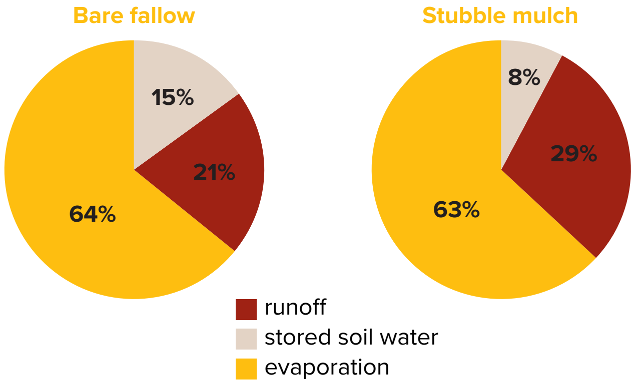

Figure 4: *Retained stubble leads to more stored soil water, mostly due to a reduction in runoff.*

Source: Felton et al. 1987

MORE INFORMATION

Developments in stubble retention in cropping systems in southern Australia

VIDEOS

WATCH: GCTV4: Managing stubble

Increasing soil carbon

Retaining stubble increases the input of carbon to soil. Stubble is approximately 45% carbon by weight and represents a significant input of carbon to soil. However, it can take decades for the practice of retaining stubble to increase the amount of soil organic carbon. In cropping trials with ley pasture rotations at Wagga Wagga, researchers showed that after 10 years, stubble retention generated 2 t/ha more soil organic carbon than burnt-stubble plots to a depth of 10 cm in a red chromosol. After 25 years the inclusion of a clover pasture in the rotation in the same trial had a greater effect on soil organic carbon increases, even with tillage, compared to stubble retention. Retaining stubble may only increase soil carbon where it is coupled with cultivation, but not with direct drilling.

The carbon to nitrogen ratio (C:N) of residues is an important factor in determining the contribution they will make to carbon sequestration, as the ratio governs how quickly residues decompose. Pulse residues (C:N 20:1 to 41:1) decompose faster than wheat residues (C:N 45:1 to 178:1). Faster decomposition may improve nutrient availability for the following crop, but reduce the sequestration of carbon from residues into soil.

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. The addition of organic matter with retained stubbles supports soil life, and can improve soil structure, infiltration and water-holding capacity. These benefits are greater when integrated with no-till practices. [38]

Management practices affecting stubble cover

Stubble burning, grazing and cultivation are the main management practices that reduce stubble cover. A single-tillage operation using a chisel plough, for example, can reduce stubble coverage by 30–40 % (Table 4) [39]. It is recommended that stubble cover be maintained as long as possible in the fallow, and that planting and fertilising machinery be adapted to minimise disturbance. Where cultivation is required in order to control herbicide resistant weeds, this should be carried out as a one-off operation. [40]

38 Carson J, Flower K. Benefits of retaining stubble: NSW. Soilquality.org, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

39 DEEDI (2011) Measuring and managing stubble cover: photostandards for cereals. Department of Employment, Economic Development and Innovation, https://www.grainsbmp.com.au/images/documents/Stubble cover final.pdf

40 Soilquality.org. Benefits of retaining stubble: Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-in-qld

VIDEOS

WATCH: GCTV15: 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

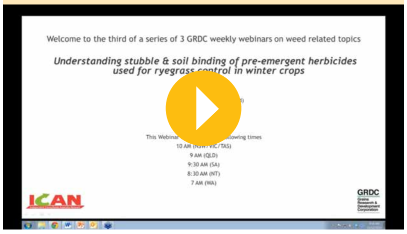

Table 4: *Estimated reduction in wheat or barley stubble cover from different tillage operations.*

Implement	Residue buried by each tillage operation (%)	
	Fresh stubble	Old (brittle) stubble
Disc plough	60–80	80–90
Chisel plough	30–40	40–60
Blade plough	20–30	30–50
Boomspray	Negligible	Negligible

Source: DEEDI

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

1.4 Fallow chemical plant-back effects

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

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods (e.g. sulfonylureas such as chlorsulfuron). This is shown in the Table 5 where known. [41] Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, as the sulfonylureas are. Labels display the plant-back periods, which are usually listed under a separate plant-back heading or under a heading such as 'Protection of crops' in the general instructions section. [42]

Part of the management of herbicide resistance includes rotating herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines) may be a problem in some paddocks. Remember that plant-back periods begin after rainfall occurs. [43]

Table 5: *Residual persistence of common pre-emergent herbicides.*

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19	High. Persists longer in high pH soils. Weed control commonly drops off within 6 weeks
Glean® (chlorsulfuron)	28–42	High. Persists longer in high pH soils. Weed control longer than Logran.
Diuron	90 (range 1 month to 1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Has been observed to have long-lasting activity on grass weeds such as black grass or stink grass (*Eragrostis* spp.) and to a lesser extent broadleaf weeds such as fleabane.
Atrazine	60–100, up to 1 year if dry	High. Has been observed to have long-lasting (>3 months) activity on broadleaf weeds such as fleabane.
Simazine	60 (range 28–149)	Med–high. In high pH soils, 1 year. Has been observed to have long-lasting (>3 months) activity on broadleaf weeds such as fleabane.

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

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

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

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Terbyne® (terbulthylazine)	6.5–139	High. Has been observed to have long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle.
Triflur® X (trifluralin)	57–126	High. With lower rate, 6–8 months; higher rates longer. Has been observed to have long-lasting activity on grass weeds such as black or stink grass (*Eragrostis* spp.)
Stomp® (pendimethalin)	40	Medium, 3–4 months
Avadex® Xtra (triallate)	56–77	Medium, 3–4 months
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall. Has been observed to have long-lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle.
Boxer Gold® (prosulfocarb)	12–49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall.
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than trifluralin and Boxer Gold; however, weed control persists longer than Boxer Gold.

Note that residual persistence is from broad-acre trials and paddock experiences.

Conditions required for breakdown

Most of the herbicide residues will be found in the topsoil. Warm, moist soils are required to break down most herbicides through the processes of microbial activity. For the soil microbes to be most active they need good moisture and an soil temperature range of 18–30°C. Temperatures above or below this range can adversely affect soil microbial activity, and slow herbicide breakdown. Soil type and pH also have an influence on the rate at which chemicals degrade. Very dry soil also reduces the rate of breakdown. To make matters worse, when the soil profile is very dry, a lot of rain is required to rebuild then 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 in the paddock, and opt for a crop that will not be affected.

If dry areas do get rain and the temperatures become milder, then they are likely to need substantial rain (more than is stated on the label requirement) to wet the subsoil, in order for the topsoil to remain moist for a week or more and allow the microbes to be active in the topsoil. [44]

Plant-back periods for fallowing herbicides

Herbicide plant-back restrictions should be taken into account when spraying fallow weeds prior to sowing winter crops. Many herbicide labels place time and/or rainfall restrictions on sowing certain crops and pastures after application, so as to avoid potential seedling damage. Crops such as canola, pulses and legume pastures are the most sensitive to herbicide residues, but cereal crops 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, next year's crop or pasture may an influence the grower's herbicide choice this season.

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

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, and this can significantly extend the plant-back period.

Keeping accurate records of all herbicide treatments and planning crop sequences well in advance can reduce the chance of crop damage resulting from the presence of herbicide residues (Table 6). [45]

Table 6: *Indicative plant-back intervals for a selection of fallow herbicides.*

Product	Rate	Wheat	Barley	Oats	Canola	Legume pasture	Pulse crops
2,4-D 680*	0–510 mL/ha	1 day	1 day	1 day	14 days	7 days	7 days
	510–1,150 mL/ha	3 days	3 days	3 days	21 days	7 days	14 days
	1,150–1,590 mL/ha	7 days	7 days	7 days	28 days	10 days	21 days
Amicide® Advance 700*	0–500 mL/ha	1 days	1 days	1 days	14 days	7 days	7 days
	500–980 m/ha	3 days	3 days	3 days	21 days	7 days	14 days
	980–1500 mL/ha	7 days	7 days	7 days	28 days	10 days	21 days
Kamba*	200 mL/ha	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	–	–	–	16 weeks	–	–
Lontrel™	300 mL/ha	1 week	1 week	1 week	1 week	36 weeks	36 weeks
Garlon™ 600	Various	1 week	1 week	NS	NS	NS	NS
Ally®**	Various	2 weeks	6 weeks	36 weeks	36 weeks	36 weeks	36 weeks
Logran®#	Various	–	–	–	12 months	12 months	12 months
Glean®**	Various	–	9 months	6 months	12 months	12 months	12 months
Grazon™ Extra, Grazon™ DS	Rates up to 500 mL/ha	9 months	9 months	NS	9 months	24 months	24 months
Tordon™ 75-D, Tordon™ 242	Various	2 months	2 months	NS	4 months	9 months	6 months
FallowBoss Tordon™	Up to 700 mL/ha	9 months	9 months	NS	12 months	20 months	20 months

For triticale, plant-back periods for wheat or barley are a reference point.
*15 mm rainfall required to commence plant-back period;
**, period may extend where soil pH is >7;
#, assumes 300 mm rainfall between chemical application and sowing;
NS, not specified.

Source: RMS Agricultural Consultants

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

1.4.1 Herbicide residues in soil: an Australia-wide study

The move to conservation tillage and herbicide-tolerant crop cultivars means that, more than ever before, many farmers rely on herbicides for weed control. Despite the provision of plant-back guidelines on herbicide product labels, site-specific factors such as low rainfall, constrained soil microbial activity and unfavourable pH may cause herbicides to persist in the soil beyond usual expectations. Because of the high cost of herbicide residue analysis, information about herbicide residue levels in Australian grain cropping soils is scarce.

In addition, little is known about how herbicides affect soil biological processes and what this means for crop production. This is especially the case for repeated applications over multiple cropping seasons. In Australia, herbicides undergo a rigorous assessment by the Australian Pesticides and Veterinary Medicines Association (APMVA) before they can be registered for use in agriculture. However, relatively little attention is given to the soil biology on the farm—partly because we are only now beginning to grasp its complexity and importance to sustainable agriculture. Although a few tests such as earthworm toxicity tests and effects on soil respiration are mandatory, ,functional services provided by soil organisms such as organic matter turnover, nitrogen cycling, phosphorus solubilisation and disease suppression are usually overlooked.

GRDC has co-funded a five-year project (DAN00180) to better understand the impact of greater herbicide use on the most important soil biological processes; the project will conclude in 2018. The national project, coordinated by the NSW Department of Primary Industries, and with partners in Western Australia, South Australia, Victoria and Queensland, is focussed on the effect of at least six classes of herbicides on the biology and function of five key soil types across all three grain-growing regions. [46]

There are already some results from the project. A field survey of herbicide residues in 40 cropping soils—15 in SA, 12 in WA, and 13 in NSW–Queensland—prior to sowing and pre-emergent herbicide application was conducted in 2015 (Table 7). The researchers are most interested in the effects of the herbicides that were most frequently detected. Recommendations are given to minimise potential impacts of herbicide residues on productivity and soil sustainability. We also provide detail plans for future research and the development of management tools for growers to monitor and predict herbicide persistence in soils.

The average and maximum estimated loads of glyphosate, trifluralin, diflufenican and diuron were all substantially higher in paddocks in WA compared with those in SA, NSW and Queensland. This probably reflects the lighter soil types, lower level of organic matter, dry summers and cool winters, which contribute to lower microbial activity and constrain herbicide breakdown. The higher load of atrazine in SA paddocks is probably a consequence of the higher persistence of s-triazine herbicides in alkaline soils; and the higher values for 2,4-D in the NSW–Queensland soil profiles was due to a high value in a single paddock which had recently been sprayed.

Notably, in a number of paddocks (especially in WA but also in other states), they found a higher load of glyphosate than was applied in the previous spray, demonstrating a degree of accumulation of glyphosate and its metabolite AMPA over time.

46 GRDC (n.d.) DAN00180: Does increased herbicide use impact on key biological processes?, GRDC, http://projects.grdc.com.au/projects.php?action=view_project&project_id=2416

Table 7: *Residue loads (average and maximum) of herbicide active ingredients (a.i.) in the 0–30 cm soil profile of paddocks, by region.*

Herbicide	Estimated average load across all sites (kg a.i./ha)*			Estimated maximum load detected (kg a.i./ha)*		
	NSW–Qld	SA	WA	NSW–Qld	SA	WA
AMPA	0.91	0.95	0.92	1.92	1.97	2.21
Glyphosate	0.56	0.48	0.79	2.05	1.05	1.75
Trifluralin	0.08	0.11	0.53	0.14	0.26	1.34
Diflufenican	0.01	0.03	0.04	0.02	0.05	0.09
Diuron	0.14	0.05	0.17	0.16	0.05	0.29
2, 4-D	0.20	0.02	0.01	1.00	0.05	0.02
MCPA	0	0	0	0	0	0
Atrazine	0.02	0.03	0.02	0.03	0.05	0.02
Simazine	0	0.04	0	0	0.05	0
Fluroxypyr	0.03	0	0	0.03	0	0
Dicamba	0	0	0	0	0	0
Triclopyr	0	0.04	0.01	0	0.07	0.01
Chlorsulfuron	0	0	0	0	0	0
Sulfometuron-methyl	0	0	0	0	0	0
Metsulfuron-methyl	0	0	0	0	0	0
Triasulfuron	0	0	0	0	0	0

* Calculated by multiplying mass concentration (mg/kg) detected by area and average bulk density (derived from Soilquality.org) for each soil layer

Source: GRDC

Glyphosate, trifluralin and diflufenican are routinely applied in grain cropping systems, and their residues, plus the glyphosate-metabolite AMPA, are frequently detected at agronomically significant levels at the commencement of the winter cropping season.

The risk to soil biological processes was generally considered minor when herbicides are used at label rates and given sufficient time to dissipate before re-application. However, given the frequency of glyphosate application, and the persistence of trifluralin and diflufenican, further research is needed to define critical thresholds for these chemicals to avoid potential negative impacts to soil function and crop production. [47]

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

1.5 Seedbed requirements

Seedbed preparation for triticale is very similar to that for wheat. As with all cereals, triticale should be planted into a firm seedbed near moisture. [48] A good seedbed is free of weeds, diseases and insects. To aid erosion control, use implements that will preserve previous crop residue. Substitution of herbicides for cultivation and seeding without pre-seeding tillage (minimum to no-tillage) are other practical considerations. Under conditions of dry or firm soil, seeding should be done with implements that minimise soil disturbance, such as air drills with disc or narrow openers together with press-wheels, to prevent soil drying.

MORE INFORMATION

Herbicide residues in soils: are they an issue?

Weed control in winter crops

47 M Rose, L Van Zwieten, P Zhang, D Nguyen, C Scanlan, T Rose, G McGrath, T Vancov, T Cavagnaro, N Seymour, S Kimber, A Jenkins, A Claassens, I Kennedy I (2016) Herbicide residues in soils—are they an issue? GRDC Update Paper, February 2016, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Herbicide-residues-in-soils-are-they-an-issue

48 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

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

Cereals can be conventionally sown or direct-drilled into a weed-free seedbed from March to mid-June.

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

Subsequent irrigations should be at cumulative evaporation minus rainfall (E – R) of 75 mm on grey soils and 50 mm on red soils.

Pre-irrigation completed by 1 April 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. [49]

Several approaches 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, different techniques can be used to create a seedbed (refer to Figure 5):

1. Conventional technique: ploughing in of straw, cultivation to sowing depth with a tyne/disc cultivator, conventional drilling, fertiliser spreading
2. Mouldboard ploughing + seed-drilling: ploughing-in of straw, shallow cultivation, drilling where seed and fertiliser are placed in the soil simultaneously
3. Minimal tillage: tillage of straw by cultivator, seed drilling where seed and fertiliser are placed simultaneously in the soil–straw layer
4. Shallow tillage: shallow burial of straw at the surface, seed-drilling where seed and fertiliser are placed simultaneously in the soil–straw layer.
5. Direct drilling: seed-drilling where seed and fertiliser are placed simultaneously without prior soil tillage; straw remains on the surface.

The technique used depends on many different factors, e.g. harvest residues, equipment available, soil type, climate, labour requirement.

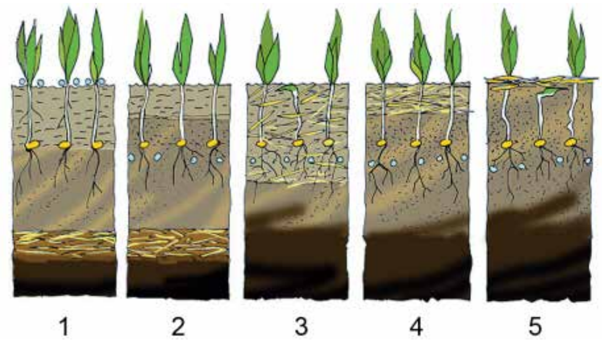

Figure 5: *Different seedbed preparation techniques give different results.*

Source: Vaderstad

Ploughing warms the soil and buries plant residues so that they do not obstruct sowing. However, ploughing also disrupts the soil structure and increases oxidation of

49 Agriculture Victoria (2105) Managing winter cereals. State Government of Victoria EDJDR, http://agriculture.vic.gov.au/agriculture/dairy/pastures-management/irrigated-pastures/managing-winter-cereals

organic material. Without ploughing, organic material and soil structure are retained, but the straw can cause problems with sowing and can transmit diseases. [50]

1.5.1 Structural decline of seedbed soil

Key points:

- Hard-setting or crusting soils usually have poor 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

Structural decline of surface soil generally results in one of two things: hard-setting or crusting (Photo 6). [51] 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 shrinks as it dries. This leads to a 'massive' soil layer, with few or no cracks and greatly reduced pore spaces. 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.

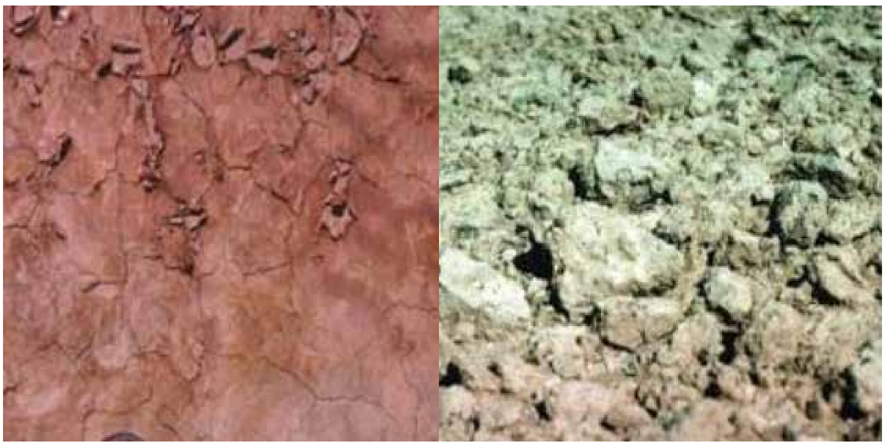

Photo 6: *Soil crusting (left) and cloddy seedbed (right) associated with high concentrations of exchangeable sodium.*

Source: Soilquality.org

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 when using management practices that increased soil organic matter and reduced traffic, to improve the 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 dispersive soils prone to hard-setting or crusting is through the addition of gypsum. This effectively displaces sodium and causes clay particles to bind together, helping to create stable soil

50 Väderstad (2015) Seedbed preparation. Väderstad AB, http://www.vaderstad.com/knowhow/seed-beds/seedbed-creation

51 Soilquality.org.. Soilquality, http://www.soilquality.org.au/factsheets/seedbed-soil-structure-decline-queensland

aggregates. A resulting reduction in the Exchangeable Sodium Percentage (ESP) and increase in the calcium:magnesium ratio may be observed. The addition of lime also adds calcium to the soil, but this technique is generally only used for soils with a low pH. [52]

1.5.2 Tillage

Tilling mixes and buries soil amendments and crop residues, eliminates existing vegetation, reduces pest populations, promotes mineralisation of soil organic matter, and creates a seedbed that facilitates mechanical planting and seed-to-soil contact.

The use of minimum soil disturbance has advantages for the production of triticale. One study noted a slight yield advantage for triticale grown under zero tillage. [53]

Research shows that one-time tillage with a chisel or offset disc in long-term, no-tillage system helped to control winter weeds, and slightly improved grain yields and profitability, while retaining many of the soil quality benefits of no-till farming systems (Photo 7). [54] Although tillage reduced soil moisture at most sites, this did not adversely affect productivity. This could be due to good rainfall received after tilling and before seeding that year. The occurrence of rain between tilling and sowing or immediately after sowing is necessary to replenish soil water lost from the seed zone. This suggests the importance of the timing of tillage and of considering the seasonal forecast. Future research will determine the best timing for strategic tillage in no-till systems (Photo 8). [55] Note that these results are from one season, and so are inconclusive. As research continues, and captures the effects of variances in seasonal conditions, more conclusive results will emerge.

Photo 7: *The impact of tilling varies with the implement used: inversion tillage using a mouldboard plough, as pictured here, results in greater impacts than using a chisel or disc plough.*

Source: GRDC

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

53 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

54 GRDC (2014) Strategic tillage. Factsheet. GRDC, https://grdc.com.au/Resources/Factsheets/2014/07/Strategic-tillage

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

VIDEOS

WATCH: GCTV11: Strategic tillage—does no-till mean never till?

WATCH: Over the Fence south: Andrew Simpson

Photo 8: *Strategic tillage can control 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: GRDC

On the downside, tillage can also result in more soil erosion and surface-water eutrophication. During the past decades, much progress has been made in reducing tillage. No-tillage crop production has increased 2.5-fold from about 45 million ha worldwide in 1999 to 111 million ha in 2009. The no-till trend has also come hand-in-hand with the increased use of herbicides to suppress weeds. [56]

In general, pre-plant tilling to prepare the seedbed, control weeds, and disrupt insect and disease life cycles improves crop establishment. However, no-till seeding is now the preferred method of crop establishment across the southern region and is highly suitable to the establishment of triticale across all soil types.

IN FOCUS

Tillage, microbial biomass and soil biological fertility

In the mid-1990s, no-tillage farmers called for an experiment to test anecdotal reports that low-disturbance tillage increased total organic carbon (TOC) in soil.

A seven-year experiment was conducted in the central wheatbelt of Western Australia on a property with deep sandy soil that was using a lupin–wheat rotation. The experiment compared the effect of three tillage types on TOC, light-fraction organic carbon (LFC), soil microorganisms and crop yields:

1. No-tillage—no soil disturbance other than seeding
2. Conservation tillage—a single pass before seeding with 13-cm-wide tynes to a depth of ~7.5 cm
3. Rotary tillage—a single intense cultivation before seeding to a depth of 8 cm, using a rotary hoe.

56 MR Ryan, SB Mirsky, DA Mortensen, JR Teasdale, WS Curran (2011) Potential synergistic effects of cereal rye biomass and soybean planting density on weed suppression. Weed science, 59 (2), 238–246.

Total organic carbon

The TOC is a measure of all carbon contained within soil organic matter. Low levels can indicate problems with unstable soil structure, low cation exchange capacity and nutrient turnover (see Soil Quality Fact Sheet: Total organic carbon).

After seven years, TOC had increased by 4.4 t/ha under no-tillage and by 2.6 t/ha under conservation tillage (Figure 6), but had decreased by 0.5 t/ha under rotary tillage.

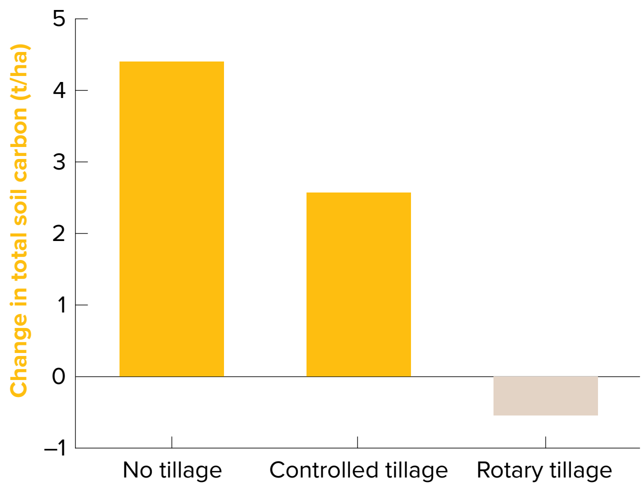

Figure 6: *Change in total soil carbon content at 0–10 cm soil depth from 1998 to 2004 in crops under three tillage regimes. No-tillage and conventional tillage treatments were not significantly different from each other; rotary tillage was significantly different from both (at P = 0.05).*

Source: Soilquality.org

Light-fraction organic carbon

The LFC consists of more recent, readily decomposable inputs of organic matter. LFC responds more quickly to management than TOC and better reflects changes in soil microbiology. The LFC decreased as tillage became more intensive.

By the end of the experiment, LFC in the top 10 cm was 0.83 t/ha under no-tillage, 0.73 t/ha under conservation tillage and 0.46 t/ha under rotary tillage.

This may indicate that less intensively tilled soils are more biologically active and have higher potential for nutrient turnover, and that TOC may increase further in the future.

On the other hand, the losses with rotary tillage of both TOC and LFC could lead to degradation of soil structure and ultimately to a decline in productivity.

Soil microorganisms

Microbial biomass carbon is a measure of carbon in the soil microorganisms (see Soil Quality Fact Sheet: Microbial biomass). Microbial biomass carbon in 0–5 cm soil decreased under rotary tillage compared with no-tillage and conservation tillage (Figure 7).

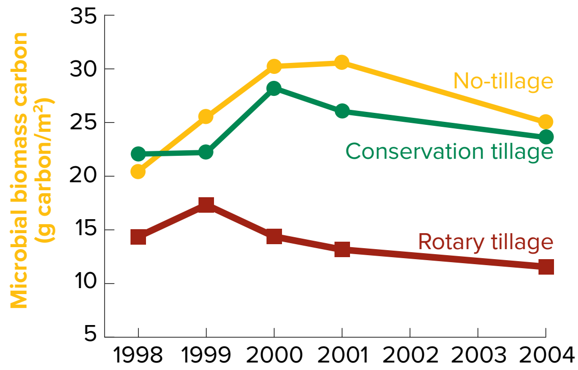

Figure 7: *Microbial biomass carbon at 0–5 cm depth of cropped soil under three tillage regimes.*

Source: Soilquality.org

Microbial biomass nitrogen was also higher under no-tillage and conservation tillage than under rotary tillage. By the end of the experiment, microbial biomass nitrogen under no-tillage and conservation tillage was 31% higher than under rotary tillage.

Tillage also decreased microbial activity in soil. The activity of the microbial enzyme cellulase at 0–5 cm soil depth was higher under no-tillage and conservation tillage than rotary tillage (Figure 8).

This indicates that less intensive cultivation may favour sustained microbial function in soil.

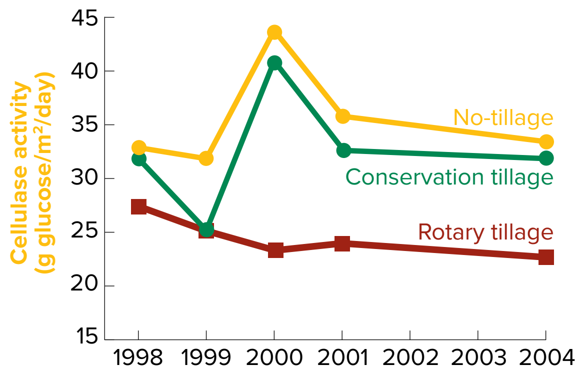

Figure 8: *Activity of the microbial enzyme cellulase at 0–5 cm depth of cropped soil under three tillage regimes.*

Source: Soilquality.org

Crop yields

Tillage practice did not affect crop yields except in one year of the trial, 2003, when lupin grain yields were higher under no-tillage (2 t/ha) and conservation tillage (1.9 t/ha) than under rotary tillage (1.6 t/ha).

Although tillage did not affect wheat grain yield, it did affect the incidence of Rhizoctonia bare patch (caused by *Rhizoctonia solani*; see Soil Quality Fact Sheet: Rhizoctonia). Wheat plants grown under both no-tillage and conventional tillage were more visibly affected by Rhizoctonia bare patch than those grown under rotary tillage.

Although overall results for no-tillage and conservation tillage were similar, they may diverge in the longer term. [57]

1.6 Soil moisture

Triticale performs well under rain-fed conditions throughout the world and excels when produced where there is good soil fertility and irrigation. [58] It is grown in areas with an annual average rainfall of about 300 mm to at least 900 mm. Very little triticale is irrigated. [59]

1.6.1 Dryland

Water availability is a key limiting factor for cereal production in the grainbelt of Australia. Varieties with improved adaptation to water-limited conditions are actively sought, and studies have been carried out to identify the physiological basis of the adaptive traits underpinning this advantage.

IN FOCUS

Soil-water extraction by dryland crops, annual pastures and lucerne in south-eastern Australia

The extraction of soil water by dryland crops and pastures in south-eastern Australia was examined in 3 studies. The first was a review of 13 published measurements of soil-water use under wheat at several locations in southern New South Wales. Of these, eight showed that crops extracted significantly more water when they were grown with an increased nitrogen supply or after a break crop. The mean additional soil-water extraction in response to extra N was 11 m, and after break crops was 31 mm.

The second study showed how good management can change crop yields and prevent the unnecessary loss of water. Researchers used the SIMTAG model to simulate growth and water use by wheat at Wagga Wagga. The model was set up to simulate two typical situations: crops that produced average district yields; and crops that might produce greater yields with good management. When simulated over 50 years of weather data, the combined water loss as drainage and run-off was predicted to be 67 mm/year for poorly managed crops and 37 mm for well-managed crops. Water outflow was concentrated in 70% of years for the poorly managed crops and 56% for the well-managed crops. In those years the mean losses were estimated to be 95 mm and 66 mm, respectively.

The third study reported on soil water measured twice each year during a phased pasture–crop sequence over 6.5 years at Junee. Mean water content of the top 2.0 m of soil under a lucerne pasture averaged 211 mm

MORE INFORMATION

GRDC, Strategic tillage in no-till systems

Organic carbon

Microbial biomass

Rhizoctonia

VIDEOS

WATCH: Adoption of no till SA Mallee

57 M Roper, J Carson, D Murphy. Tillage, Microbial biomass and soil biological fertility. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/tillage-microbial-biomass-and-soil-biological-fertility

58 M Mergoum, H Gómez-Macpherson (eds) (2004) Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, http://www.fao.org/3/a-y5553e/y5553e00.pdf

59 KV Cooper, RS Jessop, NL Darvey (2004) Triticale in Australia. In M Mergoum, H Gómez-Macpherson (eds), Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, ftp://ftp.fao.org/docrep/fao/009/y5553e/y5553e02.pdf

less than under a subterranean clover-based annual pasture and 101 mm less than under well-managed crops.

Collectively, these results suggest that lucerne pastures and improved crop management can result in greater use of rainfall than the other farming systems, which were based on growing annual pastures, and using fallow, and poor management techniques for growing crops. The tactical use of lucerne-based pastures in sequence with well-managed crops can help the dewatering of the soil and reduce or eliminate the risk of groundwater recharge. [60]

Monitoring soil moisture in dryland areas

Grain growers are under pressure to increase production across the seasons; adding to the complexity of this demand is the likelihood that, if the climate becomes more variable, rainfall may decrease or its distribution change. Even now, current cropping systems may not be maximising Water Use Efficiency, if growers are relying on subjective assessments. Few are able to monitor the amount of water available to the crop, and hence cannot supply the crop with the appropriate amount of inputs to maximise yield.

One tool that helps farmers improve Water Use Efficiency is the soil-moisture probe, but few farmers in the dryland cropping industry use it. To change that, Victoria's Department of Environment and Primary Industries will provide live deep-soil-moisture data to help dryland croppers, farmers, and advisers and managers validate the technology, as well as conducting training to interpret the data for crop decision-making. [61] Communication will include monthly broadcasts of 'The Break', soil-moisture products; and the government will piloting new formats to expand reach and impact.

This project will assist people in the grain sector to lift production and improve grain quality to meet the demand of the growing Asian consumer market (via the government's Food to Asia plan). Increasing targeted inputs and improving crop management will be accomplished by educating industry to understand soil and water interactions and critical crop growth stages, as well as factoring in seasonal forecasts.

Access to this data enables growers and advisers to:

- Measure moisture at one representative point in the paddock for a farm in the region.
- Use live soil-moisture data that is collected from a representative site for a particular rainfall region and soil type.
- Monitor local weather (rain, wind and temperature and humidity) and download historical data from an archive list for farm management records.
- Increase production and efficiencies.
- Help farmers to adapt to climate variability.
- Make informed decisions such as minimising input in low-decile years with a low soil-moisture base and maximising yield potential in more favourable conditions, based on current soil-moisture levels and incorporating knowledge from seasonal forecasts.
- Determine if measurements obtained through the life of the project could be relevant at whole-farm or even district level.

MORE INFORMATION

Soil moisture monitoring in dryland cropping areas

60 JF Angus, RR Gault, MB Peoples, M Stapper, AF Van Herwaarden (2001) Soil water extraction by dryland crops, annual pastures, and lucerne in south-eastern Australia. Crop and Pasture Science, 52 (2), 183–192.

61 Agriculture Victoria (2016) Soil moisture monitoring in dryland cropping areas. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/soil-moisture-monitoring-in-dryland-cropping-areas

1.6.2 Irrigation

Effective irrigation will influence the entire growth process, from seedbed preparation, germination and root growth, through nutrient utilisation and plant growth and regrowth, to yield and the quality of the yield.

The key to maximising irrigation efforts is uniformity. The producer has a lot of control over how much water to supply and when to apply it, but it is the irrigation system that determines uniformity. Deciding which irrigation systems is best for your operation requires a knowledge of equipment, system design, plant species, growth stage, root structure, soil composition, and land formation. Irrigation systems should encourage plant growth while minimising salt imbalances, leaf burn, soil erosion, and water loss. Water will be lost through evaporation, wind drift, run-off, and water (and nutrients) sinking deep below the root zone.

Proper irrigation management takes careful consideration and vigilant observation.

Irrigation allows primary producers to:

- Grow more pastures and crops.
- Have more flexibility in their systems and operations as the ability to access water at times when it would otherwise be hard to achieve good plant growth (due to a deficit in soil moisture) is imperative. Producers can then achieve higher yields and meet market and seasonal demands, especially if rainfall events do no occur.
- Produce higher quality crops and pastures as water stress can dramatically impact on the quality of farm produce.
- Lengthen the growing season (or start the season earlier).
- Have 'insurance' against seasonal variability and drought.
- Stock more animals per hectare and practice tighter grazing management, due to the reliability of pasture supply throughout the season.
- Maximise benefits of fertiliser applications. Fertilisers need to be watered into the ground in order to best facilitate plant growth.
- Use areas that would otherwise be less productive. Irrigation can allow farmers to open up areas of their farms where it would otherwise be too dry to grow pasture or crops. This also gives them the capability to carry more stock or to conserve more feed.
- Take advantage of market incentives for unseasonal production.
- Be less reliant on supplementary feeding (i.e. grain, hay) in grazing operations due to the more consistent supply and quality of pastures grown under irrigation.
- Improve the capital value of their property. Since irrigated land can potentially support higher density crops, pasture and animal production, it is considered more valuable. The value of the property is also related to the water licensing agreements or water rights.
- Save costs or obtain greater returns. These occur from the more effective use of fertilisers and greater financial benefits as a result of more effective agricultural productivity (both quality and quantity) and for out-of-season production. [62]

Irrigation has also been found to be effective in increasing both shoot Zn content and Zn efficiency of cereal cultivars. It has been suggested that plants become more sensitive to Zn deficiency under rain-fed than irrigated conditions. [63]

The main commercial triticale varieties are relatively tall compared with newer wheat varieties, increasing the likelihood of lodging. However, in reality, in most of the newer

62 Agriculture Victoria (2015) About irrigation. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/farm-management/soil-and-water/irrigation/about-irrigation

63 H Ekiz, SA Bagci, AS Kiral, S Eker, I Gültekin, A Alkan, I Cakmak (1998) Effects of zinc fertilisation and irrigation on grain yield and zinc concentration of various cereals grown in zinc-deficient calcareous soils. Journal of Plant Nutrition, 21 (10), 2245–2256, https://www.researchgate.net/publication/249076820_Effects_of_Zinc_fertilisation_and_irrigation_on_grain_yield_and_zinc_concentration_of_various_cereals_grown_in_zinc-deficient_calcareous_soils

varieties lodging is not considered a problem, although it is more the likely to occur with high rates of nitrogen fertiliser and under irrigated conditions (Table 8). [64]

Table 8: *Lodging scores in NVT trials, 2008.*

Variety	Score
Bogong⁽ᴅ	0/5
Jaywick⁽ᴅ	3/5
Tahara	3/5
Tobruk⁽ᴅ	0/5
Canobolas⁽ᴅ	0/5
Berkshire⁽ᴅ	1/5
JRCT 101	0/5
Yukuri	5/5
Rufus	5/5

Note: A score of 0 means the variety was not prone to lodging and a score of 5 means that the variety is prone to heavy lodging.
Source: Jessop & Fittler 2009

IN FOCUS

Genetic improvement of triticale for irrigation in south-eastern Australia

Research into winter cereal breeding in Australia has focused primarily on studying the effects of rain-fed environments. These studies typically show large genotype × environment (GE) interactions, and the complexity of these interactions acts as an impediment to the efficient selection of improved varieties. Wheat had been studied extensively; however, there were no published studies on the GE interactions of triticale in Australia under irrigated production systems.

To rectify this situation, researchers conducted trials on 101 triticale genotypes at two locations over four years. All the genotypes were subjected to intensive irrigation. The researchers measured the yield potential, GE interactions, heritability and estimated genetic gain of yield, lodging resistance, and several other traits important for breeding triticale. They found that high yield potential exceeding 10 t/ha–1 existed in the Australian germplasm tested and that, in these irrigated trials, genotype accounted for a high proportion of the variability in all measured traits. All genetic parameters such as heritability and estimated genetic gain were high compared with those tested in rain-fed environments.

They concluded that breeding triticale with improved yield and lodging resistance for irrigated environments is achievable and can be pursued with confidence in breeding programs. [65]

64 RS Jessop, M Fittler (2009) Appendix 1. Triticale production manual: an aid to improved triticale production and utilisation. In J Roake, R Rethowan, R Jessop, M Fittler, Improved triticale production through breeding and agronomy. Pork CRC, http://www.apri.com.au/1A-102_Final_Research_Report_.pdf

65 A Milgate, B Ovenden, D Adorada, C Lisle, J Lacy, N Coombes (2015) Genetic improvement of triticale for irrigated systems in south-eastern Australia: a study of genotype and genotype× environment interactions. Crop and Pasture Science, 66 (8), 782–792.

MORE INFORMATION

Agriculture Victoria: About irrigation

GRDC Update Paper: The Future of irrigation, what's in store

The future of irrigation

Climate change is likely to lead to reductions in rainfall in south-eastern Australia. These reductions in rainfall will be amplified such that proportional reductions in runoff are likely to be two–four times larger. That is, a 10% rainfall reduction will lead to a 20–40% reduction in runoff. The runoff reductions will be larger in drier catchments, making the water supply systems with drier source catchments more vulnerable. The experience of the Millennium Drought has shown that reductions in runoff under persistent climate change (~10-year drought) are larger than reductions that occur for short droughts with similar rainfall reductions in many catchments. [66]

1.7 Yield and targets

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

The average grain yield of triticale is about 2.5 t/ha, although yields vary locally from less than 1 t/ha in lower-rainfall areas and areas with soil problems to more than 7 t/ha in higher-rainfall areas with more fertile soils. [67]

In dry springs, triticale yields are 10–15% below wheat, due to triticale's longer grain-filling period. [68] However, under ideal conditions, researchers have found that triticale can out-yield wheat and barley, and sometimes oats. [69]

Observed traits suggested for the higher yields in triticale than wheat include greater early vigour, a longer spike-formation phase with same duration to flowering, reduced tillering, increased remobilization of carbohydrates to the grain, early vigorous root growth and higher transpiration use efficiency. [70]

The southern region has soils with generally low fertility, and many have subsoil constraints such as salinity, sodicity and toxic levels of some elements. However, soils in the region are diverse and some areas have very productive soils. Crop-production systems in the region are varied and include many mixed-farming enterprises that have significant livestock and cropping activities.

Achieving yield potential in the southern region depends on seasonal rainfall, especially in autumn and spring There is less dependence on stored soil moisture in the south than in the northern region.

In the southern grain-growing region, the most significant yield constraints are high soil density, sodicity and acidity. [71]

66 A Western, M Saft M, M Peel (2016): The future of irrigation—what's in store? GRDC Update Papers https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/The-future-of-irrigation-whats-in-store

67 KV Cooper, RS Jessop, NL Darvey (2004) Triticale in Australia. In M Mergoum, H Gómez-Macpherson (eds), Triticale improvement and production. FAO Plant Production and Protection Paper No. 179. Food and Agriculture Organisation, ftp://ftp.fao.org/docrep/fao/009/y5553e/y5553e02.pdf

68 Birchip Cropping Group (2004) Triticale agronomy 2004. Online Farm Trials, http://www.farmtrials.com.au/trial/13801

69 Agriculture Victoria (2012) Growing triticale. Note AG0497. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-triticale

70 S Bassu, S Asseng, R Richards (2011) Yield benefits of triticale traits for wheat under current and future climates. Field Crops Research, 124 (1), 14–24.

71 Carson J. Biological inputs: Southern Australia. Soilquality.org, http://www.soilquality.org.au/factsheets/biological-inputs-southern-grain-growing-region

IN FOCUS

Triticale v. durum wheat: a yield comparison in Mediterranean-type environments

The productivity of modern triticales makes them increasingly viable as an alternative small-grain cereal crop to durum wheat in a Mediterranean climate. Researchers compared the two species, testing a substantial number of cultivars in 20 field experiments in Italy. Grain yield per environment ranged from 3.4–7.7 t/ha-1; in 11 of the environments, the triticales as a group out-yielded the durum wheats, while in the remaining nine, the two species yielded equally. The superiority of triticale derived from its combination of setting a higher number of grains per unit area (reflecting greater ear fertility) and a similar per-unit grain weight. Triticale is well adapted to the Mediterranean environment, provided that sowing density is no less than 300 seeds per m^2, because ear fertility contributes more than tillering capacity to the number of grains set per m^2. In the 20 environments tested, temperature and water availability in the generally favourable pre-anthesis period assured triticale the possibility of realising a grain yield at least comparable to that of durum wheat. At the same time triticale out-yielded durum wheat when its flowering time fell within an optimal window, and where the post-anthesis environment was not too stressful. High ear fertility should be treated as an important trait in the breeding of small grain cereals, because of its positive influence over both yield potential and yield stability. [72]

Several tools are available to help growers maximise yields.

Before planting, identify the target yield required to be profitable:

- Do a simple calculation to see how much water you need to achieve this yield.
- Know how much soil water you have (treat this water like money in the bank).
- Think about how much risk your farm can take.
- Consider how this crop fits into your cropping plan, and consider whether the longer-term benefits to the system outweigh any short-term losses.

Avoiding a failed crop saves money now and saves stored water for future crops. [73]

Estimating crop yields

Accurate, early estimation of grain yield is an important skill. Farmers require accurate yield estimates for a number of reasons:

- crop insurance purposes
- delivery estimates
- planning harvest and storage requirements
- cash-flow budgeting.

Extensive personal experience is the best asset for estimating yield at early stages of growth. As crops near maturity, it becomes easier to estimate yield with greater accuracy.

72 R Motzo, G, Pruneddu, A, Virdis, F Giunta (2015) Triticale vs durum wheat: A performance comparison in a Mediterranean environment. Field Crops Research, 180, 63–71.

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

Estimation methods

Many methods are available for farmers and others to estimate yield of various crops. The method presented here is one that can be undertaken relatively quickly and easily. Steps are as follows:

1. Select an area that is representative of the paddock. Using a measuring rod or tape, measure out an area 1 m^2 and count the number of heads/pods.
2. Do this five times to get an average for the crop: no. of heads per m^2 (e.g. 200).
3. Count the number of grains in at least 20 heads, and calculate the average: no. of grains per head (e.g. 24).
4. Determine the 100-grain weight for the crop (in grams) by referring to table 1 in: Estimating crop yields—a brief guide.
5. No. of grains per m^2 = no. of heads per m^2 × no. of grains per head; e.g. 200 × 24 = 4800.
6. Yield per m^2 (g) = (no. of grains per m^2/100) × 100-grain weight; e.g. 4800/100 × 2.5 = 120 g.
7. Yield (t/ha) = numeric value of yield per m^2/100; e.g. 120/100 = 1.2 t/ha.

Accuracy of yield estimates depends upon an adequate number of counts being taken to get a representative average of the paddock. The yield estimate determined will be a guide only.

This type of yield estimation should be able to be used in a number of situations on a grain-growing property. Grain losses both before and during harvest can be significant and an allowance for 5–10% loss should be included in your final calculations. [74]

Yield Prophet®

Scientists at the Agricultural Production Systems Research Unit (APRSU) 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 had 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-investing or under-investing in their crop.

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.

74 Agriculture Victoria. Estimating crop yields; a brief guide. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/estimating-crop-yields-a-brief-guide

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

1.7.1 Seasonal outlook

Seasonal outlooks from the Bureau of Meteorology include:

- 3-month rainfall outlook – a description of the outlook for north, south-east and western Australia
- 3-month rainfall outlook – maps and tables showing the chances of exceeding the median or of getting a certain amount
- 3-month temperature outlook for north, south-east and western Australia
- ENSO wrap-up - regular commentary on the El Niño - Southern Oscillation
- ENSO outlooks - forecast of El Niño and La Niña events - a summary of the opinion of National Climate Centre climatologists on the outputs from eight reputable climate models
- BOM Climate Model Summary - Australian climate is influenced by temperature patterns in the Pacific and Indian Oceans. This page provides information on Pacific and Indian Ocean outlooks for the coming 6 months based on a survey of international climate models. It is updated monthly.
- Northern rainfall onset prediction - The Bureau's new northern rainfall onset outlook provides guidance on rainfall timing within the first months of the Australian northern wet season

For Victorian growers, the Department of Environment, Land, Water and Planning has a webpage, Monthly Water Report, that links to BOM's seasonal rainfall outlook.

Many researchers and developers are providing tools via mobile applications (apps) for smartphones and tablets for ground-truthing precision agriculture data. Apps and mobile devices are making it easier to collect and record data on the farm. The app market for agriculture is evolving rapidly, with new apps becoming available on a regular basis.

CliMate

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

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

One of the CliMate tools, *Season's progress?*, uses long-term (1949 to present) weather records to assess progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and with all years.

MORE INFORMATION

Yield Prophet

GRDC Update Paper, Managing data on the modern farm

DELWP, Monthly water report web page

BOM, Climate outlooks: monthly and seasonal

Climate kelpie

It explores the readily available weather data, compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons.

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

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

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

As outputs, text and two graphical presentations are used to show the current season in the context of the average and all years. Departures from the average are shown in a fire-risk chart as the departure from the average in units of standard deviation. [75]

Climate Analogues

Climate Change in Australia provides projections for Australia's natural resource management regions. Its Climate analogues tool matches the proposed future climate of a location of interest with the current climate experienced in another location by using annual average rainfall and maximum temperature.

For example, based on plausible assumptions about changes in temperature and rainfall, the future climate of Melbourne will be like the current climate of a location identified by this tool.

This approach was used to generate the analogue cases presented as examples in each of eight Cluster Reports. These reports are intended to provide regional detail for planners and decision makers. The results should capture sites of broadly similar annual maximum temperature and water balance. [76]

MORE INFORMATION

Climate Analogues

Bureau of Meteorology, Climate outlooks: monthly and seasonal

Climate Kelpie

1.7.2 Fallow moisture

For a growing crop there are two sources of water: the water stored in the soil during the previous fallow, and the rainfall that occurs while the crop is growing. As a farmer, you have some control over the stored soil water: you can measure how much you have before planting the crop. Even though Long-range forecasts and tools such as the SOI cannot guarantee that rain will fall when you need it, they are useful for indicating the likelihood of the season being wet or dry. [77]

HowWet/N?

HowWet? is a program developed by APSRU that uses records from a nearby weather station to estimate how much plant-available water has accumulated in the soil and the amount of organic N that has been converted to available nitrate during a fallow.

HowWet? tracks soil moisture, evaporation, runoff 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?* provides a comparison with previous seasons.

75 Australian CliMate—Climate tools for decision makers. Managing Climate Variability R & D Program, http://www.australianclimate.net.au

76 Climate Change in Australia. Climate analogues. Australian Department of the Environment, Bureau of Meteorology, http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/

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

This information aids the decision about what crop to plant and how much N fertiliser to apply. Many grain growers are in regions where stored soil water and nitrate at planting are important in crop-management decisions.

Questions this tool answers:

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

Inputs:

- a selected soil type and weather station.
- an estimate of soil cover and starting soil moisture.
- rainfall data input by the user for the stand-alone version of *HowOften?*

Outputs:

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

Reliability

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

Soil descriptions are based on generic soil types with standard organic C:N ratios, and as such should be regarded as indicative only and best used as a measure of relative water accumulation and nitrate mineralisation. [78]

MORE INFORMATION

How Wet/N?

1.7.3 Water Use Efficiency

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

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

Triticale is thought to use water more efficiently than oats and rye do. [79]

One study showed that triticale had similar Water Use Efficiency and resulting yield to wheat under varying soil moisture conditions. [80]

Researchers in southern Australia found that the total water use of triticale was less than that of wheat and rye, particularly at the higher rates of N. WUE of triticale was also higher at all levels of N, and increased with increasing N application, whereas the WUE in wheat and rye didn't increase after 50 kg N/ha. [81]

78 Australian CliMate—How Wet/N. Managing Climate Variability R & D Program, http://www.australianclimate.net.au/About/HowWetN

79 Mergoum, M., Pleiffer, W. H., Pena, R. J., Ammar, K., and Rajaram, S. (2004). Triticale crop improvement: the CIMMYT programme. In M. Mergoum and H. GomezMacpherson (Eds.), Triticale improvement and production (Vol. 179, pp. 11-26). Rome: Food and Agriculture Organization.

80 PK Aggarwal, AK Singh, GS Chaturvedi, SK Sinha (1986) Performance of wheat and triticale cultivars in a variable soil—water environment II. Evapotranspiration, Water Use Efficiency, harvest index and grain yield. Field Crops Research, 13, 301–315.

81 JB Golding (1989). Restricted tillering in triticale cv. currency-an impediment to grain yield? Fifth Australian Agronomy Conference, http://www.regional.org.au/au/asa/1989/contributed/crop/p1-20.htm

One study in a Mediterranean climate attributed high Water Use Efficiency and yield to triticale's stomatal conductance. [82]

IN FOCUS

Triticale grain yield and physiological response to water stress

Water availability in semi-arid regions is becoming increasingly threatened by erratic rains and frequent droughts leading to over-reliance on irrigation to meet food demand. Improving crop Water Use Efficiency (WUE) has become a priority. To understand how triticale responds to water stress, researchers carried out a two-year study in which they subjected triticale to four moisture levels, ranging from well-watered (430–450 mm) to severe stress (220–250 mm). They worked with four commercial triticale genotypes and grew them under field conditions in a hot, arid, steppe climate in South Africa. The results showed that moisture level significantly influenced grain yield and intrinsic WUE in triticale. Well-watered conditions increased grain yield, which ranged from 3.5 to 0.8 t/ha−1 in 2013, and 4.9–1.8 t ha−1 in 2014. Intrinsic WUE increased with decreasing moisture level. Flag-leaf photosynthesis and pre-anthesis assimilates contribute much less carbon to grain filling under water stress than previously thought. [83]

Water Use Efficiency can be considered at several levels:

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

Ways to increase yield

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

- 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).
- 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).
- 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).
- 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). [84]

82 R Motzo, G Pruneddu, F Giunta (2013) The role of stomatal conductance for water and radiation use efficiency of durum wheat and triticale in a Mediterranean environment. European Journal of Agronomy, 44, 87–97.

83 L Munjonji, KK Ayisi, B Vandewalle, G Haesaert, P Boeckx (2016) Combining carbon-13 and oxygen-18 to unravel triticale grain yield and physiological response to water stress. Field Crops Research, 195, 36–49.

84 JB Passioura, JF Angus (2010) Improving productivity of crops in water-limited environments. Chapter 2 in DL Sparks (ed.) Advances in Agronomy, Vol. 106. Academic Press. pp. 37–75, http://www.sciencedirect.com/science/article/pii/S0065211310060025

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) × (crop water supply (mm) – estimate of soil evaporation (mm))

In the equation, 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, and 46% achieved 13–17 kg/ha/mm.*
>
> *A practical WUE equation for farmers to use developed by James Hunt (CSIRO) is: WUE = (yield × 1000)/available rainfall, where available rainfall = (25% Nov.–March rainfall) + (growing season rainfall) – 60 mm evaporation.*

VIDEOS

WATCH: GCTV12: Water Use Efficiency Initiative

WATCH: GCTV10: Grazing stubbles and Water Use Efficiency

Agronomist's view

The French–Schultz model has been useful in providing growers with performance benchmarks. Where yields fall well below these benchmarks, it may indicate a problem 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 simply be due to seasonal rainfall distribution patterns, which are beyond the grower's control. [85]

In the grainbelt 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 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), and this affects yield potential and WUE.

Understanding how these 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 in the use of simple rules of thumb (French–Schultz) for benchmarking WUE, and discuss the importance of more integrative and dynamic modelling approaches to explore alternatives to increase WUE at the single-crop and whole-farming-systems levels (i.e. $/ha.mm). [86]

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

86 Rodriguez (2008) Farming systems design and Water Use Efficiency (WUE). Challenging the French & Schultz WUE model. GRDC Update Papers, 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

MORE INFORMATION

Water Use Efficiency of grain crops in Australia: principles, benchmarks and management

Making the most of available water in wheat production

Recent WUE trials in Tasmania

The fundamentals of increasing nitrogen use efficiency

1.7.4 Nitrogen-use efficiency

Key points:

- Improving nitrogen-use efficiency 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 six general categories. Identification of the most likely groups is useful in directing more targeted measurement and helping identify possible strategies for improvement.
- As result of seasonal effects, NUE improvement is an iterative process; therefore, consistency in the investigation strategy used and good record keeping are essential. [87]

Nitrogen-use efficiency (NUE) is the efficiency with which soil nitrate-N is converted into grain N. The nitrate-N comes from fertiliser, crop residues, manures, and soil organic matter, but it is how well and quickly this fertiliser is converted into grain that is generally of greatest concern to growers. Efficiency is reduced by some seasonal conditions, crop diseases, losses of N from the soil as gases, N leaching, or immobilisation of N into organic forms.

The type of soil type, the intensity of rainfall and the timing of fertiliser application largely determine N losses from dryland cropping soils. Insufficient rainfall after a surface application of N fertilisers can result in losses from the soil through volatilisation. The gas lost in this case is ammonia. Direct measurements of ammonia losses have found that they are generally <15% of the N applied, and even less with in-crop situations. An exception can occur with the application of ammonium sulphate to soils with free lime at the surface, where losses have been recorded as >25% of the N applied. Recovery of N applied in-crop requires sufficient rainfall for plant uptake from an otherwise dry surface soil.

A balance of nutrients is essential for profitable yields. Fertiliser is commonly needed to add the essential nutrients P and N, although the lack of other essential plant nutrients may also limit production in some situations. Knowledge of the nutrient demand of crops is essential in determining nutrient requirements. Soil testing and nutrient audits assist in matching nutrient supply to crop demand. [88]

Optimising nitrogen-use efficiency

Nitrogen fertilisers are a significant expense for broadacre farmers. Optimising use of fertiliser inputs is therefore desirable. There are three main stores of nitrogen with the potential to supply N to crops: stable soil organic matter N, rotational (plant residue) N, and soil mineral N (ammonium and nitrate). To optimise the ability of plants to use soil N, growers should first be aware of how much of each source there is, and soil testing is the best method of measuring these N sources. [89]

In recent research in the UK, it was found that triticale had higher biomass and straw yields, lower harvest index and higher total N uptake than wheat. Consequently, triticale had higher efficiency of both the uptake and use of N. [90]

In another study, NUE decreased with increasing N fertiliser rates. At an N supply of 100 kg/ha–1, the NUE of triticale was 0.14 t dry biomass/kg N. [91]

1.7.5 Double-crop options

Double cropping is growing a winter and summer crop following one another.

87 C Dowling (2014) The fundamentals of increasing nitrogen use efficiency. GRDC Update Paper, 11 February 2014. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/The-fundamentals-of-increasing-nitrogen-use-efficiency-NUE

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

89 Soilquality.org. Optimising soil nutrition, http://www.soilquality.org.au/factsheets/optimising-soil-nutrition

90 S Roques, D Kindred, S Clarke (2016) Triticale out-performs wheat on range of UK soils with a similar nitrogen requirement. The Journal of Agricultural Science, 1–21.

91 I Lewandowski, U Schmidt (2006) Nitrogen, energy and land use efficiencies of *Miscanthus*, reed canary grass and triticale as determined by the boundary line approach. Agriculture, Ecosystems & Environment, 112 (4), 335–346.

Cool-season annual forages such as triticale are well-suited to double cropped forage. [92] Planting cool-season annuals following a grain harvest is an economical way to produce high-quality forage. Two types of cool-season annual forages that are well-suited to produce double-cropped forage are small-grain cereal grasses, such as triticale, oats, cereal rye and wheat, and brassicas, which include turnip and radish.

For autumn forage, the general concept is to take advantage of the potential growing degree-days following a grain harvest. Ideally, planting a forage double crop would occur as soon as possible following grain harvest since the growing degree-days available for plant growth rapidly decline through the late summer into early autumn. The risk of failure increases with later planting dates. However, establishment costs are often low enough for many of these forages that the successful years often outweigh the years in which failure occurs. [93]

For spring forage, the winter cereals triticale, rye and wheat tend to be the best choices.

IN FOCUS

Crop sequencing for irrigated double cropping in the Murrumbidgee Valley

A project in the Murrumbidgee Valley aimed to qualify and overcome some of the potential difficulties with double cropping systems, and to provide the opportunity for growers to capitalise on their investment in irrigated agriculture. The researchers addressed the issues of herbicide residues, irrigation layouts and management, stubble management, and quantifying achievable crop yield and profitability.

The researchers conducted the trials over two years, from winter 2014 to summer 2015–16. The project had two core sites, one in Boort (northern Victoria) and the other at the Leeton Field Station (LFS) in southern NSW. At the Victorian site they focused on the technical aspects of double cropping, including herbicide options and stubble management.

They experimented with seven double-cropping rotations. The wheat–fallow–wheat–fallow (T5) rotation had the lowest Gross Margin (GM) return per hectare, of only $1,428/ha over the two years. Even though T5 had the lowest GM for $/ha, it had a much better GM return on a megalitre basis, with $216/ML.

The T5 effect is of interest, as while it had the lowest GM/ha for land use, it was one of the best for GM for water use. This implies that if water is limited, growers need to seriously consider increasing the percentage of winter crops within their rotation and using summer fallows as a break. In contrast, if water is plentiful and of low cost, a more summer crop-dominant rotation could be more profitable. [94]

MORE INFORMATION

Crop sequencing for irrigated double cropping with the Murrumbidgee Valley region

92 ME Drewnoski, DD Redfearn (2015) Annual cool-season forages for late-fall or early-spring double-crop. No. G2262. NebGuide, http://extensionpublications.unl.edu/assets/pdf/g2262.pdf

93 ME Drewnoski, DD Redfearn (2015) Annual cool-season forages for late-fall or early-spring double-crop. No. G2262. NebGuide, http://extensionpublications.unl.edu/assets/pdf/g2262.pdf

94 T Napier, L Gaynor, D Johnston, G Morris, M Rollin (2016) Crop sequencing for irrigated double cropping within the Murrumbidgee Valley region. GRDC Update Paper. 27 July 2016. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Crop-sequencing-for-irrigated-double-cropping-Murrumbidgee-Valley-site

1.8 Disease status of paddock

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

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

Crop sequencing is only a part of the integrated management of diseases. Other practices include:

- Maintaining sufficient distance from last year's paddock of the same crop, and maintaining sufficient distance 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.
- In-crop fungicide treatments. [95]

Paddock selection is an important consideration for managing crown rot, in particular, and growers should select paddocks with a low risk of the disease. Paddock risk can be determined by one or both of these methods:

- Visually assessing the levels of crown rot and root-lesion nematode (RLN) (see section 1.9) in a prior cereal crop, paying attention to basal browning.
- Having soil samples analysed at a testing laboratory.

The presence of spores of tan (yellow) spot is also an important consideration, and effective management of this disease in cereals depends on decisions made before sowing.

1.8.1 Testing soil for disease

In addition to visual symptoms, the DNA-based soil test PreDicta B™ can be used to assess the disease status of the paddock. Soil samples that include plant residues should be tested early in late summer to allow results to be returned before seeding. This test is particularly useful when sowing susceptible wheat varieties, and for assessing the risk after a non-cereal crop.

PreDicta B

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

PreDicta B (the B stands for broadacre) is a DNA-based soil testing service that identifies which soil-borne pathogens pose a significant risk to broadacre crops prior to seeding (Photo 9). It includes tests for:

- 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*).
- Blackspot of peas (*Mycosphaerella pinodes*, *Phoma medicaginis* var *pinodella* and *Phoma koolunga*).

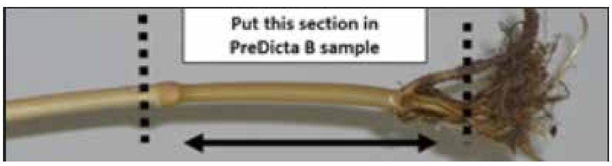

Photo 9: *PreDicta B sample.*

Source: GRDC

95 M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Paper, 13 September 2011. GRDC, http://elibrary.grdc.com.au/ark!!33517/vhnf54 t/a9ft5hf

MORE INFORMATION

PreDicta B

SARDI, Crop diagnostics

How to access the service

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.

Samples are processed weekly between February and mid-May (prior to crops being sown) every year.

PreDicta B is not intended for in-crop diagnosis. SARDI provides a diagnostic service for that.

1.8.2 Effects of cropping history

The main cropping history effects are based on the amount of nutrients available in a paddock. However, the previous crop will influence levels of both soil- and residue-borne diseases. Important diseases to consider include take-all, crown rot, yellow leaf spot, stripe rust, 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.

For diseases, there has been a focus on management of crown rot and RLN, yellow leaf spot in winter cereals, and the roles that rotational crops play, particularly the winter pulses. 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 diseases. Other practices include maintaining sufficient distance from last year's paddock of the same crop or from a paddock with residue infected with a pathogen of the intended crop; the use of high-quality, fungicide-treated seed; planting within the planting window; variety selection; and in-crop fungicide treatments. [96]

Paddock histories likely to result in high risk of disease (e.g. Rhizoctonia) include:

- durum wheat in the past 1–3 years
- winter cereal or a high grass burden from last season—crown rot fungus survives in winter cereal residues, dense stubble cover or where dry conditions have made residue decomposition slow
- break crops, which can influence crown rot in cereals by manipulating the amount of N and moisture left in the soil profile
- paddocks that have high levels of N at sowing and/or low stored soil moisture at depth [97]
- varieties grown in previous year (Photo 10). [98]

96 M Ryley (2011) Diseases shared by different crops and issues for crop sequencing. GRDC Update Papers, September 2011, http://elibrary.grdc.com.au/ark%21%2133517/vhnf54 t/a9ft5hf

97 GRDC (2009) Crown rot in cereals. GRDC Fact Sheet May 2009, https://www.grdc.com.au/~/media/AF642FA0A889465089D2B6C59E5CA22E.pdf

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

Photo 10: *Diseased patches of Rhizoctonia root rot from previous crops vary in size from less than half a metre to several metres in diameter.*

Source: DAFWA

1.9 Nematode status of paddock

Root-lesion nematodes (*Pratylenchus thornei* and *P. neglectus*) are migratory root endoparasites that are widely distributed in the wheat-growing regions of Australia. They can reduce grain yield by up to 50% in many current wheat varieties (Photo 11). *Pratylenchus neglectus* and *P. thornei* are the main RLNs causing yield loss in the southern agricultural region of Australia, and they often occur together. [99]

At least 20% of cropping paddocks in south-eastern Australia have populations of RLNs high enough to reduce yield. [100]

99 DAF Qld (2010) Test your farm for nematodes. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/crop-diseases/root-lesion-nematodes/test-your-farm-for-nematodes

100 G Holloway (2013) Cereal root diseases. Note AG0562. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

Photo 11: *Paddock showing patches caused by root lesion.*

Source: DAFWA

The roots of triticale in nematode-infested soil have been found to contain fewer nematodes than other cereals. Triticale is thus a useful rotational crop for areas infested with the root-lesion nematodes. [101]

1.9.1 Testing soil for nematodes

PreDicta B

PreDicta B can also be used for testing for the presence of nematodes:

- Cereal cyst nematode (*Heterodera avenae*).
- Root lesion nematode (*Pratylenchus neglectus* and *P. thornei*).
- Stem nematode (*Ditylenchus dipsaci*).

See section 1.8.1 above for details, including how to access the service.

MORE INFORMATION

GRDC Tips and Tactics, Root-lesion nematodes, southern region

1.9.2 Effects of cropping history

- Well-managed rotations are vital. Avoid consecutive host crops to limit populations.
- Choose varieties with high tolerance ratings to maximise yields in fields where RLN is present.
- Choose rotation crops with high resistance ratings, so that fewer nematodes remain in the soil to infect subsequent crops.

For more information, see Section 8: Nematode control

1.10 Insect status of paddock

Pests such as redlegged earth mites, blue oat mites, nematodes and, in some seasons, cutworms, pose a risk in some paddocks (Photo 12). 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.

101 V Vanstone, M Farsi, T Rathjen, K Cooper (1996) Resistance of triticale to root lesion nematode in South Australia. In Triticale: Today and Tomorrow, Springer Netherlands, pp. 557–560.

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

Photo 12: *Armyworm on a severed stem (left) and the damage caused by a combination of armyworms and herringbone caterpillars to a cereal paddock (right).*

Sources: Luke Maher, left, and James Mckee

Soil insects include:

- crickets
- earwigs
- cutworms
- false wireworms
- true wireworms

Soil-insect control measures are normally applied at sowing. Since different insects require different control measures, the species of soil insects must be identified before planting. [102]

1.10.1 Testing soil for insects

It is important to maintain a regular testing regime for the presence of insects in the soil. Recent seasons have seen a plethora of seemingly new pests and unusual damage in pulse and grain crops.

GRDC's advice to growers is to:

- Monitor crops frequently so as not to be caught out by new or existing pests.
- Look for and report any unusual pests or symptoms of damage—photographs are good.
- Remember that just because a pest is present in large numbers in one year doesn't mean it will necessarily be so next year— another spasmodic pest, e.g. soybean moth, may make its presence felt instead.
- Be aware of cultural practices that favour pests, and rotate cops each year to minimise the build-up of pests and plant diseases. [103]

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

102 DAF Qld. (2011) How to recognise and monitor soil insects. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects

103 H Brier, M Miles (2015) Emerging insect threats in northern grain crops. GRDC Update Paper, 31 July 2015. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Emerging-insect-threats-in-northern-grain-crops

Using a sweep net

Most crop monitoring for insect pests is done visually or with a sweep net. Using a shake or beating tray is another technique. Sampling pastures mostly relies on visual assessment of the sward or the soil below it. The sweep net is the most convenient sampling technique for many insects. The net should be about 38 cm in diameter, and swept in a 180° arc from one side of the sweeper's body to the other. The net should pass through the crop on an angle so that the lower lip travels through the crop marginally before the upper lip. The standard sample is 10 sweeps, taken over 10 paces, which comprises one set. This technique should be repeated as many times as practicable across the crop, and at no less than five locations. After completing the sets of sweeps, count the insects captured and average the counts to give an overall estimate of abundance. Sweep nets tend to under-estimate the size of the pest population. Their efficiency is significantly affected by temperature, relative humidity, crop height, wind speed, plant density and the operator's vigour. [104]

There are two other main sampling techniques.

Soil sampling by spade

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

Germinating-seed bait technique

Immediately following planting rain:

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

Trials have shown no difference in the type of seed used for attracting soil-dwelling insects. However, using the type of seed to be sown is likely to indicate the species of pests that could damage the proposed crop. The major disadvantage of the germinating-grain bait method is the delay between the seed placement and assessment. [105]

Identifying insects

The South Australian Research and Development Institute (SARDI) Entomology Unit provides an insect identification and advisory service. The unit identifies insects to the highest taxonomic level for species where this is possible, and can also give farmers biological information and guidelines for controlling them. [106]

GRDC's Insect ID ute guide is a comprehensive reference on the insect pests that commonly affect broadacre crops across Australia (Figure 9). It includes the beneficial insects that may help to control pests. 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 they may be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [107]

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

105 DAF Qld (2011) How to recognise and monitor soil insects. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects

106 PIRSA. Insect diagnostic service, http://pir.sa.gov.au/research/research_specialties/sustainable_systems/entomology/insect_diagnostic_service

107 GRDC. Insect ID: The ute guide. GRDC, https://grdc.com.au/Resources/Apps

The app is available for Android phones and the iPhone.

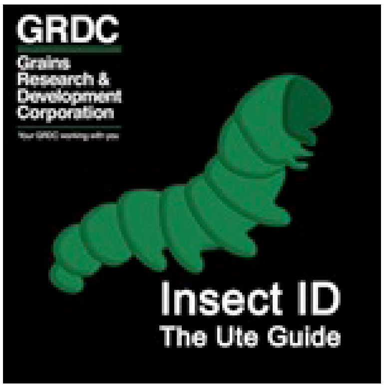

Figure 9: *Icon of GRDC's insect ID app.*

Source: GRDC

App features

The features of the app are:

- Region selection.
- Predictive search by common and scientific names.
- Comparison photos of insects side by side with insects in the app.
- Identification of beneficial predators and parasites of insect pests.
- The option to download content updates inside the app to ensure you're aware of the latest pests affecting crops for each region.
- Raises awareness of international biosecurity pests.

It is important to consider paddock history when planning for pest management. Resident pests can be easier to predict by using paddock history. Agronomic and weather data will also help to determine the likely presence (and numbers) of certain pests within a paddock. These will point towards the likely pest issues and allow growers to implement preventive options. [108] Reduced tillage and increased stubble retention have changed the cropping landscape with respect to soil-moisture retention, groundcover and soil biology, and these have 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. [109]

See Section 7: Insect control for more information.

1.10.2 Effects of cropping history

Where paddock history, paddock conditions or pest numbers indicate a high risk of pest damage a grower might decide to use pre-seeding controls to reduce pest pressure, apply a seed dressing to protect the crop during the seedling stage and plan to apply a foliar insecticide if pest numbers reach a particular level. [110]

Different soil insects occur under different cultivation systems and the way the farm is managed directly influences the type and number of these pests. Keep in mind the following:

- Weedy fallows and volunteer crops encourage soil insect build-up.

MORE INFORMATION

Pest Genie

Australian Pesticides and Veterinary Medicines Authority

108 R Jennings (2015) Growers chase pest-control answers. Ground Cover. No. 117. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Growers-chase-pest-control-answers

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

110 G Jennings (2012) Integrating pest management. SANTFA, http://www.santfa.com.au/wp-content/uploads/Santfa-TCE-Spring-12-Integrating-pest-management.pdf

- Insect numbers decline during a clean, long fallow due to lack of food.
- Large amounts of stubble on the soil surface can promote some soil insects because they are a food source, but this can also mean that pests continue feeding on the stubble instead of moving to germinating crops.
- No-tillage cropping encourages beneficial predatory insects and earthworms.
- Incorporating stubble promotes black field earwigs.
- False wireworms are found at all intensities of cultivation, but numbers decline if stubble levels are very low.

Soil-insect controls are normally applied at sowing. Since different insects require different control measures, the species must be identified before planting. Soil insects are often difficult to detect as they hide under trash or in the soil. Immature insects such as false wireworm larvae are usually found at the interface of moist and dry soil. [111]

For more information, see Section 7: Insect Control.

111 DAF Qld (2011) How to recognise and monitor soil insects. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/recognising-and-monitoring-soil-insects