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GRAINS RESEARCH & DEVELOPMENT CORPORATION

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.
- Triticale is grown in areas with an annual average rainfall of about 300 mm to at least 900 mm. Very little triticale is irrigated.

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, nutritional status, seasonal forecasts, stored soil water, and achieving a balance of risk across the farm with other crop types. [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.

There are potential environmental and economic benefits of site-specific topography-driven management of crops. Decisions regarding where to plant crops can vary depending on the management goals and complexity of the terrain. For example, crops like triticale, with its large biomass, 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]

Triticale can suit uneven paddocks and/or those with many gilgais as its tall growth habit makes harvesting more manageable in such paddocks.

Agronomist's view

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.

Frost risk

Frost damage is most frequent, and most severe, in 'frost pockets', which can vary greatly in size, depending on topography and related factors. Low lying paddocks or areas within a paddock are at higher risk of damaging frost events.

Winter cereals are most susceptible to low temperatures during the reproductive stage as reproductive parts are not protected by the leaf sheaths and ice can nucleate directly on them. As a result, complete or serious yield losses are felt when frost occurs between the booting and grain ripening stages.

Triticale has been rated as susceptible to frost damage. One study has ranked frost resistance in the order of most resistance as; rye, bread wheat, triticale, barley, oats, and durum wheat, and another study reported that triticale is the most susceptible crop, followed by wheat, barley, rye and oats. [3]

Physically mapping or marking areas identified as frost-prone will enable growers to target frost management strategies to these high-risk areas. As triticale is vulnerable to frost damage, it is important to either avoid sowing it in frost prone paddocks, or adopt other frost management strategies (e.g. time of sowing, canopy management etc.).

For more information on Frost, see Section 14: Environmental issues, Section 14.1 Frost.

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 and crop choice.

Triticale is a high-yielding grain suited to all soil types (see Photo 1), but has yield advantages over wheat and barley in some problematic soils. It does better than them on light, acid soils high in exchangeable aluminium (greater than 10% of the total cations, such as in southern NSW, north-eastern Victoria and WA). In these soils, triticale significantly out-yields wheat, barley and sometimes oats in all seasonal conditions, wet or dry. 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. [4]

In low soil fertility, triticale responds well to high inputs of seed and fertiliser. Adequate fertiliser needs to be applied to achieve optimum yields.

On good soils, and in better seasons, triticale yields are equal to or exceed those of wheat. However, in dry springs triticale yields may be 10–15% below wheat, due to its longer grainfilling period.

Of all the cereals available to farmers, triticale has the best adaptation to waterlogged soils (such as those on the northern NSW coast) and those of high pH, common to the northern parts of the northern region. [5] Triticale is also tolerant of low pH (acid soils), grows well on sodic soils and tolerates soils high in boron. Triticale has the capacity to survive utilising trace elements in soils which would be considered nutrient-deficient for any other type of crop. [6] On alkaline soils where other cereals are affected by manganese, zinc or copper deficiency, triticale is less affected.

3 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

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

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

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

Photo 1: *Paddock of triticale.*

Source: Seed Force

Soil pH

Key points:

- Triticale can grow on acidic soils and alkaline soils.
- Soil pH is a measure of the concentration of hydrogen ions in the soil solution.
- Low pH values (under 5.5) indicate acidic soils and high pH values (over 8.0) alkaline soils.
- Soil pH between 5.5 and 8 is not usually a constraint to crop or pasture production.
- Outside of the optimal soil pH range, microelement toxicity damages crops.

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

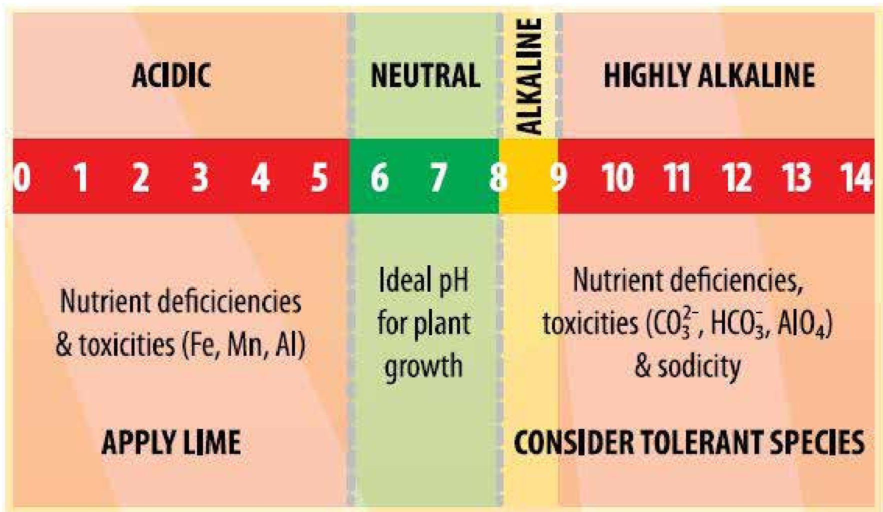


Figure 1: *Classification of soils on the basis of pH, showing the implications for plant growth and some management options.*

Source: Soilquality.org

Acidic soils

Queensland has more than 500,000 hectares of agricultural and pastoral land that has become acidic or is at risk of acidification, and more than half of the intensively used agricultural land in NSW is affected by soil acidity. Soils most at risk are the lighter-textured sands and loams with low levels of organic matter, and the naturally acidic red clay loams commonly found in areas such as the South Burnett and Atherton Tableland. The soils least likely to become acidic are the neutral to alkaline clay soils (e.g. brigalow soils and the grey–black Vertisols).

Acidic soils cause significant losses in production, and where the choice of crops is restricted to acid-tolerant species and varieties, profitable market opportunities may be reduced. In pastures grown on acidic soils, production will be reduced and some legume species may fail to persist.

There are many negative effects on plant growth and soil biology, fertility and structure when soils become too acidic. One major effect is when pH falls to 4.8. At this point aluminium starts to become more soluble where it is toxic to plants and restricts their root growth and function. At harvest this results in a yield penalty and smaller grain size, usually most noticeable in seasons with a dry finish as plants have restricted access to stored subsoil water for grain filling.

Plant species have different tolerances to soluble aluminium. There are four broad categories of plant tolerance (Highly sensitive, Sensitive, Tolerant and Highly tolerant). Plants highly sensitive to aluminium have their yields effected at low levels of aluminium (approximately Al % CEC > 2%). When pH falls below 4.5, the amount of aluminium increases markedly and even plants tolerant of aluminium will suffer yield reductions or fail to persist. [7]

Triticale can grow on acidic soils (pH less than 4.5 $CaCl_2$) (Table 1).

Table 1: *Crop sensitivity to acidity.*

Highly sensitive	**Durum wheat, most barley cultivars, faba beans, lentils, chickpeas, lucerne, medics, strawberry clover**
Sensitive	Some wheats, canola, phalaris, red clover, Balansa clover
Tolerant	Wheats, annual and perennial ryegrass, tall fescue, Haifa white and subterranean clovers
Highly tolerant	Lupins, oats, triticale, cereal rye, cocksfoot, kikuyu

Source: GRDC, modified from Brett Upjohn, 2005 NSW.

Managing acidic soils

Soil acidification is not as obvious as other soil issues such as salinity, erosion or structural decline. Symptoms are less visible, production declines are gradual and these changes are often attributed to other factors such as weather.

Soil testing

Ideally, soil samples should be taken when soils are dry and have minimal biological activity. Soil samples should be taken from a number of locations across the paddock, as pH may vary in even a small area. Samples should be taken at the surface (0–10 cm) and from the subsurface (50–60 cm) of the soil so as to detect subsurface acidity, which may underlie topsoil with an optimal pH. The location of samples need to be pinpointed accurately (e.g. by using GPS) to allow monitoring. Sampling should be repeated every 3–4 years to enable the grower to detect changes and adjust management practices.

To maintain a good soil pH profile, producers should aim for a pHCa above 5.0 in the 0–10 cm of topsoil or 5.5 if subsoil acidity issues are present. The target in the 10–30 cm zone is greater than pHCa 4.8.

7 J Small (2016) GRDC Update Papers: Crop yield impacts and management of soil acidity in Central Western NSW. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Crop-yield-impacts-and-management-of-soil-acidity-in-Central-Western-NSW

Farming practices to reduce acidification

It is most important that soil acidity be treated early. If acidity spreads to the subsoil, serious yield reduction may occur. Subsoil acidity is difficult and costly to ameliorate. Farming practices recommended to minimise acidification include:

- Match nitrogen fertiliser inputs to crop demand. Soil testing should be carried out to ensure that fertiliser rates match plant requirements.
- Use forms of nitrogen fertiliser that cause less acidification. Table 2 [8] summarises the acidifying effect of different N fertilisers. Nitrate-based fertilisers such as calcium nitrate and potassium nitrate are the least acidifying, but their higher cost limits their use to high-value horticultural crops.
- Apply nitrogen in split applications, if practicable. Application of a crop's entire fertiliser needs at planting time may contribute to soil acidification by allowing the leaching of nitrate nitrogen before the crop roots have developed sufficiently to take all of it up.
- Sow early after fallow to ensure more rapid utilisation of available N.
- Grow deep-rooting perennial species to take up nitrogen from greater depths.
- Regularly apply lime to counter the acidification inherent in the agricultural system.
- Grow crop varieties that are more tolerant of acid soils.
- Irrigate efficiently to minimise leaching.

Table 2: *Acidification potential of nitrogen fertilisers, assuming that some leaching loss of applied nitrogen occurs.*

Fertiliser	Acidification Potential
Calcium nitrate, potassium nitrate	Low
Nitram, urea, animal manure	Medium
Ammonium sulphate, MAP, DAP	High

MAP = mono-ammonium phosphate; DAP = diammonium phosphate

Source: Soilquality.org

Applying lime or dolomite

When soils are too acidic for a crop, lime or dolomite can be used to increase soil pH to the desired level. The amount required to correct an acidic pH will depend on the soil and the crop.

Above pH 4.8 aluminium becomes non-toxic in the soil, enabling the plants to develop effective root systems. Research shows that as well as improving crop yields and widening rotation options, liming has a long-term positive impact on the ecosystem by potentially boosting soil microbial activity, improving availability of major plant nutrients and helping to reduce weed seed banks. [9]

Soils with a high amount organic matter and clay will be more resistant to changes in pH and will require more lime or dolomite. To obtain an estimate of the amount of lime required to correct an existing soil-acidity problem, conduct a test of the lime-requirement or buffer pH type.

Testing is used to give a lime recommendation to raise the soil pH of the surface 10 cm of one hectare of soil to a target pH that will not limit crop yield. In general, a target pH of 5.5 is suggested.

Once the target soil pH is reached, additional lime or dolomite may still be required, depending on the crop. The acidifying effect of cropping systems is related to the amount of material removed at harvest, the amount and type of fertilisers normally used, and the amount of leaching that occurs. [10] There are opportunities to

8 Soilquality.org (2017) Soil acidity, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/soil-acidity-qld

9 GRDC (2016) Soil Acidity in WA. https://grdc.com.au/archive/key-issues/soil-acidity-in-wa/details

10 Soilquality.org (2017) Soil acidity, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/soil-acidity-qld

decrease lime rates by adjusting nitrogen fertiliser rates or by changing the form of nitrogen used. [11]

If the topsoil pH is below 5.5, recovery liming is recommended to prevent the development of subsurface acidity, even if the subsurface pH is at 4.8 (Table 3).

Table 3: *The amount of lime that may be required on sandy soils over five years to achieve a pH above 5.5 in the topsoil and 4.8 in the subsurface after 10 years. Increases in pH will depend on soil type, rainfall, lime quality and quantity applied and other farming practices, as well as the soil pH profile. Expert advice should be sought for individual recommendations as ongoing acidification resulting from agricultural production will require additional lime.*

Soil depth (cm)	pHCa	Lime amount over five years (t/ha)
0–10	<5.0	2
0–10	<5.5	1
Add to		
10–20	<4.5	2
10–20	<4.8	1
Add to		
20–30	<4.5	1
20–30	<4.8	Measure pH in 3 years

Source: GRDC

Alkalinity

Alkaline soils occupy about 23.8% of total land area in Australia. More than 30% reduction in grain productivity occurs when the pH is above 9.0. When pH is more than 9, the soils are considered highly alkaline and often have toxic amounts of bicarbonate, carbonate, aluminium and iron. Nutrient deficiency is also likely to be a major problem and the high amount of exchangeable sodium in these soils reduces soil physical fertility. On alkaline soils where other cereals are affected by manganese, zinc or copper deficiency, triticale is less affected, and can grow well compared to other crops.

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

Management

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.

Acidification to reduce pH below 9.0 can be reasonably achieved by growing legumes and the simultaneous application of gypsum. Gypsum will reduce sodicity and this can reduce alkaline pH to some extent. Growing legumes in crop rotation may help in sustaining any pH reduction. Reducing the soil pH below 9.0 enhances crop productivity in alkaline soils by avoiding the toxicity of aluminium and carbonates, nutrient deficiency and other possible microelement toxicity.

Reducing soil alkalinity by applying these treatments can increase yield by 10–30%, providing economic benefits to farmers. [12]

Salinity

Key points:

- Soil salinity varies across the landscape and within paddocks.

11 Soilquality.org (2017) Soil acidity, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/soil-acidity-qld

12 P Rengasamy (2010) GRDC Final Reports: UA00092–Chemistry and crop agronomy in alkaline soils. http://finalreports.grdc.com.au/UA00092

VIDEOS

GCTV8: Liming Acids Soils

MORE INFORMATION

Impact of soil acidity on crop yield and management in Central Western NSW

Chemistry and crop agronomy in alkaline soils

Making better liming decisions

- The severity varies over time, in response to both climate and land management.
- Soil salinity can be managed by farming actions.
- One study found that though saline soil increased the quality of protein in triticale, it decreased the quality of grain overall. [13]

What is soil salinity?

A saline soil is one that contains sufficient soluble salts (most commonly sodium chloride) that the growth of most plants is retarded, with damage occurring sooner in plants more sensitive to salt and much later in salt-tolerant plants such as saltbush. Salinity reduces a plant's ability to extract water from the soil, and specific ions in the salts can cause toxicity. A salinity outbreak is where symptoms of salinity are present.

Soils become saline via interaction with groundwater. If groundwater rises to within two metres of the soil surface, capillary action can bring water to the surface. When this happens, salts dissolved in the water are brought into the root zone, and when the water evaporates at the soil surface, concentrated salts are left behind.

Triticale and wheat are rated as highly tolerant to saline soils (Table 4), however, salinity has been found to reduce yields when values of electrical conductivity are above 6 decisiemens per metre (dS/m) throughout the root zone.

Table 4: *Tolerance of some common crops to salinity.*

High tolerance	Moderate tolerance	Low tolerance
Wheat	Lucerne	Maize
Barley	Peas	Sugar cane
Canola	Sweetcorn	Red clover
Cotton		Sub. clover
Ryegrass		
Sorghum		
Soybeans		

Source: Australian Soil Fertility manual, JS Glendinning 1999

Salinity affects crop yield and growth in dryland regions mainly by reducing Water Use Efficiency of crops through osmotic effect. Toxic effects of individual ions such as sodium can also cause yield reduction. When the osmotic pressure of the soil solution is less than (<) 700 kilopascals (kPa), there is a low rate of reduction in yield irrespective of the type of ions (salt). At these lower osmotic pressures the specific ion effect, particularly of sodium, is significant. For osmotic pressure greater than (>) 700 kPa the rate of crop yield reduction is severe. When the osmotic pressure is above 1,000 kPa, the crop yield is reduced by >50% and 80–95% of available soil water is not taken up by plants. [14]

For more information on the effects of soil salinity on triticale growth, see Section 4: Plant growth and physiology.

Signs of salinity in the paddock

Any of these signs should trigger investigations for potential salinity:

- Crop symptoms including reduced yield, and burnt leaf tips and/or margins (Photo 3). [15]
- Salt-tolerant species thriving while others grow poorly.
- Dieback of trees.

13 M Salehi, A Arzani (2013). Grain Quality traits in Triticale influenced by field salinity stress. Australian Journal of Crop Science. 7(5):580–587. In F Eudes (2015) Triticale. Springer International Publishing, Switzerland.

14 P Rengasamy (2006) GRDC Final Reports: UA00023–Improving farming systems for the management of transient salinity and risk assessment in relation to seasonal changes in southern Australia. http://finalreports.grdc.com.au/UA00023

15 DAFWA (2016) Changing land use on unproductive soils in the north-eastern agricultural region. DAFWA, https://www.agric.wa.gov.au/soil-constraints/changing-land-use-unproductive-soils-north-eastern-agricultural-region

- Waterlogged soil (separate from rain or flood events).
- Bare patches of soil.
- Wet, dark greasy patches.
- Salt crusts on the soil surface when it is dry.
- Stock congregating and licking surface salt.
- Very clear water in dams and waterways.

Photo 2: *Cereal crop suffering in a saline paddock.*

Source: DAFWA

Measuring salinity

Soil salinity varies across paddocks and farms, and vertically within the soil profile. Soil may be saline at depth but not in the topsoil. This situation indicates that there may be a future problem in the topsoil.

Samples can be taken to assess salinity by measuring the electrical conductivity (EC) of soil and water. EC is usually measured in dS/m). Distilled water has an EC of 0 dS/m, sea water has an EC of 35–55 dS/m, and the desirable limit for human consumption is 0.8 dS/m. Measurements may be taken instead of the electrical conductivity of a soil extract (ECe), of a water sample (ECw) and of irrigation water (ECiw) or drainage water (ECdw).

Dryland salinity

Dryland salinity occurs when naturally occurring salts in rocks and soil are mobilised and redistributed by water, e.g. by surface run-off after rain, the recharge of groundwater, subsurface lateral flows of groundwater, or groundwater discharge. It occurs throughout NSW (Photo 4). [16] Saline outbreaks in upland areas of the NSW Murray–Darling Basin cover around 62,000 hectares, but individual areas are usually less than 10 hectares. Most salt scalds occur in the 600–700 mm rainfall zone.

16 S Alt (2017) Salinity, New South Wales. Soilquality.org, http://soilquality.org.au/factsheets/salinity-nsw

Photo 3: *Scalding by salt.*

Photo: Graham Johnson, NSW Government.

Irrigation salinity

Irrigation salinity in NSW occurs mainly in southern NSW in the Murray and Murrumbidgee irrigation areas.

Areas of land affected by irrigation salinity have dropped sharply in the last 10 years (from 2015), from 14,000 hectares to less than 500 hectares in the Murray Valley. The mechanisms for this change are not completely understood, but are possibly due to a combination of reduced winter rainfall and better farm management and infrastructure.

Managing groundwater levels

Salinity management aims to maintain groundwater levels at least two metres below the soil surface, mainly by maximising the water plants use to reduce groundwater recharge. Useful techniques include:

- Monitoring groundwater levels.
- In low lying, non-production areas, growing species tolerant of salt and waterlogging.
- Growing perennial pastures, as they can use twice as much water as annual pastures.
- Avoiding long fallows when the profile is greater than 75% of field capacity.
- Appropriate crop selection and crop rotations.
- Efficient irrigation management.

Troubleshooting

Recognising and acting on salinity problems early is the best solution, as salinity can be a more difficult and expensive issue to correct once it is well advanced. Dryland salinity outbreaks can be managed by excluding grazing on saline areas and sowing saline tolerant species. Irrigation salinity can be managed by improving irrigation management, specifically application efficiency. Specific management of salt-affected areas could include having hill and bed shapes that minimise salt accumulation around seedlings, and pumping and recycling groundwater (although this requires advice from a hydrology consultant). [17]

Sodic or dispersive soils

Sodicity is a term given to the amount of sodium held in a soil. Dispersive soils are generally a surface problem, sodicity can be at the surface but also at depth; i.e. plant roots hit this layer and become restricted in growth and cannot extract as much water out of the profile. High sodicity causes clay to swell excessively when wet. The clay particles move so far apart that they separate (disperse). This weakens

MORE INFORMATION

Improving farming systems for the management of transient salinity and risk assessment in relation to seasonal changes in southern Australia

17 S Alt (2017) Salinity, New South Wales. Soilquality.org, http://soilquality.org.au/factsheets/salinity-nsw

the aggregates in the soil, causing structural collapse and closing-off of soil pores and hence infiltration points. For this reason, water and air movement through sodic soils is severely restricted. In crop paddocks, sodic layers or horizons in the soil may prevent adequate water penetration during irrigation, making the water storage low. Additionally, waterlogging is common in sodic soil, since swelling and dispersion closes off pores, reducing the internal drainage of the soil. Sodicity of the surface soil is likely to cause dispersion of surface aggregates, resulting in surface crusts, which can also prevent seedling emergence.

Soils with an exchangeable sodium percentage (ESP) ≥6 are classified as sodic. Poor drainage, surface crusting, hardsetting (Photo 5) and poor trafficability or workability are common when the soil has a large proportion of sodium ions (Na+), leading to reduced crop yield.

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.

Photo 4: *Soil crusting (left) and cloddy seedbed (right) associated with high concentrations of exchangeable sodium; i.e. sodic soil.*

Source: Soilquality.org

Field research in Victoria/South Australia indicates that soil salinity and sodicity can substantially reduce crop yields. The impact of sodicity was most apparent for yields in the range 3.0–3.5 t/ha, where the probability of wheat yielding in this range was 60% for sites where ESP 19% compared with 12% when ESP >19%. [18] This response is likely to be similar in triticale crops.

Crop growth is affected by salinity and sodicity in two ways: firstly, the osmotic potential effect and secondly specific ion toxicity. Salts lowers the osmotic potential (i.e. makes it more negative) or increases osmotic pressure leading to yield losses as plants cannot extract water from soils when soil solution has lower osmotic potential than the plant cell. The impact on grain productivity of rising electrical conductivity (EC) and ESP values at different depths is shown in Figure 2, which demonstrates that identifying the complete picture is essential to applying the management option.

18 Agriculture Victoria (2009) Chapter 4: Salinity and Sodicity. Subsoils Manual. http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_mgmt_subsoil_pdf/$FILE/BCG_subsoils_09_ch04.pdf

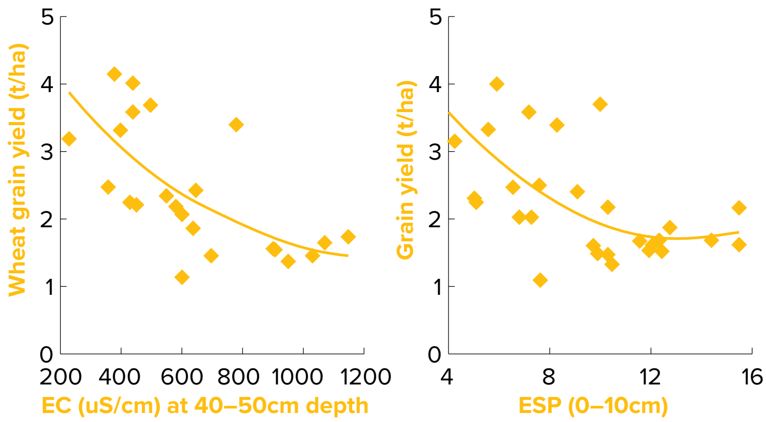


Figure 2: *Impacts of salinity and sodicity on productivity. High sodium levels in subsoil limits yields and water use in marginal cropping areas. (Grains Research & Development Corporation project no. DNR 6, final report)*

Source: Dalal R.C, Blasi M, So H.B (2002)

Sodic soils are prone to poor soil structure, particularly if the natural equilibrium between salinity and sodicity are out of balance. High salinity helps to counteract the effects of sodicity, but as described above, can cause yield issues. Both acidic–sodic and alkaline–sodic soils occur within the Northern grains zone, often within the one soil profile. Sodic soils often disperse more after mechanical disturbance (e.g. tillage) and erosion. Gypsum application to these soils improves the soil structure facilitating leaching of salts, even under dry land conditions. Correcting cation imbalances requires providing a source of the 'good' cations, $Ca2+$ and/or $Mg2+$, which might come from gypsum, lime or dolomite applications. The choice will depend on considerations such as cost, the existing cation balance in the soil and the speed at which a change is required. The application of gypsum will generally give a quicker result as it has a relatively high solubility, whereas agricultural lime has a very low solubility and therefore takes longer to observe results. It is also dependant on the pH of the soil.

The use of decision process models such as Gypsy© can be used as a guide when deciding on the cost of gypsum applications. [19]

Plant available water capacity

A key determinant of potential yield in dryland agriculture is the amount of water available to the crop, either from rainfall or stored soil water. In the Northern region, the contribution of stored soil water to crop productivity for both winter and summer cropping has long been recognized. The amount of stored soil water influences decisions to crop or wait (for the next opportunity or long fallow), to sow earlier or later (and associated variety choice) and the input level of resources such as nitrogen fertiliser.

The amount of stored soil water available to a crop - Plant Available Water (PAW)– is affected by pre-season and in-season rainfall, infiltration, evaporation and transpiration. It also strongly depends on a soil's Plant Available Water Capacity (PAWC), which is the total amount of water a soil can store and release to different crops. The PAWC, or 'bucket size', depends on the soil's physical and chemical characteristics as well as the crop being grown.

Information regarding the PAW at a point in time, particularly at planting, can be useful in a range of crop management decisions. Estimating PAW, whether through use of a

19 M Crawford (2015) GRDC Update Papers: Profit suckers–understanding salinity, sodicity and deep drainage. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/03/Profit-suckers-understanding-salinity-sodicity-and-deep-drainage

soil water monitoring device or a push probe, requires knowledge of the PAWC and/or the Crop Lower Limit (CLL).

A wide variety of soils in the Northern region have been characterised for PAWC and the characterisations are publicly available in the APSoil database, which can be viewed in Google Earth and in the 'SoilMapp' application for iPad.

The field-based method for characterising PAWC has been tried and tested across Australia, but users need to be mindful of common pitfalls that can cause characterisation errors. Knowledge of physical and chemical soil properties like texture or particle size distribution and (sub) soil constraints helps interpret the size and shape of the PAWC profiles of different soils. It can also assist in choosing a similar soil from the APSoil database.

Extrapolating from the point-based dataset to predict PAWC at other locations of interest is a challenge that needs further research. Preliminary analyses drawing on soil landscape mapping (NSW) and land resource area (LRA) mapping (Queensland) suggest that an understanding of position in the landscape and the story of its development may assist with extrapolation. This is because in many landscapes the soil properties determining PAWC are tightly linked to a soil's development and position in the landscape and these same aspects underpin soil and land resource surveys.

While the concept of using soil-landscape information to inform land management is not new, the availability of these maps on-line makes them more accessible and assists with visualising a location's position in the landscape. Combining these maps with the geo-referenced APSoil PAWC characterisations will increase the value that both resources can provide to farmers and advisors

Uncertainty of PAWC estimates translates into uncertainty in PAW. The extent to which this affects potential decision making depends on the question asked, but also needs to be viewed in terms of the spatial variability in PAW and the accuracy of the method to convert this water into a yield forecast.

Factors that influence PAWC

An important determinant of the PAWC is the soil's texture. The particle size distribution of sand, silt and clay determines how much water and how tightly it is held. Clay particles are small (< 2 microns in size), but collectively have a larger surface area than sand particles occupying the same volume. This is important because water is held on the surface of soil particles which results in clay soils having the ability to hold more water than a sand. Because the spaces between the soil particles tend to be smaller in clays than in sands, plant roots have more difficulty accessing the space and the more tightly held water. This affects the amount of water a soil can hold against drainage (DUL) as well as how much of the water can be extracted by the crop (CLL).

The effect of texture on PAWC can be seen by comparing some of the APSoil characterisations from the Northern region. The soil's structure and its chemistry and mineralogy affect PAWC as well. For example, subsoil sodicity may impede internal drainage and subsoil constraints such as salinity, sodicity, toxicity from aluminium or boron and extremely high density subsoil may limit root exploration, sometimes reducing the PAWC bucket significantly.

The CLL may differ for different crops due to differences in root density, root depth, crop demand and duration of crop growth. Some APSoil characterisations only determined the CLL for a single crop. The CLL for wheat (and triticale), barley and oats are often considered the same and that of canola can be found to be similar as well, but care needs to be taken with such extrapolations as different tolerances for subsoil constraints can cause variation between crops. [20]

MORE INFORMATION

Methods and tools to characterise soils for plant available water capacity (Coonabarabran)

20 K Verburg, B Cocks, T Webster, J Whish (2016) GRDC Update Papers: Methods and tools to characterise soils for plant available water capacity (Coonabarabran). https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Methods-and-tools-to-characterise-soils-for-plant-available-water-capacity-Coonabarabran

Testing for sodicity

The first step in determining whether a soil needs treatment for sodicity is to determine how sodic it is using a dispersion test. If this test gives a dispersion score of 6 to 16, then the soil may be gypsum responsive. In this situation do a soil test to calculate the ESP.

Ensure to sample both surface and subsurface soil layers. There is increasing evidence of the value of assessing soil-based physicochemical constraints to production, including sodicity, salinity and acidity/aluminium, from both the surface and subsoil layers. Soil sampling to greater depth (0 to 60 cm) is considered important for testing sodicity.

Applying gypsum

Gypsum contains calcium sulfate. Calcium sulfate is a salt, but unlike sodium chloride (the main component of salt in saline water tables) it is not toxic to plants. Gypsum will help to reduce swelling and dispersion of the soil through two mechanisms. These are:

1. Gypsum slightly increases the salinity of the soil solution, and hence reduces swelling. The same effect can be seen when using saline bore water, but this often contains high levels of sodium and chlorine that are toxic to plants. Gypsum will slightly increase salinity without any detrimental effect on plants.
2. Calcium from the gypsum will swap with the sodium that is held on the clay surfaces, which is then leached down the profile away from the plant roots. This reduces the sodicity of the soil and is called cation exchange.

Gypsum can provide better soil tilth, and can reduce crusting in sodic surface soils, hence improving establishment. If using gypsum where the surface soil is sodic, time the application so that rain or irrigation does not leach the gypsum from the surface soil by sowing time.

In soils with moderate surface sodicity, applying gypsum at 2.5–5.0 t/ha has been found to significantly improve wheat grain yield in Queensland (Photo 5). [21]

Photo 5: *Gypsum application (right) can help treat surface sodicity and improve grain yield under Queensland conditions.*

Source: Soilquality.org

Cultivation practices on sodic soils should be aimed at preserving soil organic matter in the surface soil. This is usually achieved by less aggressive, reduced tillage. Non-inversion tillage is useful for leaving the more sodic subsoil at depth. In many soils of the Murray and Murrumbidgee Valleys (especially red brown earths), the topsoil is non-sodic and of reasonable depth (10 to 40 cm). However, these soils will often have sodic subsoils. Gypsum applications to these soils will have little effect on the topsoil but will increase the structure, aeration and permeability of the subsoils. This is likely to increase water storage and reduce waterlogging.

21 Soilquality.org (2017) Seedbed soil structure decline, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/seedbed-soil-structure-decline-queensland

The depth of the non-sodic topsoil is an important consideration in the likely response of a sodic subsoil to gypsum improvement. Since a non-sodic topsoil is a better environment for plant growth anyway than a sodic topsoil, responses to gypsum will be low or unlikely when there is good depth of topsoil—the existing soil structure will allow optimum plant growth.

As a rough guide, if the non-sodic topsoil is greater than 15 to 20 cm deep, then a gypsum response may be unlikely. Remember, it may take a few months before gypsum leaches into the subsoil and begins to take effect.

Deep ripping

This can be used to break up compacted and poorly structured soils and to help generate structure and porosity. However, the benefits can be very short-lived. Sometimes deep ripping makes the soil worse because worked (tilled) soil disperses more readily. Ripping can bring up large clods of dispersive soil and bring toxic elements such as boron and salt to the surface. Consequently, only undertake deep ripping after careful consideration. If in doubt, first carry out deep ripping on a small test strip. After ripping apply gypsum or lime (in acid soils), preferably with additional organic matter, to help stabilise the deep ripped soil. A tramline (controlled traffic) farming system will help prevent re-compaction of the loosened soil. [22]

Lime application to sodic soils

Lime (calcium carbonate), like gypsum, is a compound containing calcium. Therefore, it can contribute to reducing the effects of sodicity. However, lime is relatively insoluble at a soil pH ($CaCl_2$) above 5. In most soils of the Murray and Murrumbidgee Valleys the pH ($CaCl_2$) is above 5, so lime is of little benefit. If the pH is below 5, lime will help to reduce both acidity and sodicity problems. A mixture of lime and gypsum may be a good option on sodic soils with a pH ($CaCl_2$) in the 5 to 6.5 range, to provide a more long-lasting effect than gypsum only. Again, soil tests and test strips are strongly recommended.

MORE INFORMATION

Sodic soil management

Sodic soils a management labyrinth

Cultivating sodic soils

dispersive and sodic soils are more prone to structural degradation than non-sodic soils. For this reason, they must be cultivated minimally and carefully. Excessive cultivation of these soils will cause major soil structure problems. In this may be evident as crusting, hardsetting and poor water penetration. [23]

Soil compaction

Soil compaction has been found to limit triticale and other cereal crops growth. Severe compaction reduces leaf numbers, leaf area and dry matter of shoots and roots, and increases shoot-to-root dry-matter ratio. In addition, high levels of soil compaction decrease 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. [24]

Subsoil compaction can reduce rooting depth of plants by slowing the rate of root penetration (Photo 6). This means roots are unable to access subsoil moisture and leachable nutrients such as nitrogen (N). This can result in poor nitrogen-use efficiencies. [25]

22 T Overheu (2017) Management of dispersive (sodic) soils experiencing waterlogging. DAFWA. https://www.agric.wa.gov.au/water-erosion/management-dispersive-sodic-soils-experiencing-waterlogging

23 NSW DPI (2009) Chapter D5. Sodic soil management. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0009/127278/Sodic-soil-management.pdf

24 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.

25 Soilquality.org (2016) Optimising soil nutrition, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/optimising-soil-nutrition-queensland

Photo 6: *A distinct compacted layer in a sandy loam. Note fractures in hard pan through which roots prefer to grow.*

Source: Soilquality.org

IN FOCUS

The impact of soil moisture and soil compaction on the growth of triticale roots

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. Plants grown in compacted soil and in soil 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 7). 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. [26]

26 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.

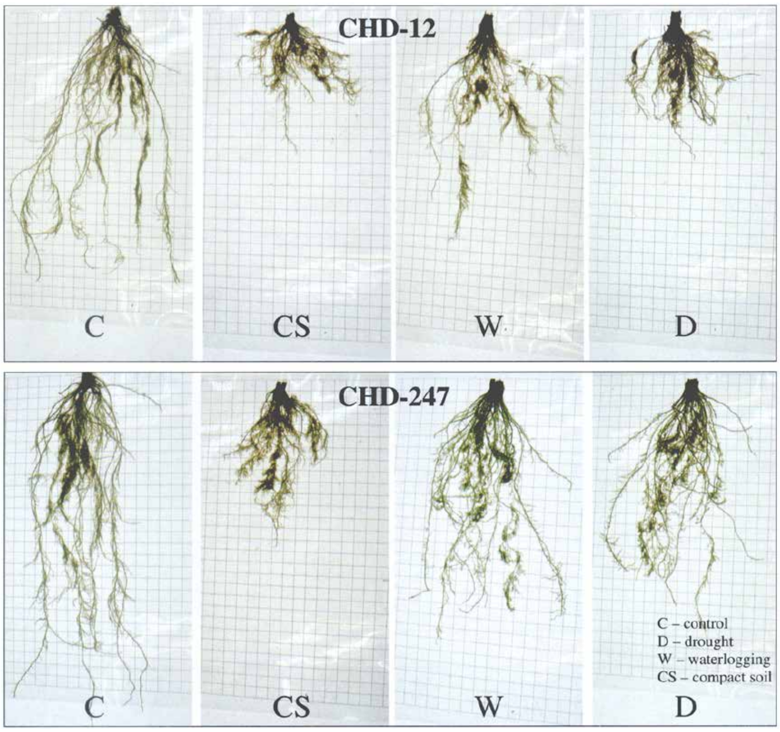


Photo 7: *Effects of compacted soil (CS), waterlogging (W) and soil drought (D) on root growth of drought-resistant (CHD-247) and drought-sensitive (CHD-12) triticale seedlings that are three weeks old.*

Deep ripping to reduce soil compaction

Key points:

- Deep ripping of compacted soils is most likely to improve grain yields on sandy soils and where compaction has occurred on upper parts of the soil profile through machinery traffic or livestock trampling.
- Deep ripping is less effective on heavy clay soils unless combined with gypsum on sodic soils prone to waterlogging.
- Deep ripping will provide little benefit if other subsoil constraints such as salinity, sodicity or acidity are also present.
- Advances in machinery, such as 'slotting' and deep placement equipment to simultaneously introduce ameliorants at depth with ripping, could increase the financial and agronomic effectiveness of this approach to managing subsoil constraints.

Soil compaction can occur in many cropping soils and may be traffic or livestock induced or naturally occurring. By limiting the ability of crops to gain access to water and nutrients, soil compaction can reduce crop growth, grain yields and quality. Deep ripping involves disturbing the soil with strong, narrow tynes, below the normal cultivation layer, often up to 40 cm, without inverting the soil. By breaking up the soil, deep ripping can free the way for roots to penetrate the soil and access water and nutrients, leading to yield increases. However, it is only effective on certain soil types and is only likely to be financially viable when combined with strategies to ameliorate other subsoil constraints such as nutrient deficiency or toxicity, or sodicity. [27]

MORE INFORMATION

Deep ripping - Factsheet

Digging deep and controlling compaction

27 GRDC (2009) Deep ripping–Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2009/06/grdc-fs-deepripping

Solodic soils

Solodic soils are leached, formerly saline soils that usually occur in semi-arid tropical environments, in which the A horizon of the soil has become slightly acid, and the B horizon is enriched with sodium-saturated clay.

In one test conducted in the Windera area of the South Burnett because of poor crop growth, two soils (a prairie and a solodic) were screened in a nutrient experiment. Triticale (var. Currency) and barley (var. Grimmet) were grown in pots as test crops. The results showed that barley and triticale suffered severe nitrogen, sulfur and copper deficiencies when grown in the solodic soil. In the prairie soil, both crops were severely nitrogen-deficient, and the barley lacked copper. Soil tests identified sulfur levels as low, and copper and boron levels as low or very low. The plants did not appear to respond to added boron. The tolerance of a range of winter cereals to these nutrient deficiencies was ranked by the effect on grain yield when grown in unfertilised soil: in descending order triticale (var. Currency), oats (var. Minhafer), barley (var. Grimmet), and wheat (var. Hartog). [28]

Subsoil constraints

Key points:

- Subsoil constraints are chemical, physical or biological properties of the subsoil that limit plant growth.
- Poor crop growth despite good starting moisture and adequate rainfall may indicate subsoil constraints.
- Good agronomic management helps minimise the water and other physiological stresses imposed by subsoil constraints.

Subsoil constraints are any soil physical or chemical characteristics located below the seedbed limiting the ability of crops or pastures to access water and nutrients. Subsoil constraints include salinity, sodicity, high soil strength and toxic concentrations of aluminium (Al) and boron (B) although a range of other factors, such as bicarbonate toxicity, nutrient deficiencies and water-logging have also been identified.

Managing subsoil constraints

Good agronomic management helps minimise the water and other physiological stresses imposed by subsoil constraints (Table 5). [29] In paddocks where subsoil constraints exist, successful cropping can be achieved by:

- Maximising fallow efficiency with short fallows.
- Controlling weeds effectively.
- Using suitable rotations that minimise disease.
- Matching nutrients to realistic yield expectations.
- Using appropriate species and cultivars.
- Sowing crops at the best time.
- having a thorough understanding of the extent of the problem—what levels? in the whole paddock or in zones that can be targeted?

28 JC Dwyer (1989) Glasshouse assessment of plant nutrient status of prairie and solodic soils from the South Burnett region. Project report. Department of Primary Industries, Queensland.

29 Soilquality.org (2017) Subsoil constraints, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/subsoil-constraints-queensland

Table 5: *Some management options for soils with high chloride and sodium concentrations.*

Low constraints <600 mg Cl/kg, <500 mg Na/kg in top 1 m of soil	Medium constraints 600–1,200 mg Cl/kg, 500–1,000 mg Na/kg in top 1 m of soil	High constraints >1,200 mg Cl/kg, >1,000 mg Na/kg in top 1 m of soil
Manage crown rot and nematodes	Consider tolerant cultivars	Match inputs to realistic yield
Try opportunity cropping to use available water	Manage crown rot and nematodes	
	Avoid legumes and durum wheat	
	Try opportunity cropping to use available water	

Source: Soilquality.org

Soil testing

Key points:

- Soil testing is a guide that gives growers a snapshot of the nutrition of a soil type in paddock at a point in time.
- The approach taken will be defined by the purpose of the investigation, variability in the area sampled, and the analysis and accuracy required.
- Sampling depth will depend on if a grower is conducting a shallow or deep test. Shallow tests are usually conducted from 0–10 or 15 cm, whilst deep tests are to a depth of 60–90 cm, depending on testing equipment available
- 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 soil sample be clear about the purpose of sampling. Different sampling approaches may be required depending on what a grower is sampling for, the soil type, the management unit (e.g. paddock), soil spatial variability (e.g. changes in soil type), the accuracy of result required, and the value given to the information provided (Photo)8[30] So before starting, define very clearly the questions that are being asked when planning to sample soil. Consult a professional soil scientist, agronomist or analytical laboratory to be sure that 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 analysis won't be compromised

30 Soilquality.org (2017) Soil sampling for soil quality, South Australia. Soilquality.org, http://www.soilquality.org.au/factsheets/soil-sampling-for-soil-quality-south-australia

Photo 8: *To be meaningful, soil sampling needs to take into account spatial variation in the soil condition. Differences in soil type, nutrient status and other soil properties may be exhibited within a paddock.*

Source: Soilquality.org

Sampling strategy

Soil properties and fertility often vary considerably, even over short distances, necessitating a sampling strategy which either integrates this variation through creating a composite sample (sampling across) or describes it through including replicate samples (sampling within). Describing the variation requires a defined sample within each different soil patch and having replicate samples analysed separately. This kind of approach might be required where there are consistent zones within a paddock 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 3A shows a random sampling that integrates the variation across the field, but samples are strategically located so that the location of samples reflects the representation of the different soil types. The sampling type in Figure 3B uses a transect method to integrate the variation across the field, and in Figure 3C equal numbers of samples are taken from each zone and the area samples kept separate to obtain different soil analyses for each zone.

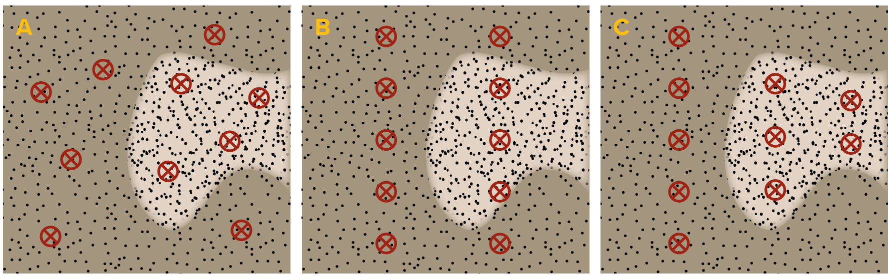


Figure 3: *Sampling strategies used to create a composite sample that integrates variation across different soil types (A and B); and a strategy to describe variation by sampling zones and analysing samples separately (C). A: haphazard samples strategically located to approximate the relative representation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

Source: Soilquality.org

Sampling equipment

Manual sampling is often used where sampling is only required to a depth of 10–15 cm and bulk density is not required. Small pogo type samplers enable quick sampling for qualitative determinations such as nutrient concentrations or the presence of disease. To avoid contamination of the sample, ensure that sampling equipment is cleaned.

For deeper samples, mechanical (hydraulic) samplers are usually required for most soil types. If using these for soil carbon sampling be careful not to contaminate samples with lubricating oil.

Sampling depth

Sampling for soil fertility or biological activity is typically done to a depth of 10–15 cm as this is where most of the organic matter and nutrient cycling occurs.

However, for mobile nutrients such as nitrate, sulfur or potassium, deeper sampling may be required.

When assessing soil carbon for accounting or budgeting purposes, a sampling depth of 30 cm is required to conform with standard accounting procedures. When sampling below 10 cm, soil samples are usually stratified by depth increments (e.g. 10 cm, 20 cm, 30 cm), although this depends 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, while plant root material is usually included, although it is generally sieved out prior to analysis.

Sample handling

Samples can be stored in polythene bags and should generally be dried or kept cool prior to analysis. Air drying (<40°C) is usually sufficient and storage below 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 then it can be reduced in size by careful quartering, ensuring that there is no discrimination against particular particle sizes. Samples are typically put through a 2 mm sieve prior to analysis. [31]

1.1.3 Paddock selection for forage cereals

Selecting a paddock for forage cereal production will depend on how it will be used on the farm. If it is to provide additional grazing, choose a well-drained paddock that can resist pugging or compaction damage from livestock. A paddock that has higher fertility and is well drained should be chosen to provide maximum dry-matter production. Chose a paddock that is not too large i.e. that can be stocked at adequate rates to ensure a uniform-like grazing down of the crop. Ensure the paddock has good water or a number of watering points if the paddock is of a reasonable size.

It is best to select a paddock that has a low level of pasture grasses or was not planted to a cereal in the previous year to avoid the risk of cereal-disease transmission. grasses can be hosts for such diseases as take-all, *Rhizoctonia* root rot, *Fusarium* blight, Crown rot 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, a summer forage crop (e.g. brassica, maize, sorghum, millet) will help to reduce grasses. [32]

31 Soilquality.org (2017) Soil sampling for soil quality, South Australia. Soilquality.org, http://www.soilquality.org.au/factsheets/soil-sampling-for-soil-quality-south-australia

32 Agriculture Victoria (2008) Establishing forage cereals. Note AG1269. Agriculture Victoria

1.1.4 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 species and 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.

Employ non-herbicide weed control options, such as harvest weed seed management, as part of a weed strategy.

For more information, see Section 6: Weed Control.

1.1.5 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. [33]

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 farming systems. 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. [34]

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 for an undersown pasture.

33 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

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

When added to a rotation, triticale may increase yields of other crops in the rotation, reduce costs, improve the 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. [35]

Triticale yields more than its wheat and rye ancestors in two types of marginal conditions: in soils where acidity and phosphorus deficiency and foliar diseases are dominant; and in the arid and semi-arid zones where drought affects crop production. [36]

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. [37] Triticale can have some disadvantages too (Table 6).

Table 6: *Advantages and disadvantages of triticale.*

Advantages	Disadvantages
Triticale is a hardy, relatively low input cereal crop with good disease resistance, particularly to some 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. [39]
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. [40]
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 in some varieties.	It can be difficult to find a market for triticale.
The extensive root system of triticale binds sandy soils, and the fibrous stubble reduces wind and water erosion. [38]	Triticale seed will carry-over into the following crop more than other cereals. It is more noticeable as a volunteer
	Triticale stubbles are slower to break down than other cereal stubbles. This can be problematic in tight rotations or in areas where burning stubbles is an issue. Soil nitrogen tie-up is often longer in triticale stubbles as well.

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

36 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/docrep/009/y5553e/y5553e00.htm

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

38 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, http://www.fao.org/docrep/009/y5553e/y5553e00.htm

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

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

VIDEOS

WATCH: The importance of crop rotation

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, yellow (tan) spot, nematodes.
- Nitrogen (N) depletion and declining soil fertility.

1.2.2 Long-fallow disorder

Soils naturally contain beneficial fungi that help the crop to access nutrients such as phosphorus (P) and zinc (Zn). The combination of the fungus and crop root is known as arbuscular mycorrhizae (AM). Many species of fungi have this association with the roots of crops. Many that are associated with crops also form structures called vesicles in the roots. The severe reduction or lack of AM shows up as long-fallow disorder: the failure of crops to thrive despite adequate moisture.

Ongoing drought in the 1990s and beyond has highlighted long-fallow disorder, where AM died out because there were too few or no host-plant roots because of long fallow periods. As cropping programs restart after dry years, an unexpected yield drop is likely because levels of AM have dropped, making it difficult for the crop to access nutrients and resulting in poor crop growth. [41] Plants seem to remain in their seedling stages for weeks and development is very slow.

The benefits of good AM levels are:

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

In general, the benefits of AM are greater at lower soil P levels, because AM increase a plant's ability to access this nutrient. Crops with higher dependency benefit more from AM (Table 7). [42]

41 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

42 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

Table 7: *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 and the careful selection of paddocks largely free of winter weeds, e.g. double-cropped from sorghum or cotton, or areas with a sequence of clean winter fallows.

When sowing dual-purpose varieties early, choose a paddock with low weed numbers and control weeds (Photo 9) [43] before the first grazing. Strategic grazing can be used to help manage weeds. [44]

Photo 9: *Spraying is part of managing fallow before sowing a dual-purpose triticale.*

Photo: Bill Gordon

Paddocks generally have multiple weed species present at the same time, making weed control decisions more difficult and often involving a compromise after assessment of the prevalence of key weed species. Knowing the paddock

43 B Gordon (2013) Review speed and boom height to improve spray deposition. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/GCS105/Review-speed-and-boom-height-to-improve-spray-deposition

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

and controlling weeds as early as possible are important for good control of fallow weeds. [45]

For advice on individual paddocks, contact a local agronomist.

The benefits of fallow weed control are significant, and include:

- Conservation of summer rain and fallow moisture, including moisture stored from last winter or the summer before in a long fallow, is integral to winter cropping, and particularly so as the climate moves towards summer-dominant rainfall.
- The highest return on investment in summer weed control (according to modelling studies) is for lighter soils or in situations where there is soil water that would support continued weed growth. [46]

The Northern Grower Alliance explored methods to control summer grasses. Key findings include:

- Glyphosate-resistant and tolerant weeds are a major threat to reduced-tillage cropping systems.
- Although residual herbicides will limit re-cropping options and do not provide complete control, they are a key part of successful fallow management.
- Double-knock herbicide strategies (i.e. the sequential application of two different weed controls) are useful but the herbicide choices and optimal timings vary with weed species so care must be taken if double-knock is to be successful.
- Other weed management tactics, e.g. crop competition, can be incorporated to assist herbicide control.
- Cultivation may need to be considered as a salvage option to avoid seedbank salvage. [47]

VIDEOS

WATCH: IWM: Double knock applications—extent of herbicide resistance in the north

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 10) [48].

Photo 10: *Broad-leafed weeds and grasses form a green bridge in a paddock.*

Source: DAFWA

45 S Peltzer (n.d.) Does long fallow have a place in Western Australia's cropping belt? Yes according to Daniel and Tim Critch of Mullewa. Agronomo, https://static1.squarespace.com/static/588df4351b10e309aeea0904/t/5a27787d24a6949cbc4b4320/1512536205147/12-Autumn-2015.pdf

46 GRDC (2012) Summer fallow: make summer weed control a priority. Factsheet. GRDC.

47 R Daniel (2014) Weeds and resistance considerations for awnless barnyard grass, chloris and fleabane. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Weeds-and-resistance-considerations-for-awnless-barnyard-grass-chloris-and-fleabane

48 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

VIDEOS

WATCH: GCTV5: Managing summer fallow

MORE INFORMATION

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

Key points for controlling 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 (e.g. stripe rust) and insects (e.g. Russian wheat aphid) can bred up and 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. [49]

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. [50]

1.3.3 Stubble retention

Key points:

- Triticale stubble is coarser than either wheat or barley stubble. [51]
- Retaining stubble has several advantages for soil fertility and productivity.
- Retaining stubble can decrease erosion, increase water infiltration rates and decrease evaporation rates
- The benefits of stubble retention are enhanced by reduced tillage and leguminous crop rotations.

Stubble retention has several advantages for soil fertility and productivity (Photo 11).

49 GRDC (2009) The essential crop management tool: green bridge control is integral to pest and disease management. Factsheet, GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2010/01/grdc-fs-greenbridge

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

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

Photo 11: *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 (Figure 4). [52] 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.

In order to protect the soil from erosion, crops need to be managed so that at least 30–40% groundcover is maintained throughout the year, but especially during the summer months when there is a greater chance of high-intensity rainfall. The amount of cover produced by crops will vary according to seasonal conditions and crop variety. However, as a general rule of thumb, a 1.5 t/ha grain yield should typically provide 90% stubble cover. The amount of cover may decrease over the fallow period, depending on whether the site is subsequently burnt, grazed or cultivated.

52 Soilquality.org (2017) Benefits of retaining stubble, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-in-qld

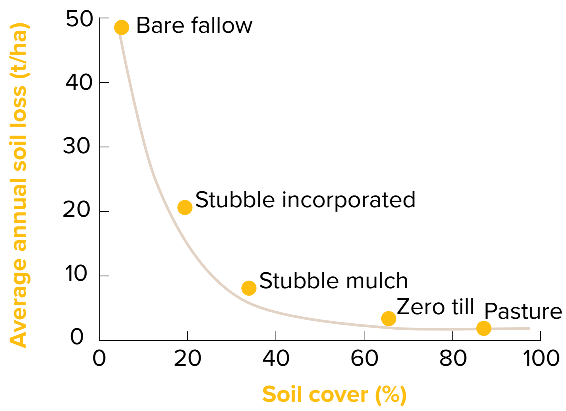


Figure 4: *Soil loss observed depending on the percentage of surface cover from sites on the eastern Darling Downs.*

Source: Soilquality.org

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 5). [53] The actual benefits realised depend on the timing and intensity of rainfall as well as the quantity and orientation of the stubble. Late summer–early autumn rains 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.

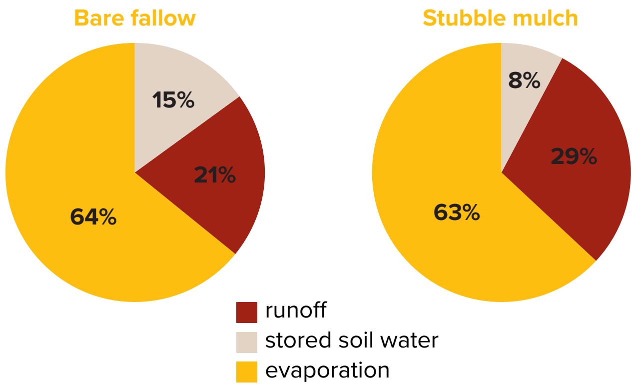


Figure 5: *When stubble is retained, more water is stored in the soil, mostly because there is less run-off.*

Source: Soilquality.org

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,

MORE INFORMATION

[Developments in stubble retention in cropping systems in southern Australia]

53 J Carson, K Flower, S Nuir, A Jenkins, S Alt (2013) Benefits of retaining stubble, NSW. Soilquality.org, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

VIDEOS

WATCH: GCTV4: Managing stubble

WATCH: GCTV15: Stubble height—part 1 and part 2

WATCH: Southern farm groups cutting through stubble issues

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 stubble returns nutrients to the soil, the amounts depend on the quality and quantity of stubble, in particular nitrogen and sulfur. 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. [54]

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 8) [55]. 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. [56]

Table 8: *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

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, this will differ between different soil types. 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 9 where known. [57] Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, as the sulfonylureas

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

55 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

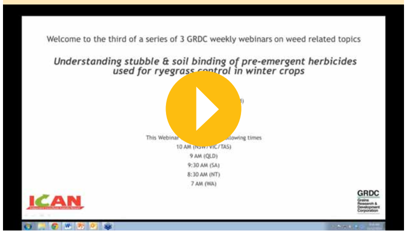
56 Soilquality.org. Benefits of retaining stubble, Queensland. Soilquality.org, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-in-qld

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

VIDEOS

WATCH: Over the Fence south: Jim Cronin

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



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. [58]

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. [59]

Table 9: *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.
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.

Source: NSW DPI

58 B Haskins (2012) Using pre-emergent herbicides in conservation farming systems. NSW DPI, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/431247/Using-pre-emergent-herbicides-inconservation-farming-systems.pdf

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

1.4.1 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 a 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. [60]

Plant-back periods for fallowing herbicides

Herbicide plant-back restrictions should be taken into account when spraying fallow weeds prior to sowing winter crops (Table 10). 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.

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. [61]

60 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

61 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/

Table 10: *Indicative plant-back intervals for a selection of relevant herbicides. Recommendations for wheat can generally be applied to triticale, however for sure to check product labels and instructions.*

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

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

Source: RMS

1.4.2 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 (APVMA) 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. [62]

There are already some results from the project. A field survey of herbicide residues in 40 cropping soils (13 in NSW and Qld, 15 in SA, 12 in WA) prior to sowing and pre-emergent herbicide application was conducted in 2015 (Table 11). 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.

62 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 11: *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

Conclusions

From this survey, the researchers have concluded that:

- Glyphosate, trifluralin and diflufenican are routinely applied in grain-cropping systems and their residues, plus the glyphosate metabolite AMPA, are frequently detected at significant levels at the commencement of the winter cropping season.
- The risk to soil biological processes is generally 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 so that growers can avoid damaging soil function and crop production. [63]

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

MORE INFORMATION

Herbicide residues in soils: are they an issue?

Weed control in winter crops

63 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 (2016). Herbicide residues in soils: are they an issue? GRDC Update Paper. GRDC, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/herbicide-residues-in-soils-are-they-an-issue-northern

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 onto moisture. [64] A good seedbed should be weed, disease and insect free. To minimize weeds, ensure a knockdown spray prior to sowing is implemented. Planting early will help with the quick establishment of a triticale stand, and may stave off early weed pressure. [65]

When shallow sowing, the previous crop's residue will have a greater tendency to interfere with good seed-to-soil contact. Make sure good seed-to-soil contact occurs.

Ploughing buries plant residues so that they do not obstruct sowing. However, ploughing disrupts the soil structure and increases oxidation of the organic material. Without ploughing, the organic material and the soil structure are retained, but the straw can cause problems with sowing and can also transmit diseases, which can also occur if the material is ploughed in. [66]

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

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

Following the initial irrigation, subsequent irrigations should be at a cumulative evaporation, less the rainfall interval of 75 mm on grey soils and 50 mm on red soils. [67]

1.5.1 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. [68]

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 12). [69] 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. Note that these results are from one season (2012), and so are inconclusive. As research continues, and captures the effects of variances in seasonal conditions, more conclusive results will emerge.

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64 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/docrep/009/y5553e/y5553e00.htm

65 UVM Extension Crops and Soils Team (2011) Triticale. University of Vermont, http://northerngraingrowers.org/wp-content/uploads/TRITICALE.pdf

66 Vaderstad (2015) Seedbed preparation. Vaderstad, http://www.vaderstad.com/knowhow/seed-beds/seedbed-creation

67 Agriculture Victoria (2015) Managing winter cereals. Agriculture Victoria

68 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/docrep/009/y5553e/y5553e00.htm

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

VIDEOS

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

WATCH: Over the Fence south: Andrew Simpson

MORE INFORMATION

GRDC, Strategic tillage in no-till systems

Organic carbon

Microbial biomass

Rhizoctonia

Photo 12: *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. [70]

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. [71] It is grown in areas with an annual average rainfall of about 300 mm to at least 900 mm. Very little triticale is irrigated. [72]

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.

Technologies to support decision-making

In this context, several technologies provide a level of information that is useful in supporting decisions about paddock and crop management without excessive investment.

Devices for soil monitoring

In-situ devices that have relatively small zones of measurement and rely on good contact between their sensor and the soil to measure soil water are at a disadvantage in shrink–swell soils where soil movement and cracking are typical. This is more important in dryland than in irrigated systems, as seasonal soil water levels vary from above the capacity of the paddock to wilting point or even lower. This means that high levels of error are likely, although this can be mitigated by using more devices to increase the number of measurements made so as to achieve confidence in results.

70 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.

71 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/docrep/009/y5553e/y5553e00.htm

72 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, http://www.fao.org/docrep/009/y5553e/y5553e00.htm

However, this comes at an increased capital cost. Some devices (e.g. capacitance, and time domain reflectometry) also have an upper measurement limit, beyond which they are inaccurate. This may be a problem on high-clay soils where moisture content at drained upper limit is likely to be >50% volumetric, the common limit for these devices.

By comparison, the use of a portable electromagnetic induction (EMI) device to measure bulk electrical conductivity and calculate soil water has a number of advantages. The EMI is quick to use, allowing for greater replication, it measures the soil moisture of a large volume of soil (to 150 cm depth), is not affected by cracking or soil movement, and does not require installation of an access tube, thus making it available for use on multiple paddocks. However, it is unsuitable for use in saline soils and does not apportion soil water to particular layers within the soil profile. [73]

Despite the extensive range of monitoring instruments now available, measuring paddock soil moisture is still a considerable challenge. Among the suite of instruments on offer, one that is increasingly being used by researchers and agronomists is the EM38, an EMItool. It is proving to be useful in precision agriculture and environmental monitoring, and is now commonly used to provide rapid and reliable information on soil salinity and soil management zones, both of which relate well to crop yield. It is also used to monitor soil water in the root-zone, providing an efficient means of monitoring crop water use and plant-available water (PAW) in the soil profile throughout the growing season. This helps managers make better-informed decisions about the application, timing and conservation of irrigation water and fertiliser. EM38 datasets have also proved valuable in testing and validating water-balance models that are used to extrapolate to other seasons, management scenarios and locations. Soil calibrations or qualitative assessments done with the EM38 can be used to reckon estimates of soil water in the root-zone. This information is vital in farm-management decisions based on accurate knowledge of soil PAW. [74]

MORE INFORMATION

Farming systems in the northern cropping region: an economic analysis

Modelling of soil water

Simulation of the water balance can be considered as an alternative to field-based soil-water monitoring. Considering the error inherent in field measurements and issues with the installation of sensing devices, there is a reasonable argument that the modelling of the water balance, when initialised with accurate plant-available water capacity (PAWC) and daily climate information, is likely to be as accurate as taking direct measurements. APSIM and Yield Prophet successfully predict soil water and they could be considered for both fallow and cropping situations. CliMate is a logical choice for managing water in fallow periods. [75]

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 a particular 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.

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

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

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

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 intensity 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. [76]

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. [77]

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 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 12). [78]

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

77 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

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

Table 12: *Lodging scores in NVT trials, 2008.*

Variety	Score
Bogong(PBR)	0/5
Jaywick(PBR)	3/5
Tahara	3/5
Tobruk(PBR)	0/5
Canobolas(PBR)	0/5
Berkshire(PBR)	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 and Fittler 2009

Inefficient irrigation can lead to water and nutrients draining through the root-zone, which is a waste of water and fertilisers, and leads to rising and contaminated water tables. Inefficient water use can also mean unnecessary pumping from rivers. [79]

IN FOCUS

Dry matter accumulation and changes in forage quality during primary growth and regrowth of irrigated winter cereals

Selected cultivars of oats (three), barley (two), wheat (three), cereal rye (one) and triticale (three) were grown under irrigation at Trangie, NSW, in 1978 and 1980. Dry-matter accumulation and changes in the moisture, nitrogen and phosphorus content and dry-matter digestibility of forage were monitored at intervals of about 21 days during uninterrupted primary growth (June–September 1980). In a split-plot design the crops were cut at 80 days, at 80 and 122 days, and at 80, 122 and 164 days after sowing. Regrowth was sampled two or three times to determine dry-matter yield and quality.

Most cultivars accumulated 16–20 t/ha of dry matter by the end of sampling in late September, although cereal rye yielded only 14 t/ha. Early maturing Minhaffer oats produced the highest yield when uncut, but regrew poorly after cutting. Under a 42-day cutting interval, oats and barley yielded 12–13 t/ha, winter wheat yielded 10–11 t/ha, and triticale yielded 10–12 t/ha. The nitrogen and phosphorus content of all forages decreased in a linear way during primary growth. Oats and wheat had were similarly digestible, and began to decrease rapidly 40–50 days before heads emerged in mid-August. The early maturing barley and triticale cultivars were less digestible than the oats. With regular cutting, the nitrogen content and digestibility of all cultivars was maintained above 2.7% and 72% respectively.

Dry-matter accumulation was described by mathematical equations which allowed cultivars under different cutting regimes to be compared. They also allowed dry matter and digestible dry matter yields from different systems of cutting to be predicted for irrigated cereals in western New South Wales. [80]

79 R Swinton, G Creighton (2009) Irrigation essentials for north coast farmers in NSW. NSW DPI, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/349705/Irrigation-essentials-for-North-Coast-farmers-in-NSW.pdf

80 DK Muldoon (1986) Dry matter accumulation and changes in forage quality during primary growth and three regrowths of irrigated winter cereals. Animal Production Science, 26 (1), 87–98.

MORE INFORMATION

Irrigation essentials for north coast farmers in NSW

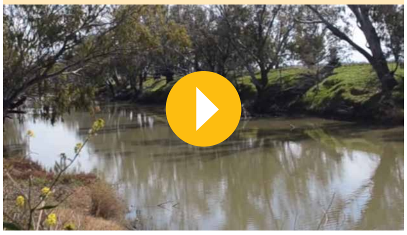
NSW DPI, Irrigation

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

GRDC Update Paper, Understanding soils, irrigation layouts and agronomy effects of non-rise crop yields

VIDEOS

WATCH: Over the Fence North: Irrigation investment pays in herbicide resistant weed fight



The future of irrigation

Climate change is likely to lead to reductions in rainfall in some areas. It is predicted that the affects will be amplified by much greater reductions in run-off: i.e., a 10% drop in rainfall will lead to a 20–40% reduction in run-off. The effect will be larger in drier catchments, making the water supply systems in these catchments more vulnerable. The experience of the Millennium Drought has shown that reductions in run-off under persistent climate change (~10 year drought) are larger than reductions that occur for short droughts with similar rainfall reductions in many catchments. [81]

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. [82]

In dry springs, triticale yields are 10–15% below wheat, due to triticale's longer grain-filling period. [83] However, under ideal conditions, researchers have found that triticale can out-yield wheat and barley, and sometimes oats. [84]

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. [85]

In trials in NSW, researchers compared yield performances for grain-only triticale (Table 13). [86] No recent data is available for north-western NSW as only a limited number of trials were conducted from 2008 to 2015.

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

82 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, http://www.fao.org/docrep/009/y5553e/y5553e00.htm

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

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

85 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.

86 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW DPI, https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

Table 13: *Grain-only yield performance experiments, 2008–2015, compared with Fusion(PBR) (which = 100%).*

Variety	North-east Fusion(PBR) = 4.14 t/ha	Number of trials	South-east Fusion(PBR) = 4.57 t/ha	Number of trials	South-west Fusion(PBR) = 6.09 t/ha	Number of trials
Astute(PBR)	104	6	105	10	–	–
Berkshire(PBR)▲	95	15	93	29	100	6
Bison(PBR)	101	6	101	10	–	–
Bogong(PBR)▲	99	15	96	29	104	6
Canobolas(PBR)(PBR)▲	97	13	95	26	106	5
Cho(PBR)(PBR)er(PBR)▲	89	15	87	29	87	6
Fusion(PBR)	100	11	100	22	100	5
Goanna	87	10	86	18	91	4
Hawkeye(PBR)	95	15	95	29	102	6
Jaywick(PBR)	92	15	93	29	103	6
KM10	87	4	89	7	–	–
Rufus▲	85	15	84	29	87	6
Tahara▲	84	15	83	29	86	6
Tobruk(PBR)▲	85	5	85	11	–	–
Tuckerbox	76	13	76	25	85	5
Yowie	86	11	86	22	96	5
Yukuri	74	15	75	29	95	6

▲Outclassed: Berkshire(PBR), Bogong(PBR), Canobolas(PBR)(PBR), Cho(PBR)(PBR)er(PBR), Rufus, Tahara and Tobruk(PBR) (all stripe rust) *Includes some irrigation trials
The table presents data of NVT 'production value' multi-environmental trials on regional mean basis from 2008–2015.

Source: NSW DPI

IN FOCUS

Yield and yield structure of triticales compared with wheat in northern New South Wales

The yields and yield structure of cultivars of triticales and bread wheats (with a range of phasic development patterns in both species) were compared in two field experiments at Narrabri in northern New South Wales. The experiments were performed on a grey cracking clay soil with irrigation to prevent severe moisture stress. Triticales, both early and midseason types, appeared to have reached equivalent yields to well-adapted wheat varieties. Averaged over the two experiments and all sowings, the triticales yielded 19% better than the bread wheats. Triticales were generally superior to wheat in all components of yield of the spike (1,000-grain weight, grain number, spikelet and spikelet number, spike), although the wheats produced more spikes per unit area. The triticales also had higher harvest indexes than the wheats. [87]

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

- Do a simple calculation to see how much water needed to achieve this yield.

87 G Sweeney, RS Jessop, H Harris (1992) Yield and yield structure of triticales compared with wheat in northern New South Wales. Animal Production Science, 32 (4), 447–453.

- Know how much existing soil water there is (treat this water like money in the bank).
- What the nutritional status of the paddock is
- 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. [88]

Estimating crop yields

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

- Crop insurance.
- Delivery estimates.
- Planning harvest and storage requirements.
- Cash-flow budgeting.

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

Estimation methods

There are many methods available for farmers and others to estimate the yield of various crops. Some are straightforward, whereas others are more complicated. The method below can be undertaken relatively quickly and easily. The steps are:

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 (or pods).
2. Do this five times to get an average of the crop.
3. Count the number of grains in at least 20 heads (or pods), and average.
4. Determine the grain weight for the crop concerned.

The accuracy of yield estimates depends on taking an adequate number of counts so as to get a representative average for the paddock. The yield estimate will only be a guide and assumptions made from the estimates contain a degree of uncertainty. This type of yield estimation is one of the easiest and quickest to complete and should be able to be used in a number of situations on a grain-growing property. As grain losses before and during harvest can be significant, factor in an allowance for 5–10% loss in final calculations. [89]

Yield Prophet

Scientists have aimed to support farmers' capacity to achieve yield potential by developing the Agricultural Production Systems Simulator (APSIM), a model of farming systems 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 them in their decision-making. It is an online crop-production model that gives users real-time information about their crops. This tool provides growers with integrated production-risk advice and monitoring decision-support relevant to farm management. By matching crop inputs with potential yield in a given season, by using scenario analysis of different management options, Yield Prophet subscribers may avoid over- or under-investing in their crop. Yield Prophet has enjoyed a measure of acceptance and adoption amongst innovative farmers and has made valuable impacts in terms of assisting farmers to manage climate variability at a paddock level.

88 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

89 Agriculture Victoria (2015) Estimating crop yields: a brief guide. Note AG1420. Agriculture Victoria, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/estimating-crop-yields-a-brief-guide

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

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 ~1,000 soils, chosen as representative of the production area.
- Historical and current climate data taken from the nearest Bureau of Meteorology (BOM) weather station.
- Paddock-specific rainfall data recorded by the user (optional).
- Individual crop details.
- Fertiliser and irrigation applications during the growing season.

MORE INFORMATION

Yield Prophet

Optimising performance of current northern cropping farming systems

1.7.1 Seasonal outlook

Queensland

The Science Delivery Division of the Department of Science, Information Technology and Innovation (DSITI) produces a monthly climate statement which interprets seasonal climate outlook information for Queensland. The monthly climate statement is based on DSITI's own information and also draws on information from national and international climate agencies.

DSITI's assessment of the probability of rain is based on the state of the ocean and atmosphere, and their similarity with previous years. In particular, it monitors the current and projected state of the El Niño–Southern Oscillation (ENSO), sea-surface temperature (SST) anomaly maps and the Southern Oscillation Index (SOI). Based on this information, it uses two systems to calculate rainfall probabilities for Queensland:

- DSITI's SOI phase system, which produces seasonal rainfall probabilities based on phases of the Southern Oscillation Index.
- The department's experimental SPOTA-1 (Seasonal Pacific Ocean Temperature Analysis, version 1), which monitors Pacific Ocean SSTs from March to October each year to provide long-lead outlooks for summer rains from November to March.

Outlooks based on both the SOI-Phase system and SPOTA-1 are free, although a password is required to access the experimental SPOTA-1 information. [90]

The Queensland Alliance for Agriculture and Food Innovation produces seasonal outlooks for wheat producers in Queensland. These short, free reports are written in an easy-to-read style. [91]

New South Wales

The NSW seasonal conditions report is issued each month and contains information on, among other things, rainfall, water storages, crops, and livestock. It is available to landholders to help them make informed decisions on how they manage operations, and prepare for seasonal conditions and drought. Seasonal conditions reports are

90 DSITI (2015) Seasonal climate outlook. Queensland Government, https://www.longpaddock.qld.gov.au/seasonalclimateoutlook/

91 Queensland Alliance for Agriculture and Food Innovation (2017) Crop outlook. University of Queensland, https://qaafi.uq.edu.au/industry/crop-outlook

MORE INFORMATION

Download CropMate for iPhones from the App Store on iTunes.

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

Climate Analogues

Climate Change in Australia, Cluster reports

Bureau of Meteorology, Climate outlooks: monthly and seasonal

Climate Kelpie

also used by the Regional Assistance Advisory Committee to make recommendations on potential support for farm businesses, families and communities. [92]

CropMate

CropMate is an online tool that was developed by NSW Department of Primary Industries. It can be used in pre-season planning to analyse average temperature, rainfall and evaporation. It provides seasonal forecasts and information about influences on climate, such as the impact of the SOI on rainfall. The CropMate decision tool provides estimates of soil water and N, frost and heat risk, as well as gross margin analyses of the various cropping options.

CliMate

Australian CliMate is a suite of climate analysis tools delivered on the web, or via iPhone, iPad and iPod Touch devices. CliMate allows growers to interrogate climate records to ask questions about 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.

One of the CliMate tools, How's the Season?, uses weather records from 1949 to the present to assess the progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and with all years. It explores the readily available weather data, compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons. (The other tools available are How Often?, How Hot/Cold?, How Wet/N?, How Likely?, How's El Niño?, and How's the Past?)

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

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

For inputs, How's the Season? 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. [93]

Climate Analogues

The tool Climate Analogues is used to help understand what the climate in a region might be like in the future. It is one of several tools developed by Climate Change in Australia, in which CSIRO and the Bureau of Meteorology have joined forces to make climate-change projections based on natural resource management regions. Climate Analogues uses annual average rainfall and maximum temperature to match the proposed future climate of a location of interest with the current climate in another location. For example, based on plausible assumptions about changes in temperature and rainfall, the future climate of Melbourne might be like the current climate of a location identified by this tool. Results should capture sites of broadly similar annual maximum temperature and water balance. [94]

92 NSW DPI (n.d.) Seasonal conditions reports. NSW DPI, https://www.dpi.nsw.gov.au/climate-and-emergencies/droughthub/information-and-resources/seasonal-conditions

93 Australian CliMate, https://climateapp.net.au/

94 Climate Change in Australia (2016) Climate Analogues. CSIRO and BOM, http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/

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. Growers have some control over the stored soil water, by measuringhow much water is available before planting the crop. Even though long-range forecasts and tools such as the SOI cannot guarantee that rain will fall when it's needed, they are useful for indicating the likelihood of the season being wet or dry. [95]

HowWet N?

Another CliMate tool, HowWet/N? is a program that uses records from a nearby weather station to estimate how much PAW has accumulated in the soil and the amount of organic N that has been converted to an available nitrate during a fallow. HowWet/N? tracks daily soil moisture, evaporation, run-off and drainage. Accumulation of available N in the soil is calculated based on surface soil moisture, temperature and soil organic carbon.

HowWet/N?:

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

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

The questions this tool answers are:

- How long should a fallow period be for particular areas and sequences? (If the soil is almost full, maybe the fallow can be shortened.)
- Given the soil type 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 the weather station.
- An estimate of soil cover and starting soil moisture.
- Rainfall data input by the user for the stand-alone version of How Often?

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

Soil descriptions are based on generic soil types with standard organic carbon (C) and C:N ratios, and as such should be regarded as indicative only. They are best used as a measure of relative water accumulation and nitrate mineralisation. [96]

95 J Whish (2013) Impact of stored water on risk and sowing decisions in western NSW. GRDC Update Paper. 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

96 Australian CliMate. How Wet/N, https://climateapp.net.au/A04_HowWetN

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 uses water more efficiently than oats and rye do. [97] One study showed that triticale had similar Water Use Efficiency and resulting yield to wheat under varying soil moisture conditions. [98]

Researchers in 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. [99]

One study in a Mediterranean climate attributed high Water Use Efficiency and yield to triticale's stomatal conductance. [100]

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). [101]

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97 M Mergoum, HG Macpherson (2004). *Triticale improvement and production* (No. 179). Food & Agriculture Organisation.

98 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.

99 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

100 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.

101 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

VIDEOS

WATCH: GCTV12: Water Use Efficiency Initiative

WATCH: GCTV10: Grazing stubbles and Water Use Efficiency

MORE INFORMATION

Water Use Efficiency: optimizing farming systems performance and balancing fallow length and sowing decisions

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

Making the most of available water in wheat production

The French–Schultz approach

The French–Schultz model is widely used to provide growers with a benchmark of potential crop yield based on available soil moisture and likely rainfall during growth.

In this model, potential crop yield is estimated as:

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

where crop water supply is an estimate of water available to the crop, i.e. soil water at planting plus in-crop rainfall, minus soil water remaining at harvest.

The French–Schultz model has been useful in giving growers performance benchmarks. Where yields fall well below these benchmarks, it may indicate something wrong with the agronomy of the crop or a major limitation in the environment. For example, there could be hidden problems in the soil, e.g. root diseases, or soil constraints affecting yields. Another possibility is that apparent underperformance could be simply due to seasonal rainfall distribution patterns, which are beyond the grower's control. [102]

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

WUE = (yield x 1000) / available rainfall

where available rain = (25% Nov.–Mar. rain) + (GSR)–60 mm evaporation.

Agronomist's view

Challenging the French-Schultz model

The application of the French–Schultz model for the Northern Region has been challenged in recent times.

In the wheatbelt of eastern Australia, rainfall shifts from winter-dominated in the south (South Australia and 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 times varying between October in the south and August in the north.

In eastern Australia, crops are therefore exposed to contrasting climatic conditions during the critical period for grain formation; i.e. a window of ~20 days before and 10 days after flowering, which 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 implications for management and breeding of the shift from winter to summer rainfall between southern and northern regions. 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 levels of the single crop and the whole farm systems; i.e. $/ha/mm. [103]

102 GRDC (2009) Water Use Efficiency: Converting rainfall to grain. Factsheet. GRDC, https://grdc.com.au/__data/assets/pdf_file/0029/225686/water-use-efficiency-north.pdf.pdf

103 D Rodriguez, V Sadras (2008) Farming systems design and Water Use Efficiency (WUE): Challenging the French & Schultz WUE model. GRDC Update Paper, 13 June 2008. GRDC, 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

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.
- There are a number of causes of inefficiency. Identification of the most likely groups is useful in directing targeted measurement and helping identify possible strategies for improvement.
- Good record keeping is essential.
- Recent has shown that triticale has a higher biomass and straw yields, lower harvest index and higher total N uptake than wheat. Consequently, triticale had higher N uptake efficiency and higher N use efficiency. [104]

Nitrogen-use efficiency (NUE) is how well 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 less than 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 found to be over 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. [105]

In recent research, 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. [106]

MORE INFORMATION

The fundamentals of increasing nitrogen use efficiency

Optimising nitrogen-use efficiency

Nitrogen fertilisers are a significant expense for broadacre farmers, so optimising the use of fertiliser inputs is important in reducing this cost. There are four main sources of nitrogen available to crops: stable organic nitrogen, rotational nitrogen, ammonium, and nitrate. To optimise plants' ability to use soil nitrogen, growers should first be aware of how much of each source there is. The best method of measuring these nitrogen sources is soil testing. [107]

1.7.5 Double-crop options

Double cropping is growing a winter and summer crop following one another. This is often part of opportunity cropping which involves making the best use of rainfall by planting crops according to soil-moisture reserves. In some instances this will involve

104 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, 155) 261–281.

105 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

106 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, 155, 1–21.

107 R. Quinlan (2017) Optimising soil nutrition. Soilquality.org, http://www.soilquality.org.au/factsheets/optimising-soil-nutrition

double-cropping, at other times long fallows might be used to build up soil moisture for a more reliable crop.

Cool-season annual forages such as triticale are well-suited to double cropped forage. [108] 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 that are suited to the southern parts of the northern region.

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. [109]

For the more northern parts of the northern region, double cropping options would include following a sorghum crop with chickpeas as a autumn plant or the growing of mungbeans following a winter cereal crop.

MORE INFORMATION

High profit farming in northern Australia

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.

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. [110]
- Growing more tolerant crops or varieties

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.
- Assessing volunteer plants for any visual signs of disease
- Assessing stubble for any visual signs of disease (e.g. yellow leaf spot ot taan spot)
- Testing seed for disease
- controlling volunteers and any green bridge

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.

108 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

109 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

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

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 13). 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*).

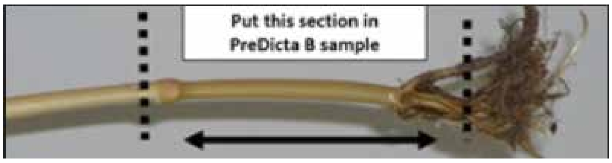

Photo 13: *PreDicta B sample.*

Source: GRDC

MORE INFORMATION

PreDicta B

SARDI, Crop diagnostics

How to access the service

Growers can access PreDicta B diagnostic testing services through a SARDI-accredited agronomist. They will interpret the results and give advice on management options to reduce the 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 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 (Table 14). [111] Transmission from neighbouring paddocks and volunteers are key concerns with some diseases and insects e.g. aphids and Russian wheat aphid. 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, RLN and 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.

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

Table 14: *Significant pathogens shared by different crops.*

Pathogen/Nematode	Common name	Sorghum	Maize	Sunflower	Summer pulses	Cotton	Winter cereals	Winter pulses
Pratylenchus thornei	root-lesion nematode	-	-	-	✓✓ m,s	-	✓✓	✓✓ c,f
Pratylenchus neglectus	root-lesion nematode	✓✓				nt	✓✓	✓✓ c
Fusarium graminearum	head blight	✓	✓✓	-	-	-	✓✓	-
Macrophomina phaseolina	charcoal rot	✓✓	✓✓	✓✓	✓✓ m,s,g	✓	-	✓
Sclerotinia sclerotiorum, S. minor	sclerotinia rot	-	-	✓✓	✓✓ s,m,g	-	-	✓✓ c,f,p
Sclerotium rolfsii	basal rot	✓	✓	✓	✓✓ s,g	✓	-	-
Fusarium verticillioides	fusarium stalk and cob rot	✓	✓✓	-	-	-	-	-
Fusarium semitectum	fusarium head blight and stalk rot	✓✓	✓	-	-	-	-	-

Two ticks = major disease, one tick = recorded but generally a minor disease. c = chickpeas, f = faba beans, g = peanuts, m = mungbeans, p = field peas, s = soybeans, nt = not tested.

Source: GRDC

MORE INFORMATION

GRDC, Cereal Diseases: The Ute Guide

Paddock histories likely to result in high risk of disease e.g. crown rot, include:

- Durum wheat in the past 1–3 years.
- Winter cereal or a high grass burden from last season—crown-rot fungus survives in winter-cereal residues, dense stubble cover or where dry conditions have made residue decomposition slow.
- Break crops, which can influence crown rot in cereals by manipulating the amount of nitrogen (N) and moisture left in the soil profile.
- Paddocks that have high levels of N at sowing and/or low stored soil moisture at depth. [112]
- Wheat varieties grown in previous year (Photo 14). [113]

For more information, see Section 9: Diseases.

112 GRDC (2009) Crown rot in cereals: understanding the disease underpins effective management. Factsheet. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2009/05/crown-rot-in-cereals-fact-sheet-southern-western-regions

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

Photo 14: *Diseased patches 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 cereal -growing regions of Australia. They can reduce grain yield by up to 50% in many current wheat varieties (Photo 15). *Pratylenchus neglectus* and *P. thornei* are the main RLNs causing yield loss in the northern agricultural region of Australia, and they often occur together. [114]

P. thornei is the most damaging species and occurs commonly in the Northern Region. *P. neglectus* occurs less frequently than *P. thornei* but is still quite common. *P. neglectus* is common in southern NSW.

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. [115]

114 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

115 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.

Photo 15: *Paddock showing patches caused by root-lesion nematode.*

Source: DAFWA

1.9.1 Testing soil for nematodes

PreDicta B

Among the soil-borne pathogens that PreDicta B can test for are these 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.

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. 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.

Soil-dwelling insect pests can seriously reduce plant establishment and populations, and subsequent yield potential (Photo 16). [116]

MORE INFORMATION

GRDC Tips and Tactics, Root-lesion nematodes, Northern Region

116 cesar (2015) Impact of armyworm caterpillars ramps up. PestFacts. Issue 8. cesar, http://www.cesaraustralia.com/sustainable-agriculture/pestfacts-south-eastern/past-issues/2015/pestfacts-issue-no-8-27th-august-2015/impact-of-armyworm-caterpillars-ramps-up/

Photo 16: *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: [117]

- cockroaches
- crickets
- earwigs
- black scarab beetles
- cutworms
- false wireworms
- true wireworms.
- slatters
- slugs
- snails

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. [118]

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. For example, in the Northern Region, the most notable examples are:

- Detection of Russian Wheat Aphid in cereal crops in southern NSW.
- The Etiella moth, which has occurred in concentrations of up to 60/m^2 in vegetative and podding soybeans and mungbeans.
- Severe scarab damage in sorghum and winter cereals.
- The bean pod borer west of the Great Dividing Range.
- The appearance of soybean stem fly in regions adjoining the Darling Downs, well south of its 'normal' range.
- Plague numbers of a mysterious plant hopper in in mungbeans, sorghum and millet in the summer of 2014–15.

117 DAF Qld. Soil insects in Queensland. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/a-z-insect-pest-list/soil-insects

118 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

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, 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. [119]

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.

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. [120]

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. [121]

GRDC's Insect ID ute guide is a comprehensive reference on the insect pests that commonly affect broadacre crops across Australia (Figure 6). 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. [122]

The app is available for Android phones and the iPhone.

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119 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

120 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

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

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

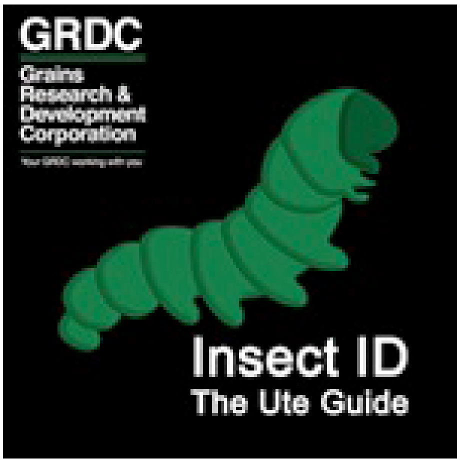

Figure 6: *Icon of GRDC's insect ID app.*

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. [123] 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. [124]

See Section 7: Insect control for more information.

MORE INFORMATION

Pest Genie

Australian Pesticides and Veterinary Medicines Authority

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. [125]

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:

123 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

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

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

- Weedy fallows and volunteer crops encourage soil insect build-up.
- Insect numbers decline during a clean, long fallow due to lack of food.
- Summer cereals followed by volunteer winter crops promote the build-up of earwigs and crickets.
- 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. [126]

For more information, see Section 7: Insect Control.

126 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