SOUTHERN
SEPTEMBER 2018

GRDC GROWNOTES™

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

CEREAL RYE

SECTION 1

PLANNING AND PADDOCK PREPARATION

Planning/Paddock preparation

Key messages:

- Relatively inexpensive and easy to establish, cereal rye (*Secale cereale*) outperforms all other cover crops on infertile, sandy or acidic soil or on poorly prepared land. It is widely adapted, but grows best in cool, temperate zones such as in southern Australia.
- Rye prefers light loams or sandy soils and it will germinate even in quite dry soil. It also will grow in heavy clays and poorly drained soils, and some cultivars tolerate waterlogging.
- The optimum pH($CaCl_2$) for rye growth is ~4.5–7.5. [1] It is also tolerant of high levels of aluminium (Al). [2]
- Rye can establish in very cool weather. It will germinate at temperatures as low as ~1°C. Vegetative growth requires temperatures of 3°C or higher. [3]
- Rye is used for early sowings as a dual-purpose cereal, providing abundant, quick, early stock feed and as a grain-only crop, and for erosion control. [4]
- Cereal rye is adapted to all soils; however, its major fit is on the lighter acid soils where yields are usually 70–100% of wheat and triticale yields when sown between May and June. [5]

1.1 Paddock selection

1.1.1 Topography

The topographic variations typical of large agricultural paddocks can have a substantial impact on dynamics of soil mineral nitrogen (N) as well as on performance of crops. Spatial variations in soil organic matter, soil microbial biomass, natural drainage, plant growth, and water and nutrient redistribution caused by topography are the main factors controlling the dynamics of soil mineral N. Along with weather, landscape topographic patterns account for most of the variations in plant-available N.

Potential environmental and economic benefits are gained from site-specific, topography-driven cover-crop management. Management decisions regarding where to plant crops can vary depending on the management goals and complexity of the terrain. For example, cover crops seem to be particularly advantageous on eroded infertile slopes, where legumes bring the needed N inputs and rye does not result in substantial N reductions; all cover crops contribute to erosion control and carbon sequestration in such terrain. On the other hand, if N leaching is the major concern, a rye cover crop can be particularly advantageous for scavenging nitrate-N in low depression areas. [6]

---

1 NSW Agriculture (2000) Understanding soil pH. Acid Soil Action Leaflet No. 2. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167187/soil-ph.pdf

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

3 SARE (2007) Cereal rye. Managing cover crops profitably. 3rd edn. Sustainable Agriculture Research and Education, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

4 P Matthews, JL McCaffery, L Jenkins (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

5 P Matthews, JL McCaffery, L Jenkins (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

6 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, e0143358, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0143358

IN FOCUS

Topography mediates the influence of cover crops on soil nitrate levels

Knowledge about cover crop effects on N comes mostly from small, flat research plots, and performance of cover crops across topographically diverse agricultural land is poorly understood. This research assessed effect of a Cereal rye cover crop on potentially mineralisable N (PMN) and nitrate-N levels across a topographically diverse landscape. The study looked at conventional, low-input, and organic management strategies. The managements were implemented in 20 large undulating fields in the US starting from 2006. Data collection and analysis were conducted during three growing seasons 2011–13. Observational microplots with and without cover crops were laid within each field on three contrasting topographical positions of depression, slope and summit. Soil samples were collected four or five times during each growing season and analysed for nitrate-N and PMN. Rye cover crop had a significant 15% negative effect on nitrate-N in topographical depressions but not in slope and summit positions (Figure 1). The magnitude of the cover-crop effects on soil mineral N across topographically diverse fields was associated with the amount of cover crop growth and residue production. The results emphasise the potential environmental and economic benefits that can be generated by implementing site-specific topography-driven cover-crop management in row-crop agricultural systems. [7]

7 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, e0143358, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0143358

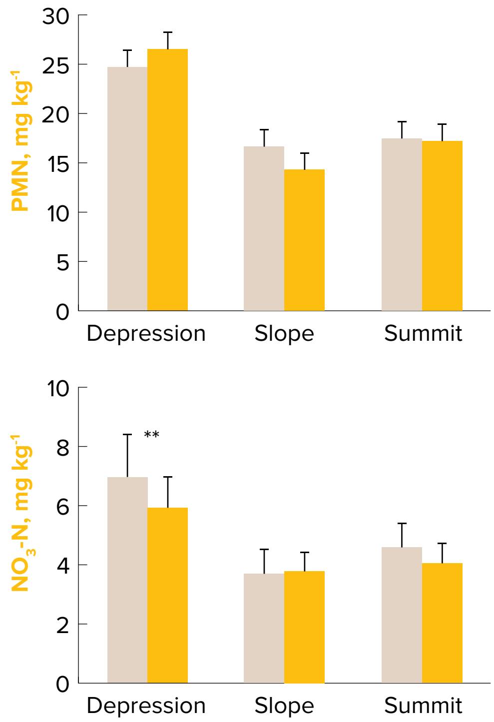


Figure 1: *Soil potential mineralisable N (PMN) and nitrate-N in bare and covered microplots of the studied topographical positions following rye cover crops. Data shown are the averages from 2011–13 results. Vertical lines are standard errors. Cases where the differences between covered and bare microplots were statistically significant are marked **P < 0.05 and *P < 0.1.* [8]

1.1.2 Soil

Soil characteristics (surface and subsurface) such as soil pH, sodicity, salinity, acidity, texture, drainage characteristics and compaction will affect choice of crop. Cereal rye is relatively inexpensive and easy to establish, and it outperforms other cover crops such as wheat on infertile, sandy or acidic soil or on poorly prepared land. [9]

Rye prefers performs well on light loams or sandy soils (Photo 1), and it will germinate even in quite dry soil. It also will grow in heavy clays and poorly drained soils, and some cultivars tolerate waterlogging. [10]

8 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, e0143358, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0143358

9 UVM Extension Crops & Soils Team (2011) Cereal rye. Northern Grain Growers Association, http://northerngraingrowers.org/wp-content/uploads/RYE.pdf

10 SARE (2007) Managing cover crops profitably. 3rd edn. Sustainable Agriculture Research and Education,, http://www.sare.org/publications/covercrops.htm

Photo 1: *Cereal rye growing well on sandy soils in the Mallee, 2017.*

Photo: Rob Sonogan

Rye tolerates high levels of Al in acid soils, and performs (critical concentration of $CaCl_2$-extractable Al 1.7–2.7 mg/L). [11] Cereal rye is even more tolerant of high aluminium levels than triticale, also regarded as an acid-soil-tolerant crop choice. [12]

Rye on erosion-prone soils

Rye's ability to withstand sand blast enables it to produce a soil-binding cover on land where other cereals will not grow. Under conditions where wheat, oats or barley will grow to only a few centimetres high, or they may even be blown away, rye will often grow vigorously and reach a height of at least one metre.

A further reason for using cereal rye on erosion-prone soils is that its grain and straw are the cereal least preferred by sheep. Sheep provided with more than one choice of stubble within a paddock will preferentially graze other stubbles before they will eat rye stubble.

After the crop is harvested, the tough, resilient stubble is generally left as a protective cover to reduce wind erosion of the soil and to assist colonisation by other species (Photo 2). Stubble of rye breaks down more slowly than that of other cereals, ensuring soil cover for a long period. [13]

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

12 P Matthews, JL McCaffery, L Jenkins (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

13 Agriculture Victoria (2013) Growing cereal rye. State Government of Victoria EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

Photo 2: *Wind-erosion-prone sites before and after cereal rye providing groundcover for protection.*

Source: Managing land classes for better feed utilisation

Rye is often sown on exposed sandy areas in dry regions to check sand drift. However, the weather in the spring in such regions is too dry to allow a good grain-set, and grain yields are thus highly variable. [14]

Soil pH

Key points:

- Low pH values (less than 5.5) indicate acidic soils and high pH values (more than 8.0) indicate alkaline soils.
- Soil pH between 5.5 and 8 is not usually a constraint to crop or pasture production.
- The optimum soil pH($CaCl_2$) for growth of cereal rye is ~4.5–7.5. [15]
- In South Australia, over 60% of agricultural soils are alkaline.
- Outside of the optimal soil pH range, microelement toxicity damages crops.

Soil pH is influenced by chemical reactions between soil components and water. It is affected by the various combinations of positively charged ions (of sodium, potassium, magnesium, calcium, Al, manganese and iron) and negatively charged ions (sulfate, chloride, bicarbonate and carbonate). Soil pH directly affects the concentration of major nutrients and the forms of microelements available for plant uptake and can result in deficiencies or toxicities (Figure 2).

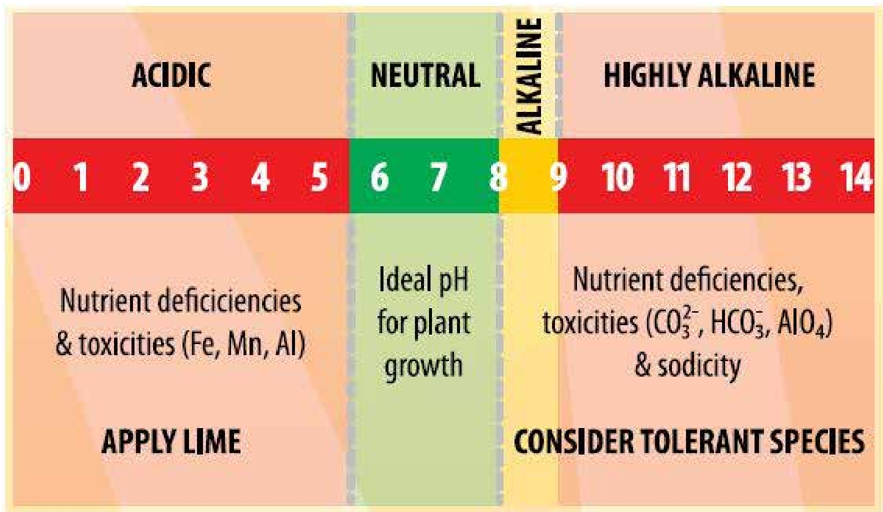


Figure 2: *Classification of soils on the basis of pH (in 1:5 soil:water), the implications for plant growth, and some management options.* [16]

Source: Soil Quality Pty Ltd

14 RL Reid (Ed.) (2013) The manual of Australian agriculture. Elsevier.

15 NSW Agriculture (2000) Understanding soil pH. Acid Soil Action Leaflet No. 2, NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/167187/soil-ph.pdf

16 P Rengasamy. Soilquality.org. Soil pH—South Australia. Fact Sheets, Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/soil-ph-south-austral

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

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

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

Measurement of soil pH

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

Soil pH can be measured by a simple device called an ion electrode inserted into a mixture of one part soil to five parts water. Scientists dealing with acid soils with pH <5 prefer to measure soil pH by mixing soil in a calcium chloride ($CaCl_2$) solution. This is not suitable for soils with a pH >5 because some of the ions in these soils (mainly bicarbonate and carbonate) become bound to the calcium and are removed from solution, which then causes an inaccurate pH reading. Soils with pH >5 should be measured in water.

Managing soil pH

Alkaline soils

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

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

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

Acid soils

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

Soils prone to becoming acidic will need liming every few years. Seek advice on an appropriate liming regime from your local agricultural advisor. [17]

VIDEOS

WATCH: GCTV8: Liming Acids Soils.

1.1.3 Sampling soil quality

Key points:

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

17 P Rengasamy. Soilquality.org. Soil pH—South Australia. Fact Sheets, Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/soil-ph-south-austral

Before deciding how to sample the soil, be clear about the purpose of your sampling. Different sampling approaches may be required depending on what you are sampling for, the soil type, the management unit (e.g. paddock), soil spatial variability (changes in soil type, dunes–swales, etc.), the accuracy required of the result, and the value placed on the information provided (Photo 3). Before starting, define very clearly the question you are asking of your soil samples. Consult a professional soil scientist, agronomist or your analytical laboratory to be sure that your soil samples are taken at the right time, from the right depth, in the right place and in the appropriate number, and are stored in such way that the required analysis is not compromised. If quantitative soil analyses (kg/ha) are required, soil bulk density must also be measured, and this requires considerable care. [18]

Photo 3: *To be meaningful, soil sampling needs to take into account spatial variation in soil condition. Differences in soil type, nutrient status and other soil properties may be exhibited within a paddock.*

Source: Soil Quality Pty Ltd

Sampling strategy

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

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

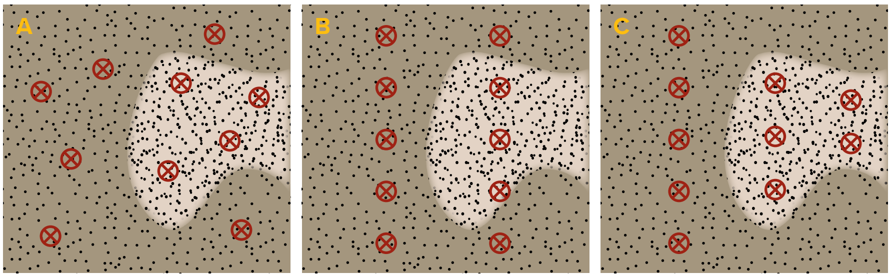


Figure 3: *Sampling strategies used to create a composite sample that integrates variation across different soil types (A & B), and a strategy to describe variation by sampling zones and analysing samples separately (C). Panel A: haphazard samples strategically located to approximate the relative representation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

Source: Soil Quality Pty Ltd

Sampling equipment

Manual sampling is often used where sampling is only required to 10 cm and bulk density is not required. Small pogo-type samplers enable quick sampling for qualitative determinations such as nutrient concentrations or disease presence. To avoid contamination, ensure that your sampling equipment is cleaned before starting. For greater depths, mechanical (hydraulic) samplers are usually required for most soil types. If using these for soil carbon sampling, take care not to contaminate samples with lubricating oil.

Sampling depth

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

Sample handling

Samples can be stored in polyethylene bags but should generally be dried or kept cool prior to analysis. Air-drying (<40°C) is usually sufficient and storage <4°C usually arrests most biological activity. Dried samples can be broken up if clods are present, and any stones removed. If the amount of material collected is too great to manage and ship, it can be reduced in size by careful quartering, ensuring no discrimination against particular particle sizes. Samples are typically put through a 2-mm sieve prior to analysis. [19]

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

1.1.4 Biological inputs

Key points:

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

MORE INFORMATION

Biological inputs – Southern grain growing region

Yield constraints in the Southern Region

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

Yield potential in the region depends on seasonal rainfall, especially in autumn and spring, with less dependence on stored soil moisture than in the Northern Region. [20]

1.2 Paddock rotation and history

The hardiest of cereals, rye can be seeded later in autumn than other cover crops and still provide considerable dry matter, an extensive soil-holding root system, significant reduction of nitrate leaching and exceptional weed suppression (Table 1). Cereal rye has multiple environmental benefits because it can be used for groundcover, reducing wind erosion, and increasing soil water retention.

Paddocks with higher fertility are preferred because most crops are sown for the dual purposes of grazing and grain. Rye is often used as a grazed cover crop undersown with medic or subterranean clover pasture on lighter soil types, to provide groundcover while the clover establishes.

Tolerance to take-all disease may make cereal rye suitable for sowing after grassy pastures. [21]

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

21 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

Table 1: *Benefits and disadvantages of including cereal rye as part of crop rotations.*

Benefits of cropping cereal rye	Disadvantages of cropping cereal rye
Lower input cost than other cereal crops	Low yielding
Provides good groundcover and helps to prevent soil erosion	Difficult to get grain to markets
Taller and quicker-growing than wheat, rye can serve as a windbreak and hold moisture over winter	Lots of trash, making it difficult to seed through
Can increase soil organic carbon	Can attract armyworms
Establishes well on poor sandy soil	It has a weedy nature. Volunteer rye will usually appear for two–three years after a crop has been grown, contaminating following cereal cops
Extensive root system	It can be difficult to find a market for cereal rye grain. [25]
Requires less water than wheat crops	
Can retain up to 45 kg of excess N.	
Increases the availability of exchangeable K in the topsoil [22]	
Can attract significant numbers of beneficial insects such as lady beetles [23]	
Resistant to cereal-cyst nematodes and a poor host to root-lesion nematode (*Pratylenchus neglectus*) providing an alternative management approach for these diseases [24]	

Rye can be used to build up the fertility of sandy, infertile soils. Few other cool-season green manure crops are as productive on poor soils. Rye used as a green manure serves as a storehouse of soil nutrients for a following cash crop.

Rye can also improve water quality because the plant's extensive root system can take up excess soil N that would otherwise leach to contaminate groundwater or surface water bodies. The N taken up slowly becomes available to subsequent crops as the residues gradually decompose. Rye roots can also extract potassium and other nutrients from deep in the soil profile and bring them to the surface, where they become available to subsequent crops. Considerable fertility improvement in the topsoil can be expected when growing rye. [26]

Rye is one of the best cool-season cover crops for outcompeting weeds, especially small-seeded, light-sensitive annuals. Along with conservation tillage practices, rye provides soil protection on sloping paddocks and holds soil loss to a tolerable level. Rye can serve as an overwintering cover crop after maize, or before or after soybeans, fruits or vegetables. It should not be used before a cereal crop such as wheat or barley unless it can be killed reliably and completely; volunteer rye seed lowers the value of other grains. [27]

Cereal rye is the preferred cereal option for erosion control because it withstands adverse conditions such as cold, waterlogging, low soil pH and drought better than

22 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

23 SARE (2007) Managing cover crops profitably. 3rd edn. Sustainable Agriculture Research and Education, http://www.sare.org/publications/covercrops.htm

24 L Martin (2015) Growing cereal rye to increase carbon and prevent wind erosion. Liebe Group, http://www.liebegroup.org.au/wp-content/uploads/2015/03/Case-Study-Jeff-Pearse-March-2015.pdf

25 Natural Resources SA (2014) Managing land classes for better feed utilisation. Government of South Australia DEWNR, http://www.naturalresources.sa.gov.au/files/e7e04254-1bae-4763-9400-a38700980519/managing-land-classes-for-better-feed-utilisation-walsh-case-study-gen.pdf

26 H Valenzuela, J Smith (2002) Sustainable agriculture green manure crops: rye. University of Hawai'i, http://www.ctahr.hawaii.edu/oc/freepubs/pdf/GreenManureCrops/rye.pdf

27 SARE (2007) Cereal rye: Managing cover crops profitably. 3rd edn, SARE Outreach Handbook Series Book 9, University of Maryland, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

other cereals. Cereal rye has a more extensive root system in the top 30 cm than both wheat and oats. This root system increases soil stabilisation and allows the plant to explore more of the topsoil profile, increasing the plant's tolerance to dry conditions. [28]

Cereal rye's resistance and tolerance to take-all makes it a useful break crop for sowing before susceptible wheat, triticale or barley crops. (Note: the exception is the widely grown variety Bevy, which has poor resistance to take-all.) Rye can also be sown in situations where take-all is expected—following grassy pasture on soils that are unsuitable for oats. [29]

Although rye is susceptible to the same insects that attack other cereals, serious infestations are rare.

Allelopathic effects

Cereal rye produces several compounds in its plant tissues and releases root exudates that apparently inhibit germination and growth of weed seeds. These allelopathic effects, together with cereal rye's ability to smother other plants with cool-weather growth, make it an ideal choice for weed control (Photo 4).

These allelopathic compounds may also suppress germination of small-seeded vegetable crops if they are planted shortly after the incorporation of cereal rye residue. Large-seeded crops and transplants rarely are affected. There is evidence that tillering plants have lesser amounts of allelopathic compounds than seedlings. [30]

Photo 4: *High level of weed suppression exerted by a rye cover crop.*

Source: Food and Agriculture Organization of the United Nations

For more information, see Section 6: Weed control.

1.2.1 Rotation issues

Self-sown cereal rye can be a problem in subsequent cereal crops because of a high level of seed dormancy, so generally it should be sown after other cereal crops. When sown the year before a broadleaf crop such as lupins, volunteer cereal rye can be controlled with herbicides. [31]

In rotations that include a cereal, rye may replace wheat, oats, or barley. [32]

Highest yields of rye occur when it is planted on summer fallow. Growing rye repeatedly on the same land increases the chance of ergot (caused by the fungus

28 P Matthews JL McCaffery, L Jenkins (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

29 Wrightson Seeds (2010) Forage focus—Southern Green forage ryecorn, Wrightson Seeds, http://www.pggwrightsonseeds.com.au/assets/FTP-Uploads/Forage_Focus/Cereals/FF_Southern-Green-Forage-Ryecorn.pdf

30 V Grubinger (2010) Winter rye: A reliable cover crop. University of Vermont, https://www.uvm.edu/vtvegandberry/factsheets/winterrye.html

31 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

32 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Alternative field crops manual: Rye. Purdue University, https://hort.purdue.edu/newcrop/afcm/rye.html

Claviceps purpurea) and some other diseases. A varied crop rotation with less susceptible crops is recommended. [33]

1.2.2 Break cropping

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

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

Although cover crops do not normally produce income, they are important because they protect the soil and give other benefits (Table 2). Bare soil is easily damaged, so it is best to protect it by maintaining plant cover. [34]

The main crops used for cover cropping, such as oats, cereal rye, brown (or Indian) mustard (*B. juncea*) and forage rape, host nematodes and many of them enable rapid multiplication of nematodes. Much of the practice being adopted on-farm in Australia involves the use of crops that can provide green-manure benefits, but in most cases, these crops host and multiply nematodes, and there is little information about their impacts on other soilborne fungi. [35]

33 Alberta Government (2016). Fall rye production. Agdex 117/20-1. Alberta Agriculture and Forestry, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

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

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

VIDEOS

WATCH: The importance of crop rotation.

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

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

Source: NSW DPI

1.2.3 Long-fallow disorder

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

Benefits of AM formation are:

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

In general, the benefits of AM are greater at lower soil P levels because AM increase a plant's ability to access this nutrient. Crops species vary in their dependency on AM for growth. [36]

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

1.3 Fallow weed control

Paddocks with well-managed brown-manure or fallow periods significantly lower the risk of a poor crop and financial performance (Photo 5). The best form of weed control is rotation and careful selection of paddocks largely free from winter weeds, e.g. vetch that has been brown-manured.

Photo 5: *Spraying weeds when small is the key to effective long fallow.*

Source: AGRONOMO

Paddocks generally have multiple weed species present at the same time, making weed-control decisions more difficult and often involving a compromise after assessment of the prevalence of key weed species. Knowledge of the paddock's characteristics and history, and early control of weeds, is important for good control. Information is provided below for the most common problem weeds; however, for advice on individual paddocks contact your local agronomist.

Benefits of fallow weed control are significant:

- Conservation of summer rain and fallow moisture (this can include moisture stored from last winter or the summer in a long fallow) is integral to winter cropping, particularly in low-rainfall cropping areas and in regions where the climate moves towards summer-dominant rainfall.
- Modelling studies show that the highest return on investment in summer weed control is for lighter soils or in situations where soil water that would support continued weed growth is present. [37]

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

IN FOCUS

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

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

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

Despite the widespread adoption of no-till farming systems in the region, few published studies have considered the benefits of residue management during the summer fallow relative to weed control, and fewer quantify the impacts of summer fallow weeds or identify the mechanisms by which they influence subsequent crop yield. Over 3 years (2009–11), identical experiments on adjacent sand and clay soil types at Hopetoun in the southern Mallee were conducted to quantify the effects of residue management (standing, removed, or slashed) and summer fallow weed control (chemical control) compared with cultivation on accumulation of soil water and N and subsequent crop yield. The presence of residue (2.4–5.8 t/ha) had no effect on soil-water accumulation and a small negative effect on grain yield on the clay soil in 2011. Controlling summer weeds (*Heliotropium europaeum* (heliotrope) and volunteer crop species) increased soil-water accumulation (mean 45 mm) and mineral N (mean 45 kg/ha) before sowing on both soil types in two years of the experiment with significant amounts of summer fallow rain (2010 and 2011). Control of summer weeds increased grain yield of canola by 0.6 t/ha in 2010 and of wheat by 1.4 t/ha in 2011. Using the data from these experiments to parameterise the APSIM model, simulation of selected treatments with historical climate data (1958–2011) showed that an extra 40 mm of stored soil water resulted in an average additional 0.4 t/ha yield, most of which was achieved in dry growing seasons. An additional 40 kg N/ha increased yield in wetter growing seasons only (mean 0.4 t/ha on both soil types). The combination of extra water and N that was found experimentally to result from control of summer fallow weeds increased subsequent crop yield in all season types (mean 0.7 t/ha on sand, 0.9 t/ha on clay). The co-limitation of yield by water and N in the Mallee environment means that yield increases due to summer weed control (and thus returns on investment) are very reliable. [38]

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

VIDEOS

WATCH: GCTV5: Managing summer fallow.

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 6) [39].

Photo 6: *Broad-leafed weeds and grasses form a green bridge in paddock.*

Source: DAFWA

Key points for control of the green bridge:

- Outright kill of the weeds and volunteers is the only certain way to stop them from hosting diseases and insects.
- Diseases and insects can quickly spread from the green bridge or summer weeds, 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 also depletes soil moisture and nutrients that would otherwise be available to following crops and can have an allelopathic effect. [40]

39 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

40 GRDC (2009) Green bridge—the essential crop management tool. GRDC Fact Sheet, http://www.grdc.com.au/uploads/documents/GRDC_GreenBridge_FS_6pp.pdf

MORE INFORMATION

GRDC: Summer fallow weed management.

VIDEOS

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

1.3.2 Management strategies

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

Practices such as controlled traffic farming and long-term no-till seek to change the very nature of soil structure to improve infiltration rates and improve plant access to stored water by removal of compaction zones.

Shorter term management decisions can also have a great impact on how much plant-available water is stored at sowing. These include decisions such as crop sequence or rotation that dictate the length of the fallow and amount of stubble cover, how effectively fallow weeds are managed, stubble management, and decisions to till or not at critical times.

Many factors influence how much plant-available water is stored in a fallow period; however, good weed management consistently has the greatest impact. [41]

1.3.3 Benefits of stubble retention

Key points:

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

Historically, stubble has been burnt in southern Australia to create an easier passage for seeding equipment, enhance seedling establishment of crops, and improve control of some stubble-borne diseases and herbicide-resistant weeds.

However, the practice of burning stubble has declined because of concerns about soil erosion, loss of soil organic matter and air pollution. Stubble is increasingly being retained, which has several advantages for soil fertility and productivity (Photo 7).

Summer rainfall and warmer conditions promote decomposition of stubble. [42]

Photo 7: *Cereal direct-drilled into previous season's stubble in the Southern growing region.*

Photo: Rob Sonogan, 2013

41 J Cameron, A Storrie (2014) Summer fallow weed management. GRDC, https://grdc.com.au/Resources/Publications/2014/05/Summer-fallow-weed-management

42 Soilquality.org (2013) Benefits of retaining stubble—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

Reducing erosion risk

One of the main benefits of stubble retention is reduced soil erosion. Retaining stubble decreases erosion by lowering wind speed and raindrop energy at the soil surface and decreasing runoff. Groundcover of at least 50% 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 relative to burning paddocks. It also increased rainfall infiltration. [43]

Increasing soil-water content

A major advantage of retaining stubble is that it increases soil-water content by decreasing runoff and increasing infiltration (Figure 4). The actual benefits depend on the timing and intensity of rainfall as well as the quantity and orientation of 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 mineralisation and availability of N for the subsequent crop. [44]

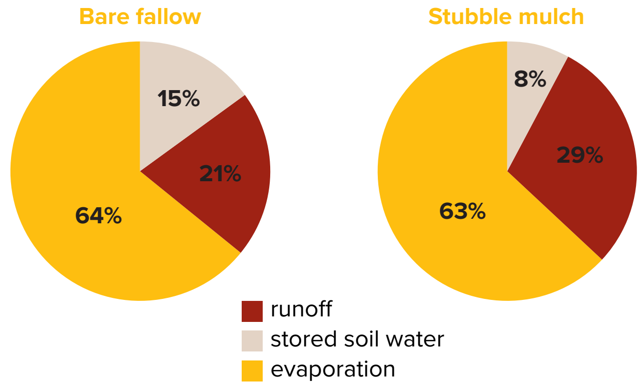


Figure 4: *Retained stubble leads to more stored soil water, mostly due to a reduction in runoff.*

Source: Felton et al. 1987, reproduced in Scott et al. 2010; from Soil Quality Pty Ltd

Increasing soil carbon

Retaining stubble increases the input of carbon to soil. Stubble is ~45% carbon by weight and represents a significant input of carbon to soil. It can take decades for retained stubble to increase the soil organic carbon (SOC). After 10 years, stubble retention generated 2 t/ha more SOC than stubble-burnt plots to a depth of 10 cm in a Red Chromosol during cropping trials with ley pasture rotations at Wagga Wagga. [45] After 25 years, inclusion of a clover pasture in the rotation in the same trial had a greater effect on SOC increases, even with tillage, than stubble retention. [46] Retaining stubble may increase SOC only where it is coupled with cultivation, but not with direct drilling. Latest findings indicate that SOC increases are extremely difficult to achieve and may be related more to annual rainfall than to any surface treatment.

VIDEOS

WATCH: Managing Stubble.

WATCH: Stubble height part 1 and part 2.

WATCH: Southern farm groups cutting through stubble issues.

43 Soilquality.org (2013) Benefits of retaining stubble—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

44 Soilquality.org (2013) Benefits of retaining stubble—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

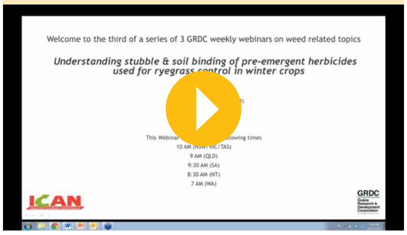
45 BJ Scott, Eberbach L, J Evans, LJ Wade (2010) Stubble retention in cropping systems in Southern Australia: benefits and challenges. EH Graham Centre Monograph No. 1. NSW Industry & Investment/Charles Sturt University, https://www.csu.edu.au/__data/assets/pdf_file/0007/922723/stubble-retention.pdf

46 KY Chan, MK Conyers, GD Li, KR Helyar, G Poile, A Oates, IM Barchia (2011) Soil carbon dynamics under different cropping and pasture management in temperate Australia: Results of three long-term experiments, *Soil Research* **49**: 320–328, http://www.publish.csiro.au/sr/SR10185

VIDEOS

WATCH: Over the Fence south: Jim Cronin.

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



MORE INFORMATION

Developments in stubble retention.

The carbon to nitrogen ratio (C:N) of residues is an important factor in determining the contribution they will make to carbon sequestration as it governs how quickly residues decompose. Pulse residues (C:N between 20:1 and 41:1) are more decomposable than wheat residues (C:N between 45:1 and 178:1). Faster decomposition may improve nutrient availability for the following crop but reduce the sequestration of carbon from residues into soil. [47]

Other benefits of stubble retention

Stubble retention returns nutrients to the soil, but the amounts depend on the quality and quantity of stubble. Wheaten stubble from a high-yielding crop may return up to 25 kg available N/ha to the soil. The addition of organic matter with retained stubbles supports soil organisms and can improve soil structure, infiltration, biological activity and water-holding capacity. These benefits are greater when integrated with no-till practices. [48]

Management practices affecting stubble cover

Stubble burning, grazing and cultivation are the main management practices with the potential to reduce stubble cover. A single tillage operation using a chisel plough, for example, can reduce stubble coverage by 30–40% (Table 3).

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 for control of herbicide-resistant weeds, this should be carried out as a one-off operation. [49]

Table 3: *Estimated percentage reduction in wheat or barley stubble cover from different tillage operations; i.e. amount of residue buried by each tillage operation (reproduced from Measuring and managing stubble cover: ~~Photo~~ standards for winter cereals).*

Implement	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: Soil Quality Pty Ltd

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

1.4 Fallow chemical plant-back effects

Some herbicides have a long residual persistence. 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 illustrated in Table 4.

Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the 'Protection of crops etc.' heading in the 'General Instructions' section of the label. Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop.

47 Soilquality.org (2013) Benefits of retaining stubble—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

48 Soilquality.org (2013) Benefits of retaining stubble—NSW. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-nsw

49 Soilquality.org. Benefits of retaining Stubble—Queensland. Soil Quality Pty Ltd, http://www.soilquality.org.au/factsheets/benefits-of-retaining-stubble-in-qld

Management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonylureas, triazines) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs. [50]

Table 4: *Half-life of common pre-emergent herbicides and residual persistence in broadacre trials and on-farm.* [51]
Note that it is preferable to use plant-back periods (see Table 5).

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

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

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

Conditions required for breakdown

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

Where conditions allowing breakdown of herbicide residues do not occur until just prior to sowing, crops that are sensitive to the residues potentially present on the paddock should not be planted. Rather, opt for a crop that will not be affected by the suspected residues.

If dry areas do receive rain and the temperatures become milder, substantial rain (more than the label requirement) is likely needed to wet the subsoil so that the topsoil can remain moist for a week or more. This allows the microbes to be active in the topsoil where most of the herbicide residues will be found. [52]

Soil type and pH also have an influence on the rate at which chemicals degrade.

Plant-back periods for fallow herbicides in the Southern Region

Herbicide plant-back restrictions should be taken into account when spraying fallow weeds prior to sowing winter crops. Owing to potential seedling damage, many herbicide labels place time and/or rainfall restrictions on the sowing of certain crops and pastures after application. 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 crop or pasture planned for the coming year. In some cases, the crop or pasture planned for the following year may also influence herbicide choice.

The following points are especially relevant:

- Phenoxy herbicides such as 2,4-D ester, 2,4-D amine and dicamba, require 15 mm rainfall to commence the plant-back period when applied to dry soil. There are anecdotal reports of summer-applied phenoxy herbicides staying residual in the lightest textured, low organic matter soils of the Mallee. These residues are thought to accumulate and adversely affect cereal, canola and pulse germinations. Rates of phenoxy herbicides on these soils should be monitored.
- Group B herbicide products 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.
- Group I herbicide products such as Lontrel™, Grazon™ and Tordon™ break down very slowly under cold or dry conditions, which 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 damage to crops from herbicide residues (Table 5). [53]

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

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

Table 5: *Indicative plant-back intervals for a selection of fallow herbicides. For cereal rye, plant-back periods for wheat or barley are a reference point. *15 mm rainfall required to commence plant-back period; **, period may extend where soil pH is >7; #, assumes 300 mm rainfall between chemical application and sowing; NS, not specified.*

Product	Rate	Wheat	Barley	Oats	Canola	Legume pasture	Pulse crops
2,4-D 680*	0–510 mL/ha	1 day	1 day	1 day	14 days	7 days	7 days
	510–1,150 mL/ha	3 days	3 days	3 days	21 days	7 days	14 days
	1,150–1,590 mL/ha	7 days	7 days	7 days	28 days	10 days	21 days
Amicide® Advance 700*	0–500 mL/ha	1 days	1 days	1 days	14 days	7 days	7 days
	500–980 m/ha	3 days	3 days	3 days	21 days	7 days	14 days
	980–1500 mL/ha	7 days	7 days	7 days	28 days	10 days	21 days
Kamba*	200 mL/ha	1	1	1	7	7	7
	280 mL/ha	7	7	7	10	14	14
	560 mL/ha	14	14	14	14	21	21
Hammer® 400 EC		No residual effects					
Nail® 240 EC		No residual effects					
Goal®		No residual effects					
Striker®		No residual effects					
Sharpen®	26 g/ha	–	–	–	16 weeks	–	–
Lontrel™	300 mL/ha	1 week	1 week	1 week	1 week	36 weeks	36 weeks
Garlon™ 600	Various	1 week	1 week	NS	NS	NS	NS
Ally®**	Various	2 weeks	6 weeks	36 weeks	36 weeks	36 weeks	36 weeks
Logran®#	Various	–	–	–	12 months	12 months	12 months
Glean®**	Various	–	9 months	6 months	12 months	12 months	12 months
Grazon™ Extra, Grazon™ DS	Rates up to 500 mL/ha	9 months	9 months	NS	9 months	24 months	24 months
Tordon™ 75-D, Tordon™ 242	Various	2 months	2 months	NS	4 months	9 months	6 months
FallowBoss Tordon™	Up to 700 mL/ha	9 months	9 months	NS	12 months	20 months	20 months

Source: RMS Agricultural Consultants

1.4.1 Herbicide residues in soil—an Australia-wide study

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

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

Recently, the Grains Research and Development Corporation (GRDC) co-funded a five-year project to improve understanding of the potential impacts of increased herbicide use on key soil biological processes. This national project, coordinated by the NSW Department of Primary Industries with partners in Western Australia, South Australia, Victoria and Queensland, is focused on the effect of at least six different herbicide classes on the biology and function of five key soil types across all three grain-growing regions.

Part of this project was a field survey of herbicide residues in 40 cropping soils prior to sowing and pre-emergent herbicide application in 2015 (Table 6). A literature search of herbicide impacts to soil biology was also undertaken. The relevance of the residues to soil biological processes and crop health was considered, with a focus on those herbicides most frequently detected. Recommendations were given to minimise potential impacts of herbicide residues on productivity and soil sustainability. The project will continue with further research and the development of management tools for growers to monitor and predict herbicide persistence in soils.

Table 6: *Estimated residue loads (average and maximum) of herbicide active ingredients (a.i., kg/ha) in the 0–30 cm soil profile of paddocks, by region, calculated by multiplying mass concentration (mg/kg) detected by area and average bulk density (derived from soilquality.org) for each soil layer.*

Herbicide	Average load across all sites			Maximum load detected		
	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

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

The risk to soil biological processes was generally considered minor when herbicides are used at label rates and given sufficient time to dissipate before re-application. However, given the frequency of glyphosate application, and the persistence of

MORE INFORMATION

GRDC Update Paper: Herbicide residues in soils—are they an issue?

NSW DPI: Weed control in winter crops.

trifluralin and diflufenican, further research is needed to define critical thresholds for these chemicals to avoid potential negative impacts to soil function and crop production. [54]

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

1.5 Seedbed requirements

The cereal rye paddock should be well prepared and relatively moist for good germination. [55] Good seed–soil contact is necessary for proper germination and emergence. For best results, plant rye in a firm seedbed. Preparation of soil for rye is similar to that for wheat, but is usually for a shorter period and does not include fallowing. [56]

A good seedbed is free of weeds, diseases and insects. If rye is grown on light-textured soils subject to wind erosion, pre-seeding tillage should be kept to a minimum. To aid erosion control, use implements that will preserve previous crop residue. Substitution of herbicides for cultivation and seeding without pre-seeding tillage (minimum to no-tillage) are other practical considerations. Under conditions of dry or firm soil, seeding should be done with implements that minimise soil disturbance, such as air drills with disc or narrow openers together with press-wheels, to prevent soil drying.

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

To minimise the risk of ergot infection, mowing of roadside and headland grass prior to seedset will reduce or eliminate a major source of re-infestation. [57]

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

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

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

Pre-irrigation completed by 1 April is a safe option in most years. Later irrigations can cause problems by making the ground too wet for both sowing and grazing. If not pre-irrigated, then the crop should be sown following sufficient rainfall to wet the soil to 100 mm depth. [58]

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

The seedbed lays the foundations for crop establishment. However, different techniques can be used to create a seedbed (refer to Figure 5):

1. Conventional technique: ploughing in of straw, cultivation to sowing depth with a tyne/disc cultivator, conventional drilling, fertiliser spreading

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

55 UVM Extension Crops and Soils Team (2011) Cereal rye. Northern Grain Growers Association, http://northerngraingrowers.org/wp-content/uploads/RYE.pdf

56 RL Reid (Ed.) (1990) The manual of Australian agriculture. Elsevier.

57 Alberta Government (2016) Fall Rye Production. Alberta Agriculture and Forestry, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex1269/$file/117_20-1.pdf

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

2. Mouldboard ploughing + seed-drilling: ploughing-in of straw, shallow cultivation, drilling where seed and fertiliser are placed in the soil simultaneously
3. Minimal tillage: tillage of straw by cultivator, seed drilling where seed and fertiliser are placed simultaneously in the soil–straw layer
4. Shallow tillage: shallow burial of straw at the surface, seed-drilling where seed and fertiliser are placed simultaneously in the soil–straw layer.
5. Direct drilling: seed-drilling where seed and fertiliser are placed simultaneously without prior soil tillage; straw remains on the surface.

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

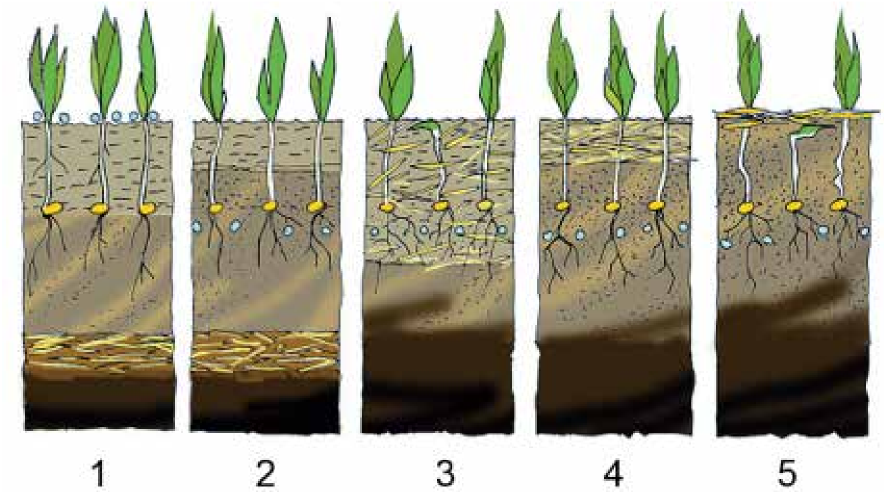


Figure 5: *Diagram demonstrating the results of different seedbed-preparation techniques. See corresponding points in text list above for description.*

Source: Vaderstad

Ploughing warms the soil and buries plant residues so that they do not obstruct sowing. However, ploughing also disrupts the soil structure and increases oxidation of organic material. Without ploughing, organic material and soil structure are retained, but the straw can cause problems with sowing and can transmit diseases. [59]

1.5.1 Seedbed soil structure decline

Key points:

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

Background

A decline in surface-soil structure generally results in crusting or hard-setting (Photo 8). A surface crust is typically <10 mm thick and when dry can normally be lifted off the loose soil below. Crusting means that the seedling must exert more energy to break through to the surface, thus weakening it. A surface crust can also form a barrier, reducing water infiltration.

Breakdown in soil structure caused by rapid wetting can lead to hard-setting. Once wet, the unstable soil structure collapses and then shrinks as it dries. This leads to

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

a massive soil layer with little or no cracking and greatly reduced pore space. This hard-set, massive structure is associated with poor infiltration, low water-holding capacity and a high soil strength. In many instances, this causes patchy establishment and poor crop and pasture growth. This tends to be less of a problem with cereal rye in the Mallee because it is not sown on heavy-textured soils there, but rather, on sand or loamy sands when other cereals fail.

Photo 8: *Soil crusting (left) and cloddy seedbed (right) associated with high concentrations of exchangeable sodium.*

Source: Soilquality.org

Management to improve seedbed soil structure

To decrease the level of crusting or hard-setting in soils, it is necessary to stabilise soil structure. For example, in one study, amelioration of a hard-setting grey clay was best achieved by using management practices to increase soil organic matter and reduce traffic, thereby improving soil structure. [60] Removing or reducing stock when the soil is saturated also helps to avoid compaction, smearing and 'pugging' of the soil surface.

An option for stabilising the structure of dispersive soils is the addition of gypsum. The calcium in gypsum effectively displaces sodium and causes clay particles to bind together, helping to create stable soil aggregates. A reduction in exchangeable sodium percentage and increase in ratio of calcium to magnesium may be observed. Addition of lime also adds calcium to the soil; however, this is generally used only for soils of low pH. [61]

1.6 Soil moisture

1.6.1 Dryland

Water availability is a major limiting factor for crop production in the grainbelt of Australia. Cereal rye can enhance water penetration and retention. [62]

60 Hamilton G, Fisher P, Braimbridge M, Bignell J, Sheppard J and Bowey R (2005) Managing grey clays to maximise production and stability. Department of Agriculture, Western Australia Bulletin 4666, http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1033&context=bulletins

61 J Sheppard, F Hoyle.. Seedbed soil structure decline. Soil Quality Pty Ltd, www.soilquality.org.au/factsheets/seedbed-soil-structure-decline

62 EA Oelke, ES Oplinger, H Bahri, BR Durgan, DH Putnam, JD Doll, KA Kelling (1990) Rye. Corn Agronomy, University of Wisconsin Extension, http://corn.agronomy.wisc.edu/Crops/Rye.aspx

IN FOCUS

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

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

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

The third study reported on soil water measured twice each year during a phased pasture–crop sequence over 6.5 years at Junee. Mean water content of the top 2.0 m of soil under a lucerne pasture averaged 211 mm less than under a subterranean clover-based annual pasture and 101 mm less than under well-managed crops.

Collectively, these results suggest that lucerne pastures and improved crop management can result in greater use of rainfall than the other farming systems, which were based on growing annual pastures, and using fallow, and poor management techniques for growing crops. The tactical use of lucerne-based pastures in sequence with well-managed crops can help the dewatering of the soil and reduce or eliminate the risk of groundwater recharge. [63]

Monitoring soil moisture in dryland areas

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

One tool that helps farmers improve Water Use Efficiency is the soil-moisture probe, but few farmers in the dryland cropping industry use it. To change that, Victoria's Department of Environment and Primary Industries will provide live deep-soil-moisture data to help dryland croppers, farmers, and advisers and managers validate the technology, as well as conducting training to interpret the data for crop

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

decision-making. [64] Communication will include monthly broadcasts of 'The Break', soil-moisture products; and the government will piloting new formats to expand reach and impact.

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

Access to this data enables growers and advisers to:

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

MORE INFORMATION

Soil moisture monitoring in dryland cropping areas

1.6.2 Tillage

Tillage mixes and buries soil amendments and crop residue, eliminates existing vegetation, reduces pest populations, promotes mineralisation of soil organic matter, and creates a seedbed that facilitates mechanical planting and seed–soil contact (Photos 9 and 10).

Research at five sites in Queensland and northern New South Wales has shown that one-time tillage with chisel or offset disc in a 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. Tillage reduced soil moisture at most sites; however, this decrease in soil moisture did not adversely affect productivity. This could be due to good rainfall received after tillage and prior to seeding and during the crop of that year. Rainfall between the tillage and sowing or immediately after sowing is necessary to replenish soil water lost from the seed zone. This suggests the importance of timing of tillage and of considering the seasonal forecast. Future research will determine the best timing for strategic tillage in no-till systems. [65] Note that these results are from one season and research is ongoing, so any impacts are likely to vary with subsequent seasonal conditions.

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

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

Photo 9: *The impact of tillage varies with the tillage implement used: inversion tillage using a mouldboard plough, as pictured, results in greater impacts than using a chisel or disc plough.*

Source: GRDC

Photo 10: *Strategic tillage can provide control for herbicide-resistant weeds and those that continue to shed seed throughout the year. Here it has been used for control of awnless barnyard grass in fallow.*

Source: GRDC

However, tillage can also increase soil erosion and surface water eutrophication. During the past 30 years, much progress has been made in reducing tillage. No-tillage crop production has increased 2.5-fold from about 45 million hectares worldwide in 1999 to 111 million hectares in 2009. One downside of this trend is increased use of herbicides for weed suppression. [66]

In general, pre-plant tillage to prepare the seedbed, control weeds, and disrupt insect and disease life cycles improves crop establishment. However, with cereal rye or other cereal grains, no-till establishment is an effective option that allows maintenance of the no-till system. Conventional seedbeds are prepared by ploughing, discing and harrowing the soil prior to seeding. Seeding depth depends upon the species being sown. [67]

VIDEOS

WATCH: Strategic tillage, does no-till mean never till?

WATCH: Over the Fence South: Andrew Simpson – Strategic tillage.

66 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, 238–246, http://www.bioone.org/doi/abs/10.1614/WS-D-10-00110.1

67 WS Curran, DD Lingenfelter, L Garling. Cover crops for conservation tillage systems. Penn State Extension, http://extension.psu.edu/plants/crops/soil-management/conservation-tillage/cover-crops-for-conservation-tillage-systems

IN FOCUS

Tillage, microbial biomass and soil biological fertility

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

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

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

Total organic carbon

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

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

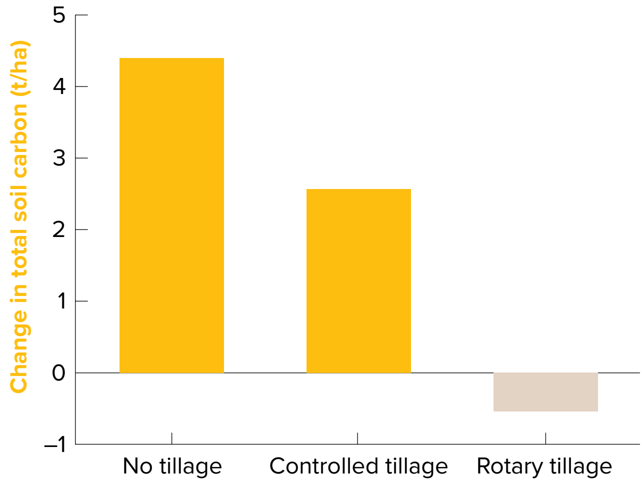


Figure 6: *Change in total soil carbon content at 0–10 cm soil depth from 1998 to 2004 in crops under three tillage regimes. No-tillage and conventional tillage treatments were not significantly different from each other; rotary tillage was significantly different from both (at P = 0.05).*

Source: Soilquality.org

Light-fraction organic carbon

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

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

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

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

Soil microorganisms

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

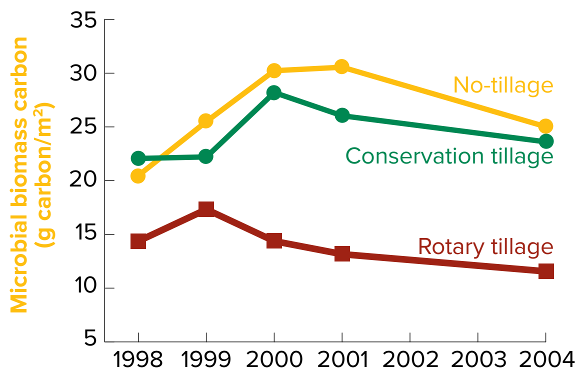


Figure 7: *Microbial biomass carbon at 0–5 cm depth of cropped soil under three tillage regimes.*

Source: Soilquality.org

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

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

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

MORE INFORMATION

GRDC Tips and Tactics: Strategic Tillage

VIDEOS

WATCH: Adoption of NoTill SA Mallee.

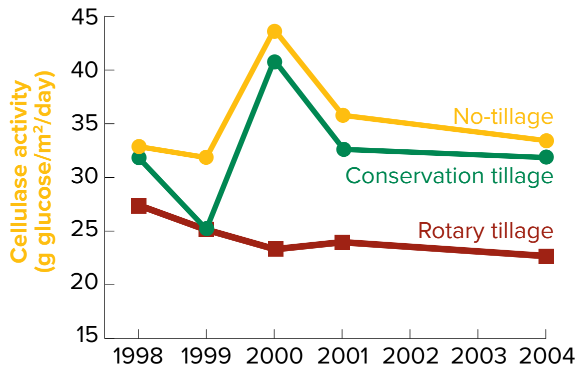


Figure 8: *Activity of the microbial enzyme cellulase at 0–5 cm depth of cropped soil under three tillage regimes.*

Source: Soilquality.org

Crop yields

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

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

Although overall results for no-tillage and conservation tillage were similar, they may diverge in the longer term. [68]

1.6.3 Irrigation

Irrigation is the controlled application of water to land for the purpose of agricultural production. Effective irrigation will influence the entire growth process: seedbed preparation, germination, root growth, nutrient utilisation, plant growth and regrowth, yield and quality.

The keys to maximising irrigation efficiency are uniformity and timing. Although the producer can control the quantity and timing of water supply, the irrigation system determines uniformity. Deciding on the most suitable irrigation system for your operation requires 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 burns, soil erosion, and water loss. Losses of water will occur though evaporation and runoff, and from water (and nutrients) sinking deep below the root-zone.

Irrigation management requires careful consideration and vigilance.

Benefits of irrigation:

- Increased production of pastures and crops.

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

- More flexibility in systems/operations with the ability to access water when needed to achieve good plant growth and thus higher yields and to meet market/seasonal demands, especially if rainfall events do not occur.
- Higher quality crops and pastures—water stress can reduce the quality of farm produce.
- Lengthening of the growing season (or in starting the season earlier).
- Insurance against seasonal variability and drought.
- Higher stocking rates of animals and tighter grazing management due to reliability of pasture supply throughout the season.
- Maximising benefits of fertiliser applications—fertilisers need to be 'watered into' the soil to facilitate plant growth.
- Use of areas that would otherwise be less productive—irrigation can allow farmers to open up land that would otherwise be too dry to grow pasture or crops, enhancing carrying capacity or feed conservation.
- Ability to take advantage of market incentives for unseasonal production.
- Less reliance on supplementary feeding (grain, hay) in grazing operations due to the more consistent supply and quality of pastures grown under irrigation.
- Improved capital value of the property—irrigated land has potential to support higher crop, pasture and animal production, so is considered more valuable. The value is also related to the water-licensing agreements.
- Cost saving and greater returns—cost benefits from the more effective use of fertilisers and financial benefits of more effective agricultural productivity (both quality and quantity) and out-of-season production are likely. [69]
- Effective in increasing shoot zinc (Zn) content and Zn efficiency of cereal cultivars—it has been suggested that plants become more sensitive to Zn deficiency under rainfed conditions. [70]

However, cereal rye may not respond to irrigation as well as other cereal crops. In one study, cereal varieties accumulated 16–20 t/ha of dry matter by the end of sampling in late September, whereas cereal rye yielded only 14 t/ha. [71]

IN FOCUS

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

Selected cultivars of oats (3), barley (2), wheat (3), cereal rye (1) and triticale (3) were grown under irrigation at Trangie, NSW, in 1978 and 1980. Dry matter (DM) accumulation and changes in moisture, nitrogen (N) and phosphorus (P) content and DM digestibility of forage were monitored at intervals of ~21 days during uninterrupted primary growth (June–September 1980). In a split-plot design with three cutting intensities, the crops were cut at 80 days, 80 and 122 days, and 80, 122 and 164 days after sowing. Regrowth was sampled on two or three occasions to determine DM yield and quality. Most cultivars accumulated 16–20 t DM/ha by the end of sampling in late September; 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

69 Agriculture Victoria. About irrigation. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/farm-management/soil-and-water/irrigation/about-irrigation

70 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, 2245–2256.

71 DK Muldoon (1986) Dry matter accumulation and changes in forage quality during primary growth and three regrowths of irrigated winter cereals. *Australian Journal of Experimental Agriculture* 26, 87–98, http://www.publish.csiro.au/an/EA9860087

12–13 t/ha, winter wheat yielded 10–11 t/ha and triticale yielded 10–12 t/ha. Nitrogen and P content of all forages decreased linearly during primary growth. Oats and wheat had similar digestibility, which began to decrease rapidly 40–50 days before head emergence (mid-August). Early-maturing barley and triticale cultivars had lower digestibility than oats. Regular cutting maintained the N content and digestibility of all cultivars above 2.7% and 72%, respectively. DM accumulation was described by mathematical equations that allowed cultivars to be compared under different cutting regimes. Equations also allowed DM and digestible DM yields from different systems of cutting to be predicted for irrigated cereals in western NSW. [72]

MORE INFORMATION

Agriculture Victoria: About irrigation

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

The future of irrigation

Climate change is likely to lead to reductions in rainfall in south-eastern Australia. These reductions in rainfall will be amplified such that proportional reductions in runoff are likely to be two–four times larger. That is, a 10% rainfall reduction will lead to a 20–40% reduction in runoff. The runoff reductions will be larger in drier catchments, making the water supply systems with drier source catchments more vulnerable. The experience of the Millennium Drought has shown that reductions in runoff under persistent climate change (~10-year drought) are larger than reductions that occur for short droughts with similar rainfall reductions in many catchments. [73]

1.7 Yield and targets

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

The average yield of cereal rye in Victoria is low and quite variable: 0.4–1.8 tonnes per hectare. Spring rainfall has a major influence on yield in the Mallee because the lighter soils have a low water-holding capacity; low spring rainfall will lead to lower yields. Another factor in the low yields is that, unlike other cereals, rye must be cross-pollinated. In hot weather, much of the pollen dries out before it can fertilise neighbouring plants; the result is that grain does not set properly. A third factor in the low yields is that most varieties of rye require a relatively long period for grain formation; this means that rye grain can often be small and shrivelled. [74]

In cereal rye, 53–58% of total grain yield is produced by lateral shoots, depending on the cultivar and the growing conditions. [75]

Cereal rye is adapted to all soils; however, its major fit is on the lighter acid soils where yields are usually 70–100% those of wheat and triticale when sown between May and June.

On traditional wheat soils, yields of cereal rye are ~50–70% of wheat yields. When sown late (in July), and in dry springs, yields are often <50% those of comparable wheat. Although it heads early, its longer grain-filling period and later maturity limit its performance in the western areas of the grainbelt. [76]

72 DK Muldoon (1986) Dry matter accumulation and changes in forage quality during primary growth and three regrowths of irrigated winter cereals. *Australian Journal of Experimental Agriculture* 26, 87–98, http://www.publish.csiro.au/an/EA9860087

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

74 Agriculture Victoria (2013) Growing cereal rye. Victorian State Government EDJTR, http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-cereal-rye

75 K Hakala, K Pahkala (2003) Comparison of central and northern European winter rye cultivars grown at high latitudes. *The Journal of Agricultural Science*, 141, 169–178.

76 P Matthews, JL McCaffery, L Jenkins (2016) Winter crop variety sowing guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

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

- Do a simple calculation to see how much water is needed to achieve this yield. [77]
- Know how much soil water is available (treat this water like money in the bank).
- Think about how much risk your farm can carry.
- Consider how this crop fits into your cropping plan, will the longer term benefits to the system outweigh any short-term losses?
- Avoiding a failed crop saves money now and saves stored water for future crops. [78]

Estimating crop yields

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

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

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

Estimation methods

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

1. Select an area that is representative of the paddock. Using a measuring rod or tape, measure out an area 1 m^2 and count the number of heads/pods.
2. Do this five times to get an average for the crop: no. of heads per m^2 (e.g. 200).
3. Count the number of grains in at least 20 heads, and calculate the average: no. of grains per head (e.g. 24).
4. Determine the 100-grain weight for the crop (in grams) by referring to table 1 in: Estimating crop yields—a brief guide; or in this case for cereal rye, assume 40,000 seeds per kg, from Matthews *et al.* (2016, table 14, p. 27). [79] Then (1000/40,000) × 100 = 2.5 g.
5. No. of grains per m^2 = no. of heads per m^2 × no. of grains per head; e.g. 200 × 24 = 4800.
6. Yield per m^2 (g) = (no. of grains per m^2/100) × 100-grain weight; e.g. 4800/100 × 2.5 = 120 g.
7. Yield (t/ha) = numeric value of yield per m^2/100; e.g. 120/100 = 1.2 t/ha.

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

This type of yield estimation should be able to be used in a number of situations on a grain-growing property. Grain losses both before and during harvest can be significant and an allowance for 5–10% loss should be included in your final calculations. [80]

77 J Whish (2013) Sorghum yield risk vs starting soil moisture. GRDC Update Papers, August 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Sorghum-yield-risk-vs-starting-soil-moisture

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

79 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2016.pdf

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

Yield Prophet®

Scientists at the Agricultural Production Systems Research Unit (APRSU) have aimed to support farmers' capacity to achieve yield potential by developing the Agricultural Production Systems Simulator (APSIM). APSIM is a farming systems model that simulates the effects of environmental variables and management decisions on crop yield, profits and ecological outcomes.

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

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

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

The simulations provide a framework for farmers and advisers to:

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

Farmers and consultants use Yield Prophet® to match crop inputs with potential yield in a given season. This is achieved primarily by conducting scenario analyses in which the effects of alternative management options on crop yield and potential profitability can be assessed and applied, and can thereby influence decision-making.

How does it work?

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

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

MORE INFORMATION

Yield Prophet

1.7.1 Seasonal outlook

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

The NSW Seasonal Conditions Reports are issued each month and contain information on rainfall, water storages, crops, livestock and other issues. They are available to landholders to help them make informed decisions on how they manage operations, and prepare for seasonal conditions and drought.

MORE INFORMATION

GRDC Update Paper: Managing data on the modern farm

BoM: Australia Bureau of Meteorology climate outlooks

GRDC: Climate kelpie

For Victorian growers, the Victorian State Government publishes the Monthly Water Report including updates from the Bureau of Meteorology on local rainfall forecasts and seasonal climate outlook.

Mobile applications (apps) are providing tools for ground-truthing of precision agriculture data. Apps and mobile devices are making it easier to collect and record data on-farm. The app market for agriculture is evolving rapidly, with new apps becoming available on a regular basis. [81]

CliMate

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

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

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

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

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

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

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

As outputs, text and two graphical presentations are used to show the current season in the context of the average and all years. Departures from the average are shown in a fire-risk chart as the departure from the average in units of standard deviation. [82]

Climate analogues

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

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

This approach was used to generate the analogue cases presented as examples in each of eight Cluster Reports. These reports are intended to provide regional detail for planners and decision makers. The results should capture sites of broadly similar annual maximum temperature and water balance. [83]

81 R Heath (2013) Managing data on the modern farm. GRDC Update Papers, February 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Managing-data-on-the-modern-farm

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

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

1.7.2 Fallow moisture

For a growing crop, there are two sources of water: the water stored in the soil during the fallow, and the water that falls as rain while the crop is growing. As a farmer, you have some control over the stored soil water; you can measure how much you have before planting the crop. Long-range forecasts and tools such as the Southern Oscillation Index can indicate the likelihood of the season being wet or dry; however, they cannot guarantee that rain will fall when it is needed. [84]

HowWet?

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

HowWet? tracks soil moisture, evaporation, runoff and drainage on a daily time-step. Accumulation of available N in the soil is calculated based on surface soil moisture, temperature and soil organic carbon. *HowWet?* provides a comparison with previous seasons.

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

Questions this tool answers:

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

Inputs:

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

Outputs:

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

Reliability

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

Soil descriptions are based on generic soil types with standard organic C:N ratios, and as such should be regarded as indicative only and best used as a measure of relative water accumulation and nitrate mineralisation. [85]

1.7.3 Water Use Efficiency

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

---

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

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

- 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; and
- the crop's ability to convert biomass into grain.

Water Use Efficiency can be considered at several levels:

- Fallow efficiency (%) is the efficiency with which rainfall (mm) during a fallow period is stored for use by the following crop. Calculated as: fallow efficiency = (change in plant-available water during fallow × 100)/fallow rainfall.
- Crop WUE (kg/ha/mm) is the efficiency with which an individual crop converts water transpired (or used) (mm) to grain (kg/ha). Calculated as: crop WUE = grain yield/(crop water supply – soil evaporation).
- Systems WUE (kg/mm) is the efficiency with which rainfall is converted to grain over multiple crop and fallow phases. Calculated as: systems WUE = total grain yield/total rainfall.

Strategies to increase yield

In environments where yield is limited by water availability, there are four ways to increase yield: [86]

1. Increase the amount of water available to a crop through practices such as good control of summer weeds, stubble retention, long fallow and early sowing to increase rooting depth.
2. Increase the proportion of water that is transpired by crops rather than lost to evaporation or weeds. This can be achieved by early sowing, early N application, vigorous crops and varieties, narrow row spacing, high plant densities, stubble retention and good weed management.
3. Increase the efficiency with which crops exchange water for carbon dioxide to grow dry matter (i.e. transpiration efficiency) through early sowing, good nutrition and use of varieties with high transpiration efficiency.
4. Increase the total proportion of dry matter that is grain (i.e. improve the harvest index) by using early-flowering varieties and varieties with high harvest index, delayed N application, wider row spacing, low plant densities and disease minimisation practices.

The last three of these all improve WUE. [87]

The French–Schultz approach

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

In this model, potential crop yield is estimated as:

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

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

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

87 J Hunt, R Brill (2012) Strategies for improving Water Use Efficiency in western regions through increasing harvest index. GRDC Update Papers, April 2012, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/04/Strategies-for-improving-wateruse-efficiency-in-western-regions-through-increasing-harvest-index

MORE INFORMATION

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

NSW DPI Agnote: Making the most of available water in wheat production.

VIDEOS

WATCH: GCTV12: Water Use Efficiency Initiative.

WATCH: GCTV10: Grazing stubbles and Water Use Efficiency.

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

A practical WUE equation for farmers to use developed by James Hunt (CSIRO) is: WUE = (yield × 1000)/available rainfall, where available rainfall = (25% Nov.–March rainfall) + (growing season rainfall) – 60 mm evaporation.

Agronomist's view

The French–Schultz model has been useful in providing growers with performance benchmarks. Where yields fall well below these benchmarks, it may indicate a problem with the crop's agronomy or a major limitation in the environment. There could be hidden problems in the soil such as root diseases, or soil constraints affecting yields. Alternatively, apparent underperformance could simply be due to seasonal rainfall distribution patterns, which are beyond the grower's control. [88]

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

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

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

Researchers have analysed some of the consequences of the shift from winter to summer rainfall between southern and northern regions in terms of implications for management and breeding. They advise caution in the use of simple rules of thumb (French–Schultz) for benchmarking WUE, and discuss the importance of more integrative and dynamic modelling approaches to explore alternatives to increase WUE at the single-crop and whole-farming-systems levels (i.e. $/ha.mm). [89]

1.7.4 Nitrogen-use efficiency

Nitrogen use efficiency (NUE) is the efficiency with which soil nitrate-N is converted into grain N. The nitrate-N comes from fertiliser, crop residues, manures, and soil organic matter, but efficiency of conversion of fertiliser into grain is generally of greatest concern to growers. Efficiency is reduced by seasonal conditions, crop diseases, losses of N from the soil as gases, N leaching or immobilisation of N into organic forms. [90]

Improving NUE

Improving N-use efficiency (NUE) begins with identifying and measuring meaningful NUE indices, and comparing them with known benchmarks and contrasting N-management tactics. Some useful NUE indices are:

- agronomic efficiency of applied N (kg yield increase per kg N applied)
- N transfer efficiency (kg N in grain/kg total crop-available N)

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

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

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

- economic agronomic efficiency (value of yield increase with applied N/cost of N fertiliser applied).

Potential causes of inefficiency can be grouped into six general categories:

- supply greater than demand
- inefficient N uptake
- applied but temporarily unavailable to the growing crop (immobilisation)
- applied or mineralised but lost to soil through leaching, volatilisation, denitrification
- available but not taken up because of positional or timing problems, or root restriction
- taken up but not transferred to grain.

Identification of the most likely category is useful in directing more targeted measurement and helping to identify possible strategies for improvement.

Because of seasonal effects, improvement of NUE is an iterative process. Therefore, consistency in investigation strategy and good record keeping are essential. [91]

Optimising N fertiliser use

Nitrogen fertilisers are a significant expense for broadacre farmers. Optimising use of fertiliser inputs is therefore desirable. There are three main stores of nitrogen with the potential to supply N to crops: stable soil organic matter N, rotational (plant residue) N, and soil mineral N (ammonium and nitrate). To optimise the ability of plants to use soil N, growers should first be aware of how much of each source there is, and soil testing is the best method of measuring these N sources. [92]

IN FOCUS

Environment and genotype influence on grain protein concentration of wheat and rye

Protein is a primary quality component of cereal grains. Cultivar and agronomic trials were conducted in Canada to determine the influence of genotype and environment on wheat and rye grain protein concentration and NUE for grain protein production. Minimum protein concentration of 95.4 g protein/kg dry grain was expressed when cultivars were produced under high productivity conditions on soils with low total plant-available N. Maximum protein concentration at high levels of N varied from 130 to 231 and 107 to 177 g protein/kg dry grain for winter wheat and rye, respectively. At low levels of total available N, the NUE for grain protein production approached 80%. The NUE for grain protein production dropped off rapidly for subsequent increments of N fertiliser. These observations indicate that management systems designed to produce cereals with high grain protein concentrations will have a very low NUE for grain and grain protein production. [93]

MORE INFORMATION

GRDC Update Paper: The fundamentals of increasing nitrogen use efficiency

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

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

93 DB Fowler, J Brydon, BA Darroch, MH Entz, AM Johnston (1990) Environment and genotype influence on grain protein concentration of wheat and rye. *Agronomy Journal* 82, 655–664.

1.7.5 Double crop options

Cool-season annual forages such as cereal rye are well suited to use as double-cropped forage. [94]

Planting cool-season annuals following 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 cereal grasses such as oats, cereal rye, triticale and wheat, and brassicas which include turnip and radish.

For autumn forage, the general concept is to take advantage of the potential growing-degree-days following grain harvest. Ideally, planting a forage double-crop would occur as soon as possible following grain harvest because 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 outweigh the years in which failure occurs. [95]

For spring forage, the winter cereals rye, triticale and wheat tend to be the best choices. Rye is the best choice for early spring pasture and produces much growth before being terminated for timely planting of a row crop. Some rye varieties also provide enough autumn growth for some light grazing if planted early enough. Rye also may be the most reliable crop when planted under stressful conditions. [96]

1.8 Disease status of paddock

Although cereal rye is susceptible to fewer diseases than other cereals [97], it important to know the disease status of a paddock before planting.

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

1.8.1 Cropping history effects

The main cropping history effects are based on the amount of nutrients available in a paddock. However, the previous crop will influence levels of both soil- and residue-borne diseases. Important diseases to consider include take-all, crown rot, yellow leaf spot, stripe rust, and Wheat streak mosaic virus. Transmission from neighbouring paddocks and volunteers are key concerns with some diseases. Controlling the 'green bridge' of over-summering cereals and weeds is an important strategy.

For diseases, there has been a focus on management of crown rot and RLN, yellow leaf spot in winter cereals, and the roles that rotational crops play, particularly the winter pulses. Crop sequences also affect the incidence and severity of major diseases of summer crops, especially those diseases that have several summer, and in some instances winter, crop hosts.

Crop sequencing is only a part of the integrated management of diseases. Other practices include maintaining sufficient distance from last year's paddock of the same crop or from a paddock with residue infected with a pathogen of the intended crop;

94 ME Drewnoski, DD Redfearn (2015) Annual cool-season forages for late-fall or early-spring double crop. NebGuide, University of Nebraska, http://extensionpublications.unl.edu/assets/pdf/g2262.pdf

95 ME Drewnoski, DD Redfear (2015) Annual cool-season forages for late-fall or early-spring double crop. NebGuide, University of Nebraska, http://extensionpublications.unl.edu/assets/pdf/g2262.pdf

96 Cropwatch (2012) Considerations for late summer planted forage crops. University of Nebraska, http://cropwatch.unl.edu/considerations-late-summer-planted-forage-crops

97 SARE (2007) Cereal rye: Managing cover crops profitably. 3rd edn. SARE Handbook, Sustainable Agriculture Research and Education, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

the use of high-quality, fungicide-treated seed; planting within the planting window; variety selection; and in-crop fungicide treatments. [98]

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

- durum wheat in the past 1–3 years
- winter cereal or a high grass burden from last season—crown rot fungus survives in winter cereal residues, dense stubble cover or where dry conditions have made residue decomposition slow
- break crops, which can influence crown rot in cereals by manipulating the amount of N and moisture left in the soil profile
- paddocks that have high levels of N at sowing and/or low stored soil moisture at depth [99]
- varieties grown in previous year (Photo 11). [100]

Photo 11: *Diseased patches of Rhizoctonia root rot from previous crops vary in size from less than half a metre to several metres in diameter.*

Source: DAFWA

1.8.2 Soil testing for disease

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

PreDicta B

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

PreDicta B is a DNA-based soil testing service that identifies which soilborne pathogens pose a significant risk to broadacre crops prior to seeding (Photo 12).

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

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

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

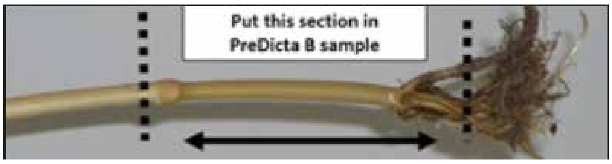


Photo 12: *Taking a sample for a PreDicta B test for crown rot.*

Source: GRDC

PreDicta B includes tests for:

- take-all (*Gaeumannomyces graminis var. tritici* and *G. graminis var. avenae*)
- Rhizoctonia barepatch (*Rhizoctonia solani AG8*)
- crown rot (*Fusarium pseudograminearum and F. culmorum*)
- blackspot of filed peas (*Mycosphaerella pinodes, Phoma medicaginis var. pinodella* and *Phoma koolunga*).

Accessing PreDicta B testing service

Growers can access PreDicta B diagnostic testing services through an agronomist accredited by the South Australian Research and Development Institute (SARDI). They will interpret the results and give you advice on management options to reduce your risk of yield loss.

SARDI processes PreDicta B samples weekly between February and mid-May (prior to crops being sown) every year, to assist growers with their cropping programs.

PreDicta B is not intended for in-crop diagnosis. See SARDI's Crop diagnostic webpage for other services.

For more information, see Section 9: Diseases.

1.8.3 Nematode status of paddock

Pratylenchus thornei and *P. neglectus* (both RLN) are migratory root endoparasites that are widely distributed in the wheat-growing regions of Australia and can reduce grain yield by up to 50% in many current wheat varieties (Photo 13). *Pratylenchus neglectus* and *Pratylenchus thornei* are the main RLN species causing yield loss in the southern agricultural region of Australia, and they can often occur together. [101]

At least 20% of cropping paddocks in south-eastern Australia have populations of RLNs high enough to reduce yield. [102]

101 QDAF (2010) Test your farm for nematodes. Queensland Department of Agriculture and Fisheries, July 2010, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/crop-diseases/root-lesion-nematodes/test-your-farm-for-nematodes

102 Agriculture Victoria (2013) Cereal root diseases. State Government of Victoria EDJTR, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-root-diseases

Photo 13: *Paddock showing patches caused by root-lesion nematodes.*

Source: DAFWA

Rye is relatively resistant, and can help to reduce root-knot nematodes (*Meloidogyne* spp.) and other harmful nematodes. [103]

Nematode testing of soil

PreDicta B includes tests for:

- cereal cyst nematode (*Heterodera avenae*).
- RLN (*Pratylenchus neglectus and P. thornei*).
- stem nematode (*Ditylenchus dipsaci*).

Effects of cropping history on nematode status

- Well-managed rotations are vital. Avoid consecutive host crops to limit populations.
- Choose wheat 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.

MORE INFORMATION

GRDC Tips and Tactics: Root-lesion nematode Southern Region

1.9 Insect status of paddock

Rye in the paddock is generally free from insect pests. Where problems arise, growers should contact their local agronomist or relevant state government department for advice.

Although rye is susceptible to the same insects that attack other cereals, serious infestations are rare. Rye reduces insect pest problems in rotations and attracts significant numbers of beneficials such as ladybird beetles. [104]

103 SARE (2007) Cereal rye: Managing cover crops profitably. 3rd edn. SARE Handbook, Sustainable Agriculture Research and Education, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

104 SARE (2007) Cereal rye: Managing cover crops profitably. 3rd edn. SARE Handbook, Sustainable Agriculture Research and Education, http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

Pests such as redlegged earth mites, blue oat mites, nematodes and, in some seasons, cutworms may 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.

Soil insects include:

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

1.9.1 Sampling of paddocks and soil for insects

Recent seasons have seen seemingly new pests and unusual damage in pulse and grain crops. Growers are advised to:

- Monitor crops frequently so as not to be caught out by new or existing pests.
- Look for and report any unusual pests or damage symptoms—photographs are useful.
- Just because a pest is present in large numbers in one year does not mean it will be so the next year. Another spasmodic pest may make its presence felt.
- Be aware of cultural practices that favour pests and rotate cops each year to minimise the build-up of pests and plant diseases. [105]

Sampling methods

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

Sweep net

The majority of crop monitoring for insect pests is done with a sweep net, or visually. Use of a shake/beating tray is an alternative. Sampling of pastures mostly relies on visual assessment of the sward or the soil below it.

The sweep net is the most convenient sampling technique for many insects. The net should be ~38 cm in diameter, and swept in a 180° arc from one side of the sweeper's body to the other. The net should pass through the crop at such an angle that the lower lip travels through the crop marginally before the upper lip. The standard sample is 10 sweeps, taken over 10 paces. This sampling 'set' should be repeated as many times as practicable across the crop, and at no less than five locations. After completing the sets of sweeps, counts should be averaged to give an overall estimate of abundance. Sweep nets tend to underestimate the size of the pest population. Sweep-net efficiency is significantly affected by temperature, relative humidity, crop height, wind speed, plant density and the operator's vigour. [106]

Soil sampling by spade

Method:

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

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

106 DNPE Victoria (2000) Sampling methods for insects and mites. In Insectopedia—an electronic insect pest management manual for south-eastern Australian grain and pasture pests. The State of Victoria, Department of Natural Resources & Environment, http://ipmguidelinesforgrains.com.au/insectopedia/introduction/sampling.htm

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:

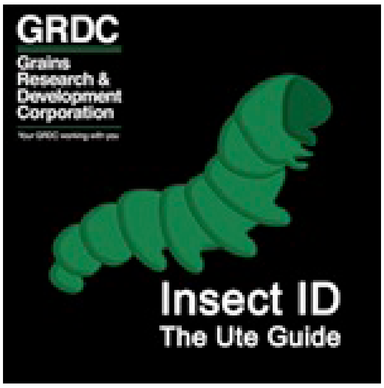
1. Soak insecticide-free crop seed in water for at least two hours to initiate germination.
2. Bury a dessertspoon of the seed under 1 cm of soil at each corner of a square 5 m × 5 m at five widely spaced sites per 100 ha.
3. Mark the position of the seed baits, because large populations of soil insects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

Trials have shown no difference in the type of seed used for attracting soil-dwelling insects. However, use of the type of seed that is to be sown as a crop is likely to indicate the species of pests that could damage that crop. The major disadvantage of the method is the delay between the seed placement and assessment. [107]

1.9.2 Identification

The SARDI Entomology Unit provides an insect identification and advisory service. The unit identifies insects to the highest taxonomic level for species where possible and can give farmers biological information and guidelines for control. [108]

Insect ID: The Ute Guide



The Insect ID Ute Guide, available on Android and iPhone, is a comprehensive reference guide for insect pests commonly affecting broadacre crops and growers across Australia, and includes the beneficial insects that may help to control them. Photos have been provided for multiple life-cycle stages, and each insect is described in detail, with information on the crops they attack, how they can be monitored, and other pests with which they may be confused. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [109]

App features:

- region selection
- predictive search by common and scientific names
- ability to compare photos of insects side-by-side with insects in the app
- identification of beneficial predators and parasites of insect pests

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

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

109 GRDC (2016). Resources: Apps Grains Research and Development Corporation, https://grdc.com.au/Resources/Apps

MORE INFORMATION

Pest Genie Pty Ltd: Pest Genie

Australian Pesticides and Veterinary Medicines Authority: APVMA

- option to download content updates in-app with the latest pests affecting crops for each region
- ensures awareness of international bio-security pests.

1.9.3 Effect of cropping history

It is important to consider paddock history when planning for pest management. Resident pests can be easier to predict by using paddock history and agronomic and weather data to determine the likely presence (and numbers) of certain pests within a paddock. This will point towards the likely pest issues and allow growers to implement preventive options. [110]

Reduced tillage and increased stubble retention have changed the cropping landscape with respect to soil moisture retention, groundcover and soil biology, and this has affected the abundance and types of invertebrate species being seen in crops. These systems increase invertebrate biodiversity and influence beneficial species such as carabid and ladybird beetles, hoverflies and parasitic wasps. However, these systems also create conditions more favourable for many pests such as slugs, earwigs, weevils, beetles and many caterpillars. [111]

See Section 7: Insect control for more information.

Where paddock history, paddock conditions or pest numbers indicate a high risk of pest damage, a grower might decide to use pre-seeding control measures 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. [112]

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

- Weedy fallows and volunteer crops encourage soil insect build-up.
- Insect numbers decline during a clean long fallow due to lack of food.
- Summer cereals followed by volunteer winter crops promote the build-up of earwigs and crickets.
- High levels of stubble on the soil surface can provide a food source for some soil insects; however, this can also mean that pests continue feeding on the stubble instead of germinating crops.
- No-till encourages beneficial predatory insects and earthworms.
- Incorporating stubble promotes black field earwig populations.
- False wireworms are found under all intensities of cultivation but numbers decline if stubble levels are very low.

Soil-insect control measures are normally applied at sowing. Because different insects require different control measures, the species of soil insects 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 moist–dry soil interface. [113]

For more information, see Section 7: Insect Control.

110 R Jennings (2015) Growers chase pest-control answers. GRDC Ground Cover, June 2105, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Growers-chase-pest-control-answers

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

112 G Jennings (2012) Integrating pest management. South Australian No-Till Farmers Association, Spring 2012, http://www.santfa.com.au/wp-content/uploads/Santfa-TCE-Spring-12-Integrating-pest-management.pdf

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