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GROWNOTES™

VETCH

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Contents

Introduction

Introduction

A.1 Crop overview

Vetch (*Vicia* spp.) is a legume offering significant benefits to grain growers, despite being only a minor crop (Photo 1). Vetches are classified broadly as either grain or forage legumes. Vetch is more commonly grown for forage and hay than for use as a grain crop. [1]

Vetch has been adopted by Australian farmers as a legume rotation crop where drought is the major environmental stress. Vetch is better adapted to these regions than field peas, chickpeas, lentils, faba beans or lupins. [2]

Photo 1: *Common vetch (Morava⦸).*

Photo: Stuart Nagel

Vetch is not grown for human consumption, however, it is a very versatile crop, allowing decisions about its end-use to be made during the year. While providing stock feed over winter, it then has a number of end-use options - as a grain, hay, silage and pasture or as green or brown manure.

As a legume, it can fit well into cereal and canola rotations, providing nitrogen to the soil, and can potentially reduce the incidence of diseases in succeeding crops. Vetch can also be used as a management tool against resistant weed development, though it is important to note that there are few herbicides registered for in-crop control. [3]

Vetch can be a valuable addition to continuous cropping systems. The income from vetch hay combined with highly effective non-chemical weed control and water conservation, especially preceding higher value such as canola, can make the legume hay crop a good option. However, soil cover is reduced for vetch hay

1 R Matic (2010) Vetch summary 2010. SARDI. Online Farm Trials. http://www.farmtrials.com.au/trial/14055

2 R Matic (2015) GRDC Final Reports: DAS00013 – Vetch variety improvement for Australian field crop farming systems. https://grdc.com.au/research/reports/report?id=268

3 K Penfold (2006) Vetch interest puts pressure on supply. Groundcover GRDC. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-60/vetch-interest-puts-pressure-on-supply

compared with brown manure and this low cover can be an issue with low-biomass grain legumes on erosion-prone areas. [4]

In mixed farm operations, vetch is a viable winter grazing crop which can be eaten down and then locked up and either made into hay or stripped for grain. Vetch is often grown solely for grazing and is sprayed out in the spring when the bulk of the crop has been removed. This also offers an opportunity to control spring weeds when a knockdown spray such as glyphosate is used

Vetch is grown in a wide range of soil types from light sands to heavier clay soils.

In higher rainfall areas (>400 mm/year), most farmers prefer to produce grain; in drier areas (350–400 mm/year) farmers like to use vetch crops for hay or silage. In lower rainfall regions vetch is commonly grown for grazing and green manuring. [5]

In 2005/06, 142 introductions passed quarantine and were tested for the targeted traits in comparison with advanced lines and present varieties. Eleven *Vicia* species/subspecies were tested for use as hay crops.

The Australian National Vetch Breeding Program found that the common vetch (*V. sativa*) and hairy/fodder/winter vetch (*V. villosa)* species/subspecies are useful in Australia for hay/silage production. The plants of these two species have most targeting traits.

The other species are smaller plants and most of them are prone to shattering. Palestine vetch (*V. Palestine)* is the most drought tolerant, but the lowest in dry matter production. Purple vetch (*V. benghalensis*) has hard seeds and is not reliable in the crop rotations. Bitter vetch (*V. ervilia)* is a better vetch. It is a small plant with a better test as a green manure and grain is not recommended to use for any stock feed. All Hungarian vetch (*V. pannonica)* tested introductions are prone to shattering. [6]

A.1.1 Types of vetch

Common vetch varieties are mainly relatively short season, early maturing types which are more suited to grain or dual purpose situations.

Purple vetch are long season, late maturing annuals suitable for fodder production in cropping country. This variety regenerates poorly and not suitable for permanent pastures.

Woolly pod vetch can be used as a pasture plant, hay/silage and green manuring crop. Plant establishment is much slower than common vetches (in 10–12 weeks reaching 10–15 cm high). These varieties in Australian conditions grow rapidly during the second part of vegetation and generally are higher in dry matter production than common vetches. [7] This species is medium-late maturing cultivars with very high levels of 'hard' seed. It is more suited to permanent pastures. Woolly pod vetch is not recommended in cropping country where regeneration could be a problem in cereal crops. [8]

A.1.2 Vetch for feed grain

Vetch is a very good source of crude protein. It has high digestibility of dry matter and is high in metabolisable energy. [9]

Grain or common vetch (*Vicia sativa*) varieties Morava⚖, Rasina⚖, Blanchefleur and Languedoc are grown for forage, hay, grain, green manure or grazing (Photo 2). Grain vetch for ruminants is considered similar to field peas, but much smaller in size.

4 J Kirkegaard (2017) Careful management required to sustain continuous cropping. GRDC E-Newsletter.

5 R Matic, S McColl (2013) Which vetch is my farming system? Online Farm trials. http://www.farmtrials.com.au/trial/16634

6 R Matic (2007) Improved vetch varieties for fodder production. Rural Industries Research and Development Corporation.

7 R Matic, S Nagel, G Kirby (2008) Woolly pod Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Woolly_pod_vetch.htm

8 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

9 K Penfold (2006) Vetch interest puts pressure on supply. Groundcover GRDC. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-60/vetch-interest-puts-pressure-on-supply

MORE INFORMATION

Pulses nutritional value and their role in the field industry

Vetch interest puts pressure on supply

Photo 2: *Vetch grain.*

Source: Pulse Australia

Grain vetches are not generally recommended for monogastrics. There is evidence that bitter vetch is a suitable grain for ruminants, but use in monogastrics should be treated with caution. Grain supply of bitter vetch is very limited. [10]

Common vetch grain is rich in the following main characteristics: crude protein 28–32%; digestibility 71–89% and metabolisable energy 9.8–13.7MJ/kg DM. Grain from common vetches can be used without limit in rations together with cereals to feed ruminants, or in cereal grain mix up to 25% for pigs. [11]

For more information about Vetch feed quality, see Section 2: Pre-planting, section Vetch for feed grain.

A.1.3 Vetch for forage

Information gathered from district agronomists, farmer advisors, seed distributors and field days indicate that over 65% of vetch production is used for hay/silage. [12] Vetch hay and silage are highly palatable for all ruminants. Cutting vetch for hay and silage at the flowering-early podding stage means that many weeds are also cut before they begin setting seed, which reduces weed populations in the following crop, saves herbicide applications and decreases the risk of herbicide resistance development.

Vetch hay is a very rich source of protein and metabolisable energy and is highly digestible for all ruminants (Table 1). Australian dairy farmers are increasingly adopting vetch hay as one of the main forage sources to increase milk production. Vetch hay or silage has been reported to have increased milk production per cow by more than 12% compared with meadow/grass or cereal hay. [13]

Table 1: *Hay samples measurements of quality. Data from DPI Hamilton Pastoral and Veterinary Institute (1999–2005) and Agrifood Technology (2007–2011).*

Hay	No. of samples		Crude Protein (%)	Metab. Energy (MJ/kg DM)	Dry matter digestibility (%)
Oaten	870	Mean	7.2	9.1	63.0
		Range	1.7–17.9	5.6–11.4	41.3–78.0
Lucerne	273	Mean	19.6	9.4	65.4
		Range	9.6–26.3	5.3–11.1	39.2–75.7
Clover	40	Mean	17.5	9.1	66.9
		Range	10.6–24.0	7.7–10.5	57.5–79.4
Medic	67	Mean	19.3	9.5	65.6
		Range	13.7–23.9	7.5–11.2	53.4–76.2
Vetch	229	Mean	20.2	9.0	62.9
		Range	15.6–26.2	7.2–11.0	51.2–74.9

Source: Online Farm Trials

10 W Hawthorne (2006) Pulses nutritional value and their role in the feed industry. Pulse Australia Pty Ltd. http://www.pulseaus.com.au/storage/app/media/using_pulses/2006_Pulses-Feed-value-livestock.pdf

11 R Matic, S McColl (2013) Which vetch is my farming system? Online Farm trials. http://www.farmtrials.com.au/trial/16634

12 R Matic (2007) Improved vetch varieties for fodder production. Rural Industries Research and Development Corporation.

13 R Matic, S McColl (2013) Which vetch is my farming system? Online Farm trials. http://www.farmtrials.com.au/trial/16634

MORE INFORMATION

Using pulses for forage

All common vetch varieties are similar in palatability for green grazing. Common vetches can be grazed from 10–15 cm high to the end of pod maturity. [14]

For more information on grazing vetch, see Section 2: Pre-planting, sections 2.1.2 Vetch for forage and 2.1.4 Grazing/cutting of vetch.

A.1.4 Vetch for manuring

In subtropics in northern New South Wales and southern Queensland, vetch is used mainly as a green manure in cotton production, orchards and vineyards. [15]

Vetch has the ability to offer substantial benefits to soil fertility and can contribute to improvements in soil structure and organic matter. It also provides a weed and disease break for cereals in a crop rotation. The Australian National Vetch Breeding Program (ANVBP) results across five sites in southern Australia over three years have shown after a vetch grain crop, total nitrogen in the soil increased by 56 kg/ha. After vetch hay production 94 kg/ha of nitrogen was returned to the soil, and after green manuring there was an increase of 154 kg/ha of soil nitrogen. Cereal yields following vetch are usually at least 30–50% higher than continuous cropping cereals. [16] [17]

A green crop of vetch can be worked into the soil with cultivation equipment to boost organic matter content. More commonly the vetch crop is brown manured by desiccating using a knockdown herbicide to kill both the vetch and weeds, and allowed to decompose over the fallow period before being worked into the soil at sowing.

Producing large volumes of biomass makes vetch a good green or brown manure crop. This is because vetch returns large amounts of organic matter to the soil, which, in turn, boosts biological activity. Add to this its ability to fix nitrogen and it provides the ideal manure crop. There are three key reasons for manuring legumes:

- management of weeds, particularly if they are herbicide-resistant;
- boost soil nitrogen; and
- conserve soil moisture for subsequent crops.

The main disadvantage of a manure crop compared to a non-cropped fallow is the cost of establishment (seed plus sowing) and herbicides. Despite the manure phase being cash-flow negative in the first season, a crop production system involving a manure crop can be more economic than continuous cropping.

To gauge the true value of legumes in a crop sequence, the input costs and crop returns need to be considered over the whole crop sequence in terms of net income per hectare per year. [18]

A.2 Growing region

The Northern growing region stretches from southern NSW to northern Queensland. Common vetch is more commonly grown in the winter cropping regions while woolly pod vetch is more common in the sub-tropical areas of the Northern region.

Vetch is a minor crop in the Northern region, with a small amount grown for grain in southern NSW and mainly grown for hay/silage, grazing and green or brown manuring elsewhere in the region.

The north has a relatively high seasonal rainfall and production variability compared with the other two regions. Both summer and winter crops are important for profit.

14 R Matic, S McColl (2013) Which vetch is my farming system? Online Farm trials. http://www.farmtrials.com.au/trial/16634

15 R Matic, S Nagel, G Kirby (2008) Woolly pod Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Woolly_pod_vetch.htm

16 I Rochester (2004) Rotational vetch lifts cotton yields and profit. Farming Ahead 150, pp. 54–55.

17 M Unkovich, J Pate, P Sanford (1997) Nitrogen fixation by annual legumes in Australian Mediterranean agriculture. Australian Journal of Agricultural Research 48, pp. 267–293.

18 GRDC (2013) Manuring of Pulses. GRDC Fact Sheet https://grdc.com.au/Resources/Factsheets/2013/09/Manuring-of-Pulse-Crops

Yield depends, to a significant degree, on conservation of soil moisture from summer-dominant rainfall. The Northern Region has the highest diversity of crop production, including maize, sorghum and tropical pulses as well as wheat, barley, winter-growing pulses and oilseeds

Key characteristics of the Northern growing region include:

- Tropical and subtropical climate
- Yield depends upon conservation of soil moisture from subtropical rainfall
- Substantial enterprise size
- Diversity in crop choice, need for new crops e.g. pulses
- Premium on high-protein wheats for export and domestic markets
- High-potential yields
- Competition with cotton

Winter crops grown in the Northern region include; wheat, barley, oats, chickpeas, triticale, faba beans, lupins, field peas, canola, safflower and linseed.

Summer crops grown in the Northern region include; sorghum, sunflowers, maize, mungbeans, soybeans, cotton and peanuts.

A.3 Brief history

In the early 1990s, vetch production in Australia collapsed due to a lack of information regarding toxicity, and the emergence of rust and ascochyta as a disease problem. Another limiting factor was the weediness of vetches (hard seededness). However, this was overcome by the release of Morava⍉ with 100% soft seed and the availability of herbicides to control volunteer vetches in cereal crops. In the 1990s, Australian vetch production dropped to under 20,000ha/annum. After the release of soft seeded varieties, vetch production increased dramatically and has remained high. The area sown to vetch increased from 35,000ha in 1998 to over 250,000ha per year in 2015, due to the promotion of the versatility of the crop and its variety of end use options. [19]

Since it began in 1992, the National Vetch Breeding Program (NVBP) funded by the Grains Research and Development Corporation (GRDC) has focused on breeding common vetch (*Vicia sativa*) varieties for Australian farmers for use as hay/silage, grazing, grain and green manuring. In 2005, the program also included the breeding/selection of woolly pod vetches (*Vicia villosa*) for grazing, hay/silage and green manuring.

A South Australian Grains Industry Trust Fund (SAGIT) project was added to the program in 2008, investigating the potential of new vetch species/varieties for very low rainfall areas in southern Australia. This program is investigating *Vicia palaestina* (leaf dense vetch – LDV), *V. macrocarpa* (big leaf vetch – BLV), *V. articulate* (Bard vetch) and *V. obicularis* (small erect vetch). From this SAGIT project Leaf dense vetch (*V. palaestina*) has shown the best results in areas with less than 300 mm average annual rainfall and the program will concentrate on this species to deliver varieties to farmers for grazing, hay/silage, green manuring and further investigate its potential for grain use. [20]

Vetch has become an increasingly important crop for the less productive areas in southern Australian cropping regions.

A.3.1 Breeding objectives

The Vetch Breeding Program has adopted the most appropriate breeding, selecting and testing methods to provide farmers with improved vetch varieties that possess higher grain and dry matter yields, wider adaptability in Australian cropping

19 R Matic (2015) GRDC Final Reports: DAS00013 – Vetch variety improvement for Australian field crop farming systems. https://grdc.com.au/research/reports/report?id=268

20 S Nagel, R Matic, G Kirby (2011) Vetch in Australia farming systems. SARDI. http://eparf.com.au/wp-content/uploads/2014/12/2011–26.-Vetch-in-Australian-farming-systems.pdf

environments, resistance to major diseases to avoid chemical cost/use, fit into crop rotations and increase farm productivity.

Vetch for grain production means it must be high yielding, disease-resistant, particularly to rust, with low toxins, large seeds, soft seeds, non-shattering and high-protein.

Vetch for pasture, hay or green manure must have high winter yield, palatability, adaptability to grazing, compatibility with sown cereals, high herbage, disease resistance and low alkaloid content in foliage. [21]

The Australia National Vetch Breeding Program (ANVBP) focuses on breeding varieties with:

- high yields of grain and dry matter
- resistance to rust, ascochyta and botrytis
- soft seed to avoid weed problems in following crops
- lower toxins in the grain for inclusion as a stock feed
- varieties adapted to lower rainfall areas where other crops are performing poorly
- non-shattering pods. [22]

21 K Penfold (2006) Vetch interest puts pressure on supply. Groundcover GRDC. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-60/vetch-interest-puts-pressure-on-supply

22 R Matic, S McColl (2013) Which vetch is my farming system? Online Farm trials. http://www.farmtrials.com.au/trial/16634

Planning/Paddock preparation

Key messages

- There are many benefits to including vetch in cropping sequences including; nitrogen fixation and increased weed and pest control options.
- Vetch is sensitive to highly saline, sodic and acidic soils and cannot tolerate long periods (7 days) of waterlogging.
- Vetch should be sown into a clean seedbed, with weeds controlled prior to planting with cultivation and/or herbicides. Post emergent herbicide options for weed control in vetch is limited.
- Vetch is well suited to no-till, standing stubble systems.
- To reduce the risk of disease, vetch should be sown into paddocks only once every four years.
- Caution should be taken that vetch does not carry over to following pulse crops in the rotation. For example, zero tolerance of vetch in lentils.

Vetch can be a valuable addition to continuous cropping systems. The income from vetch hay combined with highly effective non-chemical weed control and water conservation, especially preceding higher value and risky crops such as canola, can make the legume hay crop a good option. However, soil cover is reduced for vetch hay compared with brown manure and this low cover can be an issue with low-biomass grain legumes on erosion-prone areas. [1]

1.1 Paddock selection

Vetches are potentially adapted to most areas of Australian farming land. [2]

The crop is adapted to and grown in most soil types and rainfall areas in southern and Australia, with grain yields similar to pea yields in these areas. It is also grown in New South Wales and southern Queensland (mostly as a green manure).

1.1.1 Rainfall

Vetch is suited to areas with annual rainfall of 300–750 mm (growing season rainfall 200–350 mm). Early flowering varieties (Rasina(D) & Langedoc) are suited to lower rainfall zones, and Morava(D) and Blanchefleur for higher rainfall zones. These forage vetches can grow successfully in areas of 400 to 650 mm of annual rainfall (Table 1).

Table 1: *Recommended Vetch grain variety according to rainfall zones (mm).*

<350	350–400	400–450	450–600	>600
Rasina(D)	Rasina(D)	Morava(D)	Morava(D)	Morava(D)
Cummins	Blanchefleur	Rasina(D)	Rasina(D)	Timok(D)
Volga(D)	Cummins	Blanchefleur	Timok(D)	
Timok(D)	Morava(D)	Cummins		
	Volga(D)	Volga(D)		
	Timok(D)	Timok(D)		

Source: SARDI

1 J Kirkegaard (2017) Careful management required to sustain continuous cropping. GRDC E-Newsletter.

2 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

1.1.2 Soil conditions for vetch production

Soils in the Northern region tend to have a moderate to high percentage of clay and vary in colour from yellow through to red, brown, grey and black. Major soil types are Vertosol, Dermosol, Chromosol, Sodosol, Kandosol and Ferrosol. [3]

Vetch is adapted to a broad range of soils, from acidic granite and sandstone soils through to highly alkaline and/or heavy clay soils (Table 2). It grows better than field peas on more hard-setting soils.

Table 2: *Vetch soil requirements.*

Factor	Vetch adaptation
Soil pH requirement	5.0–9.0
Soil texture	Loamy sand-clay
Drought adaptation strategies	Drought escape
Waterlogging	Sensitive
Boron toxicity/sodicity	Moderately tolerant
Salinity	Moderately sensitive
Surface crusting	Sensitive

Source: B French, P White, 2005

MORE INFORMATION

Soil acidity and liming

Vetch is sensitive to long periods (over 7 days) of waterlogging or saline conditions, and should be grown on well-drained soils. [4] Vetch yield declines when soil ECe is less than 3.0 dS/m. Yield declines at the rate of 11% for each unit increase in ECe. This is because vetch has poor root penetration into sodic soils. [5]

Vetch prefers neutral soils, but can grow in slightly acid (pH 6.3) to alkaline (7.5–7,8pH) soils. [6] Vetch is more tolerant to acid soils than most other legumes.

In trials on alkaline and acid soil types (sandy loam, heavy clay, and non-wetting sand in low to high rainfall areas), vetch showed good tolerance to all soil types over three years. An extra 1 mm of rain was found to produce an extra 18–24 kg of vetch dry matter in these trials. [7]

Vetch does not perform at high levels of exchangeable aluminium in the soil, having a similar tolerance to that of sub clover and white clover, but less than that of serradella. [8]

Lime pelleting at sowing is recommended when planting into acid soils below pH 5.5. [9]

1.1.3 Sodic or dispersive soils

Sodicity is a term given to the amount of sodium held in a soil. Dispersive soils are generally a surface problem, sodicity can be at the surface but also at depth; i.e. plant roots hot this layer and become restricted in growth and cannot extract as much water out of the profile. High sodicity causes clay to swell excessively when wet. The clay particles move so far apart that they separate (disperse). This weakens the aggregates in the soil, causing structural collapse and closing-off of soil pores. For this reason, water and air movement through sodic soils is severely restricted. In crop paddocks, sodic layers or horizons in the soil may prevent adequate water

3 D Herridge. (2011). Managing legume and fertiliser N for Northern grains region. http://www.ini2016.com/pdf-posters/Herridge.pdf

4 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

5 CRDC. Comparative advantages/disadvantages of rotation crops with cotton. http://www.cottoninfo.com.au/sites/default/files/tools/CottonRotation/Rotation_chart_Page_1small.pdf

6 R Matic, S Nagel, G Kirby (2008) Woolly pod Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Woolly_pod_vetch.htm

7 R Matic (2007) Improved vetch varieties for fodder production. Rural Industries Research and Development Corporation.

8 NSW DPI. Namoi Woolly pod vetch. http://www.dpi.nsw.gov.au/agriculture/pastures-and-rangelands/species-varieties/namoi-woolly-pod-vetch

9 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

penetration during irrigation, making the water storage low. Additionally, waterlogging is common in sodic soil, since swelling and dispersion closes off pores, reducing the internal drainage of the soil. Sodicity of the surface soil is likely to cause dispersion of surface aggregates, resulting in surface crusts.

Soils with an exchangeable sodium percentage (ESP) ≥6 are classified as sodic. Poor drainage, surface crusting, hardsetting (Photo 1) and poor trafficability or workability are common when the soil has a large proportion of sodium ions (Na+), leading to reduced crop yield.

A surface crust is typically less than 10 mm thick and when dry can normally be lifted off the loose soil below. Crusting forces the seedling to exert more energy to break through to the surface, thus weakening it. A surface crust can also form a barrier reducing water infiltration.

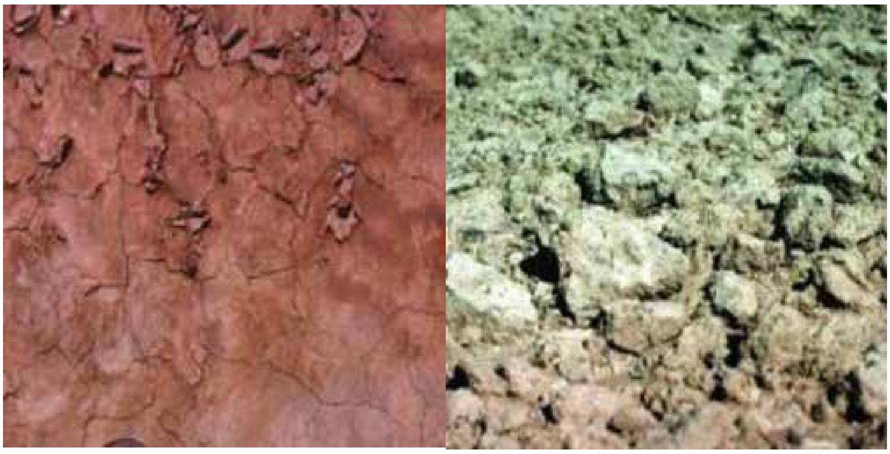


Photo 1: *Soil crusting (left) and cloddy seedbed (right) associated with high concentrations of exchangeable sodium; i.e. sodic soil.*

Source: Soilquality.org

Field research in Victoria/South Australia indicates that soil salinity and sodicity can substantially reduce crop yields. [10] Vetch yield declines when soil ECe is less than 3.0 dS/m. Yield declines at the rate of 11% for each unit increase in ECe. This is because vetch has poor root penetration into sodic soils. [11]

Crop growth is affected by salinity and sodicity in two ways: firstly, the osmotic potential effect and secondly specific ion toxicity. Salts lowers the osmotic potential (i.e. makes it more negative) or increases osmotic pressure leading to yield losses as plants cannot extract water from soils when soil solution has lower osmotic potential than the plant cell. Grain productivity decreases as electrical conductivity (EC) and ESP of the soil increases.

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

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

11 CRDC. Comparative advantages/disadvantages of rotation crops with cotton. http://www.cottoninfo.com.au/sites/default/files/tools/CottonRotation/Rotation_chart_Page_1small.pdf

very low solubility and therefore takes longer to observe results. It is also dependant on the pH of the soil.

The use of decision process models such as Gypsy© can be used as a guide when deciding on the cost of gypsum applications. [12]

Plant available water capacity

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

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

Information regarding the PAW at a point in time, particularly at planting, can be useful in a range of crop management decisions. Estimating PAW, whether through use of a soil water monitoring device or a push probe, requires knowledge of the PAWC and/or the Crop Lower Limit (CLL).

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

Factors that influence PAWC

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

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

The CLL may differ for different crops due to differences in root density, root depth, crop demand and duration of crop growth. Some APSoil characterisations only determined the CLL for a single crop. [13]

MORE INFORMATION

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

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

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

Testing for sodicity

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

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

Applying gypsum

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

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

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

In soils with moderate surface sodicity, applying gypsum at 2.5–5.0 t/ha has been found to significantly improve wheat grain yield in Queensland. [14] Be wary that gypsum application may reduce nodulation in lupin crops. This was found in trials in Western Australia, where the increased salt levels in the soil due to gypsum application was found to impair lupin nodulation. [15]

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

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

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

MORE INFORMATION

Lime, gypsum and dolomite for acid soils

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

15 S Loss, L Moreschi (2004) Lime, gypsum and dolomite for acid soils. Liebe Group. Online farm trials. http://www.farmtrials.com.au/trial/10345?search_num=4

Deep ripping

This can be used to break up compacted and poorly structured soils and to help generate structure and porosity. However, the benefits can be very short-lived. Sometimes deep ripping makes the soil worse because worked (tilled) soil disperses more readily. Ripping can bring up large clods of dispersive soil and bring toxic elements such as boron and salt to the surface. Consequently, only undertake deep ripping after careful consideration. If in doubt, first carry out deep ripping on a small test strip. After ripping apply gypsum or lime (in acid soils), preferably with additional organic matter, to help stabilise the deep ripped soil. A tramline (controlled traffic) farming system will help prevent re-compaction of the loosened soil. [16]

Lime application to sodic soils

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

MORE INFORMATION

Sodic soil management

Sodic soils a management labyrinth

Cultivating sodic soils

dispersive and sodic soils are more prone to structural degradation than non-sodic soils. For this reason, they must be cultivated minimally and carefully. Excessive cultivation of these soils will cause major soil structure problems. In this may be evident as crusting, hardsetting and poor water penetration. [17]

1.1.4 Soil salinity

Key points:

- Soil salinity varies across the landscape and within paddocks.
- The severity varies over time, in response to both climate and land management.
- Soil salinity can be managed by farming actions.
- Vetch is sensitive to long periods (over 7 days) of saline conditions.

What is soil salinity?

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

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

Salinity affects crop yield and growth in dryland regions mainly by reducing Water Use Efficiency of crops through osmotic effect. Toxic effects of individual ions such as sodium can also cause yield reduction. When the osmotic pressure of the soil solution is less than (<) 700 kilopascals (kPa), there is a low rate of reduction in yield irrespective of the type of ions (salt). At these lower osmotic pressures the specific ion effect, particularly of sodium, is significant.
For osmotic pressure greater than (>) 700 kPa the rate of crop yield reduction is

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

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

severe. When the osmotic pressure is above 1,000 kPa, the crop yield is reduced by >50% and 80–95% of available soil water is not taken up by plants. [18]

Measuring salinity

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

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

Dryland salinity

Dryland salinity occurs when naturally occurring salts in rocks and soil are mobilised and redistributed by water, e.g. by surface run-off after rain, the recharge of groundwater, subsurface lateral flows of groundwater, or groundwater discharge. It occurs throughout NSW (Photo 2). [19] Saline outbreaks in upland areas of the NSW Murray–Darling Basin cover around 62,000 hectares, but individual areas are usually less than 10 hectares. Most salt scalds occur in the 600–700 mm rainfall zone.

Photo 2: *Scalding by salt.*

Photo: Graham Johnson, NSW Government

Irrigation salinity

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

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

Managing groundwater levels

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

- Monitoring groundwater levels.

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

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

MORE INFORMATION

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

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

Troubleshooting

Recognising and acting on salinity problems early is the best solution, as salinity can be a more difficult and expensive issue to correct once it is well advanced. **Dryland salinity** outbreaks can be managed by excluding grazing on saline areas and sowing saline tolerant species. **Irrigation salinity** can be managed by improving irrigation management, specifically application efficiency. Specific management of salt-affected areas could include having hill and bed shapes that minimise salt accumulation around seedlings, and pumping and recycling groundwater (although this requires advice from a hydrology consultant). [20]

1.1.5 Soil pH

Vetch grows best on soils with neutral pH. Lime pelleting at sowing is recommended when planting into acid soils below pH 5.5. [21]

Acidic soil

Acidic soils are an impediment to agricultural production. More than half of the intensively used agricultural land in NSW is affected by soil acidity.

Acidity reduces the survival of Rhizobia and the effective infection of legume roots. When rhizobia are affected by soil acidity it shows as poor nodulation and results in reduced nitrogen fixation. Often Rhizobium bacteria are more sensitive to soil acidity than the host plant. Lime pelleting of inoculated legume seed is used to protect the inoculum against drying out and contact with fertiliser. Sowing into bands of limesuper also creates an environment suitable for survival of the inoculum in an acidic soil.

Management

If only the top 10 cm of the soil profile is acidic it can be readily corrected by applying and incorporating finely ground limestone. However, if acidification of the soil continues and the surface pHCa drops below 5.0 the acidity will leach into the subsurface soil (Figure 3). The further the acidity has moved down the profile the greater the effect on plant growth and the more difficult it is to correct. This is called subsurface soil acidity and is a long-term degradation of the soil.

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

21 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

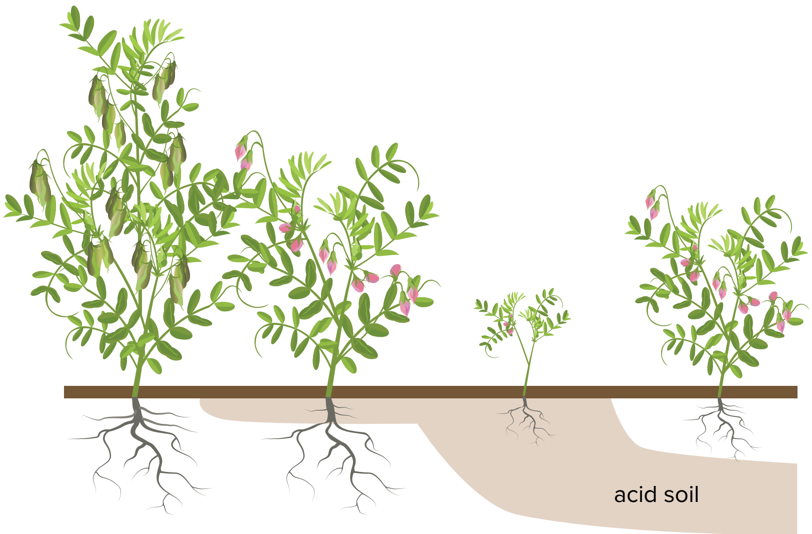


Figure 1: *The development of subsoil acidity and the implications for acid sensitive plants. a) No acidic soil problemsb) Acidification starts at the surface restricting surface root development. c) Acidity is leached to depth when the pHCa of the surface soil drops below 5.0 and all root growth is restricted. d) Subsurface soil acidity is permanent as surface applied lime only corrects acidity in the surface soil.*

Source: NSW DPI

There are a number of agronomic practices to reduce soil acidification including; growing acid tolerant crops, reducing leaching of nitrate nitrogen, using less acidifying fertilisers and preventing erosion of topsoil. However, the most direct way of improving soil acidity is through liming.

Application of finely crushed limestone, or other liming material, is the only practical way to neutralise soil acidity. Limestone is most effective if sufficient is applied to raise the pHCa to 5.5 and it is well incorporated into the soil. Where acidity occurs deeper than the plough layer, the limestone will only neutralise subsurface soil acidity if the pHCa of the surface soil is maintained above 5.5. The liming materials most commonly used are agricultural limestone and dolomite, but other materials are available.

Recommended liming rates based on a standard soil test are given in Table 3. Apply limestone before the most acid sensitive crop or pasture in a rotation as it gives the best economic return. If the limestone will not be effectively incorporated due to reduced tillage then apply the limestone a year before the most sensitive crop and apply it at a slightly heavier rate. These two actions will enhance lime movement into the top soil. The time of the year when lime is applied is not important. Limestone begins to become effective as soon as the soil is moist and reaches its major impact after 12–18 months.

Table 3: *Limestone required (fine and NV>95) to lift the pH of the top 10 cm of soil to 5.2. Colour codes group limestone rates to the nearest 0.5 t/ha.*

Soil test ECEC (meq/100 g)	Lime required (t/ha) to lift the pH of the top 10 cm:			
	from 4.0 to 5.2	from 4.3 to 5.2	from 4.7 to 5.2	from 5.2 to 5.5
1	1.6	0.8*	0.3*	0.2*
2	2.4	1.2	0.5*	0.4*
3	3.5	1.7	0.7	0.5*
4	3.9	2.1	0.9	0.6
5	4.7	2.5	1.1	0.7
6	5.5	3.0	1.2	0.8
7	6.3	3.3	1.4	1.0
8	7.1	3.8	1.6	1.1
9	7.9	4.2	1.8	1.2
10	8.7	4.6	1.9	1.3
15	12.5	6.7	2.8	1.9

*It is recognised that low rates of lime are impractical to apply, but over-liming can cause nutrient imbalances, particularly in these light soils.

KEY: Limestone rates per hectare

0.5 t/ha	1.0 t/ha	1.5 t/ha	2.0 t/ha	2.5 t/ha	3 to 4 t/ha	Split applications are advised

Source: NSW DPI

Because limestone moves very slowly down through the soil, incorporation should be to the depth of the acidity problem (or as deep as practicable) for the most effective and speedy response. [22]

Testing soil

Soil pH is a measure of the concentration of hydrogen (H +) ions in the soil solution, measured on a logarithmic scale from 1 to 14, with 7 being neutral (Figure 2). The lower the pH, the greater the acidity. A soil with a pH of 4 has 10 times more acid than a soil with a pH of 5, and 100 times more acid than a soil with a pH of 6.

MORE INFORMATION

Soil acidity and liming

22 B Upjohn, G Fenton, M Conyers. (2005). Agfacts: Soil acidity and liming. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/167209/soil-acidity-liming.pdf

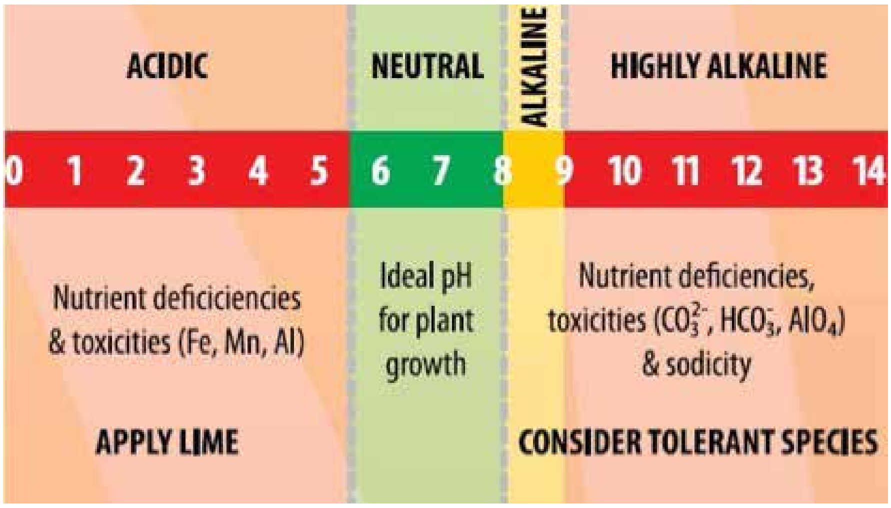


Figure 2: *Classification of soils on the basis of pH (1:5 soil:water), the implications for plant growth and some management options.*

Source: Soilquality.org

The standard measurement of soil pH uses a mixture of one part soil to five parts 0.01 M $CaCl_2$ (calcium chloride). Measured in water, pH can read 0.6–1.2 pH units higher than in calcium chloride, and soils with low total salts show large seasonal variation if pH is measured in water. Field soil pH kits give results similar to water measurements and complement periodic laboratory testing.

The best time to soil test is in autumn, two to ten days after good rain. Samples should not be taken from; overly wet or dry soils, at times of extreme high or low temperatures, within a few weeks of fertiliser applications, or within months of lime application. Sampling sites should take account of paddock variability and be recorded using GPS (Photo 3). Samples at the soil surface and subsurface will determine the soil pH profile and detect subsurface acidity. Sampling should be repeated at the same locations, same time of year and under similar conditions at least every three to four years to detect changes and allow adjustment of management practices. [23]

23 S Alt, P Gazey. (2013). Soil acidity – NSW. Soilquality.org. http://www.soilquality.org.au/factsheets/soil-acidity-new-south-wales

Photo 3: *Soil cores need to accurately reflect the main soil type in the paddock being tested.*

Photo: N Baxter, Source: GRDC

1.2 Paddock rotation and history

Northern region grain growers have embraced crop rotations for the benefits they offer for producers operating within an increasingly challenging cropping environment. More and more growers are understanding there are no quick fixes for many of the region's grain growing challenges and are turning to a farming system approach hinging on crop sequencing, herbicide rotations, integrated weed and pest management (IWM and IPM) and practices such as minimum tillage that promote soil health.

To limit the risk of disease in vetch and other pulses in the cropping sequence, vetch should be limited to no more than once in every four years in a particular paddock. [24]

Vetch is susceptible to ascochyta blight, botrytis grey mould and rusts, and it is not recommended to sow vetch into paddocks where inoculum may be present.

Sow vetch into paddocks where Group E inoculant has been present before, otherwise it is highly recommended to inoculate vetch with Rhizobia.

Vetch is often grown for its benefits to following cereal rotations.

1.3 Benefits of vetch as a rotation crop

Vetch is valued for its benefits to subsequent cereal and oil seed crops in the rotation, these benefits are usually greater than from other pulses particularly in lower rainfall areas. Vetch has been adopted by Australian farmers as a legume rotation crop where drought is the major environmental stress. Its substantial root system and its ability to flower quickly and set seed in a dry spring give it good drought tolerance. Vetch is better adapted to these regions than field peas, chickpeas, lentils, faba beans or lupins. [25]

On sandy soils vetches provide better soil protection than peas and provide better stubble retention in the soil.

24 R Matic (2010) Vetch summary 2010. SARDI. Online Farm Trials. http://www.farmtrials.com.au/trial/14055

25 R Matic (2015) GRDC Final Reports: DAS00013 – Vetch variety improvement for Australian field crop farming systems. https://grdc.com.au/research/reports/report?id=268

Vetches have the ability to offer substantial improvements in soil fertility, structure and organic matter. Vetch can increase soil nitrogen, decrease weeds and make direct drilling easier. Savings on fertiliser and herbicides for the following grain crop are two major incentives for using vetch. In addition to viable grain and forage production from vetch, cereal crop yields following a vetch crop are usually at least 30% to 50% higher than those derived from continuous cropping with cereals (Photo 4).

Vetch can provide alternative options to pulses for grain and potentially some management of frost risk. [26]

Vetch has become an increasingly important crop for the less productive areas in southern Australian cropping regions. Vetch is grown with low inputs despite the recognised nutritional and agronomic benefits it provides.

Photo 4: *The effect of rotation is clear – the canola/wheat/wheat rotation (left) had 31 kilograms of nitrogen per hectare applied, while the vetch/canola/wheat rotation (right) had 9 kg of N/ha applied.*

Source: GRDC

1.3.1 Nitrogen fixation

Vetch is a versatile nitrogen fixing legume and green manure crop offering significant benefits to graingrowers.

The amount of nitrogen returned to the soil is between 42 and 67 kilograms a hectare after grain production, up to 97 kg/ha after grazing or cutting for hay and 154 kg/ha after green manuring. [27]

For more information, see Section 5: Nutrition and fertiliser section 5.1 Crop removal rates.

Trials in the Riverine plains in 2012 exploring the amount of nitrogen produced by break crops found that vetch produced the most total plant fixed nitrogen (141 kg N/ha) followed by the arrowleaf clover (138 kg N/ha), faba beans (129 kg N/ha) and sub-clover (118 kg N/ha). These results were significantly higher than field peas (86 kg N/ha) and chickpeas 50 kg N/ha) (Table 3).

The clover and chickpeas treatments did not appear to fix nitrogen as efficiently as the other legumes with only 12–13 kg fixed N/t shoot DM compared with the faba beans and field peas fixing 15–16 kg fixed nitrogen per tonne of shoot DM or the 19 kg fixed nitrogen per tonne of shoot DM for the vetch (Table 4). [28]

26 L McMurray (2013) GRDC Update Papers: Best bet options and practices for pulses in the Mallee. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2013/08/best-bet-options-and-practices-for-pulses-in-the-mallee

27 K Penfold (2006) Vetch interest puts pressure on supply. Groundcover GRDC. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-60/vetch-interest-puts-pressure-on-supply

28 A Glover, I Trevathan, L Watson, M Peoples, T Swan (2012) Break crops in cropping systems: impacts on income, nitrogen and weeds. Riverine Plains, Online farm trials. http://www.farmtrials.com.au/trial/16519

MORE INFORMATION

[Break crops in cropping systems: impacts on income, nitrogen and weeds]

[Crop sequence trial demonstrates break crop benefits]

[Grain and graze: We grow vetch because we want our children to be farmers]

[Break crops in retained stubble systems]

Table 4: *Nitrogen fixation results for legumes sampled at peak biomass.*

Treatment	Mean shoot DM (t/ha)	Shoot N (kg N/ha)	% N fixed	Shoot N fixed (kg N/ha)	Shoot N fixed (kg N/t DM)	^Total N fixed (kg N/ha)
Vetch	5.1	120	79	95	19	141
Arrowleaf clover	6.1	100	81	80	13	138
Faba beans	5.3	105	82	85	16	129
Sub-clover	5.8	99	69	69	12	118
Field peas	4	93	64	58	15	86
Chickpeas	2	37	65	24	12	50
Lupins*	0.6	20	82	16	25	21
P-value	(<0.05)	<.001	<.001 NS	<.001	<.001	<.001
LSD	1.21	22	15	17	4	27

* Lupins were severely affected by bird damage and were not harvested. ^ Total nitrogen fixed (kg N/ha) estimates for the amount of nitrogen fixed from both the shoots and roots. Determined using root factors obtained from previous N fixation studies.

Source: Riverine plains, Online Farm Trials

MORE INFORMATION

Break crops in cropping systems: impacts on income, nitrogen and weeds

Trials in the Mallee found that vetch biomass of 3–5 t/ha can fix a total of 200–300 kg N/ha. This level of nitrogen can cause the following wheat crop to hay off if a dry summer and growing season follow the vetch production year. An early termination of vetch (at 2 t/ha biomass) can be lower risk if the seasonal outlook is dry. [29]

For more information on when to terminate vetch, see Section 11: Crop desiccation and spray out.

Trials have shown that growing vetch as either a green manure crop or for grain production before a wheat crop is one of the most cost-effective methods of achieving high yielding, high-quality wheat. An SA grower group, the Lameroo Premium Wheat Marketing Association, conducted wheat protein trials in the Southern Mallee to assess the value of vetch in a rotation and found it one of the most cost-effective methods of achieving high yielding, quality grain. In the following wheat crop, grain yield increased by 32% and protein by 1.8% when compared with cereal on cereal. [30]

1.3.2 Disease, weed and pest reduction

Vetch can reduce disease and insect risk for the following crop. [31] Vetch in cereal rotations allows growers to control diseases such as take-all and cereal cyst nematode (CCN). Disease-resistant varieties can be successfully grown without fungicide use. [32]

Vetch can also open up weed control options in a cropping sequence. They have useful tolerance to the triazine group of herbicides (e.g. atrazine). This enables vetch to be double-cropped after sorghum or maize provided that excessively high rates of atrazine have not been used in the preceding summer cereal. Any likelihood of crop damage to the vetch will be further minimised by only planting in situations where there is a reasonable profile of sub-soil moisture at planting (60 cm wet soil). [33]

29 D Ferrier, A Frischke (2016) Break crops in retained stubble systems in the Wimmera and Mallee. Birchip Cropping Group. https://thestubbleproject.wordpress.com/2016/05/31/wimmera-and-mallee-breack-crops/

30 K Penfold (2006) Vetch interest puts pressure on supply. Groundcover GRDC. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-60/vetch-interest-puts-pressure-on-supply

31 R Matic, S McColl (2013) Which vetch in my farming system? Online farm trials. http://www.farmtrials.com.au/trial/16634

32 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

33 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

Soft seeded species are suitable for use in all crop rotations, without the risk of voluntary plants creating a problem in following crops; e.g. new common vetch varieties (Morava⦇ and Rasina⦇) are soft seeded varieties and have no potential to be a weed in subsequent crops. [34]

1.3.3 Brown manuring

Brown manure cropping involves growing a grain legume crop with minimal fertiliser and herbicide inputs to achieve maximum dry-matter production before the major weed species have set viable seed.

The grain legume crop is sprayed with a knockdown herbicide before seed-set to kill the crop and weeds, ideally no later than the start of the crop's pod development to also conserve soil moisture.

A second knockdown herbicide is generally applied to achieve a 'double knock'. This is different to green manure where the crop and weeds are cultivated.

Brown manuring with legumes should be considered, especially by growers in southern New South Wales, as diminishing growing-season rainfall is putting downward pressure on yields. To counter this, most growers are increasing the quantity – and cost – of inputs, particularly herbicides and nitrogen. This adds even more to production and financial risks. [35]

Trials in southern NSW exploring rotation benefits found that grain yield increased significantly for wheat crops following a break crop (vetch, field pea, and pasture) when brown manured. There was no difference in grain yield when vetch was brown manured or cut for hay. For the hay cut treatment, wheat following vetch produced more grain than that following pasture. Cutting for hay significantly improved financial return for the rotation including vetch ($482/year) or pasture ($453/year) as a break crop compared with the brown manure option, which is higher than the continuous-wheat option with N fertiliser applied. Due to the loss of a year's income when break crops were brown manured, the gross margin was lower than grain harvested. [36]

Another trial in southern NSW from 2012–2014 found that a vetch rotation could help to increase wheat protein. There was more protein (about 0.5%) in the wheat following pulse crops that had been brown manured (12.6%) instead of harvested for grain (12.0%). There were also differences between species, with most wheat grain protein following Morava⦇ vetch and Percy field pea, and the least protein percentage following the lupin crops. This may reflect the biomass of the preceding legumes. [37]

MORE INFORMATION

[Brown manure legumes lower total crop risk]

[Increasing on-farm adoption of broadleaf species in crop sequences to improve grain production and profitability]

[Residual effects of a pulse crop phase in the farming system]

1.3.4 Green manuring

Green manuring can increase both wheat yields and grain protein.

The technique involves growing as much green matter as possible, usually vetch, and either ploughing it in or spraying it with a herbicide during the spring in the year before wheat is sown.

The main differences between green manuring and traditional long fallowing are: that the legume is sown and managed to produce maximum bulk; that grasses are sprayed out to stop any build-up of root disease pathogens; and that green manuring is done relatively late in the season when the legume was at the late flowering stage.

34 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

35 GRDC. (2015) Groundcover Issue 116: Brown maure legumes lower total crop risk. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-116-may-june-2015/brown-manure-legumes-lower-total-crop-risk

36 G Li, R Lowrie, G Poile, A Lowrie (2015) Increasing on-farm adoption of broadleaf species in crops sequences to improve grain production and profitability. NSW DPI – Southern NSW research results 2015. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/660496/Southern-NSW-research-results-2015.pdf

37 E Armstrong, L Gaynor, G O'Connor, S Ellis, N Coombes (2014) Residual effects of a pulse crop phase in the farming system. NSW DPI – Southern cropping region trial results 2014. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/561344/Southern-cropping-region-trial-results-2014.pdf

In subtropics in northern New South Wales and southern Queensland, vetch is used mainly as a green manure in cotton production, orchards and vineyards (Photo 5). [38]

Photo 5: *Vetch being slashed in late winter prior to incorporation into the soil.*

Source: Cotton Catchment Communities CRC

Vetch trials in southern Australia have shown that green manuring by ploughing increased yields by 0.64 t/ha and protein by 1.2%, while the figures for spraying were 0.34 t/ha and 0.9% protein. However, in other trials, wheat yields after spraying matched those after ploughing, especially where vetch rotted quickly because of follow-up rains. Spraying rather than ploughing may be preferable where soil is prone to erosion.

The researchers also compared returns from the green manuring with returns from simply letting the vetch mature and harvesting it, then sowing wheat back on the paddock. They found that harvesting both crops gave a better return. However, their calculations did not take into account benefits of green manuring in reducing herbicide resistance or increasing soil fertility.

The researchers recommended that in intensive cropping rotations, green manuring (e.g. with vetch) should take place every five to six years. [39]

Soil structure

Vetch has been part of trials exploring the effect of legumes on soil structure. Soil structural differences are measured with a cone penetrometer which determines the force needed to push a metal probe slowly into the soil to 600 mm depth. The results (Figure 3) indicate that the instrument penetrated the soil more easily in the vetch systems compared with the non-legume systems. This effect was more evident in the subsoil. This phenomenon has been observed in each year of the experiment. Soils that offer less resistance to root growth allows the crop to explore a larger volume of soil, thereby enabling the crop to take up more nutrients and to access more soil water. [40]

38 R Matic, S Nagel, G Kirby (2008) Woolly pod Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Woolly_pod_vetch.htm

39 A Mayfield. Groundcover Issue 12: Green boost for wheat. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-12/green-boost-for-wheat

40 I Rochester (2009) GRDC Update Papers: Using rotation crops to improve soil quality. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2009/10/using-rotation-crops-to-improve-soil-quality

MORE INFORMATION

[Manuring of Pulse Crops]

[Using rotation crops to improve soil quality]

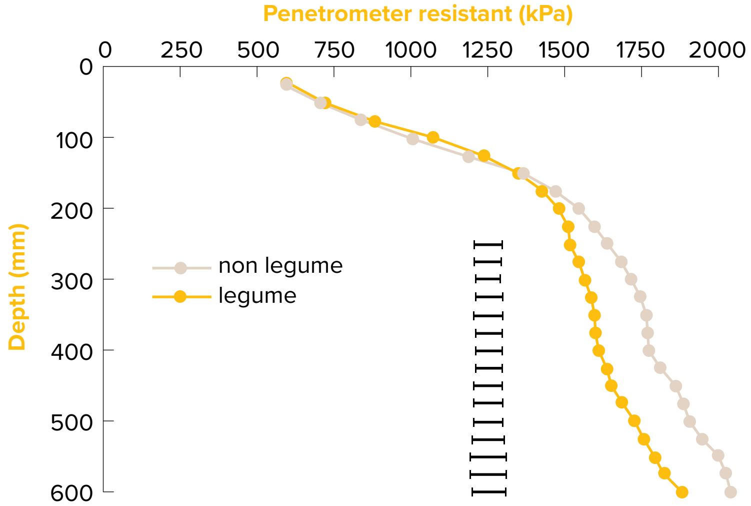


Figure 3: *Resistance to inserting the cone penetrometer in to soil was lower following a legume (vetch) crop, compared with fallow.*

Source: GRDC

1.4 Disadvantages of vetch as a rotation crop

Key points:

- Contamination of following pulse crops with vetch seed.
- Controlling weeds in vetch can be problematic. There is also risk of volunteer vetch causing problems in a cropping sequence.
- Vetch is not well-adapted to waterlogging.
- In early growth stages vetches are sensitive to redlegged earth mite, and lucerne flea, and in mid to later growth to cowpea aphids as well to Native budworm at flowering and podding stages. [41]

While cultivated vetch is still gaining popularity as a hardy pulse alternative, increasing numbers of wild vetch or tares are being viewed with alarm in some areas (Photo 6). Wild vetch has the potential to become a severe problem in the cropping systems of south eastern Australia. Once established, it is highly competitive in crops such as lupins.

Wild Vetch is an autumn-germinating annual broadleaf weed. They have a high percentage of hard seeds which may survive indefinitely and germinate if conditions are favourable. Cultivation to bury the seed and prevent germination is not effective. Seed germination trials showed vetch has the ability to germinate from a depth of 250 mm.

Vetch is classified as a Class 7 contaminant in ASW standard wheat by the Australian Wheat Board. This means that no more than one vetch seed per 0.5 L grain sample is allowed. Contamination above this level would result in the grain being rejected.

41 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

Photo 6: *Vetch tares in a paddock.*

Photo: Peter Teasdale

In early trials, simazine alone, applied post-sowing, pre-emergence, was found to provide very little vetch control. Later applications of other herbicides were more effective at retarding vetch growth. Most effective was herbicide application at the 2–3 leaf growth stage, achieving reasonable control.

Cultivated varieties of vetch are easier to control as they are not as hard-seeded as their wild relatives. Germination percentages of cultivated varieties are relatively high and with the correct timing of herbicide application can be well controlled. [42]

New common vetch varieties (Morava⦻ and Rasina⦻) are soft seeded varieties and have no potential to be a weed in subsequent crops. However, older varieties like Blanchefleur and Languenoc have 5–20% hard seeds and can potentially be a weed in the following 2–3 years. In cereal crops the voluntary common vetches can be easily controlled by many broadleaf herbicides that are regularly used for controlling broadleaf weeds.

Post emergent herbicide options for broadleaf weed control are limited.

1.4.1 Disadvantages of Woolly pod vetch

Woolly pod vetch grain cannot be used for feeding any livestock. Varieties are hard seeded (10–70%) and can occur as voluntary plants/weeds in following crops for many yrs.

Initial growth is poor and requires clean land before seeding. In early growth stages it is a very poor competitor to weeds.

Woollly pod vetch cannot perform well in low/medium rainfall (<400 mm/year) areas.

This vetch species is not well adapted to waterlogging.

In early growth stages, woolly pod vetch is sensitive to lucerne flea and in mid to later growth to cowpea aphids as well as to Heliothus in flowering and podding stages.

Herbicide options for broadleaf weed control are limited. [43]

42 A Chambers in GRDC. Groundcover Issue 16: All vetches aren't equal. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-16/all-vetches-arent-equal

43 R Matic, S Nagel, G Kirby (2008) Woolly pod Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Woolly_pod_vetch.htm

1.5 Fallow weed control

Fallows are an inherent part of farming in lower rainfall areas. The main function of a fallow is to conserve moisture and nutrients for the following crop. Fallows can also reduce the carryover of disease and the number of weeds into the next crop. The benefits of a fallow are only attained when the weeds in the fallow are controlled (Photo 7). Fallows can be used as an Integrated Weed Management (IWM) tool to target cropping weeds such as annual grasses. [44]

Photo 7: *Clean summer fallows (left) prevent soil moisture being lost to weed growth (right).*

Photo: B Collis, Source: GRDC and DAFWA

Vetch should be sown into a clean seedbed, with weeds controlled prior to planting with cultivation and/or herbicides. A wide range of products are registered for controlling weeds in fallows.

1.5.1 Herbicides

Herbicides are currently the main weed control option in fallows, with glyphosate the most commonly used herbicide. There are a range of herbicides that can be used in fallow and it is important to rotate the herbicide mode of action used in fallows. Fallows managed with a single herbicide mode of action have seen a species shift towards more herbicide tolerant weeds. Herbicide mixtures with different modes of action should be used for weed control in fallow to control a broader range of weed species. Weed control in summer can be difficult as weeds grow very quickly. Weeds are most susceptible to herbicides in the two- to four-leaf stage which can occur within 14 days of germinating rain. [45]

Spray.Seed (various trade names) and Surpass + glyphosate (various trade names for both products) are registered for controlling weeds prior to planting vetch. There is a 7 – 10 day plant-back period constraint before planting vetch following a Surpass application.

For broadleaf weed control in vetch during fallow, Dicamba 500 g/L (Kamba®500) is registered for application at 0.28 L. Dicamba 700 g/kg (Cadence®) is registered for

44 A Johnson, R Thompson. Weed control for cropping pastures in central west NSW. Chapter 5: Fallows. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/154723/Weed-control-for-cropping-and-pastures-in-central-west-NSW-Part-5.pdf

45 A Johnson, R Thompson. Weed control for cropping pastures in central west NSW. Chapter 5: Fallows. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/154723/Weed-control-for-cropping-and-pastures-in-central-west-NSW-Part-5.pdf

application at 200 g. Paraquat 135 g/L + diquat 115 g/L (Spray.Seed®250) is registered for application at 1.2–3.2 L.

2,4-D amine 700 g/L (Amicide®Advance700) is registered for application at 0.515–0.745 L. [46]

For some soil-active broadleaf herbicides to be fully effective, or to avoid crop damage, application must only occur when there is sufficient soil moisture and the soil surface is level. Herbicides applied before seeding or split between pre and post-sowing can be safer than post-sowing if the soil will be left ridged (e.g. after using knife points). [47]

1.5.2 Cultivation

Weed control in fallows may require a cultivation under certain conditions (Photo 8). Considering a cultivation does not mean returning to old techniques and machinery. For example, a shallow cultivation can be used to control seedling weed growth under hot, dry and dusty conditions when herbicides are generally not as effective. A strategically targeted cultivation is also a very effective IWM tool, especially when used in rotation with herbicides to prevent a build-up of herbicide tolerant weeds. Combining herbicide use with cultivation also reduces the risk of degrading the soil structure and increasing erosion through excessive cultivation. At the end of a long fallow which has been managed with herbicides, a shallow cultivation can be useful. This cultivation, about eight weeks prior to sowing, can be used to stimulate weed emergence of dormant weed seed if large numbers of seed are known to be present. These weeds can then be controlled prior to sowing. This technique, sometimes referred to as an 'autumn tickle' is a useful technique for reducing the soil seed bank and delaying the development of herbicide resistant weed populations. [48]

Photo 8: *Lupin fits well in minimum tillage, direct drilling, no-tillage or zero-tillage farming systems provided the physical seeding process is not affected.*

Source: GRDC

46 http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/123157/Weed-control-in-winter-crops-2017.pdf

47 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

48 A Johnson, R Thompson. Weed control for cropping pastures in central west NSW. Chapter 5: Fallows. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/154723/Weed-control-for-cropping-and-pastures-in-central-west-NSW-Part-5.pdf

1.5.3 Burning stubble on a short fallow

Stubble burning is a tool used for the control of disease and many weeds. Burning stubble must be weighed against the increased risks of nutrient loss and damage to the soil structure that can occur in a hot fire. High levels of ash can sometimes reduce the effectiveness of herbicides. The fire should aim to destroy weed seeds on the soil surface rather than burning fresh weed growth (Photo 9). Burning to reduce some weed seeds on the soil surface requires a hot fire, while for others a cool burn is sufficient. Seeds that are still attached to the parent plant and have not fallen to the ground are easier to burn. Research has found that while burning standing stubble temperatures were often hot enough to destroy annual ryegrass seed but not wild radish seed on the soil surface. Wild radish required 500˚C for 10 seconds; annual ryegrass only required 400˚C for the same period.

Photo 9: *A paddock of burnt stubble where a pulse crop was later sown at a property in Armatree about 100 kilometres north of Dubbo in northern New South Wales.*

Photo: S Cowley, Source: GRDC

Burning windrows (higher concentration of material) can produce temperatures that are hot enough for a sufficient period to kill wild radish seed on the soil surface. [49]

For more information, see Section 6: Weed control.

VIDEOS

WATCH: GCTV5: Managing summer fallow.

WATCH: Burning for weed and snail control.

MORE INFORMATION

Weed control for cropping and pastures, Chapter 5: Fallows.

1.6 Fallow chemical plant-back effects

Herbicide plant-back restrictions should be taken into account when spraying fallow weeds prior to sowing winter crops. Many herbicide labels place time and/or rainfall restrictions on sowing certain crops and pastures after application, due to potential seedling damage. Crops such as pulses and legume pastures are the most sensitive to herbicide residues. [50]

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

Most herbicide residues are broken down by microbial activity in the soil. The soil microbes require warm, moist soil to survive and 'feed' on the chemical. Degradation

49 A Johnson, R Thompson. Weed control for cropping pastures in central west NSW. Chapter 5: Fallows. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/154723/Weed-control-for-cropping-and-pastures-in-central-west-NSW-Part-5.pdf

50 RMS Agricultural consultants. (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/

of chemical residue is slower when soils are dry or cold. Soil type and pH also have an influence on the rate at which chemicals degrade.

Keeping accurate records of all herbicide treatments and planning crop sequences well in advance, can reduce the chance of crop damage resulting from herbicide residues. [51]

The following plant-back periods are a guide only based on label recommendations (Table 5). The time indicated between application and safe crop rotation intervals will depend on a range of factors including rainfall (amount and intensity), soil type (pH, soil biological activity and organic carbon), soil type variability within a paddock, and temperature and herbicide rate. Some crops are more sensitive to various herbicide groups than others. Always take a conservative approach to plant-back periods, especially with sensitive or high input crops.

Table 5: *Guidelines for crop rotations – Fallow commencement/maintenance and pre-sowing seedbed weed control.*

	Specific details	Herbicide Group	Plantback period
Associate® [1]	pH 5.6–8.5 [7]	B	-
Amicide® Advance (700 g/L) [2]	<0.5 L/ha	I	7d
	0.5–0.98 L/ha	I	7d
	0.98–1.5 L/ha	I	10d
Cadence® [2]	140 g/ha	I	-
	200 g/ha	I	-
	400 g/ha	I	-
Eclipse® 100 SC	[8]	B	
LV Ester 680 (680 g/L) [2]	<0.51 L/ha	I	7d
	0.51–1.0 L/ha	I	7d
	1.0–1.6 L/ha	I	10d
Express® [3]		B	7d
Gundy 240	[9 14]	B	
Garlon™		I	-
Goal®	[10]	G	
Grazon™ Extra [4]	NNSW 0.2 L/ha	I	-
	NNSW 0.3 L/ha	I	-
	NNSW 0.4 L/ha	I	-
	NNSW 0.6 L/ha	I	-
	SNSW <0.5 L/ha	I	
Hotshot™ [4]	NNSW<750 mL/ha	I	-
	SNSW <500 mL/ha	I	-
Kamba®500 [2]	0.2 L/ha	I	-
	0.28 L/ha	I	-
	0.56 L/ha	I	-

51 RMS Agricultural consultants. (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/

	Specific details	Herbicide Group	Plantback period
Lontrel™Advanced 600 g/L [5]	NNSW <0.04 L/ha	I	-
	NNSW 0.04–0.15 L/ha	I	-
	NNSW >0.15 L/ha [11]	I	
	SNSW <0.15 L/ha	I	9mo
	SNSW <0.15–0.25 L/ha	I	12mo
	SNSW >0.25 L/ha	I	24mo
Pyresta® [2]	250–500 mL/ha	GI	7d
	900 mL/ha	GI	7d
Starane™Advanced [6]	0.225 L/ha	I	-
	0.45 L/ha	I	-
	0.9 L/ha	I	-
Sharpen®WG		G	-
Shogun®		A	-
Terrain™500 WG [13]	30 g/ha	G	0mo
	120 g/ha		1mo
	180 g/ha		1mo
	280 g/ha		2mo
Weedmaster® Argo®	[12]		-

1 For pH 8.6 and above tolerance of crops (grown through to maturity) should be determined on a small scale, in the previous season, before sowing into larger areas.

2 When applied to dry soils at least 15 mm of rain must fall prior to the commencement of the plant-back period.

3 Express® is broken down in soil, primarily by chemical hydrolysis, but to a lesser degree by microbial degradation. Breakdown is fastest in warm, wet acid soils and slower in cold alkaline soils. For summer crops (specified on the label), if minimum soil temperatures at planting depth are less than or equal to 15°C for three consecutive days, then plant-back intervals should be extended to 21 days.

4 Plant-back periods on black cracking clays. During drought conditions the plant-back period may be significantly longer.

5 Additional rainfall requirements need to be observed – see label.

6 Do not plant susceptible crops, including cotton, pigeon peas and other pulse crops, into irrigated fields with soils containing less than 25% clay content, within 12 months of treatment with Starane™ Advanced.

7 Soil pH determined by 1:5 soil:water suspension method.

8 Do not plant susceptible crops until 9 months after application of Eclipse®. Susceptible crops include canola or other brassica crops, field peas, beans, medics, Lucerne and sub-clover.

9 Minimum recropping periods are influenced by numerous factors. See label for further information.

10 Goal® herbicide at up to 75 mL/ha may be safely applied 1 day before planting wheat, barley, oats, triticale, canola, lupins, faba beans, field peas, Lucerne, clover, medics, ryegrass, phalaris and cocksfoot and 7 days minimum before planting cotton or soybeans, provided minimum tillage planting equipment is used with minimal soil disturbance.

11 Susceptible crops should not be sown for at least 2 years when Lontrel™ Advanced at more than 0.15 L/ha has been used in northern Australia.

12 Do not disturb weeds by cultivation, sowing or grazing for 6 hours of daylight following treatment of annual weeds and 7 days for perennial weeds.

13 25 mm of rain or irrigation is necessary after application and before planting winter crop species

Key: d=days mo = months

1.6.1 Conditions required for breakdown

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

MORE INFORMATION

Herbicide residues and weed control

Risks

In those areas that do not experience conditions which will allow breakdown of residues until just prior to sowing, it is best to avoid planting a crop that is sensitive to the residues potentially present on the paddock, and opt for a crop that will not be affected by the suspected residues. In most cases, cereals or canola would be better options as these crops are comparatively less affected by herbicide residues. If dry areas do get rain and the temperatures become milder, then they are likely to need substantial rain (more than the label requirement) to wet the sub-soil, so the topsoil can remain moist for a week or more. This allows the microbes to be active in the top-soil where most of the herbicide residues will be found. Sensitive crops include legume pastures (e.g. clovers, Lucerne, or forage legumes) and pulse crops (e.g. Vetch, lupins, lentils, fieldpeas or faba beans). [52]

For more information, see Section 6: Weed control.

1.7 Seedbed requirements

Preparation of a seedbed to ensure good seed soil contact is an important element in successful crop establishment. Ensure early paddock preparation to enable timely sowing.

Vetch should be sown into a clean seedbed, with weeds controlled prior to planting with cultivation and/or herbicides. A uniform and firm seed bed is required for good results.Vetches are large seeded and capable of being planted down into soil moisture. [53]

Vetch is suited to no-till, standing stubble systems.

No till crop establishment gives a huge number of benefits, the first being less soil erosion compared to tillage. Crop residues are retained on the soil surface. This reduces evaporation and protects small plants from harsh weather events.

The introduction of cover crops into no-till farming systems can provide increased soil cover, add diversity to the system and smother weeds.

1.8 Soil moisture

MORE INFORMATION

Improving soil moisture

Moisture is a key limitation on the productivity of soil.

Three main factors affect soil moisture content:

1. how well your soil can absorb water;
2. how well your soil can store moisture; and
3. how quickly the water is lost or used.

Although these factors are strongly determined by the proportions of clay, sand and silt, good soil management also plays a critical role. [54]

1.8.1 Dryland

Vetch grows well in no-till, standing stubble paddocks (Photo 10).

Sowing systems that retain stubble help to reduce evaporation losses from the soil. Retaining stubble or plant residue from previous crops also protects the soil from erosion, reduces soil moisture loss and assists in crop growth and height.

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

53 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

54 G Reid. (2004). Improving soil moisture. Agnote DPI – 494. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/166796/improve-soil-moisture.pdf

VIDEOS

WATCH: Stubble Management.

WATCH: GCTV15: Stubble height Pt. 1. and Stubble height Pt. 2.

WATCH: GCTV4: Burning for stubble retention.

MORE INFORMATION

Stubble retention in south-eastern Australia

Maintaining profitable farming systems with retained stubble across various rainfall environments

Photo 10: *Inter-row sowing vetch into cereal stubble.*

Photo: Stuart Nagel

Stubble retention

Key points:

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

Historically, stubble has been burnt in southern and central New South Wales because it creates easier passage for seeding equipment, enhances seedling establishment of crops, and improves control of some soil-borne diseases and herbicide resistant weeds. Heavy stubble cover can reduce evaporation by as much as 50 mm during the season. This can give significant yield improvements.

The practice of burning stubble has recently declined due to concerns about soil erosion, loss of soil organic matter and air pollution. Stubble is increasingly being retained (without burning practices) which has several advantages of soil fertility and productivity. Summer rainfall and warmer conditions promote decomposition of stubble. In northern NSW over half of the original cereal stubble may be decomposed by winter sowing time, compared to southern NSW where much more of the residue remains in place.

1.8.2 Irrigation

Even in relatively high and reliable rainfall areas, natural rainfall patterns may not match the water requirements of many commercial crops. Efficient use of irrigation water means more crop can be grown for a given volume of water, an important factor now that water supplies are becoming limited and expensive. Efficient irrigation reduces operating costs because less water has to be pumped for a given yield. Inefficient irrigation can lead to water and nutrients draining through the root zone, which is a waste of water and fertilisers and leads to rising and contaminated water tables.

Vetch is not often sown in irrigated farming operations in the Northern growing region.

MORE INFORMATION

Irrigation and drainage management plans: Part 1 and Part 2

Choosing the right soil moisture monitoring device

1.9 Yield and targets

It is important for growers to be able to predict yields and targets of their crops. Table 6 provides yield results for grain and dry matter production of common vetches varieties tested between 2011- 2014 in SA by the Australian National Vetch Breeding Program. Woolly pod vetch can perform better than common vetch for hay production in areas with > 400 mm/year rainfall, by 0.7–1.3 t. [55]

Table 6: *Grain and dry matter yield for common vetch varieties tested in trials in SA from 2011–2014.*

	(5 sites * 5 years)			
Variety	**Grain yield (t/ha)**	**% of Blanchefleur**	**Dry matter yield (t/ha)**	**% of Morava⦷**
Blanchefleur	2.15	100	4.03 (2009–13)	80
Rasina⦷	2.37	110	4.7 (2009–13)	93
Morava⦷	2.16	100	5.06	100
Volga⦷	2.75	128	5.51	109
Timok⦷	2.48	115	5.26	104
Mean yield	2.38		4.91	

Source: SARDI

Trials in the Northern region measured the relative biomass production of a range of forage crop options that could be utilised in grain crop rotations. Several experiments in southern Queensland showed Purple vetch cv. Popany to be less productive than snail medic and sulla, but at Tulloona in 2013 it produced similar biomass to the field pea and other vetch cultivars and more than sulla (Figures 4 and 5). [56]

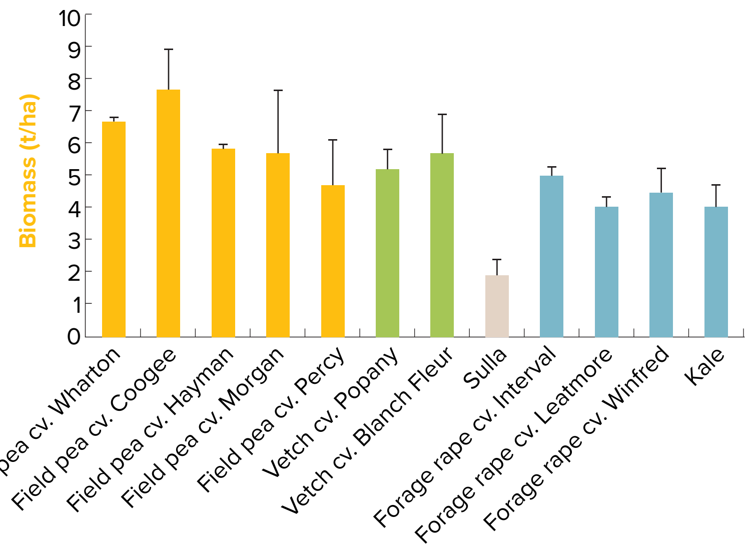


Figure 4: *Comparison of biomass production from 5 field pea cultivars (green), 2 vetch cultivars (light green), the perennial legume sulla (light green) and 4 forage brassicas at Tulloona, NSW in 2013.*

55 R Matic (2011) GRDC Final Report: New vetch varieties for grain and hay production for Australian Farmers. https://grdc.com.au/research/reports/report?id=1446

56 L Bell (2015) GRDC Update Papers: Likely fit of summer and winter forage crop options in central west farming systems. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2015/07/likely-fit-of-summer-and-winter-forage-crop-options-in-central-west-farming-systems

MORE INFORMATION

Likely fit of summer and winter forage crop options in central west farming systems

Yield Prophet®

Ground truthing Yield Prophet® in the southern NSW landscape

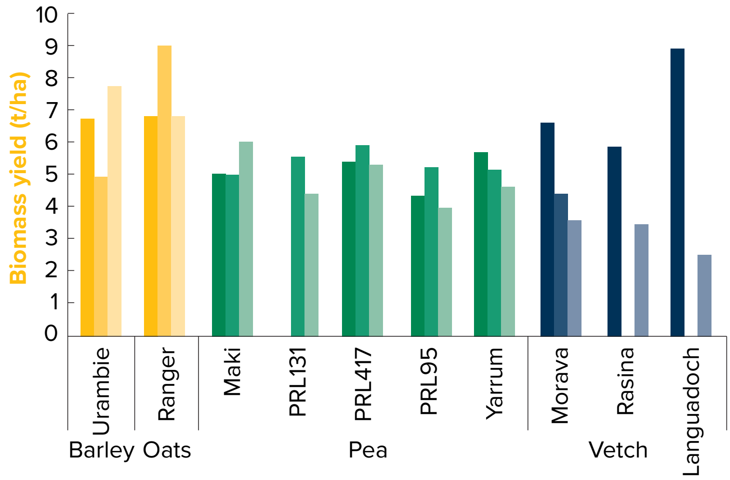


Figure 5: *Comparison of biomass production from 2 forage cereals (orange), 5 field pea cultivars (green), and 3 vetch cultivars (blue) at 3 sites in 2010 in south-western Qld; Billa Billa sown on 10 June (medium colour), Billa Billa sown 18 July (light colours) and Inglestone (darkest colours).*

Yield Prophet®

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. Scientists have aimed to support farmers' capacity to do this by developing APSIM (Agricultural Production Systems Simulator). 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 on-line 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 in decision making. By matching crop inputs with potential yield in a given season, Yield Prophet® subscribers may avoid over- or under- investing in their crop. The simulations provide a framework for farmers and advisers to:

- forecast yield
- manage climate and soil water risk
- make informed decisions about nitrogen 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, applied and influence decision making.

1.9.1 Seasonal outlook

Queensland

The Monthly climate statement, which interprets seasonal climate outlook information for Queensland, is produced by the Science Delivery Division of the Queensland Department of Science, Information Technology and Innovation (QDSITI). The statement is based on QDSITI's own information and draws on information from national and international climate agencies.

The QDSITI assessment of rainfall probabilities is based on the current state of the ocean and atmosphere and its similarity with previous years. In particular, QDSITI monitors the current and projected state of El Niño–Southern Oscillation (ENSO), referring to information such as Variation of sea-surface temperature from average and the Southern Oscillation Index (SOI). Based on this information, QDSITI uses two systems to calculate rainfall probabilities for Queensland:

- QDSITI's SOI-Phase system produces seasonal rainfall probabilities based on phases of the SOI.
- QDSITI's experimental SPOTA-1 (Seasonal Pacific Ocean Temperature Analysis version 1) monitors Pacific Ocean sea-surface temperatures from March to October each year to provide long-lead outlooks for Queensland summer (November–March) rainfall.

Outlooks based on both the SOI-Phase system and SPOTA-1 are freely available, although a password is required to access the experimental SPOTA-1 information (email: rouseabout@dsiti.qld.gov.au). [57]

Queensland Alliance for Agriculture & Food Innovation produces regular, seasonal outlooks for grain producers in Queensland. These high-value reports are written in an easy-to-read style and are free.

New South Wales

The Seasonal Conditions Report is issued each month by NSW Department of Primary Industries. It contains information on rainfall, water storages, crops, livestock and other issues. It is available to landholders to help them make informed decisions on how they manage operations, and prepare for seasonal conditions and drought.

Seasonal Conditions Reports are also used by the Regional Assistance Advisory Committee in making recommendations to the NSW Government on potential support for farm businesses, families and communities. [58]

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 ENSO 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.

57 QDSITI (2016) Seasonal climate outlook. Queensland Department of Science, Information Technology and Innovation, https://www.longpaddock.qld.gov.au/seasonalclimateoutlook/

58 NSW DPI. Seasonal conditions reports. NSW Department of Primary Industries, https://www.dpi.nsw.gov.au/climate-and-emergencies/droughthub/information-and-resources/seasonal-conditions

MORE INFORMATION

Climate Kelpie: Decision support tools for managing climate

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

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. [59]

1.9.2 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. Growers have some control over the stored soil water; i.e. measuring soil moisture before sowing. Long-range forecasts and tools such as the SOI can indicate the likelihood of the season being wet or dry; however, they cannot guarantee that rain will fall when it is needed. [60]

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 an 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?:

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

This information aids in the decision about what crop to plant and how much N fertiliser to apply. Many grain growers are in regions where stored soil water and nitrate at planting are important in crop management decisions. This is of particular importance to northern Australian grain growers with clay soils where stored soil water at planting can constitute a large part of a crop's water supply.

Questions this tool answers:

- How much longer should I fallow? If the soil is near full, maybe the fallow can be shortened.
- Given 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

59 MCV (2014) Australian CliMate—climate tools for decision makers. Managing Climate Variability R & D Program, https://climateapp.net.au/

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

- 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 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 OC and C/N ratios, and as such should be regarded as indicative only and best used as a measure of relative water accumulation and nitrate mineralisation. [61]

1.9.3 Water use efficiency

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

WUE relies on:

- the soil's ability to capture and store water;
- the crop's ability to access water stored in the soil and rainfall during the season;
- the crop's ability to convert water into biomass; and
- the crop's ability to convert biomass into grain (harvest index).

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

Vetch has higher WUE than chickpea, but lower than wheat (Table 7).

Table 7: *Water Use Efficiency based on total biomass (WUEdm) or grain yield (WUEgy) of different crops. Water Use Efficiency is based on the biomass or yield per mm of crop water use. Values are mean and range.*

Crop	Region	WUEdm	WUEgy
		(kg/ha.mm)	
Canola	Victoria	24.0 (17.1–28.4)	6.8 (4.7–8.9)
Canola*	NSW		13.4
Chickpea	Western Australia	16.0 (11.1–18.3)	6.2 (2.6–7.7)
Lentil		12.7 (8.5–16.7)	6.7 (2.4–8.5)
Lupin		17.3 (9.3–22.3)	5.1 (2.3–8.3)
Faba		24.2 (18.7–29.6)	10.4 (7.7–12.5)
Pea		26.2 (17.6 – 38.7)	10.5 (6.0–15.9)
Vetch		18.2 (13.4–22.4)	7.5 (5.6–9.6)
Chickpea	Tel Hadya, Syria	13.7 (9.4–18.1)	3.2 (2.1–5.2)
Lentil		8.7 (5.0–14.2)	3.8 (1.9–5.5)
Wheat	South Australia	36.1 (21.2–53.1)	15.9 (9.2–23.2)
	SE Australia		9.9 (max = 22.5)

Source: GRDC

61 MCV (2012) How Wet/N? Managing Climate Variability R & D Program, https://climateapp.net.au/

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

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

Fortunately, many cropping soils in the Northern grains region have the capacity to store large amounts of water during the fallow. [62]

Definitions and calculation of aspects of WUE are as follows:

- Fallow efficiency (%): 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): 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): the efficiency with which rainfall (mm) is converted to grain (kg) over multiple crop and fallow phases. Calculated as: SWUE = total grain yield/total rainfall.

Strategies to increase yield

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

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

The last three of these all improve WUE. [63]

1.9.4 Nitrogen use efficiency

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

In cracking clay soils of the Northern grains region, saturated soil conditions between fertiliser application and crop growth can lead to significant losses of N from the soil through denitrification. The gases lost in this case are nitric oxide (NO), nitrous oxide (N_2O) and di-nitrogen (N_2). Isotope studies have found these losses can be >30% of the N applied. Direct measurements of nitrous oxide highlight the rapidity of loss in this process.

Insufficient rainfall after surface application of N fertilisers can result in losses from the soil through volatilisation. The gas lost in this case is ammonia. Direct measurements

VIDEOS

WATCH: GCTV12: Water Use Efficiency initiative.

WATCH: GRDCTV10: Grazing stubbles and Water Use Efficiency.

62 GRDC (2009) Water Use Efficiency fact sheet. Grains Research and Development Corporation, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2010/02/water-use-efficiency-north

63 J Hunt, R Brill (2012) Strategies for improving Water Use Efficiency in western regions through increasing harvest index. GRDC Update Papers, April 2012, https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0018/431280/Strategies-for-improving-water-use-efficiency-in-western-regions-through-increasing-harvest-index.pdf

of ammonia losses have found that they were generally <15% of the N applied, even less in in-crop situations. An exception occurred with the application of ammonium sulfate to soils with free lime at the surface, where losses were >25% of the N applied. Recovery of N applied in-crop requires sufficient in-crop rainfall for plant uptake from otherwise dry surface soil. [64]

In southern NSW, experiments showed that banding of anhydrous ammonia or urea fertiliser provided a slow-release form of N to crops, thereby reducing excessive seedling growth and the risks of haying-off. Yield responses to applied N were small or negative in a drought year but larger (17 kg grain/kg N fertiliser) in favourable seasons. Gaseous loss of ammonia to the atmosphere was negligible. [65]

Optimising nitrogen use efficiency

Nitrogen fertilisers are a significant expense for broadacre farmers, so optimising use of fertiliser inputs can reduce this cost. There are three main stores of N within the soil with the potential to supply N to crops: soil organic matter, plant residues, and mineral N (ammonium and nitrate) present in the soil. To optimise the ability of plants to use soil N, growers should be aware of how much there is in each store, and soil testing is the best method of measuring these N sources. The results can then be used to determine fertiliser rates with models such as CropARM (previously known as WhopperCropper) and The Nitrogen Books. [66]

1.9.5 Double crop options

Conservative cropping systems, where crops are only planted when soil moisture levels are high, will result in high individual crop yields but relatively fewer crops and long, inefficient fallow periods. More aggressive cropping systems that include double cropping will result in a greater number of lower-yielding crops and generally more efficient use of available rainfall. The appropriate balance between aggressive and conservative systems will depend on a whole range of factors, including a grower's attitude to risk, and is the subject of ongoing research.

Double cropping into a summer forage out of a winter legume or cereal could be an effective way to break out of a winter crop rotation for 18 months – 2 years to allow control of winter crop weeds and diseases and use of alternative herbicide chemistry. The summer forage would allow some return to be achieved as opposed to a long fallow (12 months) leading into and out of summer crop (e.g. grain sorghum) in the sequence.

Vetch can bring benefits to double-cropping sequences (Table 8).

Vetch is tolerant to the triazine group of herbicides (e.g. atrazine) enabling it to be double-cropped after sorghum or maize provided that excessively high rates of atrazine have not been used in the preceding summer cereal. Any likelihood of crop damage to the vetch will be further minimised by only planting in situations where there is a reasonable profile of sub-soil moisture at planting (60 cm wet soil). [67]

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

65 JF Angus, VVSR Gupta, GD Pitson, AJ Good (2014) Effect of banded ammonia and urea fertiliser on soil properties and the growth and yield of wheat. *Crop & Pasture Science* 65, 337–352, http://www.publish.csiro.au/cp/CP13337

66 Soil Quality Pty Ltd. Optimising soil nutrition—Queensland. http://www.soilquality.org.au/factsheets/optimising-soil-nutrition-queensland

67 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

Table 8: *Summary of relative performance of winter and summer forage crop options for key attributes in grain cropping systems in central west NSW (*** - high, **-moderate, *-low).*

Forage option	Forage production	Grazing tolerance	N inputs	RLN control	Crop weed management	Residual soil water	System role/ fit
Winter forages							
Oats	***	***	-	**	*	**	Alternative to winter grain cereals
Forage brassicas	**	***	-	***	***	**	Replace canola where unviable or risky
Field pea	**	*	**	**	**	***	Replace Chickpea or Fababean, dual-purpose
Vetch	**	***	**	?	**	***	Replace winter pulses
Snail medic	**	***	**	?	**	***	Rotation with cereals, hard seed problem
Sulla		***	***	?	**	*	2–3 year phase, alternative to lucerne
Summer forages							
Forage sorghum	****	***	-	**	***	**	Transition to summer crop phase
Millet	***	**	-	***	***	***	Soil cover after winter pulses, dual-purpose
Lablab	***	**	***	***	**	**	Alternative to mungbeans
Cowpea	**	*	**	**	**	**	Alternative to mungbeans
Soybeans	***	*	***	*	**	**	Dual-purpose alternative to mungbeans

Source: GRDC

Companion species

Vetch can be grown in mixtures with annual ryegrass, volunteer cereals or sown cereals for grass/legume pasture or hay production, and with a range of summer growing grasses in the subtropics.

In Europe vetch is grown as a 'companion' crop between rows of maize and sunflower to provide nitrogen to these crops.

Vetches as an annual legume can be grown with perennial legumes to provide more bulk and feed in the first year of seeding. [68]

MORE INFORMATION

Likely fit of summer and winter forage crop options in central west farming systems

Choosing rotation crops – Fact Sheet

68 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

1.10 Disease status of paddock

Vetch is sensitive to damage from rusts, ascochyta blight and botrytis grey mould, and management action should be taken in paddocks that have a history of these diseases or are at high risk of incurring these diseases.

To limit the risk of disease in vetch and other pulses in the cropping sequence, vetch should be limited to no more than once in every four years in a particular paddock. [69]

Potential high-risk paddocks include those with bare patches, uneven growth and white heads in the previous crop; paddocks with unexplained poor yield from the previous year; newly purchased or leased land; and particular crop sequences. Very high rainfall in the previous year can also increase the likelihood of disease. [70]

1.10.1 Soil testing for disease

In addition to visual symptoms, the DNA-based soil test PreDicta B can be used to assess the 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 varieties, and for assessing the risk after a non-cereal crop.

PreDicta B

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.

Access 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 provide advice on management options to reduce the risk of yield loss.

SARDI processes PreDicta B samples weekly from February to mid-May (prior to crops being sown) every year.

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

1.10.2 Cropping history effects

Inoculum levels can build up over one year and paddocks may be vulnerable if conditions are conducive to disease. It is therefore important that growers know what the risk of soil-borne disease is before they begin sowing crops. By knowing which soil-borne pathogens pose a significant risk to broadacre crops prior to seeding, extensive losses can be avoided.

High risk cropping history includes; cereals on cereals or following grassy pastures; durum crops (e.g crown rot inoculum); and paddocks coming out of chickpeas (*Pratylenchus sp.* populations). [71]

Vetch (and other legumes) sown in the paddock in the previous four years can increase the risk of disease.

For more information, see Section 9: Diseases.

69 R Matic (2010) Vetch summary 2010. SARDI. Online Farm Trials. http://www.farmtrials.com.au/trial/14055

70 GRDC (2017) GroundCover Issue 127: Prepare for elevated 2017 disease levels. https://grdc.com.au/resources-and-publications/groundcover/groundcover-issue-127-marchapril-2017/prepare-for-elevated-2017-disease-levels

71 GRDC (2017) GroundCover Issue 127: Prepare for elevated 2017 disease levels. https://grdc.com.au/resources-and-publications/groundcover/groundcover-issue-127-marchapril-2017/prepare-for-elevated-2017-disease-levels

1.11 Nematode status of paddock

Root-lesion nematodes (RLNs)can cause yield decline in many crops. Vetch is moderately susceptible to *Pratylenchus neglectus* and susceptible to *P. thornei*. Bitter vetch is thought to be resistant to *P. neglectus*. [72] Avoid sowing vetch into paddocks that have a history of RLNs.

Small numbers of the oat race of stem nematode can sometimes be found in Blanchefleur, Languedoc and Namoi vetch. [73]

1.11.1 Nematode testing of soil

PreDicta B should be used to test soil to nematodes prior to sowing.

For more information, see Section 1.9.1 Soil testing for disease, above.

The Queensland Government also has a service: Test your farm for nematodes.

1.11.2 Effects of cropping history on nematode status

Intensive cropping of susceptible crops—particularly wheat—will lead to an increase in RLN levels in the soil. Populations build up in the soil over time and damage susceptible crops in a sequence.

When RLN are detected, rotations and variety choice are central to successfully reducing RLN populations. Only nonhost crops or resistant varieties will minimise the build-up of RLN. Tolerant crops will suffer less damage, but if these varieties are susceptible, RLN numbers can still increase. Aim to reduce populations to less than 2/g soil.

When very high populations of RLN are detected, it may take two or more resistant crops grown consecutively in rotation to reduce populations. Re-testing of soil after growing resistant crops is recommended, so that crop sequences can be adjusted if populations are still at damaging levels. Avoid very susceptible crops and varieties. [74]

For more information, see Section 8: Nematodes.

1.12 Insect status of paddock

In early growth stages vetches are sensitive to redlegged earth mite, and lucerne flea, and in mid to later growth to cowpea aphids as well to Native budworm at flowering and podding stages. [75]

1.12.1 Insect sampling of soil

Recent seasons have seen seemingly new pests and unusual damage in pulse and grain crops in the Northern grains region. 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, e.g. soybean moth, may make its presence felt.

72 V Vanstone, J Lewis (2009) Plant parasitic nematodes – Fact sheet. GRDC. https://grdc.com.au/__data/assets/pdf_file/0018/224424/plant-parasitic-nematodes-south-and-west.pdf.pdf

73 S Taylor. GRDC GroundCover Issue 22: Stem nematode. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-22/stem-nematode

74 GRDC (2015) Tips and Tactics: Root-lesion nematodes, Northern region. www.grdc.com.au/TT-RootLesionNematodes

75 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

- However, be aware of cultural practices that favour pests and rotate crops each year to minimise the build-up of pests and plant diseases. [76]

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.

Soil sampling by spade

Method:

1. Take a number of spade samples from random locations across the field.
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 germinating-grain bait method is the delay between the seed placement and assessment. [77]

1.12.2 Effect of cropping history

MORE INFORMATION

Pest Genie Australia

APVMA.

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 to the likely pest issues and allow growers to implement preventive options. [78] Reduced tillage and increased stubble retention have changed the cropping landscape with respect to soil moisture retention, groundcover and soil biology and this has also affected the abundance and types of invertebrate species being seen in crops. These systems increase invertebrate biodiversity but also create more favourable conditions for many pests such as slugs, earwigs, weevils, beetles and many caterpillars. In turn, they have also influenced beneficial species such as carabid and ladybird beetles, hoverflies and parasitic wasps. [79]

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. [80]

76 H Brier, 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

77 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

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

79 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

80 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

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 buildup.
- Insect numbers decline during a clean long fallow due to lack of food.
- Summer cereals followed by volunteer winter crops promote the buildup of earwigs and crickets.
- High levels of stubble on the soil surface can promote some soil insects due to a food source, but this can also mean that pests continue feeding on the stubble instead of germinating crops.
- No-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. [81]

See Section 7: Insect control, for more information.

81 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

Pre-planting

Key messages

- Caution needs to observed with vetch if lentils are part of the future cropping rotation. No contamination of vetch seed can be found in lentils for marketing purposes.
- Grain and hay/silage from common vetch varieties can be used to feed ruminants without limit.
- The grain can also be used in up to 20% of the ration with cereal grains in a diet for pigs.
- Vetch in crop rotations is an excellent tool to reduce problem weeds, diseases and insects.
- Vetch is one of the best crops to improve soil fertility and contribute to increase yield and protein content in following crops. [1]

2.1.1 Vetch for feed grain

Vetch is a very good source of crude protein of 27.8%. It has high digestibility of dry matter and is high in metabolisable energy. In variety choice, consider yield and adaptation to the area, disease resistance, grain quality, marketability, and proximity to receival point.

Grain vetch for ruminants is considered similar to field peas, but much smaller in size. Grain vetches are not generally recommended for monogastrics. There is evidence that bitter vetch is a suitable grain for ruminants, but use in monogastrics should be treated with caution. Grain supply of bitter vetch is very limited.

Lamb feeding experiments using Morava(PBR) and Rasina(PBR) (< 0.65% toxin in grain), showed extremely good growth. There are no issues arising from using vetch grain as a mix with cereal grains or pure to feed lambs. Inclusion of 50% and 70% vetch grain in a feed ration enabled lambs to reach target weights of 42–46 kg/head 7–11 days earlier than the control ration of pure barley grain. [2]

Common vetch is not recommended for young pigs, but can be included with caution at levels up to 35% when fed to 35–40 kg pigs without depressing performance.

Grain from common vetches can be used without limit in rations together with cereals to feed ruminants, or in cereal grain mix for pigs. [3]

Grain from woolly pod vetch varieties CANNOT be used to feed any livestock.

1 R Matic, S Nagel, G Kirby. Vetch productions and use in Australian Farming systems. Mallee Sustainable Farming. http://www.msfp.org.au/wp-content/uploads/Vetch-productions-and-use-in-Australian-farming-systems.pdf

2 R Matic (2011) GRDC Final Report: New vetch varieties for grain and hay production for Australian Farmers. https://grdc.com.au/research/reports/report?id=1446

3 R Matic, S McColl (2013) Which vetch is my farming system? Online Farm trials. http://www.farmtrials.com.au/trial/16634

Table 1: *Proximate composition and energy content of minor legume species in comparison to Field Peas.*

Component	Field Pea*	Common vetch*	Narbon Bean*	Dwarf chickling**	Grass Pea*	Bitter vetch*
Crude protein%	23.2	27.8	24.2	24.1	27.3	21.8
Ash g/kg	24.9	24.9	27.7	28	24	25.6
Fat g/kg	11.2	8.6	7.6	6	15	12.3
Crude fibre g/kg	59.4	51.0	115.3	63	73	51.0
ADF g/kg	93.3	74.0	142.6	96	85	
NDF g/kg	132.6	219	287.6	219	142	
Lignin g/kg	5.3			2	11	
Oligosaccharides %	3.53	3.45	3.37			
Phytate %	0.59	0.66	0.74	0.81	0.5 - 1.1	
Tannins %	0.37	0.64	0.72	0.46	0 - 0.8	
TIA mg/g	1.29	2.40	0.29	0.19	1.7 - 4.4	
CTIA mg/g	1.60	2.25	2.05	0.31	0 - 2.3	
Lectins dilut	4.00					
Energy MJ/kg##				18.7	19.0	
GE	18.8	18.7	16.2			
DE - sheep	-	16.0	-			
DE - pigs	14.5	-	-			
ME – sheep	11.4	12.0	-			
ME - poultry	-	-	12.0			
AME - poultry	11.5	-	-			

Source: Petterson et al (1997) ** Source Handbury and Hughes (2000, 2003) # Source Farhangi et al (1996). B. Mullan and K. Jae Cheol personal communication. ## GE is gross energy, DE is digestible energy, ME is metabolisable energy

Source: Pulse Australia

2.1.2 Vetch for forage

Forage vetches are used for hay, green manure or mid to late winter feed for grazing. Information gathered from district agronomists, farmer advisors, seed distributors and field days indicate that over 65% of vetch production is used for hay/silage. [4] Vetch hay is a very rich source of protein and metabolisable energy and is highly digestible for all ruminants. Australian dairy farmers are increasingly adopting vetch hay as one of the main forage sources to increase milk production. Vetch hay or silage has been reported to have increased milk production per cow by more than 12% compared with meadow/grass or cereal hay (Photo 1). [5]

Vetches are not suited to close grazing. They are climbing plants, with their growing points situated well above ground level. The type of grazing management required will largely be governed by whether the vetch is sown by itself, or in a mix with cereals such as oats. [6]

Common vetch varieties have some resistance to grazing after 15 nodes (30 cm high) till the start of flowering. Regrowth is dependent significantly on rain or available moisture after grazing.

All current common vetch varieties are palatable for grazing and for hay.

4 R Matic (2007) Improved vetch varieties for fodder production. Rural Industries Research and Development Corporation.

5 R Matic, S McColl (2013) Which vetch is my farming system? Online Farm trials. http://www.farmtrials.com.au/trial/16634

6 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

Morava⊕ and Rasina⊕ are resistant to rust and ascochyta and can be grazed at any time. Languedoc and Blanchefleur are susceptible to rust and ascochyta. Do NOT graze a crop if rust occurs as rust can cause abortion in pregnant cows and sheep. [7]

Ability to spread

It is not possible for vetch to be spread by animals or birds. When animals ingest the grain it breaks down completely. If soft seeded varieties are sown, any residual seed that may germinate in the following crop can be easily controlled with broadleaf herbicides. [8]

Photo 1: *Common Vetch (Morava⊕) cut for hay.*

Photo: Stuart Nagel

Common vetch crops may be harvested at different stages depending on the quality of the forage required. As the plant matures, dry matter digestibility (DMD), leaf matter and crude protein (CP) decrease, and neutral detergent fibre (NDF) and acid detergent fibre (ADF) increase. As the plant matures, DMD, leafiness and CP decreases and NDF and ADF increase. Just before flowering the nutritive value of vetches is at its best. Trials from 2002 – 2006 found that the best ratio between yield and nutritive value of hay/silage is at 50/50 flowers/pod stage (Table 2). [9]

7 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

8 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

9 R Matic (2007) Improved vetch varieties for fodder production. Rural Industries Research and Development Corporation.

Table 2: *Vetch hay analysis.*

Year	No. of samples		Crude Protein CP (%)	Dry Matter digestibility DMD (%)	Metabolise energy (MJ/kg DM)	Neutral detergent fibre NDF (%)
2002	28	Mean	25.8	65.4	9.7	41.6
		Range	(19.2–29.8)	(49.3–72.8)	(7.1–11.2)	(32.8–56.2)
2003	36	Mean	24.9	67.8	9.5	42.8
		Range	(16.3–27.3	(52.1–78.3)	(8.1–12.4)	(30.8–58.6)
2004	45	Mean	26.5	68.9	9.8	44.2
		Range	(15.2–29.9)	(57.1–75.6)	(8.4–11.6)	(32.2–52.4)
2005*	52	Mean	15.8	52.8	9.5	42.6
		Range	(9.2–18.2)	(40.8–58.6)	(6.8–11.2)	(37.4–48.6)
2006	64	Mean	28.4	68.4	10.4	43.4
		Range	(21.4–32.1)	(48.8–74.2)	(7.8–12.2)	(32.1–58.8)
Mean			24.3	64.7	9.8	42.9

Source: RIRDC

Purple varieties including Popany need to be cut at flowering/before the pod set stage. In these stages the balance of nutrition value of hay/silage is at its highest for each species.

Common vetches can be cut late, when pods contain seeds and still be fed to all ruminants, without any problem, but purple vetch grain cannot be used to feed any livestock even when still in pods.

Different forage varieties are better adapted to different rainfall zones (Table 3).

Table 3: *Vetch hay/silage/grazing and green manuring variety selection based on rainfall (mm).*

<350	350–400	400–450	450–600	>600
Rasina(b	Rasina(b	Morava(b	Morava(b	Capello(b
Blanchefleur	Morava(b	Rasina(b	Popany	Haymaker(b
Cummins	Cummins	Popany	Capello(b	Morava(b
Morava(b	Popany	Capello(b	Haymaker(b	Popany
Volga(b	Blanchefleur	Haymaker(b	Timok(b	Timok(b
Timok(b	Volga(b	Volga(b	RM4(b	RM4(b
RM4(b	Timok(b	Timok(b		
	RM4(b	RM4(b		

Source: SARDI

2.1.3 Anti-nutritional factors

Some vetches contain neurotoxins, mainly BCA (beta-cyanoalanine) and other anti-nutritional factors. Hence vetches can only be used in limited quantities for monogastrics (if at all), and contamination by wild vetches (tares) or other species may exacerbate the problem. Inactivation of BCN by autoclaving does not improve the digestibility of amino acids or digestible energy.

MORE INFORMATION

[Pulses nutritional value and their role in the field industry]

[Using pulses for forage]

[Progress towards reducing seed toxin levels in common vetch]

Anti-nutritional factors in bitter vetch include *L. canavanine*, trypsin inhibitor, catechin and a special lectin. The bitterness in bitter vetch needs to be removed by leaching with boiled water before it could be considered for humans or monogastrics. [10]

Breeding to reduce vetch toxins

Common vetch is well adapted to the low rainfall areas of southern Australia however, the seed contains high levels of the toxin, γ-glutamyl-β-cyanoalanine, which limits its use. Reducing the concentration of this toxin may allow greater marketing options and help develop vetch as a viable alternative grain crop for low rainfall areas. The genetic control of seed toxin level, and cotyledon colour were studied with the aim of developing low toxin lines of vetch with distinctive seeds. More than 3000 accessions from major international collections have been screened for seed toxin level. Using conventional breeding methods, it appears that seed toxin concentration can be reduced to about 0.3–0.4%. The work has shown that it is feasible to use conventional breeding methods to develop low toxin lines of vetch, which can then be used as a viable alternative source of protein in poultry diets. [11]

2.2 Varietal performance and ratings yield

Table 4 provides information on the most important selection/recommended criteria for planting for grain and hay, maturity, shattering resistance and hard seed percentage for each variety.

Table 4: *Varietal characteristic of vetch varieties.*

Variety	Maturity	Yield potential		Flower colour	% of pod shattering	% of hard seeds
		Grain	Dry matter			
Common Vetch Varieties (*Vicia sativa*)						
Blanchefleur	Mid	High	Mod	White	5–10	5–10
Cummins	Mid-early	High	Mod	White	5–10	5–15
Morava⒫	Late	High	High	Purple	0	0
Rasina⒫	Early-mid	High	Mod	Purple	0–2	0
Volga⒫	Early	V. high	High	Purple	0–2	2–5
Timok⒫	Mid	High	V.high	Purple	0–2	0–2
Purple Vetch (*Vicia.benghalensis*)						
Propany	Very late	Low	High	Purple	20–30	5–10
Woolly pod vetches (*VIcia villosa* subsp.)						
Haymaker⒫	Late	Low	Very high	Purple	5–10	20–30
Capello⒫	Late	Low	Very high	Purple	5–10	15–20
RM4⒫	Mid	Moderate	Very high	Purple	2–5	2–5

Source: SARDI

2.2.1 Common Vetch (*Vicia sativa*)

Common vetches are an annual pasture/forage/grain legume, extremely palatable at all growth stages, from early green shoots, as dry matter/hay or silage through to seedpods and seeds over summer.

It has very high feed values for animals as green plants and dry matter as well as grain. Herbicide tolerance; no differences between these varieties to registered

10 W Hawthorne (2006) Pulses nutritional value and their role in the feed industry. Pulse Australia Pty Ltd. http://www.pulseaus.com.au/storage/app/media/using_pulses/2006_Pulses-Feed-value-livestock.pdf

11 D Chowdhury, M Tate, G McDonald, R Hughes (2001) Progress towards reducing seed toxin levels in common vetch. The Regional Institute. http://www.regional.org.au/au/asa/2001/5/c/chowdury.htm

herbicides to control broad leaf weeds. Also, no differences between varieties to registered herbicides for grass weed control.

Languedoc

This is an early flowering and maturing variety recommended for low rainfall areas although its can lodge severely making harvest difficult under certain conditions. Languedoc generally exceeds Blanchefleur's grain yield in areas with less than 350 mm rainfall. Its hard seed content is generally around 5–10% and it is highly susceptible to rust. Languedoc grains possess 1.0–1.6% of anti-nutritional level (BCN).

Blanchefleur.

Prior to the release of Morava⦇, Blanchefleur had been the preferred grain variety in areas above 350 mm rainfall in SA. Blanchefleur has mid maturity, white flowers and reddish brown/mottled seed with orange cotyledons. Blanchefleur is very susceptible to rust. It is well suited to medium to high rainfall areas where rust is not a regular problem. Both vetch and lentils are on the prescribed grain list of AQIS due to the vetch-lentil substitution issue, this has meant export markets of orange cotyledon varieties like. Blanchefleur are limited to small bird seed markets in Europe and seed for grazing and green manure crops only. Blanchfleur grains possess 0.9–1.6% of anti-nutritional level (BCN).

Cummins

This is a mid to early maturing, white flowering variety selected from Languedoc. It is well adapted to medium to low rainfall areas where it generally yields higher than Blanchefleur. Cummins is susceptible to rust and moderate susceptible to Ascochyta blight. Cummins possess similar percentage of BCN to Blanchefleur.

Morava⦇

Morava⦇ is a rust resistant late flowering vetch variety with 100% soft seeds, develop in 1998 by SARDI's Australian National Vetch Breeding Program (ANVBP). Grain yield is superior to other vetches in the high rainfall areas and to Blanchefleur, Languedoc and Cummins in all other areas in the presence of rust. It is larger seeded and more resistant to shattering than other vetch varieties. The BCN levels of Morava⦇ are 0.65%, which is 50% lower than Blanchefleur and Languedoc. Morava⦇ produces higher herbage yields than all other common vetch varieties. Morava⦇ is later flowering and maturing than Blanchefleur and grain yield will be reduced in environments with dry finishes.

Rasina⦇

Rasina⦇ is soft seeded vetch from the ANVBP, developed in 2006. Rasina⦇ replaces Languedoc, Blanchefleur and Cummins in low to medium rainfall areas for grain production. Rasina⦇ is 5–10 days earlier than Blanchefleur and 10 to 15 days earlier than Morava⦇. A significant advantage over Languedoc, Blanchefleur and Cummins is Rasina⦇ resistance to rust and is slightly more tolerant to ascochyta blight and Botrytis. However, Rasina⦇ is not expected to replace Morava⦇ in higher rainfall districts or for hay production. The level of anti-nutritional factors is 0.6 to 0.8 compared to 0.9 to 1.6 in Blanchefleur and Languedoc, respectively. Rasina⦇ possesses a distinctive uniform dark brown speckled seed coat with dark beige cotyledons. Rasina⦇ is a PBR variety

Volga⦇

Developed in 2012 by SARDI's Australian National Vetch Breeding Program (ANVBP), Volga⦇ is high yielding grain/seed variety for low and mid rainfall areas. It is particularly suited to shorter season areas where the growing season finishes sharply. Volga⦇ has good initial establishment, is rust resistant, and earlier flowering and maturing than Blanchefleur and Rasina⦇. It will improve the reliability of vetch and economic production in crop rotations especially in low and mid rainfall areas, 330 to 380 mm per year. Earlier maturing equates to earlier nodule development. Volga⦇ has high grain and herbage yields and is well adapted to all areas where vetch is currently grown. Volgaⓓ is well suited to situations where the season finishes sharply (dry September & October, a common issue in many low to mid rainfall areas) because of its early flowering and maturing characteristics. It can be successfully grown in many Australian soil types; from non- wetting sand to heavy clay loam with pH 5.8 – 9.4, like other common vetch varieties. Volgaⓓ is moderately susceptible to ascochyta blight, whereas Moravaⓓ is susceptible. The early maturity of Volgaⓓ may limit yield potential relative to longer growing season varieties like Moravaⓓ in high rainfall areas. Toxin levels in the grain are around 0.54% lower compared to Moravaⓓ at 0.65% and Blanchefleur 0.95%. Volgaⓓ seed size is very similar to Moravaⓓ seeds (100seeds weight 7.82 g). See data in following tables. Volgaⓓ is a PBR variety

Timokⓓ

Developed in 2012 by SARDI's Australian National Vetch Breeding Program (ANVBP), was bred to complement Moravaⓓ in mid/high rainfall areas for grain/seed and especially for hay/silage production. Timokⓓ yielded more grain than Rasinaⓓ, Moravaⓓ and Blanchefleur by 9%, 18% and 21%, respectively over five years at five sites in SA. Timokⓓ has better initial establishment than Moravaⓓ, and will improve the reliability of vetch and economic production in crop rotations especially in mid and high rainfall areas, 350–450 mm/yr. Moravaⓓ will still be the preferable variety for hay/silage in rainfall areas with greater than 450 mm per year. Timokⓓ is high yielding, highly rust resistant common vetch variety, moderately susceptible to ascochyta blight, susceptible to botrytis, has good early establishment, and is a soft seeded variety. Timokⓓ matures between Rasinaⓓ and Moravaⓓ (100–105 days from seeding to full flowering). Timokⓓ is very well adapt for grain production in rainfall areas >380 mm/yr, and dry matter production is similar to Moravaⓓ in high rainfall regions (>400 mm), but 19% higher than Moravaⓓ in low to medium rainfall regions (330–380 mm). Timokⓓ is multipurpose variety--can be used for grain, hay/silage, grazing or green/brown manure. Toxin levels in the grain are around 0.57%. Seed weight is 6.88 g per 100 seeds, similar size to Rasinaⓓ 6.92 g/100seeds. See data in following tables. Timokⓓ is a PBR variety. [12]

2.2.2 Woolly pod vetches

Woolly pod vetch can be used as a pasture plant, hay/silage and green manuring crop (Photo 2).

Photo 2: *Woolly pod vetch in NSW.*

Photo: Stuart Nagel.

12 SARDI (2017) 2017 Sowing Guide, South Australia. GRDC, SARDI. http://www.nvtonline.com.au/wp-content/uploads/2017/01/SA-sowing-guide-2017_lo-res.pdf

Capelloⓓ and Haymakerⓓ

Woolly pod vetches are lower in grain yield compared with common vetches, but are much higher in dry matter production than common vetch varieties in rainfall areas >450 mm/yr. Grain from these varieties cannot be used to feed any livestock. Also, these varieties can only be grazed from the 10-node stage to podding stage. It is not recommended that grazing occur earlier and also once plants begin to develop seeds in pods. These two varieties are very good for hay/silage production in areas >400 mm of rainfall annually. Haymakerⓓ and Capelloⓓ are selected soft seed varieties from Namoi. In last few years these two varieties have become prone to hard/dormant seeds. Both varieties are owned by Heritage Seeds.

RM4ⓓ

This variety was selected by Australian National Vetch Breeding Program. RM4ⓓ is high producer of dry matter, has very good early establishment, moderately resistant to ascochyta blight, and susceptible to botrytis, soft seed variety (>94%); emerged in 15–20 days on the field; earlier in maturity by 10–15 days than Haymakerⓓ or Capelloⓓ, significantly higher in dry matter production in mid/low rainfall areas (400–650 mm/yr. RM4ⓓ is multipurpose variety- that can be used for hay/silage, grazing, green/brown manure or for seeds. RM4ⓓ can be successfully grown, like other woolly pod varieties in many Australian soil types, like other vetches is excellent for soil fertility/structure and nitrogen fixation, graze from 10 nodes up to finish flowering, for hay/silage, cut in full flowering for the best balance of feed value. RM4ⓓ performs better in grain productions than other woolly pod varieties when season finishes sharply. Herbicide tolerance: RM4ⓓ was not sensitive to any herbicides recommended/registered for use in woolly pod vetch varieties. Insect pests: RM4ⓓ is susceptible in early growth stages to redlegged earth mite and lucerne flea, like other woolly pod vetch varieties. Also, RM4ⓓ is susceptible to blue green and cowpea aphids from early growth through to pod maturity, as well as to native budworm during pod formation and filling. Grain from this variety, like other woolly pod vetches, cannot be used to feed any livestock. RM4ⓓ is a PBR variety and can be sourced from Heritage Seeds. [13]

Namoi

Namoi woolly pod vetch (*Vicia villosa* ssp. *dasycarpa* cv. Namoi) is a self-regenerating legume that was originally introduced from Turkey in 1951. It was further developed at the University of Sydney's Plant Breeding Institute at Narrabri into a useful and adaptable legume that can be grown throughout the state. It is an annual which grows from autumn to spring, and does well on many soil types and in varying climates.

Namoi been used on the North-West Slopes and in central and southern NSW as a pioneer species when developing new country. It is also very useful when rehabilitating old cultivation areas. Namoi is often sown with winter cereal fodder crops to increase protein levels in the fodder.

This cultivar is sprawling and weak-stemmed, with purple, pea-like flowers. It will grow through and over associated plants to produce a dense, intertwined sward as shown in the photo on the right.

The plant flowers profusely from late spring to early summer, producing many two-seeded to five-seeded pods. The seeds are:

- fairly large (26,500 seeds/kg);
- about half the size of field peas;
- high in protein.

Early growth, particularly from winter sowings, is very slow. The young, almost fernlike, prostrate runners are weak and easily damaged by grazing.

Namoi is adapted to a wide range of soils varying from heavy basalts to granites, but the soil must be at least moderately fertile for satisfactory production. It responds

13 SARDI (2017) 2017 Sowing Guide, South Australia. GRDC, SARDI. http://www.nvtonline.com.au/wp-content/uploads/2017/01/SA-sowing-guide-2017_lo-res.pdf

MORE INFORMATION

Namoi woolly pod vetch

well to added phosphorus and sulfur in fertilisers when soils are low to moderate in fertility. [14]

Table 5 provides dry matter yield for woolly pod and purple vetch varieties tested between 2011–2014 by the Australian National Vetch Breeding Program.

Table 5: *Dry matter as a percentage of Capelloⅅ in field trials in SA between 2011–2014.*

Variety	Dry matter (t/ha)	% of Capelloⅅ
Cappello	6.23	100.0
Haymakerⅅ	6.26 (2009–12)	100.4
RM4ⅅ	6.71	107.7
Mean yield	6.4	
Purple Vetch Variety		
Popany	5.28 (2009–12)	84.75

Source: SARDI

2.2.3 Purple Vetch (*Vicia benghalensis*)

Popany

Popany (*V. benghalensis*) is purple vetch. Grain yield is significantly lower than yields from common vetch varieties. But, seeds are smaller than seeds from common vetch varieties therefore the seeding rate are lower at approximately 30–35 kg/ ha. Grain from this variety can be used as a bird feed in mix with other recommended grains. Popany is a late maturity variety, >125 days from seeding to podding. It is a good variety in mid to high rainfall areas for hay/silage. Popany, possesses 5–10% hard seeds. This variety is resistant to rust but susceptible to ascochyta and botrytis grey mould. Seed coat is black with distinctive white hilum. [15]

2.3 Planting seed quality

Key points:

- All seed should be tested for quality including germination (high germination – above 80%) and vigour (AA test). Use large, graded seed.
- If grower retained seed is of low quality then consider purchasing registered or certified seed from a commercial supplier and always ask for a copy of the germination report.
- Careful attention should be paid to the harvest, storage and handling of grower retained seed intended for sowing.
- Calculate seeding rates in accordance with seed quality (germination, vigour and seed size). [16]

Seed quality at sowing can have a major impact on crop performance and resulting yield at the end of the season - particularly in pulse crops. Seed size, quality and germination varies between varieties, from year to year, from paddock to paddock and should be checked for each seed line to be used.

The best yields are produced by using quality seed with high germination rates. Sowing seed with low germination rates will produce a thin stand and lower yields. Some pulses may have low germination rates because they have a high percentage of dormant/hard seed or from damage during augering. Harvest and post-harvest

14 NSW DPI. Namoi Woolly pod vetch. http://www.dpi.nsw.gov.au/agriculture/pastures-and-rangelands/species-varieties/namoi-woolly-pod-vetch

15 SARDI (2017) 2017 Sowing Guide, South Australia. GRDC, SARDI. http://www.nvtonline.com.au/wp-content/uploads/2017/01/SA-sowing-guide-2017_lo-res.pdf

16 Pulses Australia. Chickpea Production: Southern and Western region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

seed damage can produce abnormal seedlings which germinate but do not develop further.

Seed quality is important for good establishment. Early seedling growth relies on stored energy reserves in the seed. Good seedling establishment is more likely if the seed is undamaged, stored correctly and from a plant that has had adequate nutrition.

Test any retained seed for germination, vigour and disease. Do not keep seed from severely diseased crops.

Check the seed analysis certificate for germination percentage and purity before purchase. Legislation requires that only the minimum germination test must be supplied on the label with certified seed. Be sure to ask for the seed analysis certificate and any disease testing for the seed lot being purchased.

Weed contamination testing

Sowing seed free of weeds cuts the risk of introducing new weeds. It also reduces the pressure on herbicides, especially with increasing herbicide resistance. Tests for purity of a sample can be conducted if requested, including the amount of weed seed contamination.

Disease testing

Seed borne diseases can pose a serious threat to yields. Seed borne diseases can strike early in the growth of the crop when seedlings are most vulnerable and result in severe plant losses and hence lower yields. Testing seed before sowing will identify the presence of disease and allow steps to be taken to reduce the disease risk. If disease is detected, the seed may either be treated with a fungicide before sowing or a clean seed source may be used. For a disease test 1 kg of seed is required, except for anthracnose where 2 kg is needed. [17]

Grower retained seed

Grower retained seed may be of poor quality with reduced germination and vigour, as well as potentially being infected with seed-borne pathogens.

Seed quality may be adversely affected by several factors including:

- Early desiccation resulting in high levels of green immature seed and smaller seed size (affecting both germination and vigour).
- Cracking of the seed coat if the seed is exposed to several wetting and drying cycles. As the seed coat absorbs moisture it expands and then contracts as it dries. This weakens the coat increasing the risk of mechanical damage during harvesting and handling operations.
- Mechanical damage can result in reduced germination and vigour and increased susceptibility to fungal pathogens in the soil at sowing (exacerbated if establishment is delayed into cold wet soils).
- Delayed harvest due to wet weather can lead to increased (i) Native budworm damage; (ii) mould infection, and (iii) risk of disease.
- Harvesting at a moisture content more than 15% can lead to problems with moulds and fungal pathogens colonising on the seed coat during storage.
- Harvesting at a moisture content under 10% can result in mechanical damage to the seed coat and/or seed splitting, which is compounded each time the seed is handled.
- Poor (temporary) storage in the rush to get harvest done in wet weather can reduce viability of the seed resulting in poor germination and emergence.

17 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2008). Grain legume handbook. *GRDC: Canberra, ACT.*

VIDEOS

WATCH: GCTV16: Extension Files – Retained Pulse Seed.

- Seed-borne diseases all reduce the viability of the seed (germination and vigour). Crop establishment is reduced and any surviving infected seedlings act as an inoculum source to initiate disease infection within the new crop. [18]

NOTE: Do not use grain for seed of pulse crops harvested from a paddock that was desiccated with glyphosate. Germination, normal seedling count and vigour are affected by its use. Read the glyphosate label.

2.3.1 Seed germination and vigour

Seed with poor germination potential or high levels of seed borne disease should not be sown. Seed borne diseases can lower germination levels.

The lower cost of this seed will be offset by the higher sowing rates needed to make up for the lower germination and the potential to introduce disease on to the property. The only way to accurately measure the seed's germination rate and disease level is to have it tested.

Always do a germination test on seed and adjust the sowing rate accordingly. Sowing quality seed is critical to achieving adequate plant density and high yields.

Germination tests can be done by seed testing laboratories or at home. For vetch, the sample size required is one kilogram for each 25 tonnes of seed. [19]

Calculating germination percentage

To calculate the germination percentage of a seed lot.

1. Using a graded seed lot, count out 100 seeds from each lot to be planted, including the damaged seeds.
2. Use a flat tray about 30 cm square and 5 cm deep (a nursery seedling raising tray is ideal). Place a single sheet of paper towel in the bottom to cover the drainage holes and fill with clean sand, potting mix or freely draining soil. (NOTE: If you don't have a tray the test can be done in any sort of self-draining container or in a cool part of the home garden.)
3. Take the 100 seeds (including the damaged ones) and sow 10 rows of 10 seeds (the rows make it easier to count the seedlings). Seeds should be sown at a normal seeding depth of 2 to 3 cm (Photo 3). (NOTE: Place the seeds on top of the sand or soil and push them in with a piece of dowel or a pencil and cover with more sand.)

18 L Jenkins, K Moore, G Cumming. Pulse Australia. Chickpea: High Quality seed. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/high-quality-seed

19 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2008). Grain legume handbook. *GRDC: Canberra, ACT.*

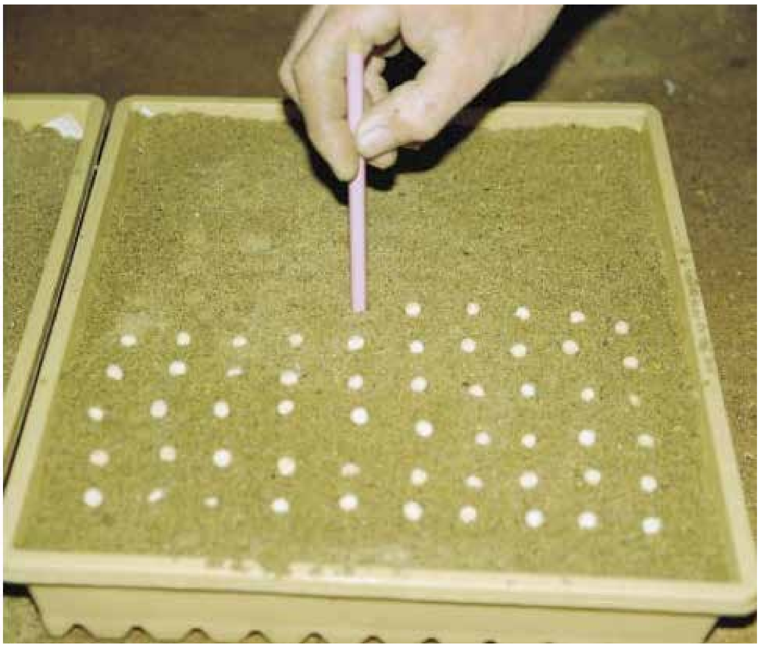


Photo 3: *Setting up a germination test in a seedling raising tray. Place 100 seeds on top of the sand and push them in 2–3 cm deep before covering.*

Photo: Di Holding, Source: NSW DPI

4. Water gently with a spray bottle. Keep moist (not wet). Overwatering will result in fungal growth on the seeds and may cause seed rot and affect normal germination.
5. Count the seedlings after 7 to 10 days, when the majority of seedlings are up. Do not wait until the late ones emerge. (These ones are damaged or have low vigour.)
6. Only normal seedlings should be counted - those with both cotyledons (seed leaves) present.
7. Calculate your germination percentage (e.g. if you count 83 normal seedlings, then your germination percentage is 83%).
8. Repeat four times. [20]

Results of this test will inform sowing rates. For more information on sowing rates, see Section 3: Planting – section 3.6 Calculating sowing rate.

MORE INFORMATION

Germination testing and seed rate calculation

Seed dormancy in Vetch

Seed dormancy

Vetch species and subspecies were assessed for dormancy in greenhouse trials in 1999. Common vetch (*Vicia sativa*) and Purple vetch (*V. benghalensis*), V. ervilia and V. articulata had no impermeable seeds. Almost all the Woolly pod vetch (*V. villosa*) accessions had a high level of impermeable seeds ranging from as low as 10% to a high of 60%. Some subspecies of common vetch (*V. sativa ssp nigra, V. sativa ssp sativa*) had higher levels of impermeable seeds ranging from 50–95%. [21]

2.3.2 Seed size

The larger the seed, the larger the endosperm and starch reserves. Although seed size does not alter germination, larger seeds emerge earlier and faster than medium and small seeds. This is because larger seeds germinate more rapidly and their roots are longer than those of smaller seeds. With adequate moisture, medium-sized seeds

20 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

21 O Modisa (1999) Seed dormancy in vetch (Vicia species). University of Melbourne. https://minerva-access.unimelb.edu.au/handle/11343/114553

will emerge in 5 or 6 days. Seed size is usually measured by weighing 100 seeds. The result is known as the 100-seed weight.

The 100-seed weight varies among varieties and from season to season. Therefore, sowing rates should be altered according to seed weight to achieve the desired plant population.

Seed grading is a good way to separate good-quality seed of uniform size from small or damaged seeds and other impurities such as weed seeds. Grading is important when sowing into soils with marginal moisture or when sowing depth is uneven. Seed size and vigour are particularly important following drought years, when there is more small seed. Not only does seed size affect seedling vigour, it can also affect sowing rate.

For more information, see Section 3: Planting, Calculating seed rate.

It is recommended that both the germination test and seed size test be done on several lots of seed (i.e. at least twice) to get a more accurate assessment of the sample.

2.3.3 Seed storage

Pulses exposed to weathering before harvest deteriorate more quickly in storage. Most pulse seed should only be stored for 12 months, although longer storage periods are possible with high quality seed provided both grain moisture and temperature within the silo can be controlled. Rapid deterioration of grain quality occurs under conditions of high temperature/moisture and with poor seed quality including weathered, cracked and diseased seed.

Pulses harvested at 14% moisture or higher must be dried before going into storage to preserve seed germination and viability. As a general rule, every 1% rise in moisture content above 11% will reduce the storage life of pulse seed by one third.

High temperatures in storage will cause deterioration in grain viability. Temperatures of stored pulse grain should not exceed an average of 25°C and preferable the average temperature should be below 20°C. In general, each 4°C rise in average stored temperature will halve the storage life of the grain. [22]

IN FOCUS

Seed dormancy and storage in vetch.

Low temperature storage (5°C) reduced the level of impermeable seeds in most species. The seed moisture was increased under low temperature storage and this resulted in higher germination. This type of storage is not suitable for long term storage but can be used if the relative humidity is reduced to about 0%. High temperature storage reduced seed moisture and encouraged seed impermeability. Fluctuating temperature of 22/11°C reduced the proportion of impermeable seeds.

Storage environment also played an important role in the development of impermeable seeds in Vicia. Dry conditions imitated by desiccator reduced seed moisture and resulted in higher levels of impermeable seeds. Seed storage under laboratory conditions had no effect on the proportion of impermeable seed. [23]

22 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.*

23 O Modisa (1999) Seed dormancy in vetch (Vicia species). University of Melbourne. https://minerva-access.unimelb.edu.au/handle/11343/114553

For more information, see Section 13: Storage.

2.3.4 Safe rates of fertiliser sown with the seed

Be wary that all pulses can be affected by fertiliser toxicity. The risk of fertiliser toxicity can be reduced by increasing the spread of seed and fertiliser in the row, reducing in-furrow fertiliser rates or separating seed and fertiliser bands.

Soil testing, including deep nitrogen and sulfur testing, is especially important following wet summers as the loss of nutrients by water-logging, leaching and summer weeds, may or may not be balanced by higher release of mineralised nutrients from the warm, moist soils. Where soil nutrient status is low, and soil moisture is high, there is the opportunity to use higher rates of fertiliser at seeding to meet the needs of the crop. While placing fertiliser in the seed row is an effective practice, germinating seeds are susceptible to damage by fertiliser. Care must be taken to create space between seed and fertiliser, especially with high fertiliser rates and under wide row spacing. If row spacing is increased but the fertiliser rate per hectare remains constant, then the amount of fertiliser in each row increases. The narrow seed spread typically created by disc seeders can also increase the potential for seedling damage by fertiliser.

The separation of seed from fertiliser is three-dimensional – along, across and down the furrow. The concept of seed bed utilisation (SBU) has been used to address this issue.

Factors to consider when selecting fertilisers and rates

Fertiliser type

All fertilisers are relatively concentrated chemical compounds that can affect delicate germinating seeds in a couple of ways.

Osmotic effect - In chemical terms fertilisers are salts and can affect the ability of the seedling to absorb water by osmosis. Too much fertiliser (salt) near the seed and desiccation or 'burn' can occur. However, fertilisers vary in salt index or burn potential depending on composition. As a general rule, most common nitrogen and potassium fertilisers have a higher salt index than phosphorus fertilisers.

Efficiency enhancers - Some strategies to enhance fertiliser efficiency, such as the use of polymer coatings or urease inhibitors will slow the rate of ammonia production and make these products less likely to cause crop damage.

Soil type and environment

Soil conditions that tend to concentrate salts or stress the germinating seed increase the potential for damage. So, the safe limit for in-furrow fertilisation is reduced with lighter soil texture (sands) and in drier soil conditions. It is also reduced when environmental conditions such as cool temperatures induce stress and/or slow germination. These can result in prolonged fertiliser-seed contact, increasing the likelihood of damage. Good rain immediately after sowing can reduce the potential for damage as salts are diluted and ammonia is dissolved, which reduces the concentrations around the seed.

Machinery configuration

The type of sowing point and seed banding boot used and the spacing between the drill rows both affect the concentration of fertiliser near seed and the likelihood of damage.

Increasing seed bed utilisation (SBU) using seeding systems - When high SBU seeding systems were combined with high seed rate, the grain yield and crop/ weed competition were both maximised. Practical options to achieve a high SBU include fitting paired row seeding boots to existing tillage systems, using greater soil disturbance ribbon sowing systems, or reducing row spacing. When tyne-based systems are used to achieve high SBU, stubble clumping is typically increased and uniformity of seeding depth decreased.

Row spacing - If the same fertiliser rate is used with different row spacings, then the amount distributed along each seeding row will increase as row spacing becomes wider. For example, the rate of fertiliser applied in a 30 cm row is basically double that of a 15 cm row. To avoid this increased fertiliser concentration in wide-row systems the safe rate of in-furrow fertiliser decreases as row spacing increases (Table 6).

Table 6: *Approximate safe rates of P with canola seed if seedbed has good soil moisture (at or near field capacity). These values can be applied to vetch.*

	25 mm (1') seed spread[2]			**50 mm (2') seed spread[2]**		
Fertiliser Type	Row spacing			Row spacing		
	180 mm (7')	229 mm (9')	305 mm (12')	180 mm (7')	229 mm (9')	305 mm (12')
	SBU[3]			SBU[3]		
	14%	11%	8%	29%	22%	17%
DAP (18:20:0)	8	6	5	17	13	10
MAP (10:22:0)	10	8	6	21	16	12
Triple Super (0:20:0)	27	21	15	55	42	33
Single Super (0:9:0)	15	12	9	31	24	18

2 Width of seed spread must be checked under field condition. Width of spread varies with air flow, soil type, moisture level, amount of stubble and other soil conditions.

3 SBU is the amount of the seedbed over which the seed/fertiliser has been spread. These models are yet to be confirmed and are a guide only – use half these rates in dry soil

Source: GRDC

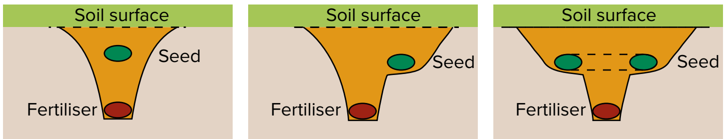
Seedbed utilisation - The concept of SBU has been used to help quantify this issue. SBU is simply the seed/fertiliser row width divided by the seed row spacing, that is, the proportion of row space occupied by the seeds. The wider the lateral seed spread, for a specific row spacing, the greater the SBU. As SBU increases, so does the safe rate of in-furrow fertilisation. The greater the lateral scatter of seed and fertiliser in the seed band or row (along, across and to depth) the more fertiliser that can be safely applied with the seed. The type of planting equipment and seed opener influences the closeness of seed-fertiliser contact (Table 7). For example, minimal lateral spread is achieved by many disc openers, with lateral spread generally increasing with share width. Double shoot/ribbon seeding openers, where seed is spread across a wider furrow, achieve the greatest lateral spread. When the lateral seed spread = share width = row spacing, a 100 per cent SBU is achievable.

Table 7: *Differences in seed bed utilization for a range of seeding points and boot combinations.*

Seeding point	**Common seed spread (mm)**	**% seed bed utilization (SBU)**		
		Row spacing (mm)		
		150	**225**	**300**
125 mm share	65	43	29	22
65 mm share	46	31	20	15
Single side band opener	36	24	16	12
Spear point	25	17	11	8
Inverted T	25	17	11	8

Source: GRDC

Openers with split banding systems can separate the seed and fertiliser laterally and vertically (Figure 1 A, B and C). The greater the angle of the fertiliser boot to the seed boot the greater the vertical separation potential between the seed and fertiliser. The width of spread must be checked under field conditions. It may vary with air velocity, ground speed, seeding depth and soil conditions. Along with seeding system crop type, fertiliser and environmental conditions must still be considered. Table 6 shows the safe rates of fertiliser urea for canola. Seedbed moisture content is also an important factor, and damage is more likely with dry soils rather than moist soils. If the soils are dry or borderline, then rates should be at least halved from those in Table 6. [24]



A. Single outlet with centre banding
Pros: Sub-seed soil disturbance, fertiliser separation banded at depth.
Cons: High draft and breakout force required compared with tillage at seeding depth, seed placement quality variable.

B. Single outlet with side banding
Pros: Sub-seed soil disturbance, fertiliser separation banded at depth, improved seed placement, good moisture transfer to seed.
Cons: High draft and breakout force required, potentially higher soil and residue disturbance.

C. Dual outlet paired row and ribbon sowing systems
Pros: Sub-seed soil disturbance, fertiliser separation, good seed placement except over centre section, higher seed-bed utilisation.
Cons: High draft and breakout force required, higher soil and residue disturbance influencing seeding depth uniformity.

Figure 1: *Three arrangements of split seed and fertiliser banding with tillage below the seeding point that illustrate the different types of seed and fertiliser separation achieved.*

Source: GRDC

MORE INFORMATION

Care with fertiliser and seed placement – GRDC Factsheet

24 GRDC (2011) Fertiliser Toxicity – Fact sheet: Care with fertiliser and seed placement. https://grdc.com.au/__data/assets/pdf_file/0019/203635/fertiliser-toxicity.pdf.pdf

Planting

Key messages

- Vetch should be inoculated with Group E rhizobia, especially in paddocks where vetch has not been grown before.
- In Western NSW, Vetch should be sown in mid-March but timing will depend on whether the crop will be grazed or cut for hay.
- Vetch target population and seeding rate differ depending on end use.
- Vetch should be sown between 3–5 cm deep with good soil cover.
- Vetch can be normally drilled, whether sown alone or in combination with cereals or cereal/forage peas, and it can also be broadcast although this is rarely done

3.1 Inoculation

Key points:

- Group F rhizobia is recommended for vetch inoculation
- Do not mix inoculants with fungicides/insecticides. Make sure to check labels for compatibility.
- Take the time to choose an inoculant type that suits conditions and farming systems.
- It's important to see how effective the inoculum has been and what state of health the nodules are in. By checking the degree of nodulation you can assess the type of inoculum product you have used and the application technique employed to get the rhizobia where it needs to be; in the roots of the growing pulse.

Nitrogen fixation by legumes does not happen as a matter of course. Compatible, effective rhizobia must be in the soil in which the legume is growing before nodulation and nitrogen fixation can occur. When a legume is grown for the first time in a particular soil, it is highly likely that compatible, effective rhizobia will not be present. In such circumstances, the rhizobia must be supplied in a highly concentrated form as inoculants.

Vetch is able to add a large amount of nitrogen to the soil, which has benefits to following crops (Table 1).

Table 1: *The range of measures of shoot dry matter (DM) production and estimates of N2 fixation for 35 commercial pulse crops sampled in farmers' fields between 2001 and 2013. Mean values for each parameter and crop species are shown in brackets.*

Legume	Number of crops	Shoot DM	Shoot N fixed		
		(t DM/ha)	(%Ndfa)	(kg N/ha)	(kg N/t DM)
Faba bean	5	7.2–8.4	68–89	117–152	16–18
		[7.6]	[74]	[135]	[17]
Lupin	11	0.9–10.2	20–82	20–150	9–21
		[5.5]	[59]	[74]	[15]
Vetch	3	4.2–6.3	54–84	53–135	13–22
		[5.1]	[69]	[89]	[17]
Lentil	3	2.0–5.3	17–82	20–104	4–20
		[4.0]	[50]	[51]	[13]
Field pea	7	2.3–5.9	8–85	12–87	2–20
		[3.9]	[53]	[45]	[14]
Chickpea	6	0.8–5.2	24–87	13–66	7–17
		[2.9]	[67]	[34]	[13]
Median all crops			68	61	16

Source: GRDC

MORE INFORMATION

Legume effects on soil N dynamics - comparisons of crop response to legume and fertiliser N

For more information on vetch nitrogen fixation, see Section 1: Planning and paddock preparation, Section 1.3 Benefits of vetch as a rotation crop, Nitrogen fixation.

Grain legumes do not need additional nitrogen (N) if the seed is effectively inoculated at planting. Profitable production of pulses is dependent on successful nodulation of the crop, which supplies more than 60% of pulse crop nitrogen. [1] The biological process of nitrogen fixation, where rhizobia located in legume root nodules convert atmospheric dinitrogen (N_2) into ammonia (NH_3) for plant growth, is one of the great agriculture success stories. *Rhizobium* bacteria that have a symbiotic relationship with pulse crops 'infect' the plant roots, forming nodules that fix atmospheric nitrogen for the pulse crop to use while it is growing (Photo 1). This free source of nitrogen ensures a healthy plant and delivers excess nitrogen that reduces the risks of cereal production in subsequent years. Nitrogen fixed by the soil bacteria rhizobia symbiotically with Australia's pasture and pulse legumes, has a national benefit of close to $4 billion annually.

1 J Evans. (2005). An evaluation of potential Rhizobium inoculant strains used for pulse production in acidic soils of south-east Australia. *Animal Production Science*, *45*(3), 257–268.

Photo 1: *Nitrogen fixing nodules on a pulse plant.*

Photo: A Mostead, Source: GRDC

Residual nitrogen in the soil is decreased by crop growth (e.g. cereals) and nitrogen fixing crops like legumes and pulses can increase nitrogen in the soil. New technology has provided growers with several methods of applying the *Rhizobium* bacteria to the soil. Inoculation adds the most efficient N-fixing bacteria (rhizobia) for the type of legume to help maximise nodulation and N-fixing ability. A following cereal crop can also benefit from an effectively inoculated legume crop. Application of essential fungicides at planting is also possible using these new delivery methods without compromising the health of the rhizobium. [2]

Vetch should be inoculated with Group E rhizobia (*Rhizobium leguminosarum bv. viciae*).

Inoculation is important to all legumes, especially under planting situations where:

- soil has not previously grown the specific legume crop
- there has been a long time interval between the planting of successive legume crops
- soil erosion has removed or depleted bacterial populations
- levelling has exposed lower soil profiles that contain low bacterial populations.

Rhizobia types vary in their ability to persist in the soil until the host pulse crop is regrown. Vetch, pea and bean rhizobia (Groups E & F) survive well in neutral to alkaline soils with good texture (loams or clays). Vetch rhizobia survive poorly in low pH or sandy soils. The safest and lowest risk option is to always inoculate the crop, especially on light textured soils.

The cost of inoculation is lowand should be applied ever year, regardless of pulse history of the paddock . A benefit of inoculating a crop where rhizobia already exist is that an improved strain will be introduced which could result in better persistence for future pulse crops. Research continues to find more robust and efficient rhizobia strains for all pulse species. The strain used today in any group will be more advanced than those introduced to a paddock in the past. [3]

VIDEOS

WATCH: GCTV13: Legumes – Sowing preparation.

2 Pulse Australia. (2015). Australian Pulse Bulletin: Pulse inoculation techniques. http://pulseaus.com.au/growing-pulses/publications/pulse-inoculation

3 Pulse Australia. (2015). Australian Pulse Bulletin: Pulse inoculation techniques. http://pulseaus.com.au/growing-pulses/publications/pulse-inoculation

Rhizobia and acidic soils

After more than 100 years of legume cultivation, many Australian soils have developed substantial populations of rhizobia that are able to nodulate commonly grown agricultural legumes. However, suitable rhizobia may still be absent from the soil if the legume has not been grown previously or where the soil is not conducive to long-term rhizobial survival. Factors such as soil composition, water content, temperature and pH can influence plant and rhizobia growth and nodule establishment.

Soil acidity alone is responsible for significant losses in global legume production, resulting from impaired plant and rhizobia growth, and due to decreased nodule development and nitrogen fixation. Legumes species differ in their nodulation and growth response to acidic soil. Generally, nodule formation is more sensitive to soil acidity than other aspects of plant growth. Rhizobia for medic, lucerne and pea (including vetch, lentil and faba bean) are particularly sensitive to acid soils (Table 2). Their number may be sub-optimal or absent where soil pH is less than 6.0, even where there has been a recent history of legume host. In low pH soil, nodule formation has been reported to be reduced by more than 90% and nodule dry weight by more than 50% in species such as soybean and pea. Low pH conditions have also been shown to affect rhizobia attachment to root hairs and root colonisation, leading to reduced nodule formation. Soil acidity is widespread in the Northern cropping region, so soil testing, inoculation and monitoring of nodulation needs to be considered when growing vetch.

Table 2: *Sensitivity of key rhizobia to pH, where red is sensitive and green is optimal.*

Rhizobia	Host legume	pH 4	pH 5	pH 6	pH 7	pH 8
Rhizobium leguminosarum bv. viciae	Vetch	(red)	(orange)	(green)	(green)	(green)

Source: GRDC

Fortunately, acid tolerant strains of many rhizobia species have been isolated. The most effective means to improve nodulation under low soil pH conditions is to use acid-tolerant legume cultivars. Nodulation can be (but not always) achieved in acidic growth conditions as long as one of the symbionts is acid-tolerant. [4]

3.1.1 Application

Pulses have historically been inoculated with rhizobia onto the seed. But now rhizobia can be purchased in a form suitable to be applied with water into the soil, or as granules that are sown with the seed from a separate box. Rhizobia inoculants are available in a number of formulations (Figure 2):

1. moist peat, the traditional and most commonly used from of inoculant in Australia. Applied as a slurry directly to the seed or a diluted and filtered slurry directly injected into the seeding furrow.
2. granular, made from peat or clay. Applied directly into the seeding furrow using a separate bin on an airseeder.
3. liquid, a water-suspension of rhizobia. Diluted product is used for direct injection of inoculant into the seeding furrow into moist soil only, within six hours of mixing with water.
4. freeze-dried powder, a concentrate which is reconstituted prior to application. Allows for direct injection of inoculant into the seeding furrow or coating the seed immediately (less than five hours) prior to sowing into moist soil. [5]

4 B Ferguson, M Lin, P Gresshoff. (2013). Regulation of legume nodulation by acidic growth conditions. *Plant signaling & behavior*, *8*(3), e23426.

5 E Armstrong, D Holding. (2015). Pulses: putting life into the farming system. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/558958/Pulses-putting-life-into-the-farming-system.pdf

Photo 2: *Forms of rhizobia (left to right): Easyrihiz freeze-dried, Nodulator granules, Alosca granules, N-Prove granules and peat inoculant.*

Photo: M. Denton, DPI Vic

Choosing an inoculant type

All types of inoculants will result in a well nodulated crop in good conditions but results may vary (Table 3).

Table 3: *Using different inoculant formulations.*

	Peat	Freeze-dried	Granular
Description	Finely ground sterilised peat containing a high density of rhizobia	Powder containing a very high density of rhizobia	Granules of peat or clay or a mixture; contain a lower number of rhizobia per gram
Storage	Winter legume inoculants – refrigerate at 4°C; summer legume inoculants – store in cool, dry place	Refrigerate at 4°C DO NOT FREEZE	Store in a cool and dry place away from direct sunlight
Common application	Mix with clean water to make a slurry, apply direct to seed. Can also be used in furrow.	Reconstitute with clean water and add protective compound. The liquid suspension is applied direct to seed or can be injected into the furrow	Granules are delivered in furrow at sowing. DO NOT allow granules to become moist during seeding as some products can cause blockages
Using additives	If used, ensure adhesive solutions are cooled before rhizobia are added. Generally NOT COMPATIBLE with mineral and organic fertilisers and pesticides; check manufacturer's guidelines	Generally NOT COMPATIBLE with mineral and organic fertilisers and pesticides; check manufacturer's guidelines	Check inoculant manufacturer's compatibility guidelines
Sowing	Best sown on day of coating into moist soil	Sow treated seed into moist soil within 5 hours of application	A third seeding box should be used to keep the granular formulation separate from fertilisers and pickled seed

Source: GRDC

When conditions are less than ideal, making the right choice becomes more critical (Table 4). Granules can vary and, depending on the product, may be dry or moist, uniform, variable, powdery, coarse or fine. The rhizobia bacteria need moisture to survive. When contained in the carrier; i.e. the peat material or the granule form, they will survive for up to 12 months when stored well. Read the expiry date before use.

However, once applied the survival rate is highly dependent on available soil moisture. This particularly applies to inoculum applied to the seed or to the soil as slurry. Dry soil conditions after sowing will kill off the rhizobia. Moisture will be needed within 2–3 days after sowing to maintain adequate numbers. If introduced rhizobia are essential for crop health, dry sowing should be avoided and caution should be used if sowing into a drying seed bed with a poor forecast for follow-up rain.

Granules by comparison are ideally suited to maintaining rhizobia numbers in dry soil for extended periods before rain arrives. The rhizobium is maintained within the granule which continues to protect it until the soil wets and the rhizobia can start multiplying. They are ideal to use if dry sowing is being considered. Additionally, they enable fungicides, which may be toxic to the rhizobia, to be applied the seed without causing a reduction in rhizobia numbers. [6]

Table 4: *Survival of rhizobia according to inoculant type and conditions at application.*

Inoculant type	Where inoculant should be applied	Survival in dry or drying soil*	Compatibility with seed applied fungicide	Time to sow after inoculation	Preparation or machinery requirements
Peat inoculums	Seed	Low	Some (check label)	24 hours	Pre-sowing/ Liquid applicator on seed
Freeze dried inoculums	Seed or in furrow (water inject)	Very low	No	Within hours	Pre-sowing
Granular forms	Seeding furrow or below seed	High	Yes	-	Separate seed box at sowing
In-furrow water injection	Seeding furrow or below seed	Very low	Yes	Within hours	Liquid applicator on seeder

*Survivial will depend on duration of dry conditions and soil pH.

Source: Pulse Australia

Always refer to the container label for inoculant application rates and check the inoculant's expiry date, and do not use old inoculant.

Likewise, keep inoculated seed in a cool shady place out of direct sunlight and treat enough seed for only one day's planting. Additionally, be cautious when using air seeders, as hot air in the distribution system may affect the inoculum. Temperatures greater than 30°C can kill the bacteria.

Seed coating in practice

- Rates of application; i.e. volumes and weights of formulation, water and seed, are given on inoculant packets
- Peat formulation is made into a slurry using clean potable water in a clean drum and mixing well
- For pasture seed, an adhesive is often added to the slurry

6 Pulse Australia (2015) Australian Pulse Bulletin: Pulse inoculation techniques. http://www.pulseaus.com.au/growing-pulses/publications/pulse-inoculation

- NOTE: Avoid fertiliser and pesticide residues and saline water
- Always grade seed first to remove pod debris and fine grain dust, which can block seeders
- Freshly prepared slurry is pumped from the drum (or poured) into the path of grain legume seed going up a slow-moving flighted auger into a grain bin
- Pasture seed, being small, can be coated in a concrete mixer or by mixing with a shovel on a concrete floor
- Most temperate pasture seed is best coated with fine lime (builders' and slaked lime should be avoided)
- Freeze-dried inoculant can be applied in the same way as peat slurry, as per manufacturer's instructions
- Allow slurry-treated seed to dry before filling air-seeders to prevent 'bridging' in the tank. [7]

The proven method of slurry inoculating the seed through an auger just prior to sowing still appears to be the cheapest and most reliable method (Photo 3). Alternative delivery methods using clay-based granules or water injection through micro-tubes are equally effective but considerably more expensive. These latter methods are best used when using sowing fungicide-dressed seed, to separate the rhizobia from the chemical.

Photo 3: *Inoculating seed through an auger. Don't forget to calibrate the amount of water required (too much will lead to sticky seeds).*

Source: GRDC

3.1.2 Compatibility with other major factors

Pesticides and fungicides

Rhizobia are living organisms. As a general rule, pesticides are toxic to rhizobia.

Almost all pulses require a fungicide applied to the seed to provide protection during early growth against foliar diseases. Occasionally an insecticide may also be needed.

Peat inoculants are also applied to the seed, bringing together two largely incompatible products. Mixing inoculum with a pesticide for seed treatment is possible with some products. Read the inoculum label to check for compatibility.

7 GRDC (2013) Inoculating legumes: the back pocket guide. http://www.agwine.adelaide.edu.au/research/farming/legumes-nitrogen/legume-inoculation/inoclegubackpocketguide.pdf

Applying the fungicide to the seed prior to the inoculum is a safer method to reduce the risk of rhizobia death. The fungicide can be applied at any time leading up to sowing. The inoculum is then applied immediately before sowing into moist soil. If in doubt, do not mix the inoculant and any pesticide.

Granular inoculants remove this risk because the rhizobia and the pesticide are not in contact. If you need to use a potentially toxic seed pesticide treatment, granular inoculant may be worth considering.

Always read the inoculant label or contact the manufacturer for up-to-date information on compatibility. [8]

Effect of fungicidal seed dressings on inoculum survival

While fungicide seed dressings reduce the longevity of the N-fixing bacteria applied to the seed (Table 5), the effect can be minimised by keeping the contact period to as short as possible.

Inoculate fungicide-treated seed as close as possible to the time of sowing.

Re-inoculate if not planted within 12 hours of treatment.

VIDEOS

WATCH: GCTV13: Legumes – Inoculant compatibility.

Table 5: *Compatibility of Group E rhizobia (for use in vetch) with seed-applied fungicides.*

Inoculant Group/crop	Fungicide type	Planting window of inoculated seed
Group E - Vetch	P-Pickle T	6 hours
	Gaucho® 600FL	4 hours

Source: GRDC

Trace elements

Rhizobia can be compatible with a few specific trace element formulations, but many are not compatible with rhizobial survival. Mixing inoculants with trace elements should only occur if the trace element formulation being used has been laboratory-tested against the rhizobial type being used.
Note the differences between inoculant types for a given trace element product, as well as differences between trace element products with a given inoculant.

3.1.3 Storing inoculant

Storing inoculant One of the main factors affecting the quality of legume inoculants is storage temperature. Legume inoculants contain live rhizobia. It is important to make sure they are kept in moderate temperatures (less than 30 °C and not frozen) away from sunlight and chemicals. Inoculant quality at the point of sale at the point of sale has been monitored.

Inoculants were purchased from retail outlets covering the grain cropping areas across Australia and the number of rhizobia in each packet or container counted. Temperatures and conditions of storage were recorded. Generally, rhizobial numbers in the inoculants remain high because the product at the point of manufacture had been prepared in a suitable carrier that prolongs rhizobial survival. However, numbers for the common legume host groups decline in rhizobial number when stored at ambient to high temperature compared to those stored at less than 10 °C (refrigerated). For the groups E, F, G, N and C there is a reduction of 22% or more in rhizobial numbers when the products are not refrigerated (Table 6). [9]

8 Pulse Australia. Pulse inoculation techniques. http://www.pulseaus.com.au/growing-pulses/publications/pulse-inoculation

9 E Hartley, G Gemell, J Hartley (2015) Use of quality legume inoculants to get the most from nitrogen fixation. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/660496/Southern-NSW-research-results-2015.pdf

MORE INFORMATION

Pulse inoculation techniques

Inoculating legumes: a practical guide (GRDC)

Inoculating legumes: the back pocket guide (GRDC)

Rhizobia inoculants fact sheet (GRDC)

Maximising the nitrogen (N) benefits of rhizobial inoculation

Table 6: *Effect of retail storage temperature on rhizobial survival in peat inoculants.*

Legume	Inoculant group	Million rhizobia/g peat		
		Refrigerated <10°C	Ambient >20°C	Difference (%)
Vetch	E	831	614	-26

Source: NSW DPI

3.1.4 Assessing nodulation

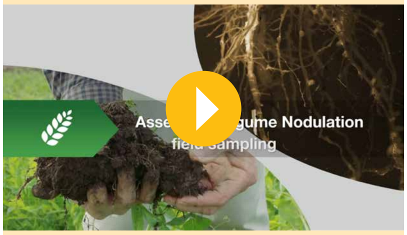
Vetch has a strong root system that develops nodules at an early stage; this provides sufficient nitrogen for the plants to use and accumulates significant amounts for the following crops (Photo 4).

Photo 4: *Vetch showing good nodulation.*

Source: Maarten Ryder

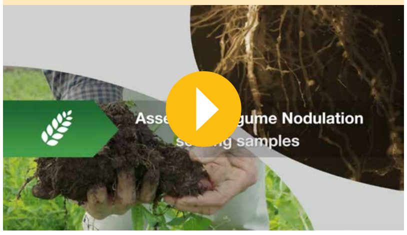
VIDEOS

WATCH: GCTV17: Legume nodulation — field sampling.



WATCH: GCTV17: Legume nodulation — sample preparation.

WATCH: GCTV17: Legume nodulation — sample scoring.

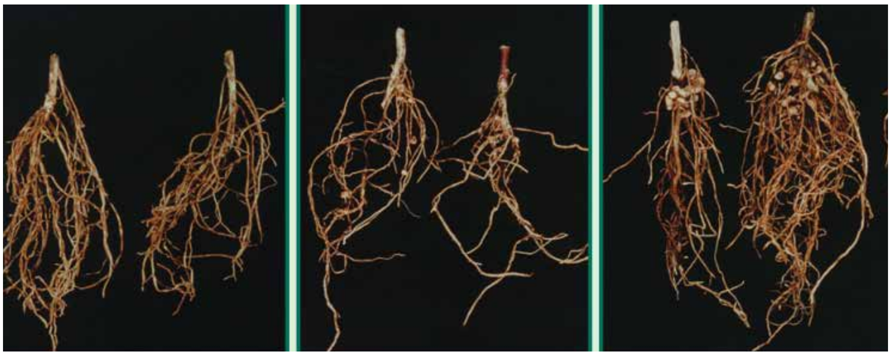


Do not assume that by applying rhizobia to the crop that the job is over. It's important to see how effective the inoculum has been and what state of health the nodules are in. By checking the degree of nodulation, you can assess the type of inoculum product you have used and the application technique employed to get the rhizobia where it needs to be; in the roots of the growing pulse. [10]

Nodules will have developed and be easily located from 8 to 10 weeks after sowing. Nodule assessment should occur any time from this point through to the end of flowering. For practical reasons, crops are more easily traversed when plants are young, and it is best to dig when the soil is moist and friable, allowing it to be easily crumbled from the roots.

To assess the effectiveness of crop nodulation and the health of nodules:

1. Carefully dig up 10 plants from each of several locations in the paddock and soak in bucket of water.
2. Locate nodules. A well-nodulated plant has nodules on the crown (where the root meets the shoot) and on the tap root and lateral roots.
3. Note their distribution, on the primary root and lateral roots.
4. Slice open a nodule. Check the colour inside the nodule. Is it pink/red or green or brown? Pink-coloured tissue indicates active N fixation.
5. Score 10 plants for nodulation and record (Photo 5).
6. Look at root health and structure. [11]



Score 0: taproot, absent; lateral, absent/few. Score 1: taproot, few/ medium; lateral, absent. Score 2: taproot, medium; lateral, absent/low.

Score 3: tap root, medium/ high; lateral, low. Score 4: taproot, high; lateral, medium. Score 5: taproot, high; lateral, medium.

Photo 5: *Photo guide to assessing legumes nodulation.*

Photos: A Gibson.

10 Pulse Australia. (2015). Australian Pulse Bulletin: Pulse inoculation techniques. http://pulseaus.com.au/growing-pulses/publications/pulse-inoculation

11 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

Nitrogen deficiency from nodule dysfunction can be caused by lack of Rhizobia, soil conditions, herbicide toxicity, or molybdenum or cobalt deficiency. Indications of poor nodulation are yellowing young leaves, yellow and/or stunted patches of plants, and lack of nodules on root systems.

If there is poor nodulation, check the inoculation strategy to ensure best management practices are followed. If both nodulation and plant performance are poor, reasons for poor nodulation need to be identified. Poor nodulation can cause 10–50% yield loss in pulse crops, as well as the lower potential nitrogen benefits to following crops. While a visual assessment will not indicate the actual level of nitrogen being fixed (only sophisticated scientific methods can do that) looking at the roots to determine if there has been a nodulation delay or failure is worthwhile.

Nodulation failure is difficult to remedy, except by adding inorganic nitrogen, which can be costly. Other possible remedies (if done immediately) include:

- In flood or sprinkler-irrigated fields, add slurry or liquid inoculant to the irrigation water
- Over-sow a granular inoculant close to the original sowing furrow. [12]

3.2 Seed treatments

It is recommended that, whenever possible, seed should be obtained from a source where the crop was free from disease. Seed treatments are a cheap and effective method for suppressing some diseases.

Fungicide use in vetch is not common, but if applied, then fungicides and principles of use are similar to those used in lentil and/or faba bean. Treating seed with products containing thiram plus thiabendazole (e.g. P-Pickel T® , Fairgro® Reaper TT®) will reduce seed infection, thereby protecting new seedlings from infection (Table 7). If infected seeds are sown untreated, botrytis seedling blight can reduce plant establishment during the growing season.

Table 7: *Pulse seed dressings 2017, Page 138, Table 69.*

Active ingredient	Fungicide group	Products	Active ingredient	Rate: (per 100 kg seed)
Thiram + Thiabendazole	M3 and 1	P-Pickel T® Fairgro® Reaper® TT	Thiram 360 g/L + TBZ 200 g/L	200 mL

Source: NSW DPI

3.2.1 Application

It is important for seed treatments to be evenly distributed on seed to ensure each seed gets an effective dose. This is enhanced for flowable seed treatments by dilution with water (refer to the label). Secondary mixing of treated seed through an auger assists to obtain even seed coverage. Correct calibration of the applicator and a consistent seed flow are critical for the recommended rate of seed treatment to be applied. [13]

3.3 Time of sowing

Time of sowing with vetch for grain production is often a compromise. Early sowing increases the risk of frost damage and leaf disease resulting from excessive foliage growth. Later sowing runs the risk of lower yields due to high temperatures and dry conditions during flowering and pod fill.

12 GRDC (2013) Inoculating legumes: the back pocket guide. http://www.agwine.adelaide.edu.au/research/farming/legumes-nitrogen/legume-inoculation/inoclegubackpocketguide.pdf

13 W Hawthorne, J Davidson, K Lindebeck (2011) Australian Pulse Bulletin PA 2011 #15: Pulse seed treatments and foliar fungicides. http://pulseaus.com.au/storage/app/media/crops/2011_APB-Pulse-seed-treatments-foliar-fungicides.pdf

MORE INFORMATION

Managing brown manure crops in southern NSW

Early sowing would be the preferred option for crops destined for hay, silage or green/brown manuring options where bulky plants are desired and frost damage is not an issue

Vetch should be sown between early-march l and the end of June, depending on break of the season (early March to May for feed/grazing end-use in lower rainfall regions). Data from ten years of trials indicate that earlier seeding times produced better yields compared with later seeding. [14]

Seeding rate may need to be increased by 10–15% if sowing is delayed beyond the optimum. [15]

3.4 Targeted plant population

Sowing rate affects plant establishment and is an important crop management decision. Sowing rate will vary depending on which legume is being planted, the region, the rainfall, the seed source and the sowing time.

In low rainfall areas, maximum dry matter and grain yields are obtained at plant densities of 50–60 plants per square metre (p/m^2). In areas with greater than 400 mm/year, plant densities of 70-80p/m^2 produced the highest yields (Table 8). [16]

For quality pastures or hay/silage use a mix of 2/3 vetch and 1/3 of rye grass or cereals (as a % of) the recommended rates for a particular area. [17]

Table 8: *Plant density and recommended seeding rates for vetch.*

End use	Common vetch varieties		Woolly pod vetch varieties		Purple vetch variety*	
	Plants density (plants per sq.m.)	Sowing rate (kg/ha)	Plants density (plants per sq.m.)	Sowing rate (kg/ha)	Plants density (plants per sq.m.)	Sowing rate (kg/ha)
Grain	40–60	40–50	40–50	25–40	40–50	25–40
Hay/ silage	50–70	50–60	50–60	30–45	50–60	30–45
Grazing	50–70	50–60	50–60	30–45	50–60	30–45
Green manure	60–70	55–65	60–70	45–50	5–60	30–45

* in Australia Popany is the only Purple vetch variety

Source: SARDI

3.5 Calculating seed requirements

The correct plant density is an important factor in maximising yield of pulse crops. To obtain the targeted density it is necessary not only to have quality sowing seed but also be able to accurately calculate seeding rates. It is surprising the difference a slight variation in seed size or germination makes to the seeding rate required to achieve a target plant density.

When sowing in areas with less than 350 mm of rainfall per year vetch for pasture, green manure or hay/silage should be

14 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

15 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.*

16 R Matic (2015) GRDC Final Reports: DAS00013 – Vetch variety improvement for Australian field crop farming systems. https://grdc.com.au/research/reports/report?id=268

17 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

Calculating 100-seed weight

To determine the 100-seed weight of a seed lot:

1. Take a representative sample of your seed lot. If it is ungraded, weigh out 50 to 100 g and remove damaged and split seed that would normally be discarded by grading.
2. Count out 200 seeds from each seed lot to be planted.
3. Weigh 200 seeds on scales accurate to 0.1 g.
4. Divide the weight by 2 to calculate the 100-seed weight.
5. Repeat four times from your sample.

3.5.1 Calculating seeding rate

Calculate a seeding rate based on a target plant population:

1. Decide on a target plant density
2. Calculate the 100-seed weight (see above)
3. Calculate the germination percentage of the seed lot (see Section 2, Section 2.3.2). Determine the establishment percentage. A realistic estimate of establishment is 80%. Take into account the likely field conditions (temperature, moisture, soil type, sowing depth, insects and disease).
4. Use the following formula to calculate seeding rate: Seeding rate for the target plant density can be calculated using germination percentage, 100 seed weight and establishment percentage (Figure 1).

Adjust sowing rates to take account of seed size, germination percentage and estimated establishment conditions.

$$\text{Seeding Rate (kg/ha)} = \frac{\text{100 seed weight\# x Target plant population* x 1000}}{\text{Germination \% x Estimated Establishment \%*}}$$

Example

100 seed weight = 21 grams

Target plant density = 25 plants/m^2 (i.e. 250,000 plants/ha)

Germination % = 95%

Estimated establishment % = 85%

$$\text{Seeding rate (kg/ha)} = \frac{21 \times 25 \times 1000}{95 \times 80}$$

= 69.08 kg/ha

#100 seed weight in grams from the variety characteristics table.
*Target plant population for your location (seek local advice)

Figure 1: *Seeding rate calculation – Desi chickpea example.*

Source: Pulse Australia

Seeding rates have been calculated for vetch based on the example above (Table 9). Seed size and germination percentage can vary so it is recommended that growers calculate seeding rate based on their seed.

Table 9: *Vetch sowing rates (kg/ha) based on 95% germination and 80% establishment.*

Variety	Seed weight (g per 100 seeds)	Seeding rate (kg/ha)				
		20	30	40	50	60
Morava⒫	7.82	20.58	30.87	41.16	51.45	61.74
Rasina⒫	6.92	18.21	27.32	36.42	45.53	54.63
Volga⒫	7.95	20.92	31.38	41.84	52.30	62.76
Blanchefleur	5.21	13.71	20.57	27.42	34.28	41.13
Timok⒫	6.88	18.11	27.16	36.21	45.26	54.32
Languedoc	6.74	17.74	26.61	35.47	44.34	53.21

Sowing depth

Sowing depths of pulses needs to be varied to take into account the crop type, soil type, herbicide used, the diseases likely to be present and the soil temperatures at sowing time; i.e. how long the crop will take to emerge. Lighter textured soils can be more prone to herbicide leaching in wet winters, hence deeper sowing in sandier soils is often recommended if applying a pre-emergent herbicide. The deepest sowings tend to be in sandy soil with warm soil temperatures and the shallowest sowings will be in heavy soils with cold soil temperatures, however there are exceptions.

Sowing depth is the key to uniform, fast emergence and establishment. Vetch should be sown at 3–5 cm and if applying a pre-emergent herbicide vetch should be sown at 5 cm. [18]

Avoid deep planting as seedlings can be weak. [19] and then be more prone to attack from insects and disease

There is a maximum depth at which the pulse crop can be safely sown to avoid poor establishment and lower seedling vigour. Sowing seed outside the suggested range above will delay emergence and slow seedling growth. Actual sowing depth should be shallower on clay soils and hard setting soils and deeper on sands. Vetch, lentils, peas and chickpeas have intermediate tolerance to deep sowing. Burying seed too deep to chase seed bed moisture for early sowing is not recommended, particularly as weed control, establishment and possibly nodulation is more likely to be poor. Deeper sowing may be needed in some districts to reduce the damage caused by birds and mice. [20]

For more information, see Section 4: Plant growth and physiology, Sowing depth section.

3.6 Sowing equipment

Key points:

- Tubulators or belt elevators are excellent for handling legumes as little or no damage occurs.
- On some airseeders the dividing heads may have to be modified because there is too little room in the secondary distributor heads to allow seeds to flow smoothly.

18 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.* https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

19 CRDC. Comparative advantages/disadvantages of rotation crops with cotton. http://www.cottoninfo.com.au/sites/default/files/tools/CottonRotation/Rotation_chart_Page_1small.pdf

20 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.* https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

- For vetch planting, maintenance and harvesting, farmers can use the same machines that are used for cereal crops (Photo 9). [21]

Photo 6: *Vetch inter-sown into cereal stubble.*

Photo: Stuart Nagel

Success with pulses may depend on the type of sowing equipment used because the large size of pulses can make sowing with conventional seeders extremely frustrating. If your seeder is not suitable for sowing a particular pulse (usually larger seeded types) in standard form there are several options available.

The machine may be adapted by minor modifications such as:

- modifying the metering mechanism using manufacturer supplied optional parts
- modifying seed tubes to reduce blockages, particularly on older machines
- modifying or replacing dividing heads on airseeders.

Most pulse seeding problems are related to seed metering and the transfer from seed meter to soil. These problems are caused by the large size of some pulses and the high seeding rates generally used.

Broadcasting pulses

If your sowing equipment is not able to cope with larger pulse seeds, it may be possible to broadcast the crop using a fertiliser spreader. The soil should be well ridged before broadcasting so that the seed will concentrate in the furrows. After broadcasting the soil should be worked shallowly with seeder and harrows or cultivator and harrows to cover the seed. When broadcasting, use a higher seeding rate than normal (20–50% higher, depending on conditions) because of the lower emergence levels. Yield is determined by final plant population rather than seeding rate. [22]

21 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

22 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

Plant growth and physiology

Key messages

- Vetch is an annual legume with semi-prostrate growth and many lateral branches bearing medium to long pods.
- Vetch uses a similar growth stage guide to lentil.
- Vetch establishment after autumn rains is significantly faster than medics and clovers; reaching 6–10 nodes (10–15 cm) in 6–8 weeks.
- Like many pulses, vetch germination and emergence rate can be decreased due to chemical residues.
- Temperature and photoperiod will also influence vetch establishment and growth.

4.1.1 Common vetch (*Vitcia sativa*)

Key characteristics:

- Plant: annual, moderate stem strength and grows as small bushes. 40–80 cm high, with multiple lateral branches from near the base.
- Stems: large climbing semi-prostrate with 9–16 internodes with multiple green to dark green leaves.
- Leaves: concave, green, hairy on both sides. The central leaf stalk contains 4–8 pair of leaves with a tendril on the top.
- Flowers: single or pair, medium (10–35 mm); colour-violet/purple or white.
- Pods: length-medium to long (40–70 mm); with 6–8 seeds.
- Seeds: medium to large (100seeds = 6.5–8.9 g); testa - brownish ornamentation; cotyledons colour:
- Morava⟨D and Languedoc - beige;
- Rasina⟨D - greenish;
- Blanchefleur - red/orange;
- Softness:
- Morava⟨D 99–100%;
- Rasina⟨D 95–100%;
- Blanchefleur and Languedoc 80–95%. [1]

4.1.2 Woolly pod vetch (*Vicia villosa*)

Key characteristics:

- Plant: winter growing annual, with multiple laterals branching from near the base (Photo 1).
- Stems: weak stemmed climbing, 40–120 cm high, green and hairy.
- Leaflets: two pair, narrow green leaflets. The central leaf stalk containing 5–10 pair of leaves with a tendril on the top.
- Flowers: small with multiple petals 5–20 (10–20 mm); colour-violet/purple.
- Pods: length 20–30 mm by 7–10 mm with 2–5 seeds.
- Seed: small to medium (100 seeds = 3.5–5.5 g). [2]

Varieties include Capello⟨D, Haymaker⟨D, Namoi and RM4⟨D.

1 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

2 R Matic, S Nagel, G Kirby (2008) Woolly pod Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Woolly_pod_vetch.htm

Photo 1: *Vetch plant at flowering.*

Photo: Stuart Nagel

4.1.3 Purple vetch (*Vicia benghalensis*)

Key characteristics:

- Plant: winter growing annual, with multiple laterals branching from near the base. Initial growth is slow.
- Stems: in early stages it is more erect than any other Vicia spp. Growth 40–100 cm high.
- Leaflets: two pair, narrow green leaflets. The central leaf stalk containing 5–9 pair of oblong narrow leaves with a branched tendril on the top.
- Flowers: small with multiple, 5–20 (10–20 mm); colour-violet/purple.
- Pods: length 25–40 mm by 8–11 mm with 3–5 seeds.
- Seed: is black and very distinctive, with a white hilum, compared to other vetch seeds, small to medium (100seeds=4.0–4.5 g). [3]

Varieties include Popany which has 5–10% hard seeds.

4.2 Plant growth stages

4.2.1 Vegetative growth stage

Vegetative growth stages are described by counting nodes on the main stem and continuing the count up the basal primary branch to include the highest fully developed leaf. Reproductive stages R1 and R2 are based on flowering, R3 to R6 on pod and seed development, and R7 and R8 on maturation.

Count the number of visible nodes on the main stem up to the node subtending the basal primary branch, and then continuing the node count up the basal primary branch to include the highest fully developed leaf.

- VE – seedling emergence, cotyledonary node visible
- V1 – the first simple leaf has unfolded at the first node

3 R Matic, S Nagel, G Kirby (2008) Woolly pod Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Purple_vetch.htm

- V2 – the second simple leaf has unfolded at the second node
- V3 – the first bifoliate leaf has unfolded at the third node
- V4 – the second bifoliate leaf has unfolded at the fourth node
- V5 – the first multifoliate leaf has unfolded at the fifth node
- Vn – the nth multifoliate leaf has unfolded at the nth node. [4]

Vetch leaves are very similar to those of lentils and the two can be confused, especially in the early growth stages (Figure 1).

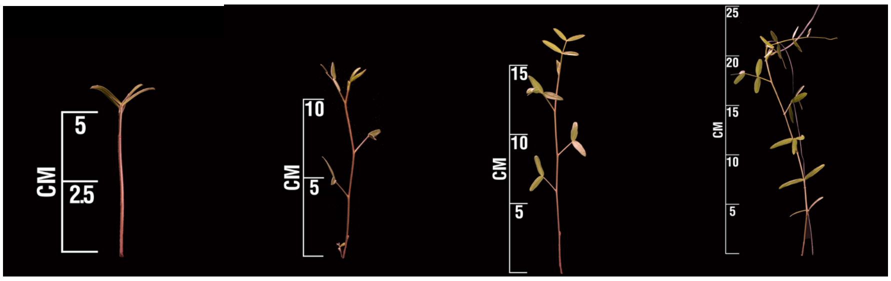


Figure 1: *Vetch during vegetative growth at the 1, 4, 5 and 6 node stages.*

In vetch growth, there is often a sequence of leaf, flower bud, flower and pod development along each branch.

4.2.2 Reproductive stage

Reproductive stages are based on flowering, pod and seed development, and on maturation. Flowering in lentil is indeterminate, occurring from axillary buds on the main stem and branches. It proceeds acropetally from lower to higher nodes.

- R1 – early bloom, one open flower at any node (Figure 2 and Photo 2)
- R2 – full bloom, flower open or has opened on nodes 10–13 of the basal primary branch
- R3 – early pod, pod on nodes 10–13 of the basal primary branch visible
- R4 – flat pod, pod on nodes 10–13 has reached its full length and is largely flat.
- R5 – early seed, seed in any single pod on nodes 10–13 fill the pod cavity
- R6 - full seed, seed on nodes 10–13 fill the pod cavities. [5]

4 Descriptors adapted from the paper by W. Erskine, F. J. Muehlbauer and R. W. Short. 1990. Stages of Development in Lentil. Exp. Agric. 26:297–302. Sourced from: NDSU https://www.ndsu.edu/pubweb/pulse-info/growthstages-pdf/LentilGrowthStages.pdf

5 Descriptors adapted from the paper by W. Erskine, F. J. Muehlbauer and R. W. Short. 1990. Stages of Development in Lentil. Exp. Agric. 26:297–302. Sourced from: NDSU https://www.ndsu.edu/pubweb/pulse-info/growthstages-pdf/LentilGrowthStages.pdf

Figure 2: *Vetch plant at the early flowering stage.*

Photo 2: *Common vetch flower.*

Photo: Stuart Nagel

Common vetch pods are medium to long in length (40–70 mm) with 6–8 seeds (Figure 3). Woolly pod vetch pods are 20–30 mm by 7–10 mm, with 2–5 seeds.

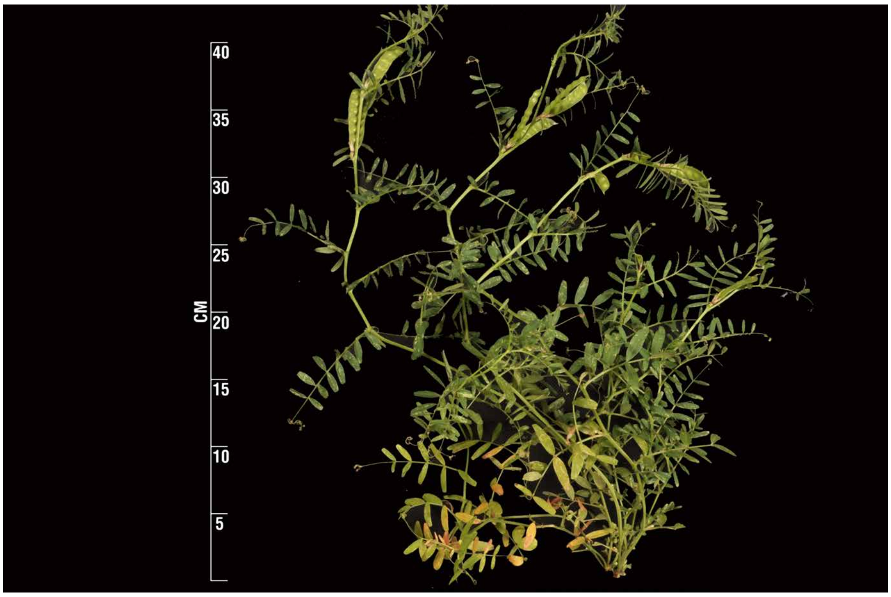


Figure 3: *Vetch plant at pod fill.*

4.2.3 Physiological Maturity

- R7 – the leaves start yellowing and 50% of the pods have turned yellow
- R8 – 90% of pods on the plant are golden-brown (Figure 4). [6]

Figure 4: *Vetch at growth stage R8.*

6 Descriptors adapted from the paper by W. Erskine, F. J. Muehlbauer and R. W. Short. 1990. Stages of Development in Lentil. Exp. Agric. 26:297–302. Sourced from: NDSU https://www.ndsu.edu/pubweb/pulse-info/growthstages-pdf/LentilGrowthStages.pdf

4.3 Germination and emergence issues

Key points:

- Vetch establishment after autumn rains is significantly faster than medics and clovers; reaching 6–10 nodes (10–15 cm) in 6–8 weeks. [7]
- Vetch has strong seedling vigour and has vigourous growth once it is well-established. [8]
- Common vetch has better initial growth and early vigour and better palatability from emergence to mature plants when compared with hairy, bitter and purple vetches. [9]

Germination and emergence are important stages in the life cycle of plants that determine the efficient use of the nutrients and water resources available to plants. The physiological process of germination depends on several environmental factors such as temperature, water potential, light and nutrients. Water and temperature are determinant factors for seed germination, with both factors, separately or jointly, affecting the germination percentage and rate.

Vetch plants are hypogeal, like field pea (Figure 5), which means the cotyledons of the germinating seed remain below the ground and inside the seed coat. Seedlings with hypogeal emergence are less likely to be killed by frost, wind erosion or insect attack as new stems can develop from buds at nodes at or below ground level. Their growth may however be slowed considerably. [10]

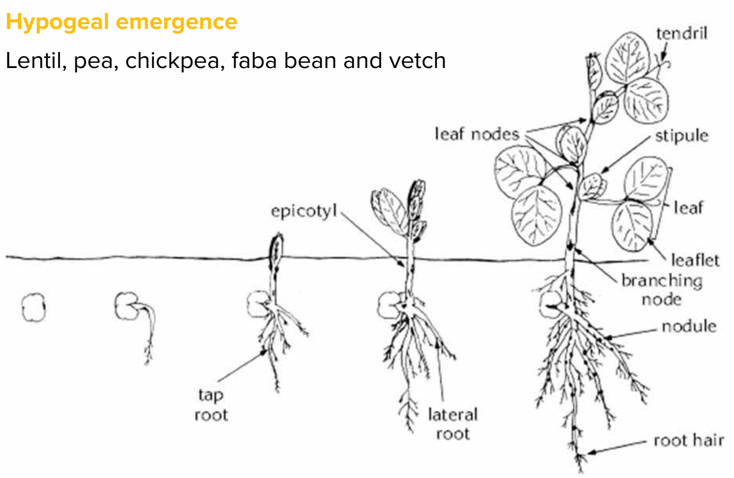


Figure 5: *Hypogeal emergence protects lentil seedlings from the effects of frost and insect damage at crop establishment.*

Source: Pulse Australia

For more information on germination and emergence issues, see the section below.

4.3.1 Sowing depth

Depth of sowing is an important agronomic practice affecting the emergence and establishment of crops, especially with early sowing under dryland conditions when temperatures and soil evaporation rates are high.

7 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

8 J Frame. Vicia sativa L. FAO. http://ecocrop.fao.org/ecocrop/srv/en/cropView?id=238003

9 R Matic (2014) GRDC Final Report: DAS00059 – Improved vetch varieties for Australian farmers and end-users. https://grdc.com.au/research/reports/report?id=1104

10 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

Sowing depth is the key to uniform, fast emergence and establishment. There is a maximum depth at which the pulse crop can be safely sown to avoid poor establishment and lower seedling vigour. Sowing seed outside the suggested range above will delay emergence and slow seedling growth. Actual sowing depth should be shallower on clay soils and hard setting soils and deeper on sands. Vetch, lentils, peas and chickpeas have intermediate tolerance to deep sowing.

Depending on paddock conditions, avoid deep planting as vetch seedlings can be weak. [11]

Vetch should be sown at 3–5 cm and if applying a pre-emergent herbicide vetch should be sown at 5 cm. [12]

Sowing depth and herbicide interaction

Pulses can be more tolerant and are able to emerge if shallow sowing is avoided. The actual depth of sowing will depend on the soil type. Herbicides leach deeper in sands than in clay soils. Some herbicides leach more than others, and heavy rain onto a dry soil surface, particularly on a sand, is worst.

For more information, see Section 3: Planting, section 3.6 Sowing Depth.

4.3.2 Chemical damage

Herbicide and pesticide residues, and high rates of fertiliser at sowing can reduce the germination and emergence of crops.

For more information, see Section 2: Pre-planting – Safe rates of fertiliser at sowing.

Many herbicide labels place time and/or rainfall restrictions on sowing certain crops and pastures after application, due to potential seedling damage. Crops such as pulses and legume pastures are the most sensitive to herbicide residues. [13]

A real problem for growers is the difficulty in identifying herbicide residues before they cause a problem. Currently, growers are limited to predicting carryover based on information provided on the product labels about soil type and climate. Herbicide residues are often too small to be detected by chemical analysis, or if the testing is possible it is too expensive to be part of routine farming practice. Once the crop has emerged, diagnosis is difficult because the symptoms of residual herbicide damage can often be confused with and/or make the crop vulnerable to other stresses, such as nutrient deficiency or disease.

For more information, see Section 1: Planning and paddock preparation, section 1.6 Fallow Chemical plant-back effects or Section 6: Weed control, Potential herbicide damage section.

4.3.3 Stubble

Vetch is a more prostrate plant and benefits from being sown into stubble retention systems. This is common practice in the Northern region. Seedlings are able to germinate and emerge through stubble. The stubble can also slow aphid flight through the crop (acts as a physical barrier) and hence reduce insect damage and potential virus incursion from the aphid vector

One study aimed to determine the effects of stubble heights and positions on seed emergence of common vetch seed. Vetch was sown into two different stubble heights (short and long) and two different stubble positions (standing and flat). The best results of sowing performance and seed emergence were observed at the plots with short and standing stubble conditions. The emergence percentage decreased

11 CRDC. Comparative advantages/disadvantages of rotation crops with cotton. http://www.cottoninfo.com.au/sites/default/files/tools/CottonRotation/Rotation_chart_Page_1small.pdf

12 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT*. https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

13 RMS Agricultural consultants. (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/

with the increase in the stubble height (76.15% and 69.31% at 12 cm and 24 cm stubble heights, respectively). [14]

4.3.4 Damaged seed

A seed that has been damaged during harvest and handling, will produce an abnormal seedling –the shoot, the root, or both may be damaged. If the root is damaged the seedling will germinate, emerge and then generally die. This is because the taproot is weak and cannot grow normally. If the shoot is damaged the seedling will germinate and may emerge. Abnormal seedlings which do emerge lack vigour making them vulnerable to the rigours of field establishment. Factors such as temperature, disease, insects, seeding depth and soil crusting are more likely to affect the establishment of weak seedlings. Those that do emerge are unlikely to survive for long, producing little dry matter and making little or no contribution to final yield. [15]

4.4 Effect of temperature, photoperiod, climate effects on plant growth and physiology

4.4.1 Temperature and photoperiod

Vetch is adapted to Mediterranean and Temperate Zones of southern Australia (10-35°C). Low temperatures restrict winter growth. The optimum temperature range for growth is 23–15°C. [16]

The optimum temperature for *Vicia sp.* seed germination was identified to be between constant 15 and 20°C. These results agree with recommendations by International Seed Testing Association of germinating most *Vicia* seeds at 20°C. [17]

Temperature is one of the main environmental variables that determine time to flowering. Various forms of temperature summations, commonly referred to as heat units and expressed in 'growing degree-days' (GDD) or in 'thermal time' (Tt), have been widely used in studies to predict phenological events for crops.

The thermal time concept is based on the assumption that a fixed amount of heat units above a base temperature (Tb) or threshold temperature, below which no development takes place, is required to complete a specific development phase (Yin et al., 1996). Although temperature is the most important factor controlling the rate of plant development, other factors such as water and light availability and daylength (DL) may modify its effects. In Mediterranean-type climates (including some areas of southern NSW), photoperiod is considered to be an important environmental signal for flower initiation.

Photoperiodism or vernalization (response to light duration, light quality and radiant energy) is a mechanism that enables plants to respond to daylength so that they flower at a specific time of the year as determined by the length of the day. However, due to the effect of temperature, a plant will not always need the same amount of calendar time to develop to a certain developmental stage.

Flowering is considered the critical stage, because environmental conditions during the reproductive phase have a major impact on final yield and the onset of flowering often determines the entire crop duration. Equally important, from a practical point of view, flowering can be easily observed in the field. Therefore, being able to predict the time of flowering may be more important than any of the other phenological

14 Altikat, S., Celik, A., & Gozubuyuk, Z. (2013). Effects of various no-till seeders and stubble conditions on sowing performance and seed emergence of common vetch. *Soil and Tillage Research*, *126*, 72–77.

15 P Matthews, D Holding. (2005). Germination testing and seed rate calculation. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/157442/pulse-point-20.pdf

16 CRDC. Comparative advantages/disadvantages of rotation crops with cotton. http://www.cottoninfo.com.au/sites/default/files/tools/CottonRotation/Rotation_chart_Page_1small.pdf

17 O Modisa (1999) Seed dormancy in vetch (Vicia species). University of Melbourne. https://minerva-access.unimelb.edu.au/handle/11343/114553

stages. Indeed, if flowering could be predicted, management decisions such as sowing date and harvest dates could be modified to maximise utilisation.

Studies on the phenology and optimal conditions for each phase of the crop cycle are essential in searching for the most suitable species and sowing times for particular regions. It has frequently been demonstrated that flowering time plasticity is a common adaptive feature of annuals, including legumes, in arid or semiarid environments. [18]

18 A Iannucci, M Terribile, P Martiniello (2008). Effects of temperature and photoperiod on flowering time of forage legumes in a Mediterranean environment. *Field Crops Research*, *106*(2), 156–162.

Nutrition and fertiliser

Key messages

- Vetch crops increase the amount of nitrogen in the soil, improving soil fertility for subsequent crops.
- The application of phosphorus (P), sulfur (S) and molybdenum (Mo) may be required to successfully establish vetch and promote vigorous growth.
- Phosphorus, potassium (K) and S requirements in vetch are similar to field peas.
- Additional nutrients are rarely required in vetch.

Fertiliser applications are the largest single variable expense for grain growers producing a crop but nutrition (e.g. nitrogen, phosphorus, potassium, sulfur and micronutrients) is a major determinant of profit. [1] Inefficient or incorrect use of fertiliser can be a substantial, but somewhat hidden, cost in the cropping operation.

However, the application of phosphorus, sulfur and molybdenum may be required to successfully establish vetch and promote vigorous growth. Soil tests are a guide to phosphorus requirements and will also give an indication of sulfur deficiency, as soils high in phosphorus will often respond to sulfur. Soils with a low pH are often deficient in molybdenum. [2]

Using good data to better understand your existing soil nutrient status before deciding on a fertiliser strategy can optimise expenditure on fertiliser and crop yields. Be sure to consider the following:

- Fertilisers are a major cost of growing a crop.
- Ensure your adviser has, or is working towards, the Fertcare Accredited Adviser standard.
- Be clear on fertiliser product choice and rate and timing of application.
- Soil testing is the only quantitative nutrient information that can be used to predict yield response to nutrients.
- Soil samples should be taken before sowing so that results and recommendations are available in time to order the right fertiliser product(s).
- Develop a strategy for deep sampling of nitrogen (N) and sulfur (S). For growers with a capacity to apply N either pre-sowing or at sowing, collect samples pre-crop (during fallow) with enough time to prepare N and S budgets and secure required fertiliser requirements.
- Choose a laboratory that has the Australasian Soil and Plant Analysis Council (ASPAC) certification for the tests they offer. National Association of Testing Authorities (NATA) accreditation is also desirable.
- Regular planned sampling of paddocks allows monitoring of fertility trends over time.

Crop production is becoming increasingly precise, but when it comes to fertiliser application, some growers often make decisions about type, time and rate based on incomplete information or a 'best guess'. Robust fertiliser decisions can be made by checking the 'four Rs' of plant nutrition, an approach developed by the International Plant Nutrition Institute that has become the cornerstone of nutrient stewardship in many countries. 4R Plant Nutrition is built around the right fertiliser source, applied at the right rate, at the right time, and in the right place. [3]

MORE INFORMATION

Better fertiliser decisions for crop nutrition

1 GRDC. More profit from crop nutrition. https://grdc.com.au/Research-and-Development/Major-Initiatives/More-Profit-from-Crop-Nutrition

2 NSW DPI. Namoi woolly pod vetch. http://www.dpi.nsw.gov.au/agriculture/pastures-and-rangelands/species-varieties/namoi-woolly-pod-vetch

3 GRDC (2013). Better fertiliser decisions for crop nutrition – Fact Sheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2013/11/grdc-fs-bfdcn

5.1 Crop removal rates

When grain is harvested from the paddock, nutrients (phosphorus, nitrogen, zinc, etc.) are removed in the grain. If, over time, more nutrients are removed than are replaced (via fertiliser) then the fertility of the paddock will fall.

Fertiliser inputs must be matched to expected yields and soil type. The higher the expected yield, the higher the fertiliser input, particularly for the major nutrients, phosphorus, potassium and sulfur.

Vetch will remove some nutrients from the soil (Table 1). However, it can also increase soil nutrients, enough so that its contribution to paddock nutrition is beneficial (Table 2).

A balance sheet approach to fertiliser inputs is a good starting point in considering the amount of fertiliser to apply to your pulse crop. Other factors such as soil type, paddock history, soil test and tissue analysis results, as well as your own experience all affect the choice of fertiliser to be used. Table 1 shows the amount of nutrients removed in each tonne of seed. Nutrient budgeting is a simple way to calculate the balance between nutrient removal (via grain) and nutrient input (via fertiliser). [4]

Table 1: *Nutrient removal (kg/tonne-1) for vetch.* [5]

	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
Vetch	26	7	22

Table 2: *Examples of net contributions of fixed N where the total amounts of N2 fixed by different legumes grown for forage, brown manure (BM) or grain have been compared to estimates of the amounts of N removed in either hay, wool, or grain, or lost by volatilization from urine patches from grazed pastures (Peoples et al. 2012 and unpublished data).*

Crop use	Total amounts of N2 fixed* (kg N/ha)	N Removed or lost (kg N/ha)	Net input of fixed N (kg N/ha)
Brown manure[A]	130	0	+130
Hay[A]	130	89 in hay	+41
Hay[B]	141	82 in hay	+59
Forage[C]	83	8 in wool + 23 lost	+52

*The amounts of shoot N fixed were adjusted to include an estimate of N contributed by the nodulated roots as described by Unkovich et al. (2010).

A = Hopetoun Vic, B = Yarrawonga Vic, C = Wagga Wagga NSW.

Source: GRDC

MORE INFORMATION

Legume effects on soil N dynamics - comparisons of crop response to legume and fertiliser N

5.2 Soil testing

Key points:

- A range of soil test values used to determine if a nutrient is deficient or adequate is termed a critical range.
- Fertiliser decisions are in part based on where the soil test falls in relation to the critical range.
- Critical ranges for combinations of nutrient, crop and soil types are being established.

4 J Walker, K Hertel, P Parker, J Edwards (2011) Lupin growth and development. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0006/516183/Procrop-lupin-growth-and-development.pdf

5 Murrell, T.S. 2005. Average nutrient removal rates for crops in the Northcentral Region. Available at http://www.ipni.net/northcentral/nutrientremoval (accessed 4 Sep. 2007, verified 18 June 2008).

- Critical ranges are being established for topsoils (0 to 10 cm) and subsoils (10 to 30 cm in some cases, or to the depth of the crop root zone in others), depending on the nutrient.
- Deeper sampling is considered essential for understanding soil nutritional status and fertiliser requirement in Northern cropping systems.

The importance of subsoil layers for nutrients such as P and K is not yet reflected in the limited soil test-crop response data available. Researchers are currently using rough rules of thumb to help interpret P and K soil tests in terms of likely fertiliser responsiveness on Northern region Vertosols.

Tests for N and S provide information on nutrient supply, while P and K tests indicate nutrient sufficiency. If critical nutrient ranges for soil and crop species are available, the soil test information can be used to support decisions about fertiliser rate, timing and placement.

Appropriate soil tests for measuring soil extractable or plant available nutrients in the Northern cropping region are:

- bicarbonate extractable P (Colwell-P), to assess easily available soil P;
- acid extractable P (BSES-P), to assess slower release soil P reserves and the build-up of fertiliser residues (not required annually);
- exchangeable K; KCl-40 extractable S or MCP-S; and
- 2M KCl extractable mineral N, to provide measurement of nitrate-N and ammonium-N.

Other measurements that aid the interpretation of soil nutrient tests include:

- soil carbon/organic matter content;
- phosphorus buffering index (PBI);
- soil salinity measured as electrical conductivity; and
- chloride and other exchangeable cations including aluminium. [6]

5.2.1 Collecting soil samples for nutrient testing

The greatest source of error in any soil testing service comes from collection of the soil. Soil sampling does not have a single, definable strategy. The strategy needs to be closely aligned to the reasons for testing. The most stringent sampling requirement occurs when the reason for sampling is predicting crop response to added fertiliser.

How many cores should be taken to represent an area? The general rule is that the more variable crop growth is in the field the more sub-samples are required to produce a meaningful paddock average. If the objective of soil sampling is monitoring trends in paddock fertility or problem solving, the number of cores representing an area can be substantially reduced.

To ensure that a sample is representative:

- check that the soil type and plant growth from where the sample is collected are typical of the whole area to be treated;
- avoid areas such as stock camps, old fence lines and headlands where nutrient concentrations are often significantly higher than the rest of the paddock;
- ensure that each sub-sample is taken to the full sampling depth;
- do not sample in very wet conditions;
- avoid shortcuts in sampling such as taking only one or two cores or a handful or a spadeful of soil, which will give misleading results; and
- avoid contaminating the sample, the sampling equipment and the sample storage bag with fertilisers, other sources of nutrients or organic materials such as oils used to lubricate deep probes. [7]

6 GRDC (2014) Crop Nutrition Factsheet: Soil testing for crop nutrition – Northern region. www.grdc.com.au/GRDC-FS-SoilTestingN

7 GRDC (2014) Crop Nutrition Factsheet: Soil testing for crop nutrition – Northern region. www.grdc.com.au/GRDC-FS-SoilTestingN

5.2.2 Sampling depth

The most common soil sampling depth for nutrient analysis is 0 to 10 centimetres for broadacre crops. This layer was chosen because nutrients, especially P, and plant roots are concentrated within this layer. To obtain more comprehensive soil data, including nutrient data, sampling below 10 cm should be considered for some nutrients.

Suggested sampling increments for key nutrients and salinity for northern cropping regions are:

- 0 to 10 cm (N, P, K and S);
- 10 to 30 cm (N, P, K and S);
- 30 to 60 cm (N and S, salinity, sodicity);
- 60 to 90 cm (N, S, salinity, sodicity); and
- 90 to 120 cm (optional) (N, salinity, sodicity).

Deeper sampling does raise issues of logistics and cost, which should be discussed with soil test providers. However, the additional information provides a clearer insight into nutrient status in the crop root zone. [8]

5.2.3 Critical values and ranges

A soil test critical value is the soil test value required to achieve 90% of maximum potential crop yield, while the critical range reflects the degree of uncertainty around the critical value. The narrower the range, the more reliable the prediction of a fertiliser response from the available data.

The critical range determines if a nutrient is likely to be deficient for crops based on whether the soil test value is greater than or less than the upper or lower critical range value (Table 3).

Table 3: *Adequate levels for various soil test results.*

Phosphorus			
	Colwell	Olsen	
Sand	20–30	10–15	
Clay	25–35	12–17	
Loam	35–45	17–23	
Potassium			
	Bicarb	Skene	Exchangeable K
Sand	50	50	Not applicable
Other soils	100	100	0.25 me/100 g
Sandy loam (field peas)	70–80	-	-
Sulfur			
	KCl		
Low	5 ppm		
Adequate	8 ppm		

Source: Grain legume handbook)

If the soil test value is less than the lower limit, the site is likely to respond to an application of the nutrient resulting in higher crop yields. For values within the range there is less certainty about whether a response will occur. Growers have to exercise judgement about the cost benefit of adding fertiliser in the coming season.

8 GRDC (2014) Crop Nutrition Factsheet: Soil testing for crop nutrition – Northern region. www.grdc.com.au/GRDC-FS-SoilTestingN

MORE INFORMATION

Soil testing for crop nutrition - Northern region Factsheet

Monitoring of soil phosphorus, potassium and sulfur to get the most out of your fertiliser dollar

If the soil test is above the critical range, fertiliser may be applied to maintain existing soil levels or a controlled rundown of nutrient reserves can be conducted until fertiliser applications become viable. Soil bulk density changes with texture and gravel content. As a rule, the bulk density of vertosols can range from 1.1 to 1.3 grams/cm3. [9]

The SoilMapp app provides details of soil bulk densities across Australia.

5.3 Plant and/or tissue testing for nutrition levels

Of the many factors affecting crop quality and yield, soil fertility is one of the most important. Producers can manage fertility by measuring the plant's nutritional status. Nutrient status is an unseen factor in plant growth, except when imbalances become so severe that symptoms appear on the plant.

Plant tissue testing is most useful for monitoring crop health, because by the time noticeable symptoms appear in a crop the yield potential can be markedly reduced. Several companies perform plant tissue analysis and derive accurate analytical concentrations however it can be hard to interpret the results and determine a course of action. As with soil tests, different plants have different critical concentrations for a nutrient. In some cases, varieties can vary in their critical concentrations (Table 4). Care should be taken to use plant tissue tests for the purpose for which they have been developed. Most tests diagnose only the nutrient status of the plants at the time they are sampled and cannot reliably indicate the effect of a particular deficiency on grain yield. [10]

Table 4: *Critical nutrient levels for lentil at flowering. These values can also be used in vetch. Any nutrient level below the critical range will be deficient; any level above will be adequate.*

Nutrients	Plant part	Critical range
Phosphorus (%)	Youngest mature leaf	0.3
Potassium (%)	Youngest mature leaf	1.8
Sulfur (%)	Youngest mature leaf	0.2
Boron (mg/kg)	Youngest mature leaf	20
Copper (mg/kg)	Youngest mature leaf	3.0
Zinc (mg/kg)	Youngest mature leaf	20

Source: Grain legume handbook

5.3.1 What plant-tissue analysis shows

Plant tissue analysis shows the nutrient status of plants at the time of sampling. This, in turn, shows whether soil nutrient supplies are adequate. In addition, plant tissue analysis will detect unseen deficiencies and may confirm visual symptoms of deficiencies. Toxic levels also may be detected.

Although usually used as a diagnostic tool for correction of future nutrient problems, plant tissue analysis from young plants will allow a corrective fertiliser application in the present season.

A plant analysis is of little value if the plants come from fields that are infested with weeds, insects and disease organisms, or if the plants are moisture-stressed or have some mechanical injury.

The most important use of plant analysis is as a monitoring tool for determining the adequacy of current fertiliser practices. Sampling of a crop periodically during the season or sampling once each year provides a record of nutrient content that can

9 GRDC (2014) Crop Nutrition Factsheet: Soil testing for crop nutrition – Northern region. www.grdc.com.au/GRDC-FS-SoilTestingN

10 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.* https://grdc.com.au/__data/assets/pdf_file/0026/209618/chapter-4-nutrition.pdf.pdf

be used through the growing season or from year to year. With soil-test information and a plant-analysis report, a producer can tailor fertiliser practices to specific soil–plant needs.

Sampling tips:

- Sample the correct plant part at the specified time or growth stage; i.e whole plant tops.
- Use clean plastic disposable gloves to sample to avoid contamination.
- Sample tissue (e.g. entire leaves) from vigorously growing plants unless otherwise specified in the sampling strategy.
- Take a sufficiently large sample (adhere to guidelines for each species provided).
- When troubleshooting, take separate samples from areas of good and poor growth.
- Where necessary, wash samples while fresh to remove dust and foliar sprays.
- After collection, keep samples cool.
- Refrigerate or dry if samples cannot be dispatched to the laboratory immediately for arrival before the weekend.
- Generally, sample in the morning while plants are actively transpiring.

Practices to avoid:

- sampling spoiled, damaged, dead or dying plant tissue
- sampling plants stressed by environmental conditions
- sampling plants affected by disease, insects or other organisms
- sampling soon after applying fertiliser to the soil or foliage
- contaminating samples with dust, fertilisers and chemical sprays or perspiration and sunscreen from hands
- sampling from atypical areas of the paddock, e.g. poorly drained areas
- sampling plants of different vigour, size and age
- combining samples from different cultivars (varieties) to make one sample
- placing samples into plastic bags, which will cause the sample to sweat and hasten its decomposition
- sampling in the heat of the day; i.e. when plants are moisture-stressed
- mixing leaves of different ages. [11]

5.4 Nitrogen

Key points:

- Nitrate (NO3–) is the highly mobile form of inorganic N in both the soil and the plant.
- To achieve maximum yields, common vetch requires 15–20 kg/ha nitrogen (N) [12] however as a legume it can produce it's own N needs if inoculated correctly.
- Woolly pod vetch has much slower initial growth than common vetch, so requires 25–50 kg/ha of nitrogen. [13]
- Sandy soils in high-rainfall areas are most susceptible to nitrate loss through leaching.
- Soil testing and N models will help to determine seasonal N requirements. [14]

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11 SoilMate (2010) Guidelines for sampling plant tissue for annual cereal, oilseed and grain legume crops. Back Paddock Co., http://www.backpaddock.com.au/assets/Product-Information/Back-Paddock-Sampling-Plant-Tissue-Broadacre-V2.pdf?phpMyAdmin=c59206580c88b2776783fdb796fb36f3

12 R Matic (2015) GRDC Final Reports: DAS00013 – Vetch variety improvement for Australian field crop farming systems. https://grdc.com.au/research/reports/report?id=268

13 R Matic, S Nagel, G Kirby (2008) Woolly pod Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Woolly_pod_vetch.htm

14 D Herridge. (2013). Managing legume and fertiliser N for Northern grains cropping. http://www.ini2016.com/pdf-posters/Herridge.pdf

Symbiotic nitrogen fixation is the mutually beneficial relationship between the pulse (or any legume) host and Rhizobium bacteria. These bacteria colonise roots during seed germination then multiply rapidly to form root nodules within 4–10 weeks. They are dependent on the host plant for water, nutrients and energy, but in return supply the plant with nitrogen (ammonium, NH4+) for direct uptake. This 'fixed' nitrogen is derived from the enormous N_2 gas resources of the earth's atmosphere (around 80%) – the same source used by the Haber and Bosch process to manufacture compound N fertiliser.

Pulses (and pasture legumes) play an essential role in the nitrogen supply chain of field crops, especially since nitrogen is one of the most limited plant nutrients worldwide. By fixing their own nitrogen during growth, pulses become independent of soil mineral nitrogen and thereby conserve or spare it. When combined, these two sources (fixed and spared N) produce large amounts of residual nitrogen for following crops, boosting both their grain yield and grain protein. Compared to manufactured nitrogen fertiliser, biologically fixed nitrogen is:

- less volatile;
- more stable;
- 'slow release';
- environmentally sustainable;
- less energy demanding to manufacture;
- cost effective;
- not subject to supply restrictions or price fluctuations; and
- not subject to the challenges of application timing and utilisation efficiency. [15]

5.4.1 Nitrogen fixation

Legumes (crop and pasture combined) are estimated to fix almost 3 million tonnes of nitrogen each year in Australia, which is worth around $4 billion. This amount of fixed N makes a substantial (around 50%) contribution to the estimated 6 million tonnes of nitrogen that are required annually for grain and animal production on Australian farms.

Vetches are an economically viable option in rotation with cereal crops. The amount of nitrogen returned to the soil is between 50 and 63 kg per ha after grain production, and between 64 and 97.9 kg per ha after cutting for hay (see Table 3). Cereal crops in the paddocks where vetch was grown in the previous one to two years was significantly superior to crops which followed cereal or fallow. The high nutrient value of vetch hay and grain as well as the additional nitrogen added to the soil by growing vetch is the main reason for including vetch in crop rotation with the cereal crops.

The NSW Department of Agriculture reported that trials demonstrated the benefits of using vetch in crop rotations. Soil nitrogen is improved, weeds are decreased, and direct drilling is easier. Savings on fertiliser and herbicides for the following grain crop are two major incentives for using vetch in rotation with cereals. Wheat after vetch hay increased yield and protein by 25% and 1.8% respectively, compared with cereal on cereal. Table 5 presents the results of nitrogen fixation after vetch grain and hay crops from three sites by three years. [16]

Vetch has been found to increase nitrogen by 50–60 kg/ha which meant a 30–50% input reduction of mineral fertilisers to reach the same yields in cereals. [17]

15 E Armstrong, D Holding. (2015). Pulses:putting life into the farming system. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/558958/Pulses-putting-life-into-the-farming-system.pdf

16 R Matic (2007) Improved vetch varieties for fodder production. Rural Industries Research and Development Corporation.

17 R Matic, S McColl (2013) Which vetch is my farming system? Online Farm trials. http://www.farmtrials.com.au/trial/16634

Table 5: *Nitrogen level before and after a vetch crop.*

Site	Soil texture	PH level (H_2O)*	Plant for	2003/04		2004/05		2005/06		Mean (kg/ha)**		Nitrogen Increase (kg/ha)
				A	B	A	B	A	B	A	B	
Blyth	Sandy loam	8.4	Grain	19	36	21	34	18	31	81.1	141.4	60.3
			Hay		42		40		43		175.1	94.0
Lameroo	Non-wetting sand	8.6	Grain	16	27	18	31	17	29	71.4	121.8	50.4
			Hay		30		34		33		135.7	64.3
Kingsford	Heavy loamy clay	7.4	Grain	25	38	27	42	22	39	103.7	166.6	62.9
			Hay		44		49		51		201.6	97.9

A = soil is taken before seeding vetch crop. B = soil taken from the same places just before seeding following crops. Nitrogen was calculated using q formula from SARDI, Soil and Plant Analysis to get total of nitrogen for 60 cm/ha: [(Nitrate Nitrogen + Ammonium Nitrogen) x 1.4] x 3. For example: Jamestown before vetch 29+6=35 x 1.4=49 x 3=147 kg; after grain vetch: 37+11=48 x 1.4=67.2 x 3=201.6; differences 201.6 – 147= 54.6 kg of Nitrogen increased.

Source: RIRDC

For more information on assessing nitrogen fixation, see Section 3: Planting, Assessing nodulation section.

5.4.2 Managing nitrogen

Topdressing pulses with nitrogen is not as effective as inoculation. Trials have shown that nitrogen topdressing of pulses results in little or no net growth or yield benefit. Inoculating pulses is most effective if the soil is moist and if residual soil nitrogen and soil rhizobia populations are low. [18]

High levels of nitrogen in the soil will inhibit nodulation and nitrogen fixation. Spreading nitrogen fertiliser may therefore reduce the amount of nitrogen fixed by the plant. [19]

'Starter' fertilisers such as MAP and DAP can be used on pulses. Some growers worry that using nitrogen on their pulse crop will affect nodulation. This is not the case with the low rates of nitrogen as supplied by MAP or DAP. A benefit from using the starter nitrogen is that early plant vigour is often enhanced and on low fertility soils, yield increases can be made. [20]

Soil testing for paddock nutrition prior to sowing is the best way to know whether crops may be at risk of nitrogen deficiency. For more information on soil testing, see Section 5.2 Soil testing, above.

MORE INFORMATION

The best return on investment: inoculating or topdressing pulses?

5.5 Phosphorus

Key points:

- Phosphorus (P) reserves have been run down over several decades of cropping.
- Testing subsoil (10 to 30 cm) P levels using both Colwell-P and BSES-P soil tests is important in developing a fertiliser strategy.
- Application rates on responsive soils should be similar to cereals to achieve optimum yields and maintain soil P levels.
- Applying P at depth (15 to 20 cm deep on 50 cm bands) can improve yields over a number of cropping seasons (if other nutrients are not limiting).

18 D Ferrier, M Peoples, L Watson (2013) The best return on investment: inoculating or topdressing pulses? Birchip cropping group. Online Farm Trials. http://www.farmtrials.com.au/trial/16655

19 P White, M Harries, M Seymour, P Burgess (2005) Producing pulses in the northern agricultural region. Department of Agriculture and Food, Western Australia, Perth. Bulletin 4656.

20 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

- Phosphorus is very important to be added when sowing Woolly pod vetch, and generally provides a good start and growth. [21]

Reserves of mineral nutrients such as phosphorus (P) have been run down over several decades of cropping with negative P budgets (removing more P than is put back in by fertilisers or crop residues). This trend has accelerated as direct drill cropping has improved yields and crop frequency, removing even more P from the soil. Consequently, limited P is now constraining yields in parts of the northern grains region, particularly in the vertosols (black and grey cracking clays).

P is largely immobile in the soil, particularly in clay soils, so P applied to the topsoil (0 to 10 cm) layer will not penetrate into the subsoil. P is being removed from the deeper subsoil layers (10 to 30 cm) to meet crop demand, especially during dry periods when crop roots cannot access dry topsoil layers and the plant relies almost exclusively on stored subsoil water.

Crops must be able to access P (and potassium (K), another essential but immobile nutrient) from the subsoil. This supply is especially important in the post-seedling stage. P (and K) levels need to be adequate down to 30 to 40 cm to drought-proof cropping systems in the Northern region, which have a greater reliance on stored soil moisture rather than in-crop rainfall. [22]

5.5.1 Managing phosphorus

Most soils where pulses are grown are deficient in available P. Drill phosphate at seeding. Banding of phosphate below the seed can increase yields on some soils, particularly those with high phosphorous retention.

Phosphorus is very important to be added when sowing Woolly pod vetch, and generally provides a good start and growth. [23]

Deep placement of phosphorus and potassium fertilisers is increasingly required in Northern region cropping programs to address low subsoil reserves of these nutrients. Apply P at depths of 15 to 20 cm and in bands 50 cm apart, or closer if possible. If the bands are any wider than 50 cm there will not be enough plant roots to reach the high P zones and meet crop demand. Applying P in bands 25 to 50 cm apart produces stronger yield responses than bands 100 cm apart. This has been shown consistently across soil types and crops.

Increasing the volume of enriched soil is more effective than just increasing P rates. The key is placing bands in different positions each cropping season. The strategy of lower rates applied more frequently will eventually enrich enough of the soil volume to overcome P limitations, due to the excellent residual value of deep-placed P.

It is important to consider soil pH (e.g. acidic soils in the Northern region) when applying P. An interaction between soil pH and phosphorus fertiliser is most likely when: there are no other major nutritional constraints to crop growth; and a large change (>0.5 pH units) has been made to subsurface pH by lime application. When these two criteria have been met, an interaction between soil pH and phosphorus fertiliser can lead to greater availability of soil phosphorus. [24]

Soil testing

It is important to assess the P status of the subsoil periodically. Test the 10 to 30 cm layer using BSES-P as well as Colwell-P soil tests. Take the opportunity to test for K at the same time. Such testing will build a more complete picture of a soil's fertility and the values from the deeper layers can be used to refine your fertiliser strategy. P and K fertility in the subsoil changes more slowly than in the top 10 cm, where starter

21 R Matic, S Nagel, G Kirby (2008) Woolly pod Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Woolly_pod_vetch.htm

22 GRDC. (2012). Crop Nutrition: Phosphorus management Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2012/11/grdc-fs-phosphorusmanagements

23 R Matic, S Nagel, G Kirby (2008) Woolly pod Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Woolly_pod_vetch.htm

24 C Scanlan. (2016). GRDC Update papers: The interaction between soil pH and phosphorus fertiliser is dynamic. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/The-interaction-between-soil-pH-and-phosphorus-fertilizer-is-dynamic

fertiliser is applied and where nutrients are deposited via crop residues. Subsoil tests are an extra expense; however, they generally only need to be done once every four to six years. Analysing grain for nutrient content provides additional information when monitoring soil fertility by accounting for the amount of nutrient removed with each harvest.

Colwell-P

The Colwell-P test uses a bicarbonate (alkaline) extraction process to assess the level of readily available soil P. It was the original test for P response in wheat in northern New South Wales. It is used with the phosphorus buffering index (PBI) to indicate the sufficiency and accessibility of P in the soil.

BSES-P

The BSES-P test was developed for the sugar industry but is now an important tool in the grains industry. BSES-P uses a dilute acid extraction to assess the size of slower release soil P reserves. These reserves do not provide enough P within a season to meet yield requirements, but they partially replenish plant-available P. Because the P measured by BSES-P releases only slowly, changes in the test value of subsoil layers may take years. Therefore, this test needs to be done only every four to six years, and is most important in the subsoil layers.

PBI

The 'buffering capacity' of a soil refers to its ability to maintain P concentration in solution as the plant roots absorb the P. The phosphorus buffering index (PBI) indicates the availability of soil P. The higher the value, the more difficult it is for a plant to access P from the soil solution. Generally, a PBI value of less than 300 (a range that would include most northern vertosols) indicates that soil P, as assessed by Colwell-P, is readily available. Colwell-P and PBI values are needed in both 0 to 10 cm and 10 to 30 cm soil tests. BSES-P is optional in the 0 to 10 cm layer but essential in the 10 to 30 cm layer. [25]

MORE INFORMATION

Phosphorus management – Northern region

Sulfur in Northern Vertosols

5.6 Sulfur

Sulfur is an essential plant nutrient required by all crops for optimum production. After N, P and K, Sulfur (S) as a secondary nutrient element appears to be most important, as S concentration in legumes is almost double that of cereals. Plants take up and use S in the sulfate (SO4-S) form, which like nitrate (NO3-N), is very mobile in the soil and is prone to leaching in wet soil conditions, particularly in sandy soils. Sulfur must be present for good nodule development on pulse crop roots.

The key processes in the sulfur cycle in the Northern cropping soils are the reactions between soil solution sulphate and soil organic S, solution sulphate and adsorbed sulphate and loss of S by leaching. From a crop's point of view, the majority of the S it acquires early in the life cycle is most likely derived from immediate release of S from crop residues that remains in the surface soil, and mineralisation of S from organic matter over the fallow period. The move to stubble retention in no till systems has led to an increase in the amount of S mineralised.

5.6.1 Managing sulfur

Historically, S has been adequate for crop growth because S was supplied in superphosphate. It is recommended that growers use fertilisers blended with a sulfur component if soil tests show a deficiency in this nutrient

., vetch responds well to added sulfur in fertilisers when soils are low to moderate in fertility. Application practices are similar to those for field peas; i.e. top-dressing S sources such as gypsum will correct soil deficiency.

25 GRDC. (2012). Crop Nutrition: Phosphorus management Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2012/11/grdc-fs-phosphorusmanagements

Sulfur is a component of organic matter, and sulphate is adsorbed on to clay, iron and aluminium oxides. Sulfur leaches in high rainfall on sandy acidic soils. Cold, wet conditions slow S mineralisation and plant uptake. Root restricting constraints such as traffic pans, disease or soil acidity will worsen S deficiency. In areas close to the sea or industrial pollution, there can be significant input of S from the atmosphere.

S soil levels are easily managed due to the high availability of S products when applied in soil systems as most soil types have a limited ability to form unavailable S complexes. Some management practices are inadvertently supplying significant amounts of S through the application of gypsum to manage sodicity, application of ammonium sulphate as a source of N and even a standard application rate of 100 kg/ha of MAP/DAP will supply approximately 1.5 kg S/ha. [26]

5.7 Potassium

Potassium (K) is required by all plant and animal life. Adequate potassium results in superior quality of the whole plant due to the improved efficiency of photosynthesis, increased resistance to some diseases and greater Water Use Efficiency. Potassium helps maintain a normal balance between carbohydrates and proteins.

K is used in many plant processes (e.g. photosynthesis, sugar transport and enzyme activation). It is particularly important in regulating leaf stomata. Plants that have adequate levels of potassium are better able to tolerate drought and waterlogging than plants deficient in potassium.

5.7.1 Managing potassium

Potassium deficiencies are most common on well drained, coarse-textured soils e.g. sandy soils and deep grey sandy duplex soils. High rates of hay or grain removal and hay production can result in K deficiency.

K deficiencies can be corrected with potassium (potash) fertiliser (K20).

The right time and right place to give the best K response is at seeding rather than topdressing. Muriate of potash is a salt and can cause damage to sensitive seeds when place together in the sowing row. The amount of damage will depend on row width, seeding points, soil texture and moisture. Banding below the seed at planting has been shown to give much better results than topdressing or pre-spreading.

The right rate will need to be higher than replacement because K is relatively immobile. If the K buffering capacity is high, and the non-exchangeable K pool is strongly depleted, the competition between the soil and plant can mean minimum rates of 50 to 100 kg K/ha are needed to see responses. If using test-strips run out at seeding, use a high rate to see if K supply is adequate.

Another consequence of the low mobility, especially in alkaline soils, is that high rates can be used to cover two or three or even more crops. It is better to use higher rates less frequently than lower rates every year.

The right source is usually MOP, mainly because it is significantly cheaper than sulfate of potash, potassium nitrate or potassium magnesium sulfate (langbenite). All commercially available K fertilisers are imported, although there is one current development to exploit greensand deposits of glauconite in WA. Some growers are concerned about adding extra chloride, but the amounts added are of little agronomic or environmental significance in adding to salt loads. [27]

MORE INFORMATION

Do we need to revisit potassium?

26 S Mason (2016) GRDC Update Papers: Monitoring of soil phosphorus, potassium and sulfur in the southern region – how to get the most out of your fertiliser dollar. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Monitoring-of-soil-phosphorus-potassium-and-sulphur

27 R Norton (2014) GRDC Update Papers: Do we need to revisit potassium? https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2014/02/do-we-need-to-revisit-potassium

5.8 Micronutrients

Key points:

- Micronutrient deficiencies are best determined by looking at the overall situation: region, soil type, season, crop and past fertiliser management.
- Soil type is useful in deducing the risk of micronutrient deficiencies.
- When tissue testing, sample the appropriate tissues at the right time. Plant nutrient status varies according to the plant's age, variety and weather conditions.
- The difference between deficient and adequate (or toxic) levels of some micronutrients can be very small.
- When applying fertiliser to treat a suspected deficiency, leave a strip untreated. Either a visual response or tissue testing can allow you to confirm whether the micronutrient was limiting.
- Adequate trace element nutrition is just as important for vigorous and profitable crops and pastures as adequate major element (such as nitrogen or phosphorus) nutrition.

Micronutrients are essential for healthy plant growth. The key challenge is accurate identification of deficiencies and knowing your risk level. Unlike the macronutrients such as nitrogen (N), phosphorus (P), sulfur (S) and potassium (K) micronutrients are only needed in small quantities. Even so, they can limit production. The most likely limiting micronutrients to Australian cropping systems are boron (B), copper (Cu), manganese (Mn), molybdenum (Mo) and zinc (Zn). Iron (Fe) can be important, especially on strongly alkaline soils.

Traditionally, cultivation distributed these micronutrients through the topsoil but the introduction of no-till and one-pass seeding equipment has led to more limited physical distribution.

Many soils in Australia are deficient in trace elements in their native condition. Despite many decades of research into trace element management, crops can still be found to be deficient in one or more of these trace elements. Just because trace element deficiencies have not been prevalent in recent years, does not mean they will not return.

There is increasing concern in some districts that trace element deficiencies may be the next nutritional barrier to improving productivity. This is because current cropping systems are exporting more nutrients to the grain terminal than ever before.

Micronutrient deficiencies can be tricky to diagnose and treat. By knowing your soil type, considering crop requirements and the season, and supporting this knowledge with diagnostic tools and strategies, effective management is possible. [28]

Of the micronutrient listed above, Zn deficiency is probably the most important because it occurs over the widest area, particularly in south eastern Australia.

5.8.1 Micronutrients for vetch growth

There are few micronutrient recommendations available specifically for vetch cropping. Because vetch is often grown in rotation with cereals, the nutritional needs of cereals often provide adequate micronutrients for vetch. However, in molybdenum deficient soils, vetch can benefit from application. This is because Mo is required for effective nodulation and can also help to successfully establish vetch and promote vigorous growth.

In most soils, molybdenum present in an unavailable form will be released by applying lime or dolomite. The effect of liming on molybdenum availability is slow and it may take several months to correct the deficiency. The amounts of lime or dolomite needed may range from 2 to 8 tonnes per hectare, depending on initial pH of the

28 GRDC. (2013). Crop nutrition Fact Sheet. Micronutrients. www.grdc.com.au/GRDC-FS-CropNutrition-Micronutrients

soil and whether it is sandy or heavy textured. Unless lime is likely to be beneficial for other reasons, it is quicker and cheaper to apply a molybdenum compound to the soil or to the crop.

Where one of the molybdenum compounds is used, the quantities recommended vary from 75 g to 1 kg/ ha depending on the crop and the molybdenum material.

Molybdenum can be applied in the following ways:

- mixed with fertiliser; or
- in solution, to;
- seedlings in the seedbed before transplanting;
- the leaves of plants in the field; or
- the soil at the base of plants in the field. [29]

MORE INFORMATION

Crop nutrition - micronutrients

29 R Weir (2004) AGFacts: Molybdenum deficiency in plants. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/166399/molybdenum.pdf

Weed control

Key messages

- Broadleaf Weed control in vetch can be problematic as some herbicide options are limited.
- Hard seeded vetch varieties can also increase the risk of volunteer vetch in subsequent crop rotations.
- Spraying herbicides should be avoided when vetch is at the flowering stage, as it will severely affect yield. [1]
- Ensure to spray under good conditions and to always keep good paddock records to avoid potential herbicide damage to own paddocks and neighbouring crops. [2]
- Monitor crops for herbicide damage and keep an eye out for potentially resistant weeds (which should then be tested).
- Vetch offers a non-herbicide option for weed control when hay is made and weeds are removed.
- Green/brown manuring is a favoured use of vetch and another tool for resistant weed control.

The total cost of weeds (revenue loss plus expenditure) to Australian grain growers is estimated at $3,318 million. [3] Effective weed control is essential for good yields and to avoid the buildup of troublesome weeds in the rotation. Plan your weed control strategy before sowing.

Pulses grown in rotation with cereal crops offer farmers opportunities to easily control grassy weeds with selective herbicides that cannot be used in the cereal years, providng herbicide resistance is not an issue. An effective kill of grassy weeds in the pulse crop will reduce root disease carry over, such as brown rot, and provide a "break crop" benefit in the following cereal crop.

Weed management in vetch is problematic, with few herbicides registered for in-crop weed control. Management of broadleaf weeds is especially difficult, with limited post emergent herbicide options for broadleaf weed control. [4] The control of broadleaf weeds should be focused on pre-emergent options. Broadleaf weeds can compete strongly with the vetch, reducing the value of the crop and potentially leading to increased weed problems in later years. Several grass herbicides are available and most of these can be tank mixed with insecticides (check labels). Avoid herbicide spraying at flowering. [5]

A weed management program should be designed to make the most of opportunities to use selective herbicides in each crop in the rotation to reduce the weed problem in the following crop. Great care should be taken in planning a cropping rotation to avoid growing a crop which may become a "weed", which cannot be controlled with selective herbicides, in the subsequent crop.

6.1.1 Volunteer vetch

Increasing numbers of wild vetch or tares is being viewed with alarm in some areas. Wild vetch has the potential to become a severe problem in the cropping systems of south eastern Australia (Photo 1). Once established, it is highly competitive in crops such as lupins.

1 R Matic (2010) Vetch summary 2010. SARDI. Online Farm Trials. http://www.farmtrials.com.au/trial/14055

2 R Matic (2010) Vetch summary 2010. SARDI. Online Farm Trials. http://www.farmtrials.com.au/trial/14055

3 R Llewellyn, D Ronning, M Clarke, A Mayfield, S Walker, J Ouzman (2016) Impact of weeds on Australian Grain production. GRDC. https://grdc.com.au/__data/assets/pdf_file/0027/75843/grdc_weeds_review_r8.pdf.pdf

4 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

5 R Matic, S McColl (2013) Which vetch is my farming system? Online Farm trials. http://www.farmtrials.com.au/trial/16634

Wild Vetch is an autumn-germinating annual broadleaf weed. They have a high percentage of hard seeds which may survive indefinitely and germinate if conditions are favourable. Cultivation to bury the seed and prevent germination is not effective. Seed germination trials showed vetch has the ability to germinate from a depth of 250 mm.

Vetch is classified as a Class 7 contaminant in ASW standard wheat by the Australian Wheat Board. This means that no more than one vetch seed per 0.5 L grain sample is allowed. Contamination above this level would result in the grain being rejected.

Photo 1: *Vetch tares in a paddock.*

Photo: Peter Teasdale

Cultivated varieties of vetch are easier to control as they are not as hard-seeded as their wild relatives. Germination percentages of cultivated varieties are relatively high and with the correct timing of herbicide application can be well controlled. [6]

New common vetch varieties (Morava⚘ and Rasina⚘) are soft seeded varieties and have no potential to be a weed in subsequent crops. However, older varieties like Blanchefleur and Languenoc have 5–20% hard seeds and can potentially be a weed in the following 2–3 years.

6.2 Integrated weed management

Weeds present one of the largest costs to grain growers and are one of the biggest influences on the management of cropping systems. Their impact is multifaceted; they affect yield and management across all seasons, and sometimes crop price. In addition, the weed challenge faced by growers is constantly evolving, with changes in weed types and their characteristics, such as herbicide resistance, requiring the ongoing adaptation of management.

The Grains Research and Development Corporation (GRDC) supports integrated weed management. Download the Integrated Weed Management Manual.

Integrated weed management (IWM) is a system for managing weeds over the long term, particularly the management and minimisation of herbicide resistance. There is a need to combine herbicide and non-herbicide methods into an integrated control

6 A Chambers in GRDC. Groundcover Issue 16: All vetches aren't equal. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-16/all-vetches-arent-equal

MORE INFORMATION

Weed management as a key driver of crop agronomy

program. Given that there are additional costs associated with implementing IWM, the main issues for growers are whether it is cost-effective to adopt the system and whether the benefits are likely to be long-term or short-term in nature.

The manual looks at these issues and breaks it down into seven clear sections, assisting the reader to make the development of an integrated weed management (IWM) plan a simple process.

Successful weed management requires a field by field approach. Knowledge of weeds and weedbank status, soil types as relevant to herbicide use as well as cropping and pasture plans are all critical parts of the picture. Knowledge of paddock history and how much summer and winter weeds have been subjected to selection to resistance (and to which herbicide modes of action) can also assist.

When resistance has been identified, knowledge of which herbicides still work becomes critically valuable information.

The following 5-point plan will assist in developing a management plan in each and every paddock.

1. Review past actions and history
2. Assess current weed status
3. Identify weed management opportunities
4. Match opportunities and weeds with suitably effective management tactics
5. Combine ideas into a management plan. Use of a rotational plan can assist [7]

An integrated weed management plan should be developed for each paddock or management zone.

In an IWM plan, each target weed is attacked using tactics from several tactic groups (see links below). Each tactic provides a key opportunity for weed control and is dependent on the management objectives and the target weed's stage of growth. Integrating tactic groups reduces weed numbers, stops replenishment of the seedbank and minimises the risk of developing herbicide-resistant weeds.

IWM tactics

- Reduce weed seed numbers in the soil
- Controlling small weeds
- Stop weed seed set
- Reduce weed seed numbers in the soil
- Hygiene - prevent weed seed introduction
- Agronomic practices and crop competition

Successful weed management also relies on the implementation of the best agronomic practices to optimise crop growth. Basic agronomy and fine-tuning of the crop system are the important steps towards weed management.

There are several agronomic practices that improve crop environment and growth, along with the crop's ability to reduce weed competition. These include crop choice and sequence, improving crop competition, planting herbicide tolerant crops, improving pasture competition, using fallow phases and controlled traffic or tramlining. [8]

6.2.1 Monitoring weeds

Record the key broadleafed and grass weed species for summer and winter and include an assessment of weed density, with notes on weed distribution across the paddock (Photo 2). Include GPS locations or reference to spatial location of any key weed patches or areas tested for resistance.

7 GRDC. Integrated weed management hub. https://grdc.com.au/Resources/IWMhub

8 DAFWA. (2016). Crop weeds: Integrated Weed Management (IWM). https://www.agric.wa.gov.au/grains-research-development/crop-weeds-integrated-weed-management-iwm

Include any data, observations or information relating to the known or suspected herbicide resistance status of weeds in this paddock. Add this information to paddock records.

Photo 2: *Scout for weeds throughout the year so that control can be applied at the optimal times.*

Source: Take Action

6.2.2 IWM in the Northern region

Broad-scale herbicide resistance is continuing to spread through the GRDC Northern Region. Growers can choose from a range of chemical and non-chemical integrated weed management tactics that delay or prevent resistance developing or control herbicide resistant weeds.

Major weeds of the northern grains region include feathertop rhodes grass, windmill grass, flaxleaf fleabane, awnless barnyard and liverseed grasses, common sowthistle, wild oats, wild radish and annual ryegrass.

Weeds cause economic losses in various ways, usually by reducing crop yields or contaminating harvested grain. Weeds use soil moisture during a fallow or cropping period, resulting in less moisture being available for the following crop.

Weed competition for moisture may result in poor crop establishment and growth, therefore reducing crop yield potential. For example, chickpea seedlings are poor competitors and even relatively low densities of Group A-resistant wild oats in chickpeas can reduce yields significantly.

Weed seed contamination of harvested grain can result in either seed grading being required or discounts on contaminated grain.

Tactic Group 1 – Deplete weed seed in the soil seedbank

Burning residues, insect predation, inversion ploughing, autumn tickle, delayed sowing.

Tactic Group 2 – Kill weeds (seedlings)

Fallow cultivation, herbicides (knockdown, double-knock, pre-emergent, post-emergent), wide rows (band spraying, inter-row cultivation), spot spraying, wick wipers, chipping, weed detector spraying, biological control.

Tactic Group 3 – Stop weed seed set

In-crop weed management (spray-topping, crop-topping, wick wipers, desiccation and windrowing), pasture spray topping, silage and hay, manuring, mulching, hay freezing, grazing.

Tactic Group 4 – Prevent viable weed seeds being added to the soil seedbank

Weed seed control at harvest (narrow header trail, chaff cart, bale direct), grazing residues.

MORE INFORMATION

GRDC Integrated Weed Management hub

Costs of key Integrated Weed Management tactics in the Northern region

VIDEOS

WATCH: Double knock application – a Grower's Experience.

WATCH: IWM: Double knock – Northern region

Tactic Group 5 – On-farm hygiene

Sow weed-free seed, manage weeds in non-crop areas, clean machinery, livestock movement, monitoring following flood events. [9]

6.2.3 Double knock

A double knock approach is generally a fallow operation where two weed control tactics with different modes of action are applied within a period of usually four to 14 days to a single flush of weeds to control survivors from the first application, thereby stopping seed set. The second tactic, or knock, may also include cultivation, heavy grazing or burning as an alternative to a herbicide. This tactic is commonly used in fallow situations, but could be used in-crop.

The most common double knock approach is to apply a systemic herbicide (for example, Groups A, I or M) when conditions are favourable for maximum translocation, followed by a contact herbicide (for example, Group L). The intervals for maximum effectiveness will depend on the type of herbicide used, weed species being targeted, the size and age of weeds, temperature and moisture conditions. Higher water rates are often used for the second knock (100 L/ha). Double knock is more expensive than a single herbicide application and may not need to be applied every year. Conduct a paddock herbicide resistance risk assessment first.

Advantages:

- Minimises seed set.
- Delays the development of glyphosate and other mode of action herbicide resistance.
- Reduces the number of glyphosate resistant weeds to be controlled in-crop.
- May improve pre-sowing weed control, very useful for minimum or zero tillage systems.

Practicalities:

- Translocated herbicide should be applied first, followed by paraquat or a paraquat and diquat mixture.
- Time between applications will vary with the main target weed species.
- Identify the weed species being targeted to determine the most cost-effective chemistry. [10]

6.2.4 Herbicides explained

Herbicides should be regarded as part of an integrated weed control strategy within the cropping rotation as it is generally easier, more effective and cheaper to use selective herbicides to remove grassy weeds in broadleaved crops and broadleaved weeds in cereal crops.

When selecting a herbicide, it is important to know crop growth stage, weeds present and plant-back period. For best results, spray weeds while they are small and actively growing. Herbicides must be applied at the correct stage of crop growth, or significant yield losses may occur. Check product labels for up-to-date registrations and application methods.

Residual and non-residual

Residual herbicides remain active in the soil for an extended period (months) and can act on successive weed germinations. Residual herbicides must be absorbed through the roots or shoots, or both. Examples of residual herbicides include imazapyr, chlorsulfuron, atrazine and simazine.

9 F Scott, T Cook. (2016). Costs of key integrated weed management tactics in the Northern region. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/678997/Costs-of-key-iwm-tactics-in-the-northern-region.pdf

10 F Scott, T Cook. (2016). Costs of key integrated weed management tactics in the Northern region. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/678997/Costs-of-key-iwm-tactics-in-the-northern-region.pdf

The persistence of residual herbicides is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall/irrigation, temperature and the herbicide's characteristics. Persistence of herbicides will affect the enterprise's sequence (a rotation of crops). Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and they are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.

Post-emergent and pre-emergent

These terms refer to the target and timing of herbicide application. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil, while pre-emergent refers to application of the herbicide to the soil before the weeds have emerged. [11]

Herbicides have been classified into a number of 'groups'. The group refers to the way a chemical works – their different chemical make-up and mode of action. [12]

Getting the best results from herbicides

1. Control weeds as early as possible in the first six weeks after sowing.
2. Make sure that the crop and weeds are at the correct growth stage for the herbicide to be used.
3. Do not spray outside the recommended crop growth stages as damage may result.
4. Do not spray when the crop or weeds are under any form of stress such as drought, water logging, extreme cold, low soil fertility, disease or insect attack, or a previous herbicide.
5. Some herbicides should not be used when weeds are wet with rain or dew or if rain is likely to occur within three or four hours.
6. Do not spray in windy conditions (over 10 - 15 km/hour) as drift from herbicides can cause damage to non-target crops. Herbicide spray can also drift in very calm conditions, especially with air temperature inversions. For more information on conditions for spraying, see Section 6.3 Conditions for spraying, below.
7. Use sufficient water to ensure a thorough, uniform coverage regardless of the method of application.
8. Use good quality water. Hard, alkaline or dirty water can reduce the effectiveness of some herbicides.
9. Maintain clean, well-cared for equipment. A poorly maintained spray unit will cost you money in breakdowns, blocked jets, poor results and perhaps worse, crop damage through misapplication.
10. After products such as Atlantis®, chlorsulfuron, Hussar® metsulfuron or triasulfuron have been used in equipment, it is essential to clean that equipment thoroughly with chlorine before using other chemicals. After using Affinity®, Broadstrike® or Eclipse® decontaminate with liquid alkali detergent.
11. Seek advice before spraying recently released pulse varieties. They may differ in their tolerance to herbicides. [13]

6.3 Conditions for spraying

When applying herbicides, the aim is to maximise the amount reaching the target and to minimise the amount reaching off-target areas. This results in:

- improved herbicide effectiveness

VIDEOS

WATCH: Over the Fence North: Weed and nutrient research delivers at Silverton.

WATCH: GCTV17: Herbicide partnership.

11 GRDC Integrated weed management, Section 4: Tactics for managing weed populations, https://grdc.com.au/resources-and-publications/iwmhub

12 Agriculture Victoria. Monitoring Tools. http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance

13 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2008). Grain legume handbook. *GRDC: Canberra, ACT.*

- reduced damage and/or contamination of off-target crops and areas.

In areas where several agricultural enterprises coexist, conflicts can arise, particularly from the use of herbicides. All herbicides are capable of drift.

When spraying a herbicide, you have a moral and legal responsibility to prevent it from drifting and contaminating or damaging neighbours' crops and sensitive areas.

All grass herbicide labels emphasise the importance of spraying only when the weeds are actively growing under mild, favourable conditions (Photo 3). Any of the following stress conditions can significantly impair both uptake and translocation of the herbicide within the plant, likely resulting in incomplete kill or only suppression of weeds:

- moisture stress (and drought)
- waterlogging
- high temperature–low humidity conditions
- extreme cold or frosts
- nutrient deficiency, especially effects of low N
- use of pre-emergent herbicides that affect growth and root development; i.e. simazine, Balance®, trifluralin, and Stomp®
- excessively heavy dews resulting in poor spray retentions on grass leaves

Photo 3: *Boom spray on crop.*

Source: DAFWA

Ensure that grass weeds have fully recovered before applying grass herbicides.

6.3.1 Minimising spray drift

Before spraying

- Always check for susceptible crops in the area, for example broadleaf crops such as grape vines, cotton, vegetables and pulses, if you are using a broadleaf herbicide.
- Check sensitive areas such as houses, schools, waterways and riverbanks.
- Notify neighbours of your spraying intentions.

The Cotton Field Awareness Map is provided free of charge with the purpose of minimising off-target damage from downwind pesticide application, particularly during fallow spraying. Users can also access the map to check the location of the paddock(s) they may be planning to spray to assess the proximity of the nearest cotton crop.

During spraying

- Always monitor weather conditions carefully and understand their effect on 'drift hazard'.
- Do not spray if conditions are not suitable, and stop spraying if conditions change and become unsuitable.
- Record weather conditions (especially temperature and relative humidity), wind speed and direction, herbicide and water rates, and operating details for each paddock.
- Supervise all spraying, even when a contractor is employed. Provide a map marking the areas to be sprayed, buffers to be observed and sensitive crops and areas.
- Spray when the temperature is less than 28°C.
- Where surface temperature inversion conditions exist, it is unsafe for spraying due to the potential for spray drift.
- Maintain a downwind buffer. This may be in-crop, for example keeping a boom's width from the downwind edge of the field.
- Minimise spray release height.
- Use the largest droplets that will give adequate spray coverage.
- Always use the least-volatile formulation of herbicide available.
- If there are sensitive crops in the area, use the herbicide that is the least damaging.

6.3.2 Types of drift

Sprayed herbicides can drift as droplets, as vapours or as particles:

- *Droplet drift* is the easiest to control because, under good spraying conditions, droplets are carried down by air turbulence and gravity, to collect on plant or soil surfaces. Droplet drift is the most common cause of off-target damage caused by herbicide application. For example, spraying of fallows with glyphosate under the wrong conditions often leads to severe damage to establishing crops.
- *Particle drift* occurs when water and other herbicide carriers evaporate quickly from the droplet, leaving tiny particles of concentrated herbicide. This can occur with herbicide formulations other than esters. This form of drift has damaged susceptible crops up to 30 km from the source.
- *Vapour drift* is confined to volatile herbicides such as 2,4-D ester. Vapours may arise directly from the spray or evaporation of herbicide from sprayed surfaces. Use of 2,4-D ester in summer can lead to vapour drift damage of highly susceptible crops such as tomatoes, cotton, sunflowers, soybeans and grapes. This may occur hours after the herbicide has been applied.

In 2006, the Australian Pesticides and Veterinary Medicines Authority (APVMA) restricted the use of highly volatile forms of 2,4-D ester. The changes are now seen with the substitution of lower volatile forms of 2,4-D and MCPA. Products with lower 'risk' ester formulations are commonly labelled with LVE (low volatile ester). These formulations of esters have a much lower tendency to volatilise, but caution should remain as they are still prone to droplet drift.

Vapours and minute particles float in the airstream and are poorly collected on catching surfaces. They may be carried for many kilometres in thermal updraughts before being deposited.

Sensitive crops may be up to 10,000 times more sensitive than the crop being sprayed. Even small quantities of drifting herbicide can cause severe damage to highly sensitive plants.

6.3.3 Factors affecting the risk of spray drift

Any herbicide can drift. The drift hazard, or off-target potential, of a herbicide in a particular situation depends on the following factors:

- Volatility of the formulation applied. Volatility refers to the likelihood that the herbicide will evaporate and become a gas. Esters volatilise (evaporate), whereas amines do not.
- Proximity of crops susceptible to the particular herbicide being applied, and their growth stage. For example, cotton is most sensitive to Group I herbicides in the seedling stage.
- Method of application and equipment used. Aerial application releases spray at 3 m above the target and uses relatively low application volumes, while ground-rigs have lower release heights and generally higher application volumes, and a range of nozzle types. Misters produce large numbers of very fine droplets that use wind to carry them to their target.
- Size of the area treated. The greater the area treated the longer it takes to apply the herbicide. If local meteorological conditions change, particularly in the case of 2,4-D ester, then more herbicide is able to volatilise.
- Amount of active ingredient (herbicide) applied. The more herbicide applied per hectare, the greater the amount available to drift or volatilise.
- Efficiency of droplet capture. Bare soil does not have anything to catch drifting droplets, unlike crops, erect pasture species and standing stubbles.
- Weather conditions during and shortly after application. Changing weather conditions can increase the risk of spray drift.

Volatility

Many ester formulations are highly volatile compared with the non-volatile amine, sodium salt and acid formulations. Table 1 is a guide to the more common herbicide active ingredients that are marketed with more than one formulation.

Table 1: *Relative herbicide volatility.*

Form of active ingredient	Full name	Product example
Non-volatile		
Amine salts		
MCPA DMA	dimethylamine salt	MCPA 500
2,4-D DMA	dimethylamine salt	2,4-D Amine 500
2,4-D DEA	diethanolamine salt	2,4-D Low Odour® 500
2,4-D IPA	isopropylamine salt	Surpass® 300
2,4-D TIPA	triisopropanolamine salt	Tordon® 75-D
2,4-DB DMA	dimethylamine salt	Buttress®
dicamba DMA	dimethylamine salt	Kamba 500
triclopyr TEA	triethylamine salt	Tordon® RegrowthMaster
picloram TIPA	triisopropanolamine salt	Tordon® 75-D
clopyralid DMA	Dimethylammonium salt	Lontrel® Advanced
clopyralid TIPA	triisopropanolamine salt	Archer®
aminopyralid TIPA	triisopropanolamine salt	Hotshot®
Other salts		
MCPA Na salt	sodium salt	MCPA 250
MCPA Na/K salt	sodium & potassium salt	MCPA 250
dicamba Na salt	sodium salt	Cadence®

Form of active ingredient	Full name	Product example
Non-volatile		
Some volatility		
Esters		
MCPA EHE	ethylhexyl ester	LVE MCPA
MCPA IOE	isooctyl ester	LVE MCPA
triclopyr butoxyl	butoxyethyl ester	Garlon® 600
Picloram IOE	isooctyl ester	Access®
2,4-D ehe	ethylhexyl ester	2,4-D LVE 680
fluroxypyr M ester	Methyl heptyl ester	Starane® Advanced

Source: NSW DPI

Minimising drift

A significant part of minimising spray drift is the selection of equipment to reduce the number of small droplets produced. However, this in turn may affect coverage of the target, and therefore the possible effectiveness of the pesticide application. This aspect of spraying needs to be carefully considered when planning to spray.

As the number of smaller droplets decreases, so does the coverage of the spray. A good example of this is the use of air-induction nozzles that produce large droplets that splatter. These nozzles produce a droplet pattern and number unsuitable for targets such as seedling grasses that present a small vertical target.

In 2010, APVMA announced new measures to minimise the number of spray drift incidents (Table 2). The changes are restrictions on the droplet-size spectrum an applicator can use, wind speed suitable for spraying and the downwind buffer zone between spraying and a sensitive target. These changes should be evident on current herbicide labels. Hand-held spraying application is exempt from these regulations.

Table 2: *Nozzle selection guide for ground application.*

Factor	Distance downwind to susceptible crop is <1 km	Distance downwind to susceptible crop is 1–30 km and more
Risk	High	Medium
Preferred droplet size (to minimise risk)	coarse to very coarse	medium to coarse
Volume median diameter (microns)	310	210
Pressure (bars)	2.5	2.5
Flat fan nozzle size #	11008	11004
Recommended nozzles (examples only)	Raindrop: Whirljet® Air induction: Yamaho Turbodrop® Hardi Injet® AI Teejet® LurmarkDrift-beta®	Drift reduction: DG TeeJet® Turbo TeeJet® Hardi® ISO LD 110 Lurmark® Lo-Drift
Caution	Can lead to poor coverage and control of grass weeds Requires higher spray volumes	Suitable for grass control at recommended pressures Some fine droplets

Volume median diameter (VMD): 50% of the droplets are less than the stated size and 50% greater.

Refer to manufacturer's selection charts, as range of droplet sizes will vary with recommended pressure. Always use the lowest pressure stated to minimise the small droplets.

Source: DPI NSW

VIDEOS

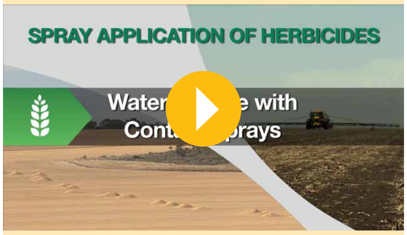
WATCH: Nozzle Selection

WATCH: Travel Speed

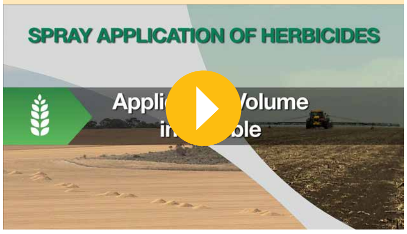
VIDEOS

WATCH: Spray deposition

WATCH: Water volume with contact sprays



WATCH: Application volume in stubble



Spray release height

- Operate the boom at the minimum practical height. Drift hazard doubles as nozzle height doubles. If possible, angle nozzles forward 30° to allow lower boom height with double overlap. Lower heights, however, can lead to more striping, as the boom sways and dips below the optimum height.
- 110° nozzles produce a higher percentage of fine droplets than 80° nozzles, but they allow a lower boom height while maintaining the required double overlap.
- Operate within the pressure range recommended by the nozzle manufacturer. Production of driftable fine droplets increases as the operating pressure is increased.

Size of area treated

When large areas are treated, greater amounts of active herbicide are applied and the risk of off-target effects increases due to the length of time taken to apply the herbicide. Conditions such as temperature, humidity and wind direction may change during spraying.

Application of volatile formulations to large areas increases the chances of vapour drift damage to susceptible crops and pastures.

Capture surface

Targets vary in their ability to collect or capture spray droplets. Well grown, leafy crops are efficient collectors of droplets. Turbulent airflow normally carries spray droplets down into the crop within a very short distance.

Fallow paddocks or seedling crops have poor catching surfaces. Drift hazard is far greater when applying herbicide in these situations or adjacent to these poor capture surfaces.

The type of catching surface between the sprayed area and susceptible crops should always be considered in conjunction with the characteristics of the target area when assessing drift hazard.

Weather conditions to avoid

Turbulence

- Updrafts during the heat of the day cause rapidly shifting wind directions. Spraying should be avoided during this time of day.

Temperature

- Avoid spraying when temperatures exceed 28°C.

Humidity

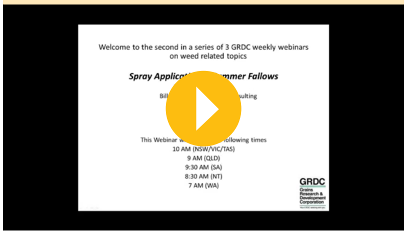
- Avoid spraying under low relative humidity conditions; i.e. when the difference between wet and dry bulbs exceeds 10°C.
- High humidity extends droplet life and can greatly increase the drift hazard under inversion conditions. This results from the increased life of droplets smaller than 100 microns.

Wind

- Avoid spraying under still conditions.
- Ideal safe wind speed is 3–10 km/h, a light breeze (when leaves and twigs are in constant motion).
- A moderate breeze of 11–14 km/h is suitable for spraying if using low-drift nozzles or higher volume application, say 80–120 L/ha. (Small branches move, dust is raised and loose paper is moving.)

VIDEOS

WATCH: Advances in weed management—Webinar 2—Spray application in summer fallows



MORE INFORMATION

Surface temperature inversions and spraying factsheet

Inversions

The most hazardous condition for herbicide spray drift is an atmospheric inversion, especially when combined with high humidity. An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, usually less than 50 m thick. Air will not rise above this blanket, and smoke or fine spray droplets and particles of spray deposited within an inversion will float until the inversion breaks down.

Do not spray under inversion conditions.

Inversions usually occur on clear, calm mornings and nights. Windy or turbulent conditions prevent inversion formation. Blankets of fog, dust or smoke and the tendency for sounds and smells to carry long distances indicate inversion conditions.

Smoke generators or smoky fires can be used to detect inversion conditions. Smoke will not continue to rise but will drift along at a constant height under the inversion 'blanket'. [14]

6.4 Pre-emergent herbicides

Pre-emergent herbicides control weeds between radicle (root shoot) emergence from the seed and seedling emergence through the soil. Some pre-emergent herbicides may also provide post-emergent control. This is the most effective way to control broadleaf weeds in vetch.

Good knowledge of possible weed burdens will help identify potential vetch paddocks and herbicides that may need to be applied prior to crop emergence. [15]

6.4.1 Incorporation by sowing

Incorporation by sowing (IBS) is when a herbicide is applied just before sowing (usually in conjunction with a knockdown herbicide such as glyphosate and soil throw from the sowing operation incorporates the herbicide into the seedbed.

Application of pre-emergent herbicides pre-sowing and then incorporating them into the seed bed during the sowing process will often increase safety to crops because the sowing operation removes a certain amount of herbicide away from the seed row. This can conversely reduce weed control for the very same reason, as chemical is moved out of the seed row. In this case, it is wise to include a water soluble herbicide into the mix aiming to have some herbicide wash into the seed furrow.

The preferred method of applying pre-emergent herbicides in conservation farming systems is by incorporation by sowing, as crop safety is maximised, stubble remains standing to protect the seedbed, and soil disturbance is minimised.

In vetch, Trifluralin should be incorporated by sowing and provides a range of broadleaf and grass control when used in combination with post-sowing, pre-emergent applications of Metribuzin. [16]

6.4.2 Benefits and issues for pre-emergent herbicides

- The residual activity of pre-emergent herbicides controls the first few flushes of germinating weeds while the crop or pasture is too small to compete.
- Good planning is needed to use pre-emergent herbicides as an effective tactic. It is necessary to consider weed species and density, crop or pasture type, soil condition and rotation of crop or pasture species.
- Soil activity and environmental conditions at the time of application play an important role in the availability, activity and persistence of pre-emergent herbicides.

14 A Storrie (2015) Reducing herbicide spray drift. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/content/agriculture/pests-weeds/weeds/images/wid-documents/herbicides/spray-drift

15 R Matic (2010) Vetch summary 2010. SARDI. Online Farm Trials. http://www.farmtrials.com.au/trial/14055

16 R Matic (2010) Vetch summary 2010. SARDI. Online Farm Trials. http://www.farmtrials.com.au/trial/14055

- Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase. [17]

The important factors in getting pre-emergent herbicide to work effectively while minimising crop damage are:

- to understand the position of the weed seeds in the soil; the soil type (particularly amount of organic matter and crop residue on the surface);
- the solubility of the herbicide; and
- its ability to be bound by the soil.

6.4.3 Understanding pre-emergent herbicides

With the increasing incidence of resistance to post-emergent herbicides across Australia, pre-emergent herbicides are becoming more important for weed control. Pre-emergent herbicides typically have more variables that can affect efficacy than post-emergent herbicides. Post-emergent herbicides are applied when weeds are present and usually the main considerations relate to application coverage, weed size and environmental conditions that impact on performance. Pre-emergent herbicides are applied before the weeds germinate and a number of other considerations come into play. The various pre-emergent herbicides behave differently in the soil and may behave differently in different soil types. Therefore, it is essential to understand the behaviour of the herbicide, the soil type and the farming system in order to use pre-emergent herbicides in the most effective way.

Pre-emergent herbicides have to be absorbed by the germinating seedling from the soil. To do so, these herbicides need to have some solubility in water and be in a position in the soil to be absorbed by the roots or emerging shoot. The dinitroaniline herbicides, such as trifluralin, are an exception in that they are absorbed by the seedlings as a gas. These herbicides still require water in order to be released from the soil as a gas. Therefore, weed control with pre-emergent herbicides will always be lower under dry conditions.

6.4.4 Behaviour of pre-emergent herbicides in the soil

Behaviour of pre-emergent herbicides in the soil is driven by three key factors:

- solubility of the herbicide,
- how tightly the herbicide is bound to soil components, and
- the rate of breakdown of the herbicide in the soil.

Characteristics of some common pre-emergent herbicides are given in Table 3.

The water solubility of herbicides ranges from very low values for trifluralin to very high values for chlorsulfuron. Water solubility influences how far the herbicide will move in the soil profile in response to rainfall events. Herbicides with high solubility are at greater risk of being moved into the crop seed row by rainfall and potentially causing crop damage. If the herbicides move too far through the soil profile they risk moving out of the weed root zone and failing to control the weed species at all. Herbicides with very low water solubility are unlikely to move far from where they are applied.

17 DAFWA. (2016) Herbicides. https://www.agric.wa.gov.au/herbicides/herbicides?page=0%2C2

Table 3: *Water solubility, binding characteristics to soil organic matter and degradation half-life for some common pre-emergent herbicides.*

Herbicide	Water solubility		Koc		Degradation half-life (days)
	mg L-1 (at 20 C and neutral pH)	Rating	mL g-1 (in typical neutral soils)	Rating	
Trifluralin	0.22	Very low	15,800	Very high	181
Pendimethalin	0.33	Very low	17,800	Very high	90
Pyroxasulfone	3.9	Low	223	Medium	22
Triallate	4.1	Low	3000	High	82
Prosulfocarb	13	Low	2000	High	12
Atrazine	35	Medium	100	Medium	75
Diuron	36	Medium	813	High	75.5
S-metolachlor	480	High	200	Medium	15
Triasulfuron	815	High	60	Low	23
Chlorsulfuron	12,500	Very High	40	Low	160

Source: University of Adelaide

The important factors in getting pre-emergent herbicides to work effectively while minimising crop damage are: to understand the position of the weed seeds in the soil; the soil type (particularly amount of organic matter and crop residue on the surface); the solubility of the herbicide; and its ability to be bound by the soil. Managing all these factors is complex, but some rules of thumb are:

1. Soils with low organic matter are particularly prone to crop damage from pre-emergent herbicides (especially sandy soils) and rates should be reduced where necessary to lower the risk of crop damage.
2. The more water-soluble herbicides will move more readily through the soil profile and are better suited to post sowing pre-emergent applications than the less water soluble herbicides. They are also more likely to produce crop damage after heavy rain.
3. Pre-emergent herbicides need to be at sufficient concentration at or below the weed seed (except for triallate which needs to be above the weed seed) to provide effective control. Keeping weed seeds on the soil surface will improve control by pre-emergent herbicides.
4. High crop residue loads on the soil surface are not conducive to pre-emergent herbicides working well as they keep the herbicide from contact with the seed. More water soluble herbicides cope better with crop residue, but the solution is to manage crop residue so that at least 50% of the soil surface is exposed at the time of application.
5. If the soil is dry on the surface, but moist underneath there may be sufficient moisture to germinate the weed seeds, but not enough to activate the herbicide. Poor weed control is likely under these circumstances. The more water soluble herbicides are less adversely affected under these conditions.
6. Many pre-emergent herbicides can cause crop damage. Separation of the product from the crop seed is essential. In particular care needs to be taken with disc seeding equipment in choice of product and maintaining an adequate seeding depth. [18]

18 Preston C. (2014). Understanding pre emergent cereal herbicides. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2014/03/understanding-pre-emergent-cereal-herbicides

MORE INFORMATION

Using pre-emergent herbicides in conservation farming systems.

Gearing up to use pre-emergent herbicides.

GRDC Pre-emergent herbicides Factsheet.

How pre-emergent herbicides work.

Seeding systems and pre emergence herbicides

Top tips for using pre-emergent herbicides:

- Only use pre-emergent herbicides as part of an integrated weed control plan including both chemical and non chemical weed control practices.
- Preparation starts at harvest. Minimise compaction and maximise trash spreading from the header
- Minimise soil disturbance allowing weed seeds to remain on the soil surface.
- Leave stubble standing rather than laying it over.
- Knife points and press wheels allow greatest crop safety. Avoid harrows.
- If using a disc seeder understand the mechanics of your machine and the limitations it may carry compared to a knife point and press wheel.
- Pay attention to detail in your sowing operation and ensure soil throw on the inter row whilst maintaining a seed furrow free from herbicide.
- Ensure the seed furrow is closed to prevent herbicide washing onto the seed.
- IBS rather than PSPE for crop safety.
- Understand herbicide chemistry. Choose the right herbicide in the right paddock at the right rate. [19]

6.5 Post-plant pre-emergent herbicides

Post-sowing, pre-emergent herbicides use is when a pre-emergent herbicide is applied after sowing (but before crop emergence) to the seedbed.

Post-plant pre-emergent herbicides are primarily absorbed through the roots, but there may also be some foliar absorption.

When applied to soil, best control is achieved when the soil is flat and relatively free of clods and trash. Sufficient rainfall (20–30 mm) to wet the soil through the weed root-zone is necessary within 2–3 weeks of application. Best weed control is achieved from Pre-sowing, Pre-emergence application because rainfall gives the best incorporation. Mechanical incorporation pre-sowing is less uniform, and so weed control may be less effective. If applied pre-sowing and sown with minimal disturbance, incorporation will essentially be by rainfall after application. Weed control in the sowing row may be less effective because a certain amount of herbicide will be removed from the crop row.

6.6 In-crop herbicides: knock downs and residuals

It is important to consider growth stage in making herbicide management decisions (Table 4).

A number of herbicides are registered for controlling grass weeds in vetch. These herbicides include Shogun, Fusilade Forte, Targa and Verdict.

Many weed populations have some tolerance to post-emergent herbicides.

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

Table 4: *Herbicides registered for weed control in vetch in the Northern region. Group A*

Active ingredient	Notes
butroxydim	Do not graze or cut for stock food for 14 days after application
fluazifop	Do not graze or cut for stock food for 21 days after application or remove stock from treated area 7 days before slaughter
haloxyfop	Broadleaf herbicides should not be added to products containing haloxyfop. Apply products containing haloxyfop and broadleaf herbicides at least a week apart. Do not graze or cut for stock food for 28 days after application
propaquizafop	Do not graze or cut for stock food for 3 days after application
quizalofop	Do not harvest for 12 weeks after application Do not graze or cut for stock food for 28 days after application

Source: NSW DPI

*Note: For pulses, the window for application for selective grass control herbicides (Group As) is generally dictated by regulatory requirements to avoid residues in produce that exceed levels acceptable to various markets. Check the labels for individual herbicides but pulse crop safety for most Group As is not influenced by growth stage up to at least flowering.

For up to date registrations, chemical Witholding Periods and other label information, see the APVMA search facility.

6.6.1 Application

Key points:

- Knowledge of a product's translocation and formulation type is important for selecting nozzles and application volumes.
- Evenness of deposit is important for poorly or slowly translocated products.
- Crop growth stage, canopy size and stubble load should influence decisions about nozzle selection, application volume and sprayer operating parameters.
- Robust rates of products and appropriate water rates are often more important for achieving control than the nozzle type, but, correct nozzle type can widen the spray window, improve deposition and reduce drift risk.
- Travel speed and boom height can affect control and drift potential.
- Appropriate conditions for spraying are always important. [20]

In-crop herbicides will normally require a different set of nozzles compared to those used in summer fallow spraying and application of pre-emergent herbicides.

In-crop post-emergent herbicides should be applied as an upper-end medium to lower-end coarse droplet spectrum depending on the particular herbicide being used.

Remember that this must be combined with the relevant application volume to get enough droplets per square centimetre on the target to achieve good coverage. You must also match the nozzles to your spray rig, pump and controller and desired travel speed.

Operate within the recommended ground speed range and apply the product in a higher application volume. The actual recommended application volume will vary with the product and situation, so read the label and follow the directions.

20 GRDC Factsheets: In-crop herbicide use. (2014). https://grdc.com.au/GRDC-FS-InCropHerbicideUse

MORE INFORMATION

Weed control in Winter crops

GRDC In-crop herbicide use Factsheet.

Pre-harvest herbicide use factsheet

GRDC-funded trials http://www.farmtrials.com.au/trial/13574

How to get the most out of post-emergent herbicides:

Consider application timing—the younger the weeds the better. Frequent crop monitoring is critical.

Consider the growth stage of the crop.

- Consider the crop variety being grown and applicable herbicide tolerances.
- Know which species were historically in the paddock and the resistance status of the paddock (if unsure, send plants away for a 'Quick-Test').
- Do not spray a crop stressed by waterlogging, frost, high or low temperatures, drought or, for some chemicals, cloudy/sunny days. This is especially pertinent
- for frosts with grass-weed chemicals.
- Use the correct spray application:
- Consider droplet size with grass-weed herbicides, water volumes with contact chemicals and time of day.
- Observe the plant-back periods and withholding periods.
- Consider compatibility if using a mixing partner.
- Add correct adjuvant. [21]

6.7 Herbicide tolerance ratings, NVT

Vetch is tolerant to most grass-selective herbicides and intolerant of herbicides residues from cropping phase, particularly sulfonylurea herbicides.

Vetch is susceptible to spray topping herbicides (Glyphosate, Paraquat & Diquat) as well as to most broad leaf herbicides that are used in cereal crops. [22]

Vetch is advantageous to cropping sequence as it can open up weed control options. They have useful tolerance to the triazine group of herbicides (e.g. atrazine). This enables vetch to be double-cropped after sorghum or maize provided that excessively high rates of atrazine have not been used in the preceding summer cereal. Any likelihood of crop damage to the vetch will be further minimised by only planting in situations where there is a reasonable profile of sub-soil moisture at planting (60 cm wet soil). [23]

6.8 Potential herbicide damage effect

Pulse crops can be severely damaged by some herbicides whether as residues in soil, contaminants in spray equipment, spray drift onto the crop or by incorrect use of the herbicide.

Some soil active herbicides used for weed control in pulses can damage crops where conditions favour greater activity and leaching.

6.8.1 Residues in Soil

Herbicides move more readily in soils with low organic matter and/or soils with more sand, silt or gravel. Herbicide movement is much less in soils with higher organic matter and higher clay contents. Damage from leaching is also greater where herbicides are applied to dry, cloddy soils than to soils which have been rolled and which are moist on top from recent rainfall.

Picloram (e.g. Tordon® 75-D) residues from spot-spraying can stunt any pulse crop grown in that area (Photo 4). In more severe cases bare areas are left in the crop where this herbicide has been used - in some cases more than five years previous. Although this damage is usually over a small area, correct identification

21 WeedSmart. Post-emergents. http://www.weedsmart.org.au/post-emergents/

22 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

23 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

of the problem avoids confusion and concern that it may be some other problem such as disease.

Photo 4: *Chemical residues from previous years can cause problems. Tordon® was used here with plants in the affected area showing stunting.*

Source: Grain Legume Handbook

Residues of sulfonylurea herbicides can persist in some soils. These residues can last for several years, especially in more alkaline soils and where there is little summer rainfall. The pulses emerge and grow normally for a few weeks and then start to show signs of stress. Leaves become off-colour, roots may be clubbed, plants stop growing and eventually die.

Refer to the labels for recommendations on plant-back periods for pulses following use of any herbicides. [24]

6.8.2 Contamination of Spray Equipment

Traces of sulfonylurea herbicides (such as chlorsulfuron, metsulfuron or triasulfuron) in spray equipment can cause severe damage to legumes when activated by some of the grass control herbicides (Photo 5).

Always clean spray tanks and lines with chlorine, according to recommendations, after using sulfonylurea herbicides and before using these grass control herbicides. Traces of Affinity® can also damage pulse crops. Decontaminate with alkali detergent. [25]

24 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2008). Grain legume handbook. *GRDC: Canberra, ACT.*

25 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2008). Grain legume handbook. *GRDC: Canberra, ACT.*

Photo 5: *Hygiene between spraying operations is essential. After using Glean® or Ally® make sure the boom spray is cleaned out with chlorine before starting on grass control in legumes. The effect as shown is dramatic.*

Source: Grain Legume Handbook

6.8.3 Spray Drift

Pulse crops can be severely damaged by some hormone herbicide sprays, such as 2,4-D ester, drifting into the crop. This can happen when these sprays are applied nearby in very windy or still conditions, especially where there is an inversion layer of air on a cool morning. When using these herbicides spray when there is some wind - to mix the spray with the crop. Do not use excessively high spray pressure as this will produce too fine a spray, which is more likely to drift onto a neighboring pulse crop. [26]

6.8.4 Residual herbicides

Pulse growers need to be aware of:

- Possible herbicide residues impacting on crop rotation choices where rainfall has been minimal.
- Herbicide residues could possibly influence crop rotations more than disease considerations.
- Weed burden in the new crop will depend on the seed set from last year.
- Herbicide efficacy and crop safety of the new crop can suffer if the soil is dry at application time.

Herbicide breakdown

Herbicides applied to paddocks in previous years may not have broken down adequately because of insufficient rainfall. Summer rainfall is not necessarily as effective as growing season rainfall in breaking down herbicide residues, so needs to be substantial and to keep the soil wet for a specified time. Read the herbicide label. It will be extremely important to know the chemical type used, as well as the plant-back periods, and the soil pH, rainfall and other requirements for breakdown. Herbicides applied two years ago could still have an impact too, as could the presence of cereal stubble with herbicides like Lontrel®.

26 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2008). Grain legume handbook. *GRDC: Canberra, ACT.*

MORE INFORMATION

Residual herbicides and weed control.

Withholding periods for dicamba or similar 'spikes' to knockdown sprays used pre-sowing may need to be longer if there is no rainfall to activate chemical breakdown, otherwise poor establishment can occur. Note that dicamba plant-backs only commence after 15 mm of rain. Alternative products with lesser or no residual may be more appropriate (e.g. carfentrazone-ethyl, oxyfluorfen). In areas that receive minimal summer-autumn rains and delayed opening rains, then the herbicide residual effect becomes far more pressing on rotation choices. Pulse following cereal could then become a higher risk situation than pulse following a pulse. [27]

6.8.5 Avoiding herbicide damage

Select a herbicide which is necessary for the weed population you have. Make sure you consider what the recropping limitations may do to future rotation options. Read the herbicide label including the fine print.

Chemical users are required to keep good records, including weather conditions, but in the case of unexpected damage good records can be invaluable, particularly spray dates, rates, batch numbers, rainfall, soil type and pH (including different soil types in the paddock).

If residues could be present, choose the least susceptible crops (refer to product labels). Optimise growing conditions to reduce the risk of compounding the problem with other stresses such as herbicide spray damage, disease and nutrient deficiency. These stresses make a crop more susceptible to herbicide residues.

Be wary of compounding a residue problem by planting a herbicide resistant crop and spraying with more of the same herbicide group. You may get around the problem with residues in the short term, only to be faced with herbicide resistant weeds in the longer term.

Group B: The sulfonylureas (SU's).

The sulfonylureas persist longer in alkaline soils (pH > 7) where they rely on microbial degradation. Residual life within the sulfonylurea family varies widely with chlorsulfuron persisting for 2 or more years and not suitable for highly alkaline soils. Triasulfuron persists for 1–2 years and metsulfuron generally persists for less than 1 year. Legumes and oilseeds are most vulnerable to SU's.

Group B: The triazolopyrimidines (sulfonamides).

There is still some debate about the ideal conditions for degradation of these herbicides. However, research in southern Australia has shown that the sulfonamides are less likely to persist than the SU's in alkaline soils. Plant back periods should be increased in shallow soils.

Group B: The imidazolinones (IMI's).

The imidazolinones are very different from the SU's as the main driver of persistence is soil type, not soil pH. They tend to be more of a problem on acid soils, but carryover does occur on alkaline soils. Research has shown that in sandy soils, they can break down very rapidly (within 15 months in alkaline soils), but in heavy clay soils they can persist for several years. Breakdown is by soil microbes. Oilseeds are most at risk. Widespread use of imi-tolerant canola and wheat in recent years has increased the incidence of imidazolinone residues.

Group C: The triazines.

Usage of triazines has increased to counter Group A resistance in ryegrass and because of high rates used on Triazine Tolerant canola. Atrazine persists longer in soil than simazine. Both generally persist longer on high pH soils. Recent research in the US indicates that breakdown rates tend to increase when triazines are used regularly as the number of microbes able to degrade the herbicide can increase. This may

27 Pulse Australia. (2015). Australia Pulse Bulletin: Residual herbicides and weed control. http://www.pulseaus.com.au/growing-pulses/publications/residual-herbicides

MORE INFORMATION

Avoiding crop damage from residual herbicides

mean that breakdown can take an unexpectedly long time in soils that have not been exposed to triazines for some years.

Group I: The phenoxys.

2,4-D used for fallow weed control in late summer may cause a problem with autumn sown crops. There have been changes to the 2,4-D label recently and not all products can be used for fallow weed control – ensure to check the label.

The label recommends to avoid sowing sensitive crops, until after a significant rainfall event. Oilseeds and legumes are very susceptible to injury from 2,4-D. [28]

Group I: The pyridines.

Clopyralid and aminopyralid can be more risky on heavy soils and in conservation cropping as it can accumulate on stubble. Even low rates can cause crop damage up to two years after application. They cause twisting and cupping, particularly for crops suffering from moisture stress.

6.9 Herbicide resistance

Vetch hay as a crop in the farm rotation is one of the best methods to reduce herbicide resistance weeds and to avoid chemical contamination of paddocks.

Vetch provides non-selective weed control options for reducing the risk of herbicide resistant weeds in cropping phases (e.g. grazing, green/brown manuring, and hay production, spray-topping). [29]

Resistance characteristics:

- Resistance remains for many years, until all resistant weed seeds are gone from the soil seed bank
- Resistance evolves more rapidly in paddocks with frequent use of the same herbicide group, especially if no other control options are used.

Action points:

- Assess your level of risk with the online glyphosate resistance toolkit.
- Aim for maximum effectiveness in control tactics, because resistance is unlikely to develop in paddocks with low weed numbers.
- Do not rely on the same MoA group.
- Monitor your weed control regularly.
- Stop the seedset of survivors. [30]

Overuse of particular groups of herbicides can lead to herbicide resistance, especially in grass weeds. Broad-scale herbicide resistance is continuing to spread through the GRDC Northern Region (Photo 6). Effective grass control in the vetch crop has the benefit of reducing the need for selective grass herbicides in the following cereal year. [31]

28 Agriculture Victoria (2013) Avoiding crop damage from residual herbicides. http://agriculture.vic.gov.au/agriculture/farm-management/chemical-use/agricultural-chemical-use/chemical-residues/managing-chemical-residues-in-crops-and-produce/avoiding-crop-damage-from-residual-herbicides

29 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

30 QDAF (2015) Stopping herbicide resistance in Queensland. Queensland Department of Agriculture and Fisheries, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

31 W Hawthorne (2007) Lupins in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Lupins-SA-Vic.pdf

Photo 6: *2,4-D resistant radish, Wongan Hills.*

Photo A Storrie, Source: GRDC

Survey work in the region has identified over 70 different weed species that impact on grain production and over 10% of these weed species have confirmed populations within Australia that are resistant to glyphosate and several other chemical modes of action (MOA) (Table 5).

Table 5: *Confirmed herbicide resistance in weed populations found in NSW and Queensland.*

Mode of Action	Resistant weeds
A (fops, dims, dens)	wild oats, paradoxa grass, annual ryegrass
B (SUs, imis etc)	annual ryegrass, wild oats, paradoxa grass, Indian hedge mustard, charlock, wild radish, turnip weed, African turnip weed, common sowthistle, black bindweed
C (triazines, ureas, amides etc)	awnless barnyard grass, liverseed grass
D (DNAs, benzamides etc)	annual ryegrass
I (phenoxys, pyridines etc)	wild radish
L (bipyridyls i.e. diquat, paraquat)	flaxleaf fleabane
M (glycines i.e. glyphosate)	annual ryegrass, awnless barnyard grass, liverseed grass, windmill grass, feathertop Rhodes grass, sweet summer grass, flaxleaf fleabane, common sowthistle
Z (dicarboxylic acids etc)	wild oats

Source: adapted from a table prepared by M Widderick, DAF, in WeedSmart

6.9.1 Why do weeds develop resistance?

Resistant weeds are naturally present in most paddocks in low numbers, even if herbicides have not been applied. Weeds not controlled by a herbicide application are either spray escapes or are naturally resistant survivors. If the resistant weeds set seed, the proportion of resistant weeds in the paddock increases. Resistant weeds will eventually dominate the population if high selection pressure is continued by repeatedly using the same herbicide group (Figure 1). Once a weed population is resistant to a herbicide it is also resistant to other herbicides with the same mode of action. Changing brand names will not control these weeds. Be aware of the mode of action group of the product, and use different chemical modes of action. Multiple resistance (to more than one mode of action) has developed in some weed populations of annual ryegrass and wild radish.

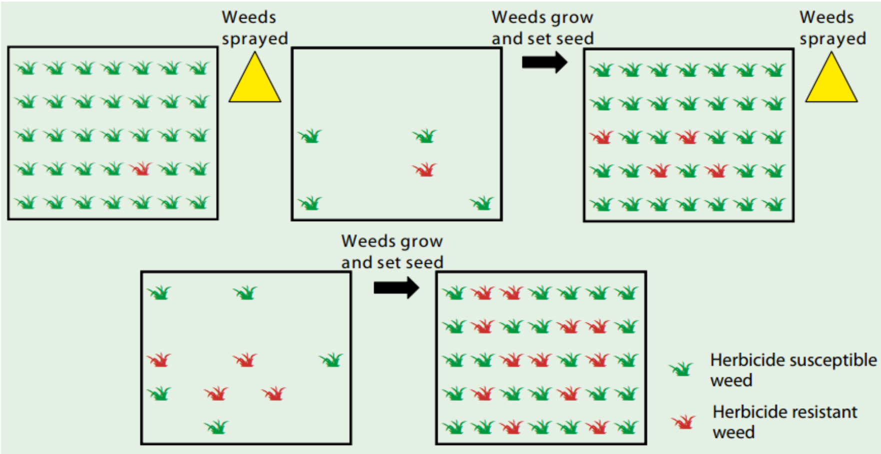


Figure 1: *Resistant weeds are naturally present in most paddocks and can dominate the population if a different herbicide mode of action or another form of weed control is not used to control them.*

Source: NSW DPI

Once resistance has developed in a paddock it will be impossible to totally eradicate all the resistant individuals. It will be necessary to adopt an IWM plan that keeps the numbers of resistant individuals at very low levels in future crops. The rate at which herbicide resistance appears in a population is affected by the selection pressure placed on the population, the initial frequency of the resistance gene and the total number of weeds treated. Resistance may develop in one location under certain conditions but may not develop in another location under similar conditions. [32]

Although growers are making good use of chemical strategies such as double knock, residual herbicides, spot spraying and weed sensing technology to preserve herbicide efficacy, there is an urgent need to investigate non-chemical options that can be added to a weed management program to target resistant weeds in the Northern region.

To avoid herbicide resistance, weed management through the rotation should minimise the need for herbicides. Avoid overuse of any one chemical group, use the least selective herbicide, and avoid the need to spray high weed populations.

6.9.2 Non-herbicide weed control in the Northern region

Diversity in cropping systems and diversity in weeds in the GRDC Northern Region calls for diversity in weed management solutions, which includes the utilisation of non-herbicide tactics.

Weeds researchers recognise that although growers are making good use of chemical strategies such as double-knock, residual herbicides, spot spraying and weed-sensing technology to preserve the efficacy of herbicides for as long as possible, there remains an urgent need to investigate non-chemical options that can be added to a weed management program to target resistant weeds, as outlined in the WeedSmart 10 Point Plan.

MORE INFORMATION

Weed control in central-west NSW – Herbicide resistance.

32 A Johnson, N Border, B Thompson, A Storrie (2007) Weed control in central west NSW – Chapter 7: Herbicide resistance. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/154726/Weed-control-for-cropping-and-pastures-in-central-west-NSW-Part-8.pdf

Strategic tillage

Most growers are keen to preserve their zero- or minimum-till farming systems because they have delivered significant benefits, and are understandably reluctant to re-introduce cultivation to control weeds. Research is under way to investigate ways to use cultivation that will have maximum effect on driving down weed numbers while having least impact on minimum-till farming. The aim of this research is to investigate the impact of different types of tilling where the weed population has blown out and intensive patch or paddock management is required.

For the research team, the key was to understand weed ecology, particularly how seed in the soil seedbank responds to different types of cultivation. The team used small plots to determine the effect of burying weed seeds on their persistence (long-term viability after burial in soil) and emergence. They also experimented to determine the displacement of seed throughout the cultivated zone using four different types of machine compared to a zero-till control.

Sowthistle emergence occurs primarily from seeds close to the soil surface, with up to 30% of viable seeds emerging over five months. Seed can emerge from a depth of up to 2 cm, with approximately 4% emergence after six months. Seed buried below 5 cm is unable to emerge, but still remains viable.

Seed persistence in fleabane was most reduced when seed was buried to 2 cm and let undisturbed for at least two years. Seed buried to a depth of 10 cm remained viable for over three years.

Feathertop Rhodes grass seed persisted for only 12 months regardless of being left on the surface or buried to 10 cm.

Barnyard grass however, persisted on the soil surface for up to two years, and when buried to 10 cm depth remained viable for over three years.

The Gyral machine placed the majority of weed seed in the 0–2 cm and 2–5 cm zones while the offset discs and one-way discs achieving burial of about half the seed below 5 cm depth.

All species responded to increased tilling intensity with reduced germinations. The message from this research is that infrequent but intense cultivation can be a useful weed-management tool within an otherwise zero-till system. Generally, once a paddock has been deeply cultivated there should be no cultivation of that area or paddock for at least four years so as to avoid the risk of bringing seed back to the soil surface.

Strategic burning

Feathertop Rhodes grass is known to colonise around mature plants, and may spread from here to form distinct weedy patches. Once it gets this big, killing the large plant at the centre of the colony is usually not possible using chemical treatments.

In this situation, the strategic burning of early infestations can effectively reduce the biomass of the part of the colony that survives and reduce the amount of viable seed present on the soil surface from 7,500 seeds/m^2 to less than 500 seeds/m^2. Growers have made effective use of a flame-thrower to burn large feathertop Rhodes grass plants during the fallow (Photo 7).

MORE INFORMATION

Non-herbicide weed control in the Northern region

Managing herbicide resistance in northern NSW

Photo 7: *Strategic burning of feathertop Rhodes grass in a fallow can be an effective way of reducing the biomass of the survivor plant and of reducing the amount of viable seed on the soil surface.*

Source: WeedSmart

Crop competition

Using crop competition by planting with a narrower row spacing and or greater planting density provides an effective offensive against common weeds. However, the effect of crop competition on its own, in commercial situations, would have to be used in conjunction with herbicide. [33]

Managing brown manure pulse crops in southern NSW

Key points:

- Brown manuring can form part of a strategy to manage herbicide resistance.
- It boosts soil nitrogen while conserving moisture for the next crop.
- Cereal diseases, such as take-all and crown rot, can be reduced through use of break crops.
- The timing of spray application is determined by the target weeds.
- The value of a pulse needs to be considered in the context of the whole rotation.

Brown manuring of pulse crops is becoming an increasingly popular tool for weed management, particularly where there is herbicide resistance, and for boosting reserves of soil nitrogen for use by the following crop.

Brown manure cropping involves growing a pulse crop to spray out using a knockdown herbicide to prevent weed seed set and maximise nitrogen fixation. This is different to green manuring, where the crop and weeds are killed by cultivation.

There are three key reasons for brown manuring pulses: to help manage weeds, particularly if there is herbicide resistance present, to boost soil nitrogen and to conserve soil moisture for subsequent crops. Some growers in southern NSW have had difficulty in marketing pulses in recent years or have experienced damage to legume hay. These factors have influenced growers to consider including brown manured crops in a rotation, rather than leaving pulses out altogether.

Anecdotal evidence suggests 20,000 or more hectares of vetch has been sown within the southern NSW system for brown manuring, hay or seed. Morava⅊ and Blanchefleur are the most common vetch varieties but growers are now moving to the earlier, higher yielding variety Volga⅊. Brown manuring also brings further benefits of addition of soil nitrogen from N_2 -fixation, extra soil moisture storage as a result of the earlier "fallow" and a more protective mulch cover over the summer period.

33 WeedSmart (2017) Non-herbicide weed control in the Northern Region. WeedSmart, http://www.weedsmart.org.au/bulletin-board/non-herbicide-weed-control-in-the-northern-region/

MORE INFORMATION

Brown manuring pulses on acidic soils in southern NSW- is it worth it?

Strategic risk management

Farm business management: making effective business decisions

VIDEOS

WATCH: Act now: Plan your weed management program

To use brown manuring for weed control, pulse crops must be desiccated at or before the milky dough stage of the target weeds. This is usually at or before the flat pod stage of the pulse, well before the crop's peak dry matter production. At this stage, the crop is growing at its maximum rate – about 80 to 100 kilograms of DM per hectare per day – and so the amount of nitrogen fixed will be reduced in proportion to its growth stage at desiccation. [34]

6.9.3 Ten-point plan to weed out herbicide resistance

WeedSmart has developed a 10-point plan that farmers can use to protect the longevity of chemicals and slow down the development of resistance. [35]

1. Act now to stop weed seedset

Creating a plan of action is an important first step in integrated weed management.

- Destroy or capture weed seeds.
- Understand the biology of the weeds present.
- Remember that every successful weed-smart practice can reduce the weed seedbank over time.
- Be strategic and committed: herbicide resistance management is cannot just happen over one year, but over many years.
- Research and plan a weed-smart strategy.
- Growers may have to sacrifice yield in the short term to manage resistance.

2. Capture weed seeds at harvest

Destroying or capturing weed seeds at harvest is the number one strategy for combating herbicide resistance and driving down the weed seedbank. There are several ways to do this:

- Tow a chaff cart behind the header.
- Use an Integrated Harrington Seed Destructor (Photo 8). [36]
- Create and burn narrow windrows.
- Produce hay where suitable.
- Funnel seed onto tramlines in controlled-traffic farming (CTF) systems.
- Use a green or brown manure crop to achieve 100% weed control and build soil nitrogen levels.

Controlling weed seeds at harvest is emerging as the key to managing the increasing levels of herbicide resistance, which is putting Australia's no-till farming system at risk.

Photo 8: *Integrated Harrington weed-seed destructor at work in the paddock.*

Source: Michael Walsh

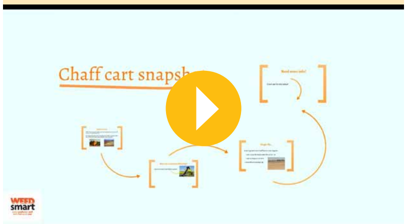
34 GRDC. (2013). Managing brown manure crops in southern NSW – Factsheet.

35 WeedSmart. Ten-point plan. WeedSmart, http://weedsmart.org.au/10-point-plan/

36 A Roginski (2012) Seed destructor shows its national potential. Ground Cover. No. 100. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-issue-100/Seed-destructor-shows-its-national-potential

VIDEOS

WATCH: Chaff carts 101

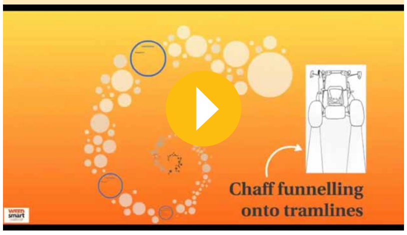


WATCH: Capture weed seeds at harvest: Harrington seed destructor

WATCH: Strategic narrow windrow burning

WATCH: The art of narrow windrow burning

WATCH: Chaff funneling onto tramlines



For information on harvest weed-seed control and its application, see Section 12: Harvest.

3. Rotate crops and herbicide modes of action

Crop rotation is beneficial to farming systems. Make sure weed management is part of the decision when planning crop rotation. Crop rotation offers many opportunities to use different weed control tactics, both herbicide and non-herbicide, against different weeds at different times. Rotating crops also gives farmers a range of intervention opportunities. For example, growers can; crop-top vetch and other pulses, windrow canola, and delay sowing some crops.

Rotations that include both broadleaf crops (e.g. pulses and oilseeds) and cereals allow the use of a wider range of tactics and chemistry.

Growers also have the option of rotating to non-crop options, e.g. pastures and fallows.

Within the rotation it is also important to not repeatedly use herbicides from the same MOA group. Some crops have fewer registered-herbicide options than others, so this needs to be considered too, along with the opportunities to use other tactics, such as the control of harvest weed seed, in place of one or more herbicide applications.

4. Test for resistance to establish a clear picture of paddock-by-paddock status

- Before harvest, sample weed seeds and resistance test to determine effective herbicide options. One such service is provided by Plant Science Consulting.
- Use the 'quick test' option to test emerged ryegrass plants after sowing to determine effective herbicide options before applying in-crop selective herbicides.
- Collaborate with researchers by collecting weeds for surveys
- Visit WeedSmart for more information on herbicide-resistance survey results.

It is clearly too late to prevent the evolution of resistance to many common herbicides. However, a resistance test when something new is observed on the farm can be very useful in developing a plan to contain the problem, and in developing new strategies to prevent this resistance evolving further.

Perhaps the best use for herbicide-resistance tests is to use them to determine if a patch of surviving weeds are worse than what the grower may have observed before. Take a GPS recording of the site location of potentially resistant weeds. These weeds may give insight into the future resistance profile of the farm if it is not contained and resistance testing in these situations can be very useful in building preventative strategies.

5. Never cut the rate

The Australian Herbicide Resistance Initiative (AHRI) has found that ryegrass being sprayed at below the advised rate of Sakura® evolved resistance not only to Sakura® but to Boxer Gold® and Avadex® too. To avoid this problem occurring:

- Use best management practice in spray application: apply according to the directions on the label.
- Consider selective weed sprayers.

VIDEOS

WATCH: Capture weed seeds at harvest: Bale Direct System

WATCH: IWM: Weed seed vdestruction—Beer can height

WATCH: Crop rotation with Colin McAlpine

WATCH: Test for resistance to establish a clear picture of paddock-by-paddock farm status

6. Don't automatically reach for glyphosate

Glyphosate has long been regarded as the world's most important herbicide, so it's common for growers to reach for it at the first sign of weeds. Resistance to this herbicide is increasing rapidly, and in some areas it may fail completely. This can be due to too much reliance on one herbicide group, giving the weed opportunity to evolve resistance.

Instead, introduce paraquat products when dealing with smaller weeds, and for a long-term solution farm with a very low seedbank. Also:

- Use a diversified approach to weed management.
- Consider post-emergent herbicides where suitable.
- Consider strategic tillage.

7. Carefully manage spray events

It's important to set up spray gear to maximise the amount of herbicide that directly hits the target. This makes the spray application more cost-effective by killing the maximum number of weeds possible, and it also protects other crops and pastures from potential damage and/or contamination.

Spray technology has improved enormously in the last 10 years, making it far easier for growers to get herbicides precisely where they need to be. Also, many herbicide labels specify the droplet spectrum to be used when applying the herbicide.

As a general rule, medium to coarse droplet size combined with higher application volumes provides better coverage of the target. Using a pre-orifice nozzle slows droplet speed so that droplets are less prone to bouncing off the target.

Using oil-based adjuvants with air-induction nozzles can reduce herbicide deposition by reducing the amount of air in the droplets. These droplets then fail to shatter when they hit the target, which increases droplet bounce.

- Stop resistant weeds from returning into the farming system.
- Focus on management of survivors in fallows.
- Where herbicide failures occur, do not let the weeds seed. Consider cutting for hay or silage, fallowing or brown manuring the paddock.
- Patch-spray areas of resistant weeds only if appropriate.

8. Plant clean seed into clean paddocks with clean borders

With herbicide resistance increasing, planting clean seed into clean paddocks with clean borders has become a top priority. Controlling weeds is easiest before the crop is planted. Once weeds have been controlled in a paddock plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant ones.

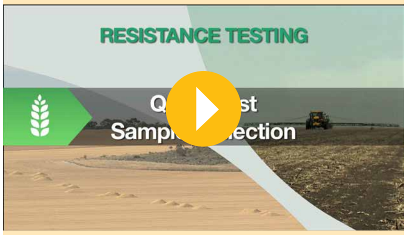
Introducing systems that increase farm hygiene will also prevent new weed species and resistant weeds. These systems could include crop rotations, reducing weed burdens in paddocks or a harvest weed-seed control such as the Harrington Seed Destructor or windrow burning.

Lastly, roadsides and fence lines are often a source of weed infestations. Weeds here set enormous amounts of seed because they have little competition, so it's important to control these initial populations by keeping clean borders.

- It is easier to control weeds before the crop is planted.
- Plant weed-free crop seed to prevent the introduction of new weeds and the spread of resistant weeds.
- An AHRI survey showed that 73% of grower-saved crop seed was contaminated with weed seed.
- The density, diversity and fecundity of weeds are generally greatest along paddock borders and areas such as roadsides, channel banks and fence lines.

VIDEOS

WATCH: IWM: Resistance Testing—‘Quick-Test’ sample collection



WATCH: IWM: Seed test—What’s involved

WATCH: Don’t cut the rate

WATCH: Don’t automatically reach for glyphosate

WATCH: Manage spray drift

9. Use the double-knock technique

The benefits of the double-knock technique is in combining two weed-control tactics with different modes of action, on a single flush of weeds. These two ‘knocks’ happen sequentially, with the second application being designed to control any survivors from the first.

One such strategy is the glyphosate–paraquat double-knock. These two herbicides use different MOAs to eliminate weeds and so make an effective team when paired. When using this combination ensure the paraquat rate is high. The best time to initiate this double-knock is after rainfall. New weeds will quickly begin to germinate and should be tackled at this small stage.

10. Employ crop competitiveness to combat weeds

There are numerous ways that growers can increase the competitive ability of crops against weeds:

- Consider narrow row spacing and increasing seeding rates.
- Consider twin-row seeding points.
- Consider east-west crop orientation.
- Use triticale and varieties that tiller well.
- Use high-density pastures as a rotation option.
- Consider brown-manure crops.
- Rethink bare fallows.

6.9.4 Suspected resistant weeds

As soon as resistance is suspected, growers should contact their local agronomist. The following steps are then recommended.

First, consider the possibility of other common causes of herbicide failure by asking:

- Was the herbicide applied in conditions and at a rate that should kill the target weed?
- Did the suspect plants miss herbicide contact or emerge after the herbicide was applied?
- Does the pattern of surviving plants suggest a spray miss or other application problem?
- Has the same herbicide or herbicides with the same MOA been used in the same field or in the general area for several years?
- Has the uncontrolled species been successfully controlled in the past by the herbicide in question or by the current treatment?
- Has a decline in the control been noticed in recent years?
- Is the level of weed control generally good on the other susceptible species?

If resistance is still suspected:

- Contact crop and food-science researchers in your state agricultural department for advice on sampling suspect plants for testing of resistance status..
- Ensure all suspect plants do not set seed.
- If resistance is confirmed, develop a management plan for future years to reduce the impact of resistance and likelihood of further spread. [37]

37 DAF Qld (2015) Stopping herbicide resistance in Queensland. DAF Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/weed-management-in-field-crops/herbicide-resistance

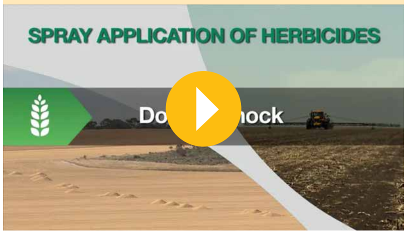
VIDEOS

WATCH: Plant clean seed into clean paddocks with clean borders

WATCH: Best results with double-knock tactic

WATCH: Double-knock application—a grower's experience

WATCH: Spray application of herbicides—Double-knock



Testing services

For testing of suspected resistant samples, contact:

- Charles Sturt University Herbicide Resistance Testing
  School of Agricultural and Wine Sciences Charles Sturt University
  Locked Bag 588
  Wagga Wagga, NSW 2678
  Phone (02) 6933 4001
- Charles Sturt University's Graham Centre weed research group
- Plant Science Consulting
  22 Linley Avenue, Prospect
  SA 5082
  email: info@plantscienceconsulting.com.au
  Phone: 0400 664 460

MORE INFORMATION

CropLife Australia

Australian Glyphosate Sustainability Working Group

Australian Herbicide Resistance Initiative

Cotton Info, Weed pack

Managing herbicide resistance in Northern NSW

Insect control

Key messages

- Integrated Pest Management strategies can be effective in controlling insect pests while reducing reliance on chemical control and help to limit pesticide resistance.
- Earth mites, aphids and caterpillars can cause serious damage to vetch.
- Take time to consider relevant withholding periods before applying chemical control.
- For current chemical control options refer to the Pest Genie or Australian Pesticides and Veterinary Medical Authority.

In early growth stages vetches are sensitive to redlegged earth mite, locusts, cutworm, slugs, snails, cabbage white butterflies and lucerne flea, and in mid to later growth to cowpea aphids as well to Native budworm at flowering and podding stages. [1]

There is limited information on the amount of damage caused by other insect pests to vetch in Australia.

Vetch supports strong populations of generalist insect predators. [2]

7.1.1 Insect sampling methods

Monitoring for insects is an essential part of successful IPMs. Correct identification of immature and adult stages of both pests and beneficials, and accurate assessment of their presence in the field at various crop stages will ensure appropriate and timely management decisions. Good monitoring procedure involves not just a knowledge of and the ability to identify the insects present, but also good sampling and recording techniques and a healthy dose of common sense.

Factors that contribute to quality monitoring:

- Knowledge of likely pests/beneficials and their life cycles is essential when planning your monitoring program. As well as visual identification, you need to know where on the plant to look and what is the best time of day to get a representative sample.
- Monitoring frequency and pest focus should be directed at crop stages likely to incur economic damage. Critical stages may include seedling emergence and flowering/grain formation.
- Sampling technique is important to ensure a representative portion of the crop has been monitored since pest activity is often patchy. Having defined sampling parameters (e.g. number of samples per paddock and number of leaves per sample) helps sampling consistency. Actual sampling technique including sample size and number, will depend on crop type, age and paddock size, and is often a compromise between the ideal number and location of samples and what is practical regarding time constraints and distance covered.
- Balancing random sampling with areas of obvious damage is a matter of common sense. Random sampling aims to give a good overall picture of what is happening in the field, but any obvious hotspots should also be investigated. The relative proportion of hotspots in a field must be kept in perspective with less heavily infested areas.

1 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

2 CRDC. Comparative advantages/disadvantages of rotation crops with cotton. http://www.cottoninfo.com.au/sites/default/files/tools/CottonRotation/Rotation_chart_Page_1small.pdf

Keeping good records

Accurately recording the results of sampling is critical for good decision making and being able to review the success of control measures (Figure 1). Monitoring record sheets should show the following:

- numbers and types of insects found (including details of adults and immature stages)
- size of insects—this is particularly important for larvae
- date and time
- crop stage and any other relevant information (e.g. row spacings, weather conditions, and general crop observations).

Consider putting the data collected into a visual form that enables you to see trends in pest numbers and plant condition over time. Being able to see whether an insect population is increasing, static or decreasing can be useful in deciding whether an insecticide treatment may be required, and if a treatment has been effective. If you have trouble identifying damage or insects present, keep samples or take photographs for later reference.

Site: Camerons
Date: 15/9/06
Row spacing: 75cm

Sample (1 m row beat)	VS	S	M	L
1	8	5	1	0
2	1	1	1	0
3	3	3	0	1
4	3	2	1	0
5	2	6	0	0
Average		3.4	0.6	0.2
Adjust for 30% mortality (S*0.7)	(3.4*0.7) = 2.4			
Mean estimate of larval number (Adjusted S)+M+L	2.4 0.6 0.2 = 3.2			

Adjust for row spacing divide by row spacing (m): 3.2 / 0.75

4.2 Density Estimate per square metre

Figure 1: *An example of a field check sheet for crops, showing adjustments for field mortality and row spacings.*

Source: QDAF

Records of spray operations should include:

- date and time of day
- conditions (wind speed, wind direction, temperature, presence of dew and humidity)
- product(s) used (including any additives)
- amount of product(s) and volume applied per hectare
- method of application including nozzle types and spray pressure
- any other relevant details.

Sampling methods

Beat sheet

A beat sheet is the main tool used to sample row crops for pests and beneficial insects (Photo 1). Beat sheets are particularly effective for sampling caterpillars, bugs, aphids and mites. A standard beat sheet is made from yellow or white tarpaulin material with heavy dowel on each end. Beat sheets are generally between 1.3–1.5

m wide by 1.5–-2.0 m deep (the larger dimensions are preferred for taller crops). The extra width on each side catches insects thrown out sideways when sampling and the sheet´s depth allows it to be draped over the adjacent plant row. This prevents insects being flung through or escaping through this row.

How to use the beat sheet:

- Place the beat sheet with one edge at the base of plants in the row to be sampled.
- Drape the other end of the beat sheet over the adjacent row. This may be difficult in crops with wide row spacing (one metre or more) and in this case spread the sheet across the inter-row space and up against the base of the next row.
- Using a one-metre stick, shake the plants in the sample row vigorously in the direction of the beat sheet 5–10 times. This will dislodge the insects from the sample row onto the beat sheet.
- Reducing the number of beat sheet shakes per site greatly reduces sampling precision. The use of smaller beat sheets, such as small fertiliser bags, reduces sampling efficiency by as much as 50%.
- Use the datasheets to record type, number and size of insects found on the beat sheet.
- One beat does not equal one sample. The standard sample unit is five non-consecutive one-metre long lengths of row, taken within a 20 m radius; i.e. 5 beats = 1 sample unit. This should be repeated at six locations in the field (i.e. 30 beats per field).
- The more samples that are taken, the more accurate is the assessment of pest activity, particularly for pests that are patchily distributed such as pod-sucking bug nymphs.

When to use the beat sheet:

- Crops should be checked weekly during the vegetative stage and twice weekly from the start of budding onwards.
- Caterpillar pests are not mobile within the canopy, and checking at any time of the day should report similar numbers.
- Pod-sucking bugs, particularly green vegetable bugs, often bask on the top of the canopy during the early morning and are more easily seen at this time.
- Some pod-sucking bugs, such as brown bean bugs, are more flighty in the middle of the day and therefore more difficult to detect when beat sheet sampling. Other insects (e.g. mirid adults) are flighty no matter what time of day they are sampled so it is important to count them first.
- In very windy weather, bean bugs, mirids and other small insects are likely to be blown off the beat sheet.
- Using the beat sheet to determine insect numbers is difficult when the field and plants are wet.

While the recommended method for sampling most insects is the beat sheet, visual checking in buds and terminal structures may also be needed to supplement beat sheet counts of larvae and other more minor pests. Visual sampling will also assist in finding eggs of pests and beneficial insects.

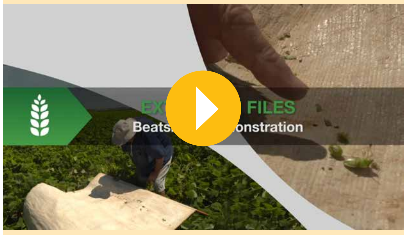
Most thresholds are expressed as pests per square metre (pests/m^2). Hence, insect counts in crops with row spacing less than one metre must be converted to pests/m^2. To do this, divide the 'average insect count per row metre' across all sites by the row spacing in metres. For example, in a crop with 0.75 m (75 cm) row spacing, divide the average pest counts by 0.75.

Other sampling methods:

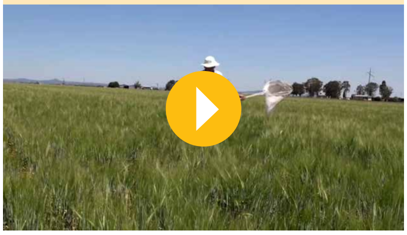
- Visual checking is not recommended as the sole form of insect checking; however it has an important support role. Leaflets or flowers should be separated when looking for eggs or small larvae, and leaves checked for the

VIDEOS

WATCH: GCTV16: Extension files—IPM beat sheet demo



WATCH: How to use a sweep net to sample for insect pests



MORE INFORMATION

IPM guidelines for monitoring tools and techniques.

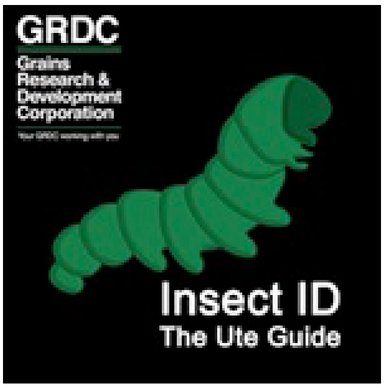
For pest identification see the A-Z pest list or consult the GRDC Insect ID: The Ute Guide.

presence of aphids and silverleaf whitefly. If required, dig below the soil surface to assess soil insect activity. Visual checking of plants in a crop is also important for estimating how the crop is going in terms of average growth stage, pod retention and other agronomic factors.

- Sweep net sampling is less efficient than beat sheet sampling and can underestimate the abundance of pest insects present in the crop. Sweep netting can be used for flighty insects and is the easiest method for sampling mirids in broadacre crops or crops with narrow row spacing (Photo 1). It is also useful if the field is wet. Sweep netting works best for smaller pests found in the tops of smaller crops (e.g. mirids in mungbeans), is less efficient against larger pests such as pod-sucking bugs, and it is not practical in tall crops with a dense canopy such as coastal or irrigated soybeans. At least 20 sweeps must be taken along a single 20 m row.
- Suction sampling is a quick and relatively easy way to sample for mirids. Its main drawbacks are unacceptably low sampling efficiency, a propensity to suck up flowers and bees, noisy operation, and high purchase cost of the suction machine.
- Monitoring with traps (pheromone, volatile, and light traps) can provide general evidence on pest activity and the timing of peak egg lay events for some species. However, it is no substitute for in-field monitoring of actual pest and beneficial numbers. [3]

Photo 1: *Sweep netting for insects (left) and use of a beat sheet (right).*

Source: DAFWA and The Beatsheet



The Insect ID: The Ute Guide is a comprehensive reference guide for insect pests commonly affecting broadacre crops and growers across Australia, and includes the beneficial insects that may help to control them. Photos have been provided for multiple life cycle stages, and each insect is described in detail, with information on the crops they attack, how they can be monitored and other pests that they may

3 QDAF (2012) Insect monitoring techniques for field crops. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/integrated-pest-management/help-pages/insect-monitoring

be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [4]

App features:

- Region selection
- Predictive search by common and scientific names
- Compare photos of insects side by side with insects in the app
- Identify beneficial predators and parasites of insect pests
- Opt to download content updates in-app to ensure you are aware of the latest pests affecting crops for each region
- Ensure awareness of international bio-security pests

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

VIDEOS

WATCH: GCTV11: GRDC's Insect ID App

7.1.2 GrowNotes Alert™

GrowNotes Alert is a free nationwide system for delivering urgent, actionable and economically important pest, disease weed and biosecurity issues directly to you, the grower, adviser and industry body, the way you want. Real-time information from experts across Australia, to help growers increase profitability.

A GrowNotes Alert notification can be delivered via SMS, email, web portal or via the iOS App. There are also three by dedicated regional Twitter handles – @GNAlertNorth, @GNAlertSouth and @GNAlertWest – that can also be followed.

The urgency with which alerts are delivered can help reduce the impact of disease, pest and weed costs. GrowNotes Alert improves the relevance, reliability, speed and coverage of notifications on the incidence, prevalence and distribution of these issues within all Australian grain growing regions.

MORE INFORMATION

IPM Guidelines website.

GrowNotes Alert™

PestFacts south-eastern

7.1.3 Cesar PestFacts

PestFacts (south-eastern) is a free email service designed to keep growers and farm advisers informed about invertebrate issues – and solutions – as they emerge during the winter growing season. The service has a focus on pests of broadacre grain crops.

PestFacts map is an interactive tool that allows users to search and view historical pest reports across Victoria and NSW. The map is updated with each issue of PestFacts to include new reports.

7.2 Integrated Pest Management

Key points:

- Long-term use of broad-spectrum pesticides for invertebrate pest control is not sustainable.
- IPM integrates cultural, biological, chemical controls – where possible, choice of control(s) is based on economic thresholds.
- An understanding of pest and beneficial insect dynamics, and how to monitor them, is essential for successful IPM.
- Reducing reliance on broad spectrum pesticides improves triple bottom line outcomes (economic, environmental and social).

Integrated pest management (IPM) reduces reliance on pesticides, especially broad-spectrum pesticides, limiting the opportunity for resistance and promoting populations of beneficial species.

The fundamental principles of IPM includes:

1. Know the enemy

4 GRDC, https://grdc.com.au/Resources/Apps

VIDEOS

WATCH: GCTV2: Integrated pest management

WATCH: Integrated pest management and pest suppressive landscapes with Phil Bowden

MORE INFORMATION

Integrated Pest Management Factsheet

Chemical control

Cultural control

Biological control

NSW DPI – Insect and mite control in field crops

2. Know the control thresholds for pests according to crop type
3. Monitor populations
4. Select appropriate control methods, giving consideration to Biological and Cultural control options.

The presence of a pest in a crop is not an automatic trigger for control. Attempting to prevent all damage is usually uneconomic. Economic thresholds help to rationalise the use of pesticides and are one of the keys to profitable pest management. The development of economic thresholds requires knowledge of pests, their damage, the crop's response to damage, and estimates of likely crop value and costs of control.

7.2.1 Healthy crops are less prone to insect damage

The overall health and vigour of a crop will influence its susceptibility to insect attack, and its ability to compensate for insect damage. Below are some of the crop production factors that can affect plant-insect interactions.

Crop rotations

- Some crop rotations can result in a greater incidence of pests for the subsequent crop, especially soil insects and seedling pests such as mites. Check specific crops for more details.
- Crops sown in paddocks previously containing long term pastures are particularly susceptible to pasture pests (e.g. mites, lucerne flea, and soil insects). This will likely be an issue in vetch so careful monitoring is recommended throughout the season.
- Rotations may also assist with weed management, reducing the potential for green bridges.

Choice and variety of crop

- Choose a variety with inherited disease and pest resistance where agronomically and economically viable
- Seedling vigour and other physiological features such as hard seed coats will help to deter pests.

Soil preparation

- Cultivation or herbicide use during a fallow to eliminate weeds will minimise pest survival opportunities.

Optimum sowing time

- Select planting windows to minimise the likelihood of major pests during critical development phases of the crop. If possible, avoid staggered plantings in adjacent fields to minimise the opportunity for pests to move between fields as the crop develops.

Successful crop establishment

- Quick uniform establishment improves a crop's ability to withstand insect (and pathogen) attack.
- Seedlings suffering from stresses (moisture, temperature or water logging) are often more susceptible to pests
- Appropriate rates of treated seed (seed dressings) may suppress soil insects as well as aphids in the first three weeks

Irrigation

- Drought stressed crops are more susceptible to damage and yield penalties.
- Stressed crops are less able to compensate for damage

Nutrition

- High nitrogen levels in plant tissue can decrease resistance and increase susceptibility to pest attacks (particularly sap-sucking pests), however more research is needed to clarify the relationship between crop nutrition and pests. Most studies assessing the response of aphids and mites to nitrogen fertiliser have documented dramatic expansion in pest numbers with increases in fertiliser rates

Weed management

- Many insects use weeds as host plants.
- Control weeds in crop but also consider adjacent fields, borders and roadsides where possible.
- Also control volunteers from previous crops

Disease management

- Diseased plants are unthrifty and susceptible to insect attack.
- Some insects can transmit diseases/viruses.
- Insect damage can expose crops to disease infestations

Hygiene and sanitation

- Some insect pests are moved by machinery (e.g. harvesters), vehicles and people – e.g. on clothing and footwear.
- Practice good farm hygiene to minimise pest movement

Pesticide use

- Minimise exposure of pesticides to bees and birds
- Apply insecticides late in the day when birds and bees have finished feeding

Environmental conditions

- Know how weather affects some pests (e.g. heavy rain may wash some aphids off plants, winds can assist insect migration, some insects reduce feeding at lower temperatures etc)

Preserve beneficial insects

- Tolerate non-economic early season damage
- Minimise early season sprays to conserve beneficials
- Learn how to encourage beneficials into your crops
- Biological formulations such as NPV, Bt and Metarhizium are highly specific and do not harm beneficials.
- Integrate cultural and biological control strategies into the production system where practical. [5]

7.2.2 Natural enemies

Beneficial species, sometimes referred to as 'natural enemies', help to control invertebrate pests as part of a successful IPM strategy. Many beneficial species occur naturally and populations can be encouraged by reducing pesticide use.

- Ladybird beetles
  - » Ladybird adults and larvae are predatory and consume prey. Adults and larvae range from 3 to 7 mm in length.
  - » Pests attacked: aphids, leafhoppers, thrips, mites, moth eggs and small larvae.
- Spiders
  - » Spiders consume adult insects and larvae. Groups that commonly occur in field crops include wolf, jumping and huntsman spiders.

5 IPM Guidelines. (2016). Growing a healthy crop. http://ipmguidelinesforgrains.com.au/ipm-information/growing-a-healthy-crop/

- » Pests attacked: most insects and mites, including other predators.
- Predatory mites
  - » Many predatory mites are found in cropping environments in Australia. Adult snout mites are 2 mm in length and are effective predators in autumn and winter. Nymphs are similar in appearance, but smaller with six legs.
  - » Pests attacked: earth mites and lucerne flea.
- Lacewings
  - » Brown and green lacewings are effective predators of a range of pests. Brown lacewing adults (6 to 10 mm) and larvae (5 mm) are both predatory. Adult green lacewings (15 mm) are not predatory; green lacewing larvae (8 mm) are camouflaged predators.
  - » Pests attacked: a wide range including moth larvae and eggs, aphids, thrips and mites.
- Carabid beetles
  - » Carabid beetle species feed mostly on ground-dwelling pests. Larvae (10 to 25 mm) and adults (5 to 25 mm) are predatory and have prominent mouthparts (mandibles) that protrude forward.
  - » Pests attacked: a wide range including true wireworms, false wireworms, moth larvae and slugs.
- Hover flies
  - » Larvae (10 mm) are effective predators of aphids. Pupae are stuck to the plant, teardrop shaped and green or brown in colour.
  - » Pests attacked: aphids.
- Damsel bugs
  - » Damsel bug adults (12 mm) and nymphs (smaller, without wings) are both predatory.
  - » Pests attacked: include moth larvae and eggs of Helicoverpa and diamondback moth, aphids, leafhoppers, mirids and mites.
- Caterpillar parasites
  - » Include beneficial species that parasitise caterpillar larvae or eggs. The adult female Trichogramma wasp (0.5 mm) lays eggs inside the moth egg. The parasitised egg turns black, but the moth larva fails to hatch; instead a parasitic wasp emerges.
  - » Pests attacked: Helicoverpa, diamondback moth, light brown apple moth, loopers and more. [6]

Conserving or supplementing beneficial insects

The impact of beneficial insects can be maximised by conserving or encouraging naturally-occurring populations and encouraging population increases, or by supplementing the natural enemy complex by releasing mass-reared beneficials into the cropping system.

Conservation and promotion of beneficial arthropods

Crop management considerations to preserve and promote beneficial activity include:

- Regular monitoring for pests and beneficials
- Awareness of thresholds for specific pests
- Tolerance of early season damage (if the crop has time to compensate)
- Are there 'hotspots' that can be treated rather than the entire field?
- Can novel approaches be used (e.g. biological formulations such as NPV or Bt, or attractants such as Magnet®)
- Awareness of insecticide choices
- Seed treatments are generally more selective than foliar sprays foliar sprays

6 S Micic, P Umina, A Weeks, H Brier. (2009). Integrated Pest Management – Factsheet. GRDC.

- Know your pesticide: selective insecticides are generally considered to be 'softer' on natural enemies, but still may be highly toxic to certain arthropod groups
- Consider longer term economic benefit (e.g. a more expensive spray now may save money over the season by reducing the risk of secondary outbreaks)

Whole-of farm considerations include:

- Farm hygiene – control weeds and volunteer crop plants to minimise pest carry-over
- Farmscaping to provide habitat for beneficials within the farming system
- Insectary crops (provide a source of nectar and enhance beneficial activity)
- Preserving native/remnant vegetation as a good habitat for beneficials (see pest-suppressive landscapes)
- Windbreaks can also offer habitat for beneficial arthropods
- Prevent pesticide drift into areas where beneficials may be residing. [7]

MORE INFORMATION

Conserving or supplementing beneficials

Insecticides and beneficial insects

When deciding whether to use chemical control in managing crop pests, ensure to consider the effects of insecticides on beneficial insects (Table 1).

Table 1: *Impact of common insecticides on beneficial insects. Note that the values provided here are generalisations and there may be exceptions (e.g. relating to specific species or time of application). Pest resurgence is included as there may be an increase in non-targeted pests following application of insecticides. This is mainly due to the demise of beneficials that may keep pests in check.*

Insecticide group *	Persistence	Overall ranking	Impact on beneficial insects				
			Predatory beetles	Predatory bugs	Parasitic wasps	Spiders	Bees
FOLIAR-APPLIED							
Bio-pesticides							
Bt	Short	Low	L	L	L	L	L
Helicoverpa NPV	Short	Low	L	L	L	L	L
Metarhizium	Short	Low	L	L	L	L	L
Petroleum spray oils	Short	Low	L	L	L	L	L
Organophosphates							
omethoate	Medium	Moderate	M	M	M	L	H
dimethoate (low rate)	Short	Moderate	M	M	M	L	H
dimethoate (high rate)	Short	High	M	M	H	M	H
methidathion	Short	High	H	H	H	H	H
Indoxacarb	Medium	Low	L	L	L	L	no data
Phenyl pyrazoles (fipronil)	Medium	Low	L	L	L	M	H
Carbamates							
pirimicarb	Short	Low	L	L	L	L	L
thiodicarb	Long	High	H	M	M	M	M
methomyl	Short	High	H	M	M	M	H
Avermectins (emamectin benzoate)	Medium	Moderate	L	H	M	M	H
Synthetic pyrethroids	Long	High	H	H	H	H	H

7 IPM Guidelines. (2016). Conserving or supplementing beneficials. http://ipmguidelinesforgrains.com.au/ipm-information/biological-control/beneficial-insects/conservation-of-beneficials/

Insecticide group *	Persistence	Overall ranking	Impact on beneficial insects				
			Predatory beetles	Predatory bugs	Parasitic wasps	Spiders	Bees
SEED DRESSINGS							
fipronil	Medium	Low	Limited data available. Seed dressings generally less disruptive than foliar-applied formulations.				
imidacloprid	Medium	Low					
imidacloprid + thiomethoxam	Medium	Low					

Symbols used in the table:

L – Low toxicity	– nil or low impact on beneficials
M — Moderate toxicity	– activity is significantly reduced but beneficial populations are able to recover in a week or so
H — High toxicity	– high proportion of beneficial population killed and re-establishment will not occur for several weeks

Persistence of pest control:
Foliar applications: short = <3 days, medium = 3–7 days, long = >10 days
Seed treatments: short = 2–3 weeks, medium 3–4 weeks, long = 4–6 weeks
*Insecticides and the groups they belong to can be found in the insecticide groups table.

Information in this table has been derived from the Cotton Pest Management Guide (2014–15).

7.3 Cowpea aphid (*Aphis craccivora*)

Aphids are a group of soft-bodied bugs commonly found in a wide range of crops and pastures. Identification of crop aphids is very important when making control decisions. Distinguishing between aphids can be easy in the non-winged form but challenging with winged aphids.

Vetch is susceptible to damage from cowpea aphids during mid-late growth stages. [8]

Adult cowpea aphids are shiny black in colour and nymphs are dull grey (Figure 2). All stages have white and black legs. Nymphs are lightly dusted with wax. When fully grown adults are approximately 2 mm long.

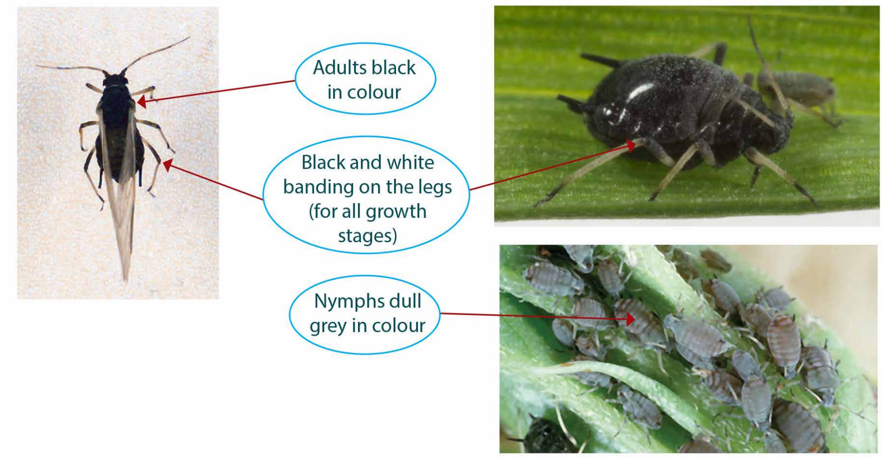


Figure 2: *Distinguishing characteristics/description of cowpea aphids*

Source: Bellati et al. 2012

The cowpea aphid is a widespread and relatively common pest of legume crops throughout Australia. They have a wide range of host plants and can tolerate warm, dry weather conditions that cause many other aphid species to suffer.

Cowpea aphids are capable of being transported (migrating on the wind) large distances from more favourable hosts, particularly during autumn. They tend to

8 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

colonise single plants before moving onto surrounding plants to form groups of plants in 'hot spots' within a crop. [9]

7.3.1 Damage caused by Cowpea aphid

Direct feeding damage

Aphids can cause direct feeding damage to plants when in large numbers (Photo 2) as they remove sap, which can cause wilting of plants. Cowpea aphids also inject toxins into the plant while feeding. Cowpea aphids form dense colonies on individual plants, with infestations usually starting on the growing tips and spreading down the stem. Initial signs of damage include yellowing or whitening of leaf veins, with heavy colonisation causing rapid wilting of leaves and eventually plant death. Other symptoms include leaf bunching and stem twisting. Secretion of honeydew by aphids can cause secondary fungal growth, which inhibits photosynthesis and can decrease plant growth.

Photo 2: *Cowpea aphid infestation on a vetch plant.*

Photo: S Nagel

In pulse crops, aphid feeding damage (in the absence of virus infection) can result in yield losses of up to 90% in susceptible varieties, and up to 30% in varieties with intermediate resistance.

Indirect damage

Cowpea aphids cause indirect damage by spreading plant viruses. Aphids spread viruses between plants by feeding and probing as they move between plants and paddocks. Cowpea aphids transmit important viruses including cucumber mosaic virus (CMV), bean yellow mosaic virus (BYMV), alfalfa mosaic virus (AMV) and pea seed-borne mosaic virus (PsbMV). Yield losses in some pulse crops as a direct result of viruses spread by cowpea aphids can reach as high as 80%. [10]

9 P Umina, S Hangartner (2015) Cowpea Aphid. Cesar PestNotes. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cowpea-aphid

10 P Umina, S Hangartner (2015) Cowpea Aphid. Cesar PestNotes. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cowpea-aphid

7.3.2 Thresholds for control

When determining economic thresholds for aphids, it is critical to consider several other factors before making a decision. Most importantly, the current growing conditions and moisture availability should be assessed. Crops that are not moisture stressed have a greater ability to compensate for aphid damage and will generally be able to tolerate far higher infestations than moisture stressed plants before a yield loss occurs.

Thresholds for managing aphids to prevent the incursion of aphid-vectored virus have not been established and will be much lower than any threshold to prevent yield loss via direct feeding. [11]

7.3.3 Management of Cowpea aphid

Monitoring

Cowpea aphids are most prominent in spring, but are also active during autumn and persist through winter. Regularly monitor vulnerable crops during bud formation to late flowering. Aphids will generally move into paddocks from roadsides and damage will first appear on crop edges. Aphid distribution may be patchy, so monitoring should include at least five sampling points over the paddock. Inspect at least 20 plants at each sampling point. Search for aphids by looking at the youngest inflorescence of each plant. Look for clusters of aphids or symptoms of leaf yellowing or leaf-curling.

In disease-prone areas, regular aphid monitoring from autumn onwards is recommended to detect aphids moving into crops, particularly along paddock edges. Symptoms of virus infections are very variable. Autumn is the critical infection period; the earliest-sown crops usually have the highest infection incidence.

Aphid infestations can be reduced by heavy rain events or sustained frosts. If heavy rain occurs after a decision to spray has been made, but before the insecticide has been applied, check the crop again to determine if treatment is still required.

Biological control

There are many effective natural enemies of aphids. Hoverfly larvae, lacewings, ladybird beetles and damsel bugs are known predators that can suppress populations. Aphid parasitic wasps lay eggs inside bodies of aphids and evidence of parasitism is seen as bronze-coloured enlarged aphid 'mummies'. As mummies develop at the latter stages of wasp development inside the aphid host, it is likely that many more aphids have been parasitized than indicated by the proportion of mummies. Naturally occurring aphid fungal diseases (*Pandora neoaphidis* and *Conidiobolyus obscurus*) can also suppress aphid populations.

Cultural control

Control summer and autumn weeds in and around crops, particularly legumes, to reduce the availability of alternate hosts between growing seasons.

Sow crops early to enable plants to begin flowering before aphid numbers peak in spring and use a high sowing rate to achieve a dense crop canopy, which will assist in deterring aphid landings. Select cultivars that are less susceptible to aphid feeding damage.

Consider seed testing to assess the level of virus infection of seed-borne viruses (e.g. CMV) before sowing.

Chemical control

The use of insecticide seed treatments can delay aphid colonisation and reduce early infestation and aphid feeding.

11 P Umina, S Hangartner (2015) Cowpea Aphid. Cesar PestNotes. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cowpea-aphid

A border spray in autumn/early winter, when aphids begin to move into crops, may provide sufficient control without the need to spray the entire paddock. Avoid the use of broad-spectrum `insurance` sprays and apply insecticides only after monitoring and distinguishing between aphid species. Consider the populations of beneficial insects before making a decision to spray, particularly in spring when these natural enemies can play a very important role in suppressing aphid populations if left untouched. [12]

Refer to the beneficial impact table (Table 1, Section 1.1.2 Natural enemies) from the IPM Guidelines website to identify products least likely to harm beneficials that aren't being targeted.

For up-to-date chemical registrations, see the APVMA website.

7.4 Lucerne flea (*Sminthurus viridis*)

The lucerne flea is an introduced pest commonly found in New South Wales, Victoria, Tasmania, South Australia and Western Australia. The lucerne flea is a springtail; this is a group of arthropods that have six or fewer abdominal segments and a forked tubular appendage or furcula under the abdomen. Springtails are one of the most abundant of all macroscopic insects and are frequently found in leaf litter and other decaying material, where they are primarily detritivores.

Vetch is susceptible to damage from Lucerne flea during early growth stages. [13]

The adult lucerne flea is approximately 3 mm long, light green-yellow in colour and often with mottled darker patches over the body (Figure 3). They are wingless and have enlarged, globular shaped abdomens. They are not related to true fleas. Newly hatched nymphs are pale yellow and 0.5–0.75 mm long, and as they grow they resemble adults, but are smaller.

12 P Umina, S Hangartner (2015) Cowpea Aphid. Cesar PestNotes. http://cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Cowpea-aphid

13 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

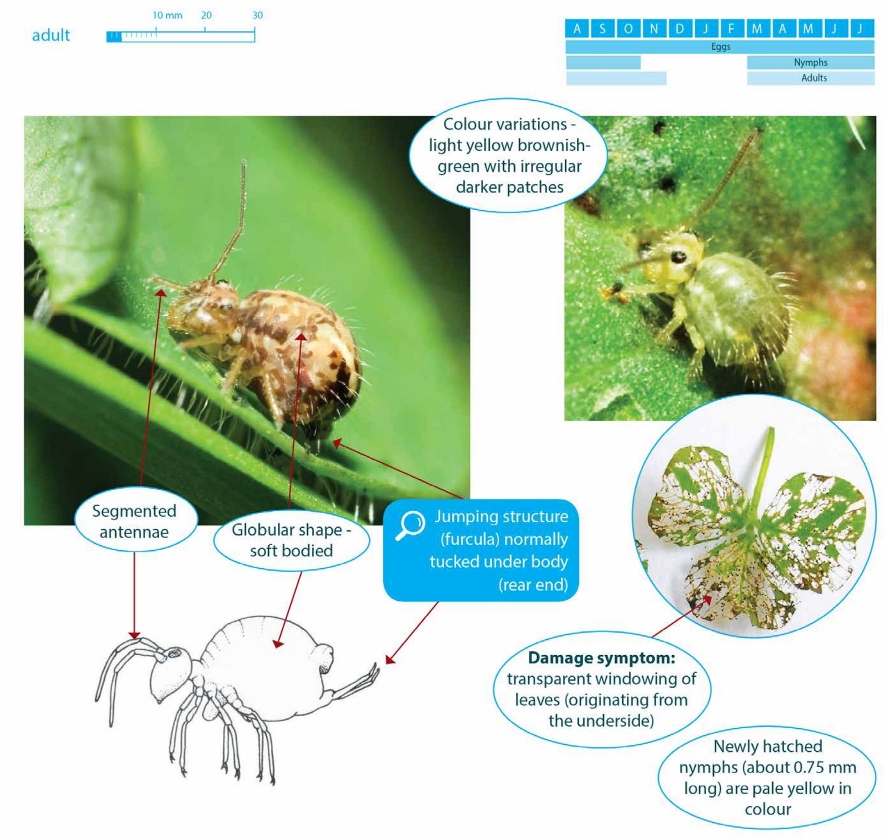


Figure 3: *Distinguishing characteristics/description of the lucerne flea*

Source: Bellati et al. 2012

Lucerne fleas have a furcula underneath their abdomen, which acts like a spring and enables them to 'spring off' vegetation when disturbed. This pest is distinctively patchy in distribution. These patches of intense feeding can move around paddocks, and can be obvious targets of spot spraying. [14]

7.4.1 Damage caused by Lucerne flea

Lucerne fleas move up plants from ground level, eating tissue from the underside of foliage. They feed through a rasping process, leaving behind a thin clear layer of leaf membrane that appears as transparent 'windows' through the leaf. In severe infestations this damage can skeletonise the leaf and stunt or kill plant seedlings. Crops and pastures are most susceptible at the time of emergence. [15]

7.4.2 Thresholds for control

As a guide, an average of 20 small holes per trifoliate legume leaf may warrant chemical control. If pasture is severely damaged it may be cost effective to spray. [16]

14 P Umina, S Hangartner, G McDonald (2016) Lucerne flea. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea

15 P Umina, S Hangartner, G McDonald (2016) Lucerne flea. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea

16 P Umina, S Hangartner, G McDonald (2016) Lucerne flea. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea

7.4.3 Management of Lucerne flea

Monitoring

Crops should be inspected frequently at, and immediately following crop emergence, when plants are most susceptible to damage. Pastures should be monitored at least fortnightly from autumn to spring, and more often in paddocks with previous lucerne flea problems. Lucerne fleas are often concentrated in localised patches so it is important to monitor paddocks entirely. Examine foliage for feeding damage, and check the soil surface for sheltering insects. Damage levels can be used to determine whether or not spraying is necessary. Monitoring usually involves working on hands and knees. Monitoring populations for growth stage as well as numbers can also be important for accurate timing of sprays.

Alternatively, lucerne fleas can be sampled using a standard petrol powered garden blower/vacuum machine. A fine sieve or stocking is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface.

Biological control

The pasture snout mite and spiny snout mite are effective predators, particularly in pastures where they can prevent pest outbreaks. Spiders and ground beetles also prey on lucerne flea. The complex of beneficial species should be assessed before deciding on control options.

Cultural control

Grazing management by reducing the height of pasture will limit food resources and increase mortality of lucerne fleas. Control broadleaf weeds (e.g. capeweed) to remove alternative food sources that would otherwise assist in population build up. In pastures, avoid clover varieties that are susceptible to lucerne flea damage, and avoid planting susceptible crops such as canola and lucerne into paddocks with a history of lucerne flea damage.

Chemical control

In paddocks where damage is likely, a border spray may be sufficient to prevent movement of lucerne fleas into the crop from neighbouring paddocks. Lucerne fleas are often patchily distributed within crops, so spot spraying may be sufficient. Do not blanket spray unless the infestation warrants it.

If the damage warrants control, treat the infested area with an insecticide three weeks after lucerne fleas first emerge in autumn. This will allow for the further hatching of over-summering eggs but will be before they reach maturity and begin to lay winter eggs. Where there is a consistent pattern of lucerne flea damage in autumn/early winter, spray four weeks after the first significant rain of the season.

In pasture, best results are achieved by spraying when there is sufficient leaf matter for the insects to feed on and shelter under. This is usually about seven days after a paddock has been cut for hay or heavily grazed, rather than immediately after hay making or grazing.

Lucerne fleas have a high natural tolerance to synthetic pyrethroids and should not be treated with insecticides from this chemical class. When both lucerne fleas and redlegged earth mites are present, it is recommended that control strategies consider both pests, and a product registered for both is used at the highest directed rate between the two to ensure effective control. [17]

Refer to the beneficial impact table (Table 1, Section 1.1.2 Natural enemies) from the IPM Guidelines website to identify products least likely to harm beneficials that aren't being targeted.

For up-to-date chemical registrations, see the APVMA website.

17 P Umina, S Hangartner, G McDonald (2016) Lucerne flea. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Lucerne-flea

7.5 Native budworm (*Helicoverpa punctigera*)

The native budworm, sometimes known as Heliothis, is a common and widespread pest of vetch, pulse crops and canola. It occurs in most years and often migrates into agricultural areas from nearby or distant rangelands.

Vetch is susceptible to damage from Native budworm during flowering and podding stages. [18]

Native budworm eggs can be found singly on the growing tips and buds of plants. They are small (about 0.5 mm in diameter) but quite visible to the naked eye after close inspection of the plant. They are white when first laid but change colour from yellow through to brown, as they get closer to hatching.

Newly hatched caterpillars (larvae) are very small (approximately 1.5 mm), light in colour with dark brown heads. They can easily be missed when inspecting a crop. They will grow through six or seven stages or instars until reaching maturity (up to 40 mm long).

Larvae vary substantially in colour that includes shades of brown, green and orange. Regardless of colour, they usually have darkish stripes along the body and bumpy skin with sparse, stiff, stout hairs (Figure 4). One distinguishing feature of *Helicoverpa* larvae is the sharp downward angling at the rear of the body. However, in contrast to cotton bollworm (aka corn earworm) and lesser budworm, larvae of native budworm have black hairs around the head and along the body.

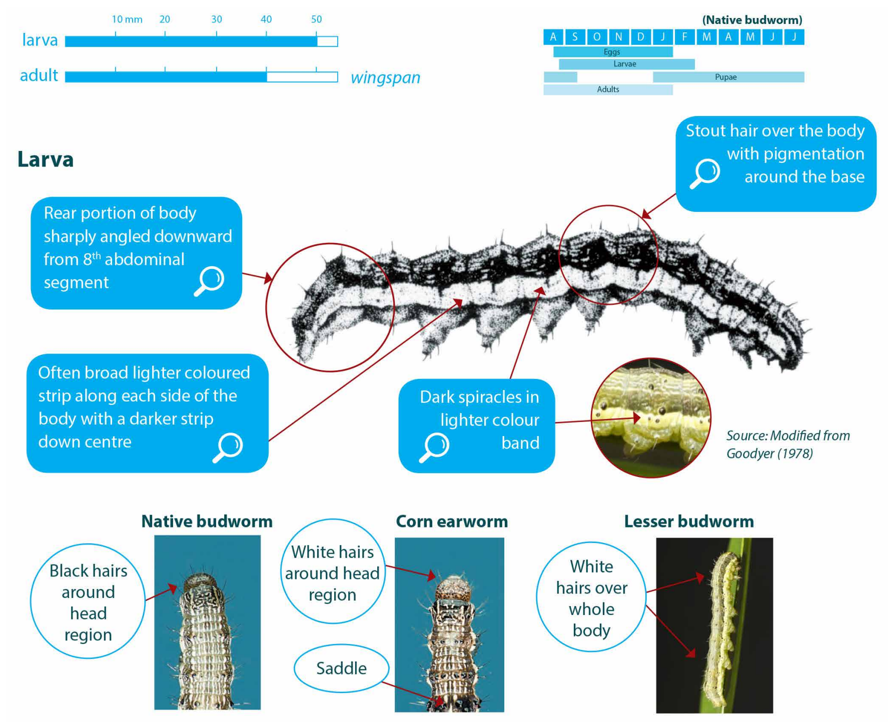


Figure 4: *Distinguishing characteristics/description of native budworm*

Source: Bellati et al. 2012

Early instar larvae, less than 7 mm, generally feed on leaves, or graze on the surface of pods. Exceptions can be following periods of unseasonably warm when even very small larvae burrow into young pods, making them difficult to monitor.

Adult moths are approximately 15–18 mm long and buff, light brown to red-brown in colour, with numerous dark spots and blotches. The hind wings of the adult moth are pale with a dark band along the lower edge and span 30–35 mm (Figure 5).

18 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

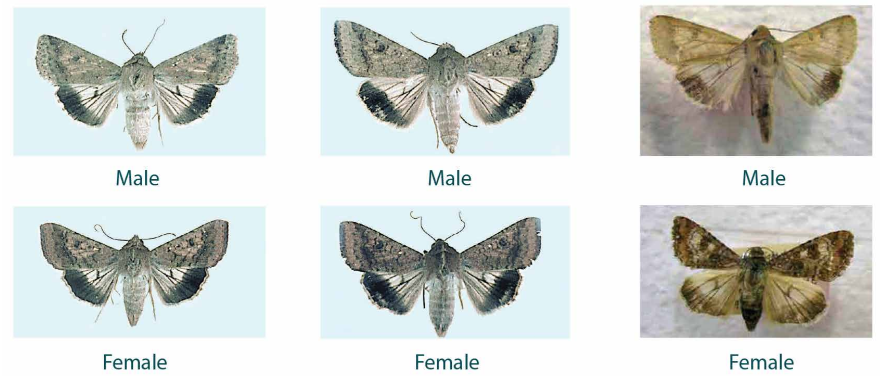


Figure 5: *Distinguishing characteristics/description of native budworm*

Source: Bellati et al. 2012

A notable feature of this pest is its capacity to migrate at high altitudes over large distances (100–1000 km) at night. The moths fly from areas where conditions do not favour another generation to where there are abundant food plants for further breeding.

Moths live for two to four weeks; they rest during the day and become active after sunset, feeding on nectar from flowers and laying eggs on many types of herbaceous plants (weeds and crops). They fly rapidly from plant to plant throughout the night in a darting motion, feeding and laying eggs; this behaviour is often used to recognise budworm moths. They are also capable of flying from paddock to paddock and of course, from one region to another. [19]

7.5.1 Damage caused by Native budworm

Budworms are at their most damaging when they feed on the fruiting parts and seeds of plants. During the formation and development of pods, vetch, field pea, chickpea, lentil and faba bean crops are very susceptible to all sizes of native budworm caterpillars. Small caterpillars can enter emerging pods and damage developing seed while larger caterpillars may devour the entire pod contents.

Holes or chewing damage may be seen on pods and/or seed heads. Grubs may be seen or may remain embedded in the pod. Losses attributed to budworms come from direct weight loss through seeds being wholly or partly eaten. Grain quality may also be downgraded through unacceptable levels of chewed grain.

Caterpillars eat increasing quantities of seed and plant material as they grow. The last two growth stages (5th & 6th instar) account for over 90% of their total grain consumption. [20]

7.5.2 Thresholds for control

Comprehensive and dynamic economic thresholds have been developed for native budworm in major pulse crops in Western Australia, which also apply to eastern Australia. Thresholds for control in vetch have not been specified, with the only the more general threshold control set at 1 larva per 10 sweeps. [21]

19 G McDonald (2015) Native budworm. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Native-budworm

20 G McDonald (2015) Native budworm. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Native-budworm

21 G McDonald (2015) Native budworm. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Native-budworm

7.5.3 Management of Native budworm

Monitoring

The use of pheromone traps (which attract male moths) provides an early warning of moth arrival and abundance, following their migration from inland regions. These should be set up in late winter or early spring. Observing the activity of moths in the crop and the presence of eggs may also be indicative of future larval activity. However, egg and early larval mortality of native budworm through natural courses can be very high. Eggs and very small larvae can be dislodged and will die after heavy rain or wind.

Either a sweep net (e.g. vetch, peas, lentils) or beat sheet (eg. chickpeas, lupins, beans) should be used to monitor larval activity in crops. Monitor field pea, faba bean, lentil and chickpea crops from budding and flowering development through to maturity for larval activity. Native budworm infestations are most problematic in spring and early summer, and may be greater when aphid infestations are heavy as the moths are attracted to the sugary honeydew produced by aphids.

During monitoring, record numbers of larvae according to size; very small (< 3 mm), small (4–7 mm), medium (8–23 mm) and large (>24 mm). Numbers of larvae used to calculate economic thresholds exclude very small larvae. Large larvae cause 90% of the damage.

Biological control

A key component to any IPM is to maximise the number of beneficial organisms and incorporate management strategies that reduce the need for pesticides. Correct identification and monitoring is the key when checking for build up or decline in beneficials. There are many natural enemies that attack native budworm. The egg stage is susceptible to the parasite *Trichogramma ivalae*, a minute wasp that has been recorded in up to 60% of eggs along with egg predators such as ladybird beetles, lacewings and spiders. Beneficials attacking larvae include shield bugs, damsel bugs, assassin bugs, tachinid flies (their larvae prey on caterpillars), orange caterpillar parasite, two-toned caterpillar parasite, orchid dupe, lacewings and spiders. Naturally occurring fungal diseases and viruses also play an important role in some seasons.

Cultural control

Windrowing or desiccating crops may be an option to advance the drying of crops when small-medium size larvae are present near crop maturity.

Chemical control

There are several insecticides registered for the control of native budworm. Timing and coverage are both critical to achieving good control. Try to target small larvae up to 7 mm in length and apply insecticides before larvae move into flowering pods. IPM options include the use of Bt (*Bacillus thuringiensis*) and nuclear polyhedrosis virus (NPV) based biological insecticides. Small larvae are generally easier to control because they are more susceptible to insecticides, and leaf feeding makes them susceptible to ingestion of active residues on the plant surface. Larvae entrenched in buds and pods will be more difficult to control and chemical residual will be important in contacting them.

The crop should be re-inspected 2 to 4 days after spraying to ensure enough caterpillars have been killed to prevent future damage and economic loss. In years of very high moth activity and extended egg lays, a second spray may be required.

In choosing a registered product, be aware of the withholding period for harvest or windrowing/ swathing which is the same as harvest. Residue testing is routinely conducted on grain destined for export and domestic stock feed markets. [22]

22 G McDonald (2015) Native budworm. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Native-budworm

Refer to the beneficial impact table (Table 1, Section 1.1.2 Natural enemies) from the IPM Guidelines website to identify products least likely to harm beneficials that aren't being targeted.

For up-to-date chemical registrations, see the APVMA website.

7.6 Redlegged earth mite (*Halotydeus destructor*)

Redlegged earth mites are one of the most important invertebrate pest species in Australian agriculture. They are very common and widespread pest of pastures and most broadacre crops.

Vetch is vulnerable to damage from Redlegged earth mites in early growth stages. [23]

Redlegged earth mites are 1 mm in length. Adults and nymphs have a velvety black body with eight orange-red coloured legs. Newly hatched mites are pinkish-orange with six legs and are 0.2 mm long (Figure 6).

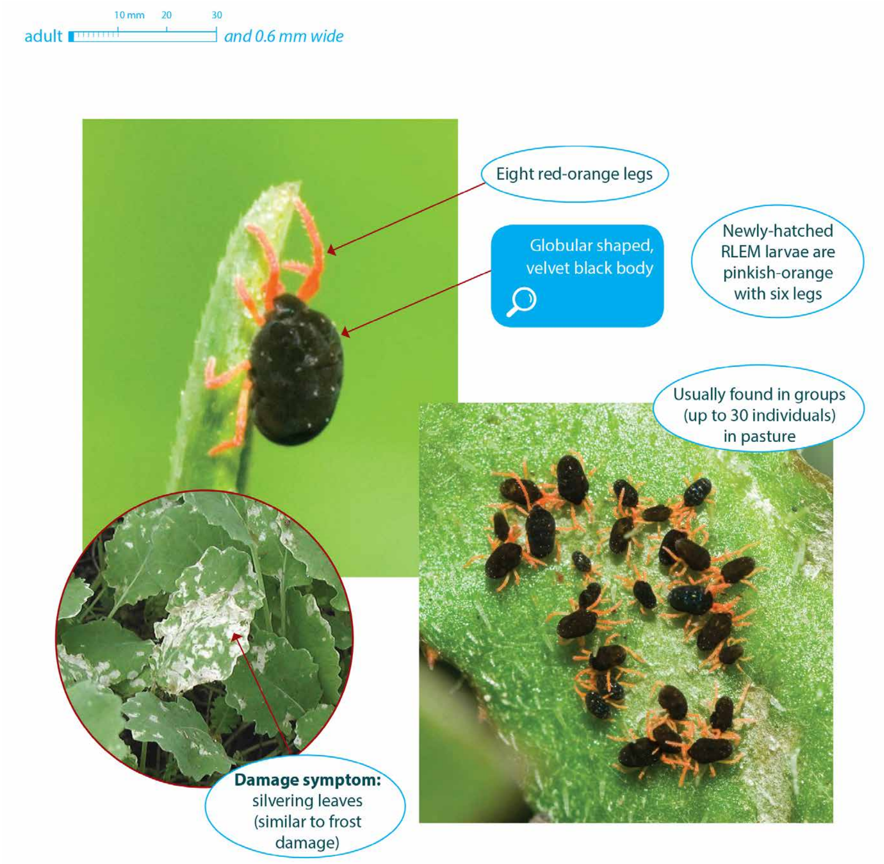


Figure 6: *Distinguishing characteristics/description of redlegged earth mites*

Source: Bellati et al. 2012

They are common and widespread, and active from autumn to late spring in southern Australia, but not as common in northern NSW, where blue oat mite are the more dominate species. Redlegged earth mites often occur in situations with other mites, such as blue oat mites, *Bryobia* mites and *Balaustium* mites.

23 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

Redlegged earth mites are often found on the leaf surface in feeding aggregations, of up to 30 individuals. In the warmer part of the day, redlegged earth mites tend to gather at the base of plants, sheltering in leaf sheaths and under debris. [24]

7.6.1 Damage caused by Redlegged earth mite

Feeding causes silvering or white discoloration of leaves and distortion or shriveling in severe infestations. Affected seedlings can die at emergence with high mite populations. Feeding symptoms can be mistaken for frost damage. Redlegged earth mites have been found to be directly responsible for a reduction in pasture palatability. [25]

7.6.2 Thresholds for control

The threshold for control in pulses is 50 mites per 100cm^2. [26]

7.6.3 Management of Redlegged earth mite

Monitoring

Inspect susceptible pastures and crops from autumn to spring for the presence of mites and evidence of damage. It is important to inspect crops regularly in the first three to five weeks after sowing. Mites are best detected feeding on the leaves in the morning or on overcast days. If mites are not observed on plant material, inspect soil for mites. Be aware of edge effects; mites move in from weeds around paddock edges. An effective way to sample mites is to use a standard petrol-powered garden blower/vacuum machine. A fine sieve or stocking is placed over the end of the suction pipe to trap mites vacuumed from plants and the soil surface.

Biological control

French *Anystis* mites can suppress populations in some pastures. Snout mites and other predatory mites are also effective natural enemies. Leaving shelterbelts or refuges between paddocks will help maintain natural enemy populations.

Cultural control

Do not sow susceptible crops (e.g. canola) into pastures or paddocks known to contain high mite numbers. Rotate paddocks with non-preferred crops (e.g. chickpeas). Pre- and post- sowing weed management (particularly broadleaf weeds) is important. Heavy pasture grazing in spring can help to reduce mite numbers the following autumn.

Chemical control

Rotate chemical classes of insecticides as resistance to synthetic pyrethroid and organophosphate chemicals has been detected (in WA). For low-moderate mite populations, insecticide seed dressings are an effective method. Avoid prophylactic sprays; apply insecticides if control is warranted. Pesticides used at or after sowing should be applied within three weeks of the first appearance of mites, before adults commence laying eggs. Insecticides do not kill mite eggs. Border spraying can be an effective way to control mites, as mites will often move in from crop edges and roadside vegetation. Carefully timed spring spraying using TIMERITE® will reduce mite populations the following autumn, but could also exacerbate other mite problems. [27]

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24 P Umina, G McDonald (2015) Redlegged earth mite. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite

25 P Umina, G McDonald (2015) Redlegged earth mite. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite

26 P Umina, G McDonald (2015) Redlegged earth mite. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite

27 P Umina, G McDonald (2015) Redlegged earth mite. Cesar PestNotes. http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Redlegged-earth-mite

Refer to the beneficial impact table (Table 1, Section 1.1.2 Natural enemies) from the IPM Guidelines website to identify products least likely to harm beneficials that aren't being targeted.

For up-to-date chemical registrations, see the APVMA website.

Nematode management

Key messages:

- Nematodes are microscopic organisms that can cause significantly yield losses to susceptible crops.
- There are two species of Root-lesion nematodes (RLN) that can cause damage to susceptible crops in the Northern region; *Pratylenchus thornei* and *P. neglectus*.
- Vetch is rated as moderately susceptible to *Pratylenchus neglectus* and susceptible to *P. thornei*.
- *P. thornei* and *P. neglectus* have been detected at potentially damaging levels in nearly 30% of paddocks in the northern part of the Northern Region, and can be common throughout the southern part of the Northern region.
- There is no easy solution to RLN infestation. Variety and crop rotation are currently the major management tools.
- Predicta B soil testing to detect the presence and abundance of nematode populations is a critical step to minimise the risk of damage.

Nematodes or 'Eelworms' are found in all soils in high numbers and with high diversity. They are microscopic unsegmented roundworms that are one of the most numerous life forms on earth. While many species are free-living and play an important part in organic matter recycling, other species are parasitic to either plants or animals. Plant parasitic nematodes live in plant roots and other plant parts, causing disease. Parasitic nematodes have many hosts and are seldom plant-specific.

Root-lesion nematodes (RLN) can cause damage to vetch crops and vetch can host RLN leading to damage in following crops. Small numbers of the oat race of stem nematode can sometimes be found in Blanchefleur, Languedoc and Namoi vetch. [1]

The aboveground symptoms of disease caused by nematodes can be difficult to detect, and may be often confused with symptoms of nutrient deficiency. Typically, plants do not thrive, are paler than normal, and may wilt in the heat of the day. Affected plants are often dwarfed, with small leaves. Sometimes, when infected plants are growing in moist, fertile soil, or during cool weather, the aboveground parts can still appear healthy. [2]

8.1 Root-lesion nematodes

Key points:

- *Pratylenchus neglectus* and *P. thornei* are the main root-lesion nematodes (RLN) that cause yield loss in the northern agricultural region of Australia. They often occur together.
- Root-lesion nematodes cost Australian growers in excess of $250 million a year.
- Root-lesion nematodes reduce the development of lateral roots, and this decreases the ability of plants to extract water and nutrients.
- Traditional break crops can also be hosts, and the host range varies for each *Pratylenchus* species.
- Yield losses can be reduced by rotation with resistant and tolerant crops and varieties, good nutrition, sowing early and testing soil.

The root-lesion nematodes are a genus of soil-borne, microscopic plant parasites that are migratory. They are widely distributed in the wheat-growing regions of Australia, the two common species in the Northern Region being *Pratylenchus thornei* (*Pt*) and *P. neglectus (Pn)*. *P. thornei* is the most damaging species and occurs commonly

1 S Taylor. GRDC GroundCover Issue 22: Stem nematode. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-22/stem-nematode

2 C. Wilkinson. (2014). Nematodes. DAFWA. https://www.agric.wa.gov.au/nematodes/nematodes

VIDEOS

WATCH: GCTV6: Root-lesion nematodes

WATCH: Understanding root-lesion nematodes

in the northern part of the Northern region (Photo 1). [3] *P. neglectus* occurs less frequently in this area, but is common and can be damaging in the southern part of the Northern region.

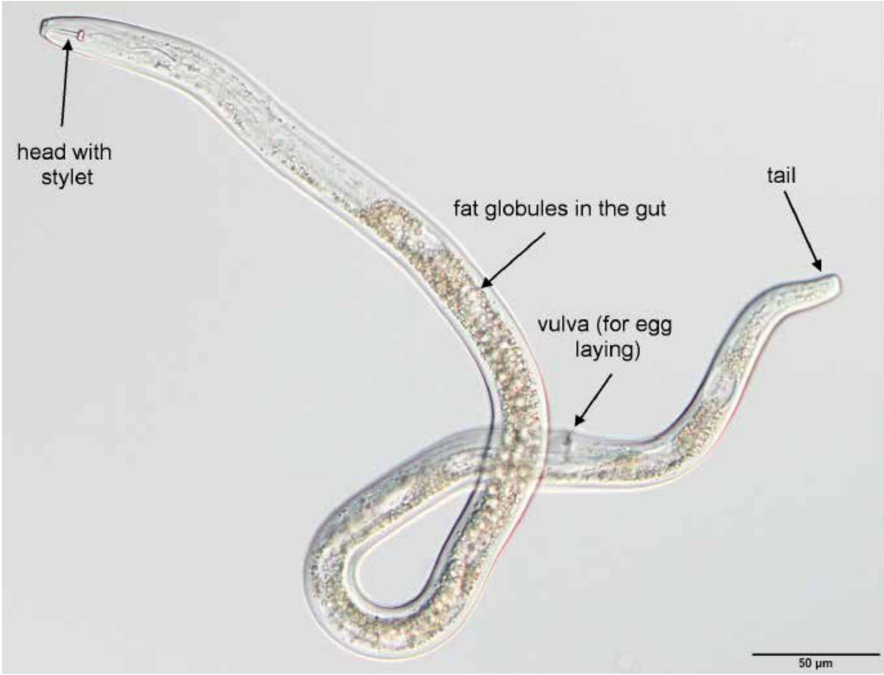

Photo 1: *A Pratylenchus thornei adult female viewed under the microscope. The nematode is approximately 0.65 mm long.*

Source: GRDC

Both species grow to ~0.5–0.75 mm in length and feed and reproduce inside the roots of susceptible crops (and other plants). They penetrate the plant root, digesting the cells' contents and laying eggs within the roots (Photo 2). [4] Nematode multiplication differs both between and within host species.

Pratylenchus thornei occurs throughout the root zone while *P. neglectus*, tends to be concentrated in the top 15 cm of the soil.

P. neglectus and *P. thornei* have a wide range of hosts and infect legumes (including vetch), oilseeds and all cereals. This species impairs root function, limiting water and nutrient uptake, and leads to poor growth and yield decline.

Big populations develop quickly following planting, so that the root systems quickly become inefficient in absorbing water and nutrients. [5]

3 GRDC (2015) Root-lesion nematodes, Northern Region. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/03/tt-rootlesionnematodes

4 J Thompson, K Owen, T Clewett, J Sheedy, R Reen (2009) Management of root-lesion nematodes in the northern grain region. DAF Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/crop-diseases/root-lesion-nematode

5 GRDC (2015) Root-lesion nematodes, Northern Region. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/03/tt-rootlesionnematodes

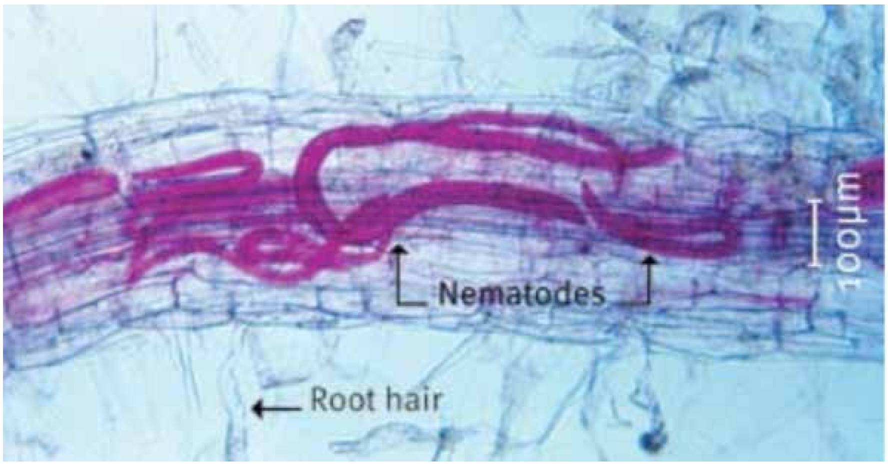

Photo 2: *Nematodes (stained to make them easy to see) in a cereal-plant root.*

Source: DAF Queensland

In 2015, SARDI generated maps of the distribution of *P. thornei* and *P. neglectus* from samples submitted for PreDicta B tests (Figure 1). [6] Results from the autumn samples show that in the northern part of the Northern Region, *P. thornei* (Pt) is more widely distributed and found in greater, more damaging populations than *P. neglectus* (Pn). In this region, paddocks with more than 15 *P. thornei*/g soil or 15,000/kg soil (ascertained by the PreDicta B test) are considered high risk for crops. However, populations of *P. thornei* classified as being of medium risk, that is 2–15/g soil or 2,000–15,000/kg soil, can cause substantial yield loss in intolerant varieties in the warm, wet growing seasons that are conducive to nematode reproduction. [7]

6 K Owen, T Clewett, J Sheedy, J Thompson (2016) Managing grain crops in nematode fields to minimize loss and optimise profit. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Managing-grain-crops-in-nematode-infested-fields-to-minimise-loss-and-optimise-profit

7 K Owen, T Clewett, J Sheedy, J Thompson (2016) Managing grain crops in nematode-infested fields to minimise loss and optimise profit. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Managing-grain-crops-in-nematode-infested-fields-to-minimise-loss-and-optimise-profit

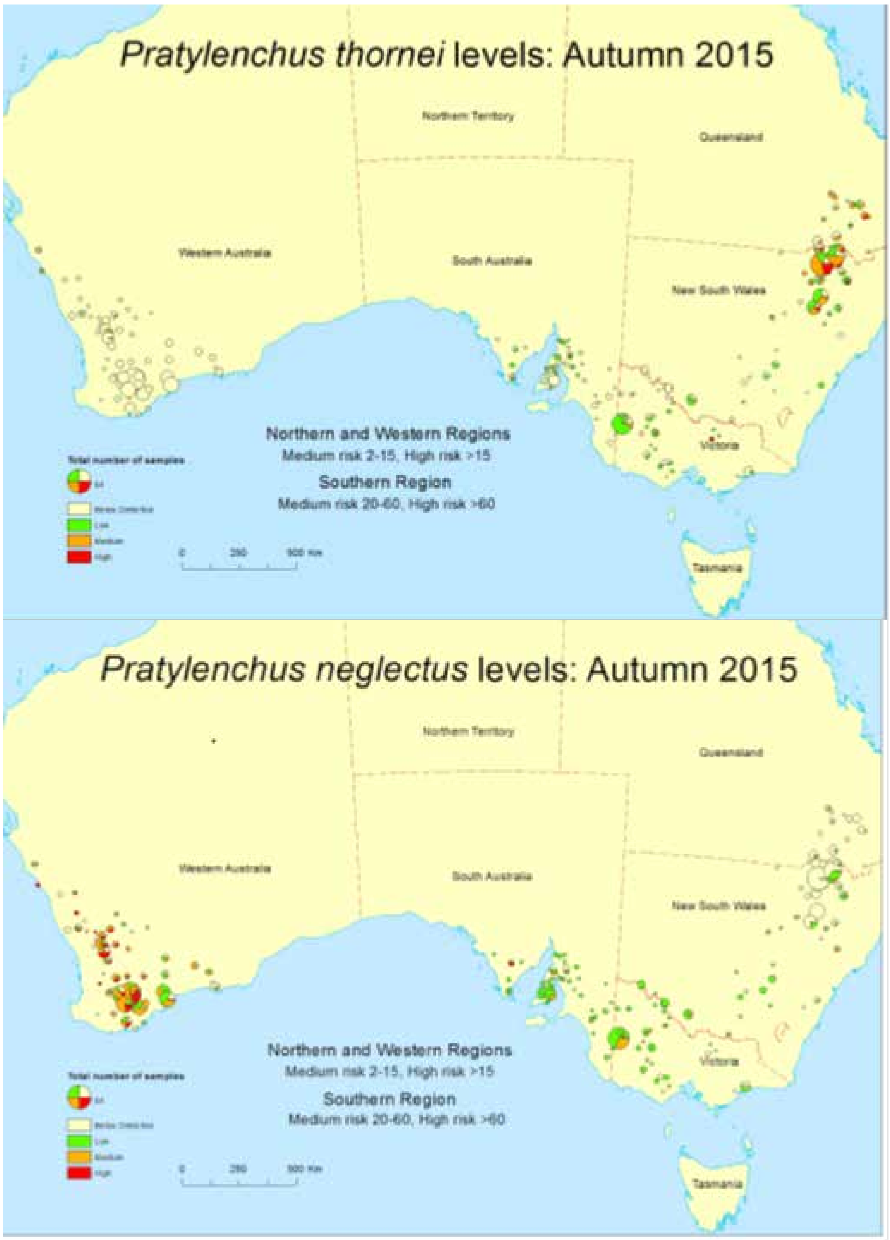

Figure 1: *The distribution of RLNs and risk of yield loss, from samples submitted for PreDicta B tests to SARDI in autumn 2015 for (top) Pratylenchus thornei and (bottom) P. neglectus.*

Source: GRDC

In a survey of soil samples from 596 paddocks in southern Queensland and northern New South Wales cropping areas consistently show *P. thornei* presence in ~60–70% of paddocks. *This nematode is* frequently present at concerning levels, detected at over 2 *Pt*/g soil in ~30–40% of paddocks. In this survey, it was found that 42% of paddocks tested had *P. thornei* alone, 27% had both species, 6% had *P. neglectus* alone, and 26% had neither species (Figure 2). [8]

MORE INFORMATION

Managing grain crops in nematode infested fields

8 J Thompson, K Owen, T Clewett, J Sheedy, R Reen (2009) Management of root-lesion nematodes in the northern grain region. DAF Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/crop-diseases/root-lesion-nematode

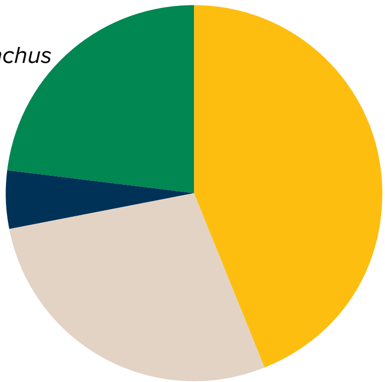

Figure 2: *A survey of nematodes in 596 paddocks in the Northern Region revealed that P. thornei is the most commonly found root-lesion nematode in the region (prior to recent region boundary changes) and that P. neglectus is also present.*

Source: DAF Queensland

8.1.1 Varietal resistance or tolerance

Some crops, varieties and plant types have different levels of resistance to different species of the *Pratylenchus* family. Vetch is moderately susceptible to *P. neglectus* and susceptible to *P.thornei*. Vetch can be a host to RLNs and is not considered a break crop against RLNs.

What does resistance and tolerance mean?

Resistant varieties will result in fewer nematodes remaining in the soil to infect subsequent crops. Tolerant varieties are able to perform well in the presence of the nematode, but they may allow nematode populations to build up.

Nematode Resistance relates to the effect of the variety on the nematode density present within the paddock (Table 1).

Table 1: *Standard disease ratings.*

Uniform rating	Management option description	In the paddock	Management action
Resistant	Growing these varieties will reduce the density of the nematode in question and so reduce yield loss in subsequent intolerant crops.	There will be a reduction in nematode densities when these varieties are grown.	Use these varieties in rotation with non-host crops to reduce nematode infestations. If using R varieties in paddocks with high nematode infestations make sure variety is also tolerant to prevent significant yield loss.

Uniform rating	Management option description	In the paddock	Management action
Moderately resistant	Growing these varieties will, to a lesser degree than growing a resistant variety, reduce the density of the nematode in question and, therefore, reduce yield loss in subsequent intolerant crops.	There will be a reduction in nematode densities when these varieties are grown.	These varieties are suitable to be grown in paddocks with high nematode infestations as they reduce nematode densities. They will, however, not reduce nematode densities to the same degree as a resistant variety. Note that if nematode densities are high tolerant to minimise yield loss.
Moderately susceptible	Growing these varieties will result in a small increase in nematode densities during the season.	Growing these varieties will increase the nematode density. However, unless the season is exceptionally favourable, growing these varieties in paddocks with low level nematode densities will only increase densities to moderate levels. If nematode densities are already moderate these varieties may result in high densities that may cause substantial loss in a following intolerant variety.	These varieties are suitable to be grown in paddocks with low nematode densities. They will, however, increase nematode densities which may be a problem for a following intolerant crop.
Susceptible	Growing these varieties will increase nematode density which may then cause problems to a following intolerant crop.	Growing these varieties will result in increases in the density of the nematode in question. However, unless the season is exceptionally favourable, growing these varieties in paddocks with a low level will only result in moderate levels. If nematode densities are already moderate these varieties can result in high levels that may cause substantial loss in a following intolerant variety.	These varieties will increase the density of nematodes in a paddock that may be of concern to a following intolerant crop. If nematode densities are high following a susceptible crop, growers should avoid intolerant crops in the following year and select a resistant crop to reduce nematode densities.

Uniform rating	Management option description	In the paddock	Management action
Very susceptible	Growing these varieties will support large multiplication rates of the nematode. It may take more than one year of a resistant variety/non-host crop to reduce the nematode densities to a level that will not affect the yield of an intolerant crop.	These varieties will support large increases in nematode numbers when grown in infested paddocks.	Growers should where possible avoid growing these varieties in infested paddocks. Also avoid growing intolerant varieties after VS varieties due to the potential for significant yield loss. A tolerant non-host crop/ resistant variety should be used following VS varieties to reduce nematode densities. If nematode densities are very high it may take more than two years of non-host/resistant varieties to reduce nematode levels to low risk densities.

Source: NVT Online)

Nematode Tolerance relates to yield of the variety in the presence of the nematode (Table 2).

Table 2: *Standard disease ratings.*

Uniform rating	Management option description	In the paddock	Management action
Tolerant	Variety will not lose yield in the presence of the nematode, even at high nematode densities.	The crop will not be affected by the presence of the nematode.	No economic management decisions required.
Moderately tolerant	These varieties can generally be sown in paddocks with low to medium levels of nematode infestations without a significant effect on grain yield occurring. These varieties can suffer yield loss (up to 10%) in the presence of high nematode densities.	Minimal yield loss will occur in the presence of the nematode (i.e. < 5%), except when nematode densities are high when up to 10% yield loss may occur.	Do not grow these varieties in paddocks with high nematode densities present. Suggest follow management recommendations to minimise yield loss for the nematode of concern.

Uniform rating	Management option description	In the paddock	Management action
Moderately intolerant	These varieties should not be grown in paddocks with medium to high nematode densities. In the presence of high nematode densities in a paddock these varieties will lose up to 30% yield.	In the presence of the nematode and in seasons conducive to disease, these varieties will lose yield and may show symptoms consistent with root damage. The expression of symptoms will be greater in paddocks with higher nematode densities.	These varieties should not be grown in paddocks with medium to high nematode densities. In the presence of high nematode densities in a paddock these varieties can lose up to 30% yield. Suggest follow management recommendations to minimise yield loss for the nematode of concern.
Intolerant	These varieties are prone to yield loss even in the presence of low nematode densities. Such varieties should not be grown in paddocks where nematodes are known to be present. In the presence of high nematode densities yield loss of up to 50% can occur.	In the presence of the nematode symptoms of root disease will often be easily found in the crop.	Do not grow these varieties in paddocks where the nematode is present at medium to high levels. Even paddocks with low nematode densities should be avoided when possible. Suggest follow management recommendations to minimise yield loss for the nematode of concern.
Very intolerant	Do not grow this variety unless the paddock is known to be nematode free or present at very low densities. High nematode densities could cause yield losses of greater than 50% to occur.	Symptoms of nematode damage will be present in these varieties even in the presence of low nematode densities.	Do not grow these varieties in paddocks where the nematode is present, even at low levels. If the variety is to be grown a soil test should be conducted prior to sowing to ensure that the paddock is free from the nematode in question. Suggest follow management recommendations to minimise yield loss for the nematode of concern.

Source: NVT Online

8.1.2 Damage caused by pest

In the southern part of the northern region *P. neglectus* can cause major losses to susceptible crops. In southern Australia *P. neglectus* has been known to reduce grain yield by 10–20% and in Western Australia is has been reported to cause losses of up to 15%. [9]

9 V Vanstone, J Lewis (2009) Plant parasitic nematodes Factsheet. GRDC.

In the northern part of the Northern region, intolerant varieties can lose more than 50% in yield when *P. thornei* populations are high. [10]

8.1.3 Conditions favouring development

Root lesion nematodes survive summer as dormant individuals in dry soil and roots, and become active after rain. They can survive several wetting/drying cycles. About three generations of the nematodes are produced each season, with the highest multiplication in spring.

Nematodes can spread through a district in surface water (e.g. floodwater) and can be moved from one area to another in soil that adheres to vehicles and machinery. They can also move via soil adhering to vehicles and farm machinery. In uninfested areas, good hygiene should be adopted. Nematodes can be spread in dust when they are in a dehydrated state over summer.

They have the ability to quickly build up populations in the roots of susceptible crops, and remain in the soil during fallow. As a result, the yield of following crops can be significantly reduced.

MORE INFORMATION

How long does it take to reduce *Pratylenchus thornei* (root lesion nematode) population in the soil?

Impact from *Pratylenchus thornei*, Macalister 2015

8.1.4 Detection

Soil testing is the best way to diagnose nematode infestations and also to inform growers' management decisions. It is important to know whether nematodes are present and which species these are, a soil test will do this for you. This is important because varietal tolerance information for *P. thornei* does not hold true for *P. neglectus*, so proper species identification can help minimise losses that arise from planting intolerant varieties in nematode-infested land.

RLN populations can persist in the soil for a long time. Once a population increases, non-host, resistant crops or fallows are required to reduce the population below the damage threshold. Planting susceptible or tolerant crops within this period will enable the rapid increase in populations to higher levels. [11]

There are two services available to test for RLNs.

Leslie Research Centre tests

The Leslie Research Centre of the Department of Agriculture and Fisheries Queensland offers a commercial test for the presence of nematodes in soil.

Since nematodes may not be evenly spread across a paddock, particularly when there are new infestations, it is important to take samples from several locations within a paddock. It is suggested that growers take nine cores in groups of three.

Nematodes are often more numerous in the subsoil than in the topsoil. Although you can have soil to a depth of 120 cm analysed, this isn't necessary. As long as soil is sampled in two layers, topsoil at 0–15 cm and subsoil at 15–30 cm, a useful result can be achieved. Use a hand corer (or a mattock if no corer is available). Topsoil-only samples can give inaccurate results and should always be accompanied by a subsoil sample. If deeper samples are already being taken for other analysis (e.g. nitrate), a nematode assessment can be made from the depths 0–30 cm, 30–60 cm and 60–90 cm.

10 B Burton, R Norton, R Daniel (2015) Root-lesion nematode: importance, impact and management. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management

11 J Whish, J Thompson (2016) How long does it take to reduce Pratylenchus thornei (root lesion nematode) population in the soil? GRDC Update Paper. GRDC, https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/how-long-does-it-take-to-reduce-pratylenchus-thornei-populations-in-the-soil

MORE INFORMATION

Leslie Research Centre, Test your farm for nematodes

Send samples to:
Soil Microbiology Section
Leslie Research Centre
PO Box 2282
Toowoomba, QLD 4350
13 Holberton Street
Toowoomba

Phone: (07) 4639 8888
Fax: (07) 4639 8800

PreDicta B tests

PreDicta B is a DNA-based soil-testing service that was developed by the South Australian Research and Development Institute (SARDI) (The B in the name stands for broadacre). The test identifies which soil-borne pathogens pose a significant risk to broadacre crops before paddocks are planted. [12]

PreDicta B can be used to test for Root-lesion nematodes including *P. neglectus* and *P. thornei*.

Growers can access PreDicta B diagnostic testing services through a SARDI accredited agronomist, who will interpret the results and give advice on management options to reduce the risk of yield loss. Samples are processed weekly between February and mid-May (prior to crops being sown).

PreDicta B is not intended for in-crop diagnosis.

8.1.5 Thresholds for control

The damage threshold for both RLNs has been estimated at 2,000 nematodes/kg soil (or 2/g soil). Control is warranted for paddocks with populations over this density. [13]

paddocks with more than 15 *P. thornei*/g soil or 15,000/kg soil are considered high risk for crops. However, populations of *P. thornei* classified as being of medium risk, that is 2–15/g soil or 2,000–15,000/kg soil, can cause substantial yield loss in intolerant varieties in the warm, wet growing seasons that are conducive to nematode reproduction. [14]

The number of nematodes in the soil can be determined by conducting soil testing, for example with a PreDicta B test.

8.1.6 Management

Key points:

- Know your enemy—test soil to determine whether RLN are a problem and which species are present.
- Select varieties rated as having a high tolerance to minimise yield losses in RLN-infected paddocks.
- To manage RLN populations, it is important to increase the frequency of RLN-resistant crops in the rotation.
- Multiple resistant crops in a rotation will be necessary for the long-term management of RLN populations.
- Avoid crops or varieties that allow the build-up of large populations of RLN in infected paddocks.
- Monitor the impact of your rotation.

12 D Lush (2014) PreDicta B sampling strategy. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2014/04/PreDicta-B-sampling-strategy

13 GRDC (2015) Root lesion nematodes. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/03/tt-rootlesionnematodes

14 K Owen, T Clewett, J Sheedy, J Thompson (2016) Managing grain crops in nematode-infested fields to minimise loss and optimise profit. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/03/Managing-grain-crops-in-nematode-infested-fields-to-minimise-loss-and-optimise-profit

There are four key strategies in reducing the risk of root-lesion nematodes:

1. Have soil tested for nematodes in a laboratory (For more information, see Section 8.1.4 Detection).
2. Protect paddocks that are free of nematodes by controlling soil and water run-off and cleaning machinery; plant nematode-free paddocks first.
3. Choose tolerant varieties to maximise yields; National Variety Trials online is a useful resource. Tolerant varieties grow and yield well when RLN are present.
4. Rotate with resistant crops to prevent increases in root-lesion nematodes (Figure 6). When high populations of RLN are detected you may need to grow at least two resistant crops consecutively to decrease populations. In addition, ensure that fertiliser is applied at the recommended rate to ensure that the yield potential of tolerant varieties is achieved. Crop rotation with resistant crops such as grain sorghum, millet, sunflower and lupins will reduce the numbers of nematodes in the soil to a level where susceptible varieties can be grown. However, it will not eliminate them completely. [15]

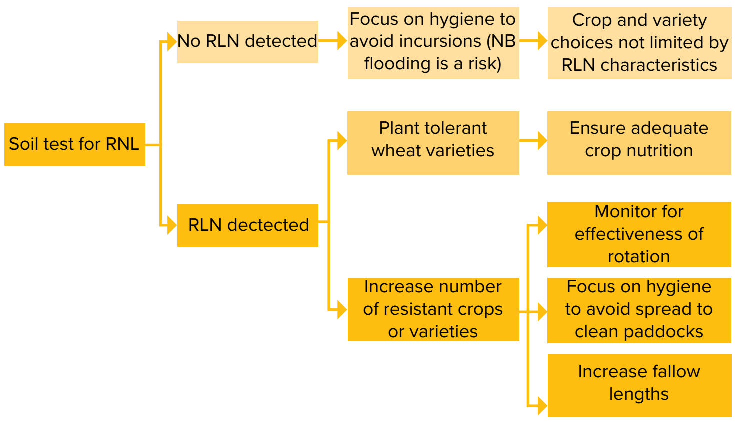

Figure 3: *The simplified RLN management flow chart. It highlights the critical first step in the management of RLN is to test soil to determine whether you have a problem to manage. Where RLN are present, growers should focus on both planting tolerant wheat varieties and increasing the number of resistant crops and varieties in the rotation.*

Source: GRDC

VIDEOS

WATCH: Root lesion nematodes part 3: What can I do?

The first step in management of RLN is to have soil tested to determine whether RLN are present in paddocks. If RLN are detected, the soil test will tell you which of the species is present and the population level in the field. If RLN are not detected, protect those paddocks from contamination by controlling movement of soil and water on the farm. Clean soil from machinery before planting or fertilising, and plant RLN-free paddocks first.

When RLN are detected, rotations and variety choice are central to successfully reducing RLN populations. Only non-host crops or resistant varieties will minimise the build-up of RLN (Tables 3 and 4). Aim to reduce populations to less than 2/g soil. Re-testing of soil after growing resistant crops is recommended, so that crop sequences can be adjusted if populations are still at damaging levels. Avoid very susceptible crops and varieties. [16] Consider re-testing in five years, particularly if there has been flooding, because RLN can move in floodwaters and in soil.

15 DAF Qld (2015) Wheat: diseases, physiological disorders and frost. DAF Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/wheat/diseases

16 GRDC (2015) Root-lesion nematodes, Northern Region. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2015/03/tt-rootlesionnematodes

Table 3: *Susceptibility of some crop and pasture species to root lesion nematode infection.*

RLN species	Susceptible crops	Moderately susceptible crops	Resistant crops
Pratylenchus neglectus	Canola, chickpeas, mustard	Common vetch, lentils	Field peas, narrow leaf lupins, faba beans, triticale, safflower, cereal rye, medic, clover
Pratylenchus thornei	Chickpeas, vetch, faba beans	Canola, mustard, field peas*, lentils	Field peas*, lupins

* New field pea varieties are more susceptible to *P. Thornei* than older varieties, so check the classification of each variety.

Source: GRDC

Table 4: *Comparison of the risk of build-up of Pratylenchus thornei and P. neglectus in crops.*

Crop	P.thornei	P.neglectus
Cereals		
Barley	Medium to high	Low to medium
Canary seed	Low	Low
Maize	Low	Low
Millet	Low	Low
Oats	Low	NT
Sorghum (grain)	Low	Medium to high
Triticale	Medium to high	Low
Wheat	Low, medium to high	Low, medium to high
Legumes		
Blackgram	High	Medium (p)
Chickpeas	Medium to high	Low to medium
Cowpeas	High	NT
Faba beans	Medium to high	Low
Field peas	Low to medium	NT
Navy beans	High	NT
Pigeon peas	Low	NT
Oilseeds		
Canola, mustard	Low to medium	Medium to high
Cotton	Low	Low
Linseed	Low	Low
Soybeans	High	Low
Sunflowers	Low	Low
Pastures, forage		
Brassica (forage)	Low to medium	NT
Lablab	Low	NT
Sorghum (forage	Low	Medium to high

Source: GRDC

VIDEOS

WATCH: Crop variety effect on nematodes

Fallow

RLN populations will generally decrease during a 'clean' fallow but the process is slow and expensive in lost potential income. Additionally, long fallows may decrease arbuscular mycorrhizae (AM) levels and create more cropping problems than they solve.

Weed control

Weeds can play an important role in the increase or persistence of nematodes in cropping soils. Thus, poor control of susceptible weeds compromises the use of crop rotations for RLN management. Wild oat, barley grass, brome grass and wild radish are susceptible to *P. neglectus*. When a pasture is included in the cropping rotation, weeds strongly influence nematode populations at the end of the pasture phase. Manage volunteer susceptible crop plants that can harbour nematodes. This will be important when growing vetch as it can be a problem volunteer crop. [17]

Nutrition

Damage from RLN reduces the ability of cereal roots to access nutrients and soil moisture, and can induce nutrient deficiencies. Although under-fertilising is likely to exacerbate the impact of RLN-affected yields, over-fertilising is unlikely to *compensate* for a poor variety choice.

Adequate nutrition (especially nitrogen, phosphorus and zinc) normally allows plants to better tolerate plant parasitic nematodes, although this does not necessarily lead to lower nematode reproduction.

Field trials in areas infested with *P. neglectus* have shown yield losses for intolerant wheat ranged from 12–33% when minimal levels of phosphorus were applied but losses were reduced to only 5% with a high (50 kg/ha) rate of phosphorus.

Nematicides (control in a drum)

There are no nematicides registered for use against RLN in broadacre cropping in Australia. Screening of potential candidates continues to be conducted, but RLN are very difficult to target because populations are frequently deep in the soil profile. [18]

Natural enemies

Biological suppression is a potential method of reducing populations of *P. thornei* and *P. neglectus*. Recent research has identified that Northern Region soils are capable of suppressing root-lesion nematodes, especially in the top layer (0–15 cm), and this capacity can be enhanced by increasing the biological activity of that soil, mainly through carbon inputs and minimising soil disturbance.

Several organisms that prey on nematodes have been found in northern soils that have the potential to reduce root-lesion nematode populations. They include the *Pasteuria* bacteria that infect and eventually kill *Pratylenchus* spp. Several species of fungi, including some that trap nematodes, and predatory nematodes have also been found.

Research is continuing to develop methods of increasing biological activity to enhance natural suppression of nematodes deeper in the soil profile.

MORE INFORMATION

Biological suppression of RLN in northern region

National Variety Trials

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

8.2 Stem nematodes

Stem nematode feeds on the emerging shoot, crown and above-ground parts of host plants, resulting in distorted and stunted growth. The population can build up rapidly as the nematode can reproduce four or five times in a season.

17 V Vanstone, J Lewis (2009) Plant parasitic nematodes Factsheet. GRDC.

18 B Burton, R Norton, R Daniel (2015) Root-lesion nematode; importance, impact and management. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/08/Root-lesion-nematodes-importance-impact-and-management

The nematode can survive and spread between districts in infected hay. Localised spread is possible by soil contamination of stock and machinery and in surface water, wind-blown stubble or soil.

Stem nematode can survive in a dehydrated form in hay and seed for 10 years or more. Weeds can play a key role in the survival of stem nematode when there are no host crops. This explains why the nematode can recur after paddocks have not grown susceptible crops for a number of years.

The oat race of stem nematode has the widest host range and high numbers can cause crop failure. Oat race can sometimes be found in Blanchefleur vetch.

What to look for

- distorted and stunted plant growth — patches of 1–100 m in emerging crops
- a plant or seed test is available through the Field Crops Pathology Unit, SARDI

What to do

- include resistant crops and varieties in planned rotations
- control host weeds
- observe farm hygiene [19]

19 GRDC Stem nematode https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-22/stem-nematode

Diseases

Key messages

- Ascochyta blight, Botrytis Grey Mould and Rust can cause major yield loss in vetch.
- Rust in vetch crops can cause abortions if fed to livestock.
- To limit the risk of disease in vetch and other pulses in the cropping sequence, vetch should be limited to no more than once in every four years in a particular paddock. [1]
- Test seed for disease inoculum and only sow disease free seed.
- Monitor crops regularly, especially in conditions that favour disease development.

The foliar diseases, rust, ascochyta blight and botrytis grey mould can significantly reduce grain and dry matter production and quality of hay, silage and grain in vetch.

9.1.1 Integrated disease management

To reduce the risk of disease damage, each year growers need to implement an integrated disease management strategy. This strategy should include sowing healthy seed, knowing variety resistance ratings, using seed dressings, paddock selection and actively monitoring crops for diseases to ensure timely foliar fungicide and/or insecticide application. Key steps in the integrated management of vetch diseases include crop rotation, stubble management, fungicide or pesticide application, variety selection and seed testing.

Disease management is critical when growing a vetch crop regardless of the end use, where possible disease resistant varieties should be planted as a preference (Table 1).

Table 1: *Disease resistance ratings for vetch varieties.*

Variety	Ascochyta blight	Botrytis Grey Mould	Rust
Common Vetch Varieties			
Blanchefleur	MS	S	VS
Cummins	MS	S	VS
Morava(b	S	VS	R
Rasina(b	MS	S	R
Volga(b	MS	S	R
Timok(b	MS	S	R
Purple Vetch			
Popany	S	VS	R
Woolly Pod Vetch Varieties			
Haymaker(b	S	VS	R
Capello(b	S	VS	R
Namoi	S	VS	R
RM4(b	MR	VS	R

Source: SARDI

1 R Matic (2010) Vetch summary 2010. SARDI. Online Farm Trials. http://www.farmtrials.com.au/trial/14055

9.1.2 Foliar fungicide use in vetch

Foliar fungicides are necessary for controlling some destructive pulse diseases (Table 2). They are most effective when applied before or at the first sign of disease, or immediately prior to weather conditions favourable for disease development as a preventative spary. Do not wait until the disease is established; i.e. apply ahead of rain fronts. The duration of protection varies with the product used, how rapidly the plants are growing, and the rainfall experienced. Any new growth after spraying is not protected. If disease persists, additional sprays will be required and should be applied prior to rain. Waiting until after a rain event allows infection to occur.

Uniform coverage of the crop foliage is important for prevention of disease. This is best achieved by using high water rates (preferably 100 L/ha by ground and 30 L/ha by air) with water pH not exceeding pH7, nozzles with a fine or extra fine droplet spectrum and an operating pressure of 400 kPa is suggested. Application onto a wet plant (heavy dew) can assist in coverage of the product. [2] if the dew is not so heavy as to be at the point of run off.

Table 2: *Fungicides for use in Vetch. Always read the label before use. Use higher rate for dense crops and if disease severe.*

Active ingredient and (group)	Product	Rate	Botrytis grey mould	Ascochyta blight	Rust
Mancozeb 750 g/kg (M3)	Dithane Rainshield® Neo Tec Manfil® Manzate® DF Manzeb® Mancozeb®	1.0–2.2 kg/ha	√	√	√
	Unizeb® Disperss 750 DF				
Carbendazim 500 g/L (1)	Howzat® Spin Flo® Boomer® Carazim® Carbendazim	500 mL/ha	√	-	-
Metiram 700 g/kg (M3)	Polyram DF®	1.0–2.2 kg/ha	√	√	√

Source: Pulse Australia

Check the APVMA website for up to date chemical registrations and labels.

9.1.3 Useful tools

Crop Disease Au app

The app Crop Disease Au, developed by the National Variety Trials, allows the user to quickly:

- Identify crop diseases.
- Compare disease-resistance ratings for cereal, pulse and oilseed varieties.
- Potentially, facilitate the early detection of exotic crop diseases.

The app brings together disease-resistance ratings, disease information and also features an extensive library of quality images that make it easier for growers to diagnose crop diseases and implement timely management strategies. Live feeds

2 W Hawthorne, J Davidson, K Lindebeck (2011) Australian Pulse Bulletin PA 2011 #15: Pulse seed treatments and foliar fungicides. http://pulseaus.com.au/storage/app/media/crops/2011_APB-Pulse-seed-treatments-foliar-fungicides.pdf

MORE INFORMATION

Field Crop Diseases Manual online

GrowNotes Alert™

from the Australian National Variety Trials (NVT) database means the apps is always up to date with the latest varieties.

If a disease cannot be identified there is also a function that allows the user to take a photo of their crop and email it to a friend or an adviser.

The precursor for this app was the Victorian Department of Economic Development, Jobs, Transport and Resources (DEDJTR) Crop Disease app developed by a team of grains pathologists. Crop Disease Au functions similarly to the old app, but provides information for all Australian grain-growing regions.

9.1.4 GrowNotes Alert™

GrowNotes Alert is a free nationwide system for delivering urgent, actionable and economically important pest, disease weed and biosecurity issues directly to you, the grower, adviser and industry body, the way you want. Real-time information from experts across Australia, to help growers increase profitability.

A GrowNotes Alert notification can be delivered via SMS, email, web portal or via the iOS App. There are also three by dedicated regional Twitter handles – @GNAlertNorth, @GNAlertSouth and @GNAlertWest – that can also be followed.

The urgency with which alerts are delivered can help reduce the impact of disease, pest and weed costs. GrowNotes Alert improves the relevance, reliability, speed and coverage of notifications on the incidence, prevalence and distribution of these issues within all Australian grain growing regions.

9.2 Ascochyta blight

Ascochyta blight is the most economically damaging disease of pulses, with an estimated cost to the Australian industry of more than $120 million in annual disease control and yield loss. [3]

Ascochyta occurs in earlier stages of vetch crop development and can reduce grain and dry matter production. [4]

Seed discoloured as a result of ascochyta infection is often heavily discounted in price and may be rejected by some buyers. Ascochyta is favoured by cool, wet conditions and is likely to be a problem in years with wet winter conditions and in high rainfall areas.

The disease is characterised by dark leaf spots show through both sides and become grey with age. Leaf spots are circular, becoming elongated; with pale centres may fall out leaving holes in leaf. Tiny black fruiting bodies develop within lesions.

Herbicide damage (particularly simazine) can be mistaken for Ascochyta blight but is usually confined to leaf margins and spots do not have grey centres with black specks.

Stems develop elongated, dark, sunken lesions; stems may split and break, causing plants to lodge.

Pods develop black, sunken lesions, which can penetrate the pod and infect the developing seed. Badly infected seeds have brown or black stains.

Ascochyta first appears on leaves of seedlings when wet, cold conditions occur, usually well before flowering. Progresses to infect upper leaves, flowers, stems and pods. Infection on mature pods leads to seed staining, especially when late rains occur preharvest.

The disease can develop on pods of windrowed crops.

3 GRDC. GroundCover Issue 116: Nationally coordinated effort to tackles ascochyta blight of pulses. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-supplements/ground-cover-issue-116-foliar-fungal-diseases-of-pulses-and-oilseeds/nationally-coordinated-effort-to-tackle-ascochyta-blight-of-pulses

4 L Sigel, J Brand, J Fanning, H Richardson (2017) Pulse Disease Guide 2017. Agriculture Victoria. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/pulse-disease-guide

MORE INFORMATION

GRDC Trials

9.2.1 Varietal resistance or tolerance

Woolly pod vetch variety RM4⚘ has the highest resistance to ascochyta blight with a rating of moderately resistant. All other woolly pod vetch, purple vetch and common vetch varieties are rated as moderately susceptible or susceptible to ascochyta blight.

For varietal disease ratings to ascochyta blight in vetch, see Table 1.

9.2.2 Conditions favouring development

Ascochyta blight can be both seed and stubble borne. Wind borne spores from infected stubbles can blow into adjacent paddocks and infect new crops. Infection can occur at any stage of plant growth, but is more significant during late flowering and pod fill. Rain splash spreads spores onto new crop growth within the crop, including pods.

Seed can remain infected for several years. Sowing infected seed can give rise to infected seedlings, and the appearance of symptoms at the seedling stage. Previously infected stubble is an important source of fungal inoculum. Spores are produced on old stubble and are spread to plants by rain splash. Further spread from plant to plant within crops then occurs through rain splash. The development of ascochyta blight epidemics is largely determined by the prevailing environmental conditions, especially the presence of moisture. Infection can occur at any stage of plant growth. Wet conditions late in the season, provides ideal conditions for pod infection which can result in seed discolouration. [5]

9.2.3 Management of disease

Ascochyta blight management begins with the use of disease-free seed. Test retained seed if there is any doubt about the disease status of the seed. Sow into paddocks that are free of infected stubble and avoid close rotations of vetch in the same paddock. Vetch has limited resistance to ascochyta so it is recommended that it is not sown in paddocks with history of the disease. If vetch must be sown, use varieties that have higher resistant ratings e.g. RM4⚘ (MR).

Destroying infected stubble by grazing and cultivation will reduce disease risk by minimising the number of spores available to infect new crops. Infected self-sown vetch volunteers that may germinate over summer must also be controlled to prevent carry-over of the disease.

Follow the recommended regional sowing rates and sowing dates. Avoid early sowing at high seeding rates as this increases exposure of seedlings to the ascochyta pathogens and produces crops with a large canopy, increased lodging and high humidity; all of which increase the risk of developing disease.

Fungicidal seed dressings registered for use on ascochyta blight, when applied correctly, will control seed-borne disease and protect young plants from early infection. Where seed is to be inoculated, apply the fungicide first and allow to dry. Apply the inoculum immediately prior to sowing. Fungicides and inoculant should never be mixed together.

Check the APVMA website for up to date chemical registrations and labels.

Detection

Monitor vetch for disease throughout the growing season but especially for ascochyta during the earlier growth stages.

When inspecting crops, look for signs of wilting in upper foliage and small areas of dead or dying plants. Check in a range of locations across the field following a 'V'

5 T Bretag, L Sigel. (2016). Ascochyta blight of lentil. Agriculture Victoria. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/ascochyta-blight-of-lentil

MORE INFORMATION

Ascochyta to be assess in Predicta®B tests.

or 'W' pattern. Spend at least 1 to 2 hours inspecting each crop for ascochyta blight. Ensure good hygiene when moving between crops and farms. [6]

If ascochyta is detected in any crop rotation actions should be taken to reduce the risk of the disease in the following crop.

New South Wales and Queensland growers can now potentially make more informed decisions on paddock selection in future seasons now that the DNA-based soil test Predicta® B will incorporate a test for *Phoma rabiei* (Ascochyta blight). [7]

9.3 Botrytis Grey Mould

Botrytis grey mould is a foliar disease caused by the fungal pathogen *Botrytis cinerea*. Botrytis grey mould (BGM) has been reported in many pulse growing countries of Asia and America but appears to be more severe in Australia. Flowers are especially vulnerable to BGM infection. *B. cinerea* does not infect cereals or grasses.

Botrytis Grey Mould can reduce grain and dry matter production in vetch in cool/wet growing seasons with high amounts of vegetative growth.

In the Northern region, *B. cinerea* has been recorded on over 138 genera of plants in 70 families. Legumes and asteraceous plants comprise approximately 20% of these records. As well as being a serious pathogen, *B. cinerea* can infect and invade dying and dead plant tissue. This wide host range and saprophytic capacity means inoculum of *B. cinerea* is rarely limiting. If conditions favour infection and disease development, BGM will occur.

B. cinerea also causes pre- and post-emergent seedling death. This happens when seed infected during a BGM outbreak, is used for sowing. Seedling disease does not need the wet conditions that are usually required for infection and spread of BGM later in the crop cycle. [8]

9.3.1 Varietal resistance or tolerance

There is little difference between vetch varieties in their resistance to BGM; varieties like Morava⦹, which produce greater levels of vegetative growth and denser canopies, will be more prone to this disease in higher rainfall areas.

All vetch varieties are rated as susceptible or very susceptible to Botrytis grey mould (see Table 1).

9.3.2 Conditions favouring development

Factors that favour infection and spread of BGM in favourable seasons include:

- early sowing (mid-April to early May) and narrow rows
- frequent overcast, showery weather
- limited supply of effective fungicides
- lack of BGM tolerant/resistant varieties

High biomass crops and early canopy closure often results in high in-crop humidity and poor penetration of fungicides. If the crop becomes lodged the situation is exacerbated.

Rainy weather not only favours the disease but wet paddocks also limit the spray opportunities for ground rigs.

6 Pulse Australia (2009) Northern Pulse Bulletin: Ascochyta blight detection in chickpea. http://www.pulseaus.com.au/storage/app/media/crops/2009_NPB-Chickpea-Ascochyta-ID-manage.pdf

7 S Jeffrey (2017) Ascochyta to be assessed in Predicta®B tests. GRDC. https://grdc.com.au/news-and-media/news-and-media-releases/north/2017/04/ascochyta-to-be-assessed-in-predicta-b-tests

8 M Ryley, K Moore, G Cumming, L Jenkins (2015) Australian Pulse Bulletin – Chickpea: Managing Botrytis Grey Mould. Pulse Australia. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

Following a season where widespread BGM infection has occurred in a district there is often a shortage of disease-free seed for planting and there is a high quantity of infected crop residue across a large area. Both of these factors will increase the disease risk for the following year. Whether BGM becomes a problem the following year will depend on seasonal conditions. [9]

9.3.3 Management of disease

Stubble management

It is likely that the pathogen can remain viable and capable of survival for as long as infected stubble remains on the soil surface. Burial of stubble removes the ability of *B. cinerea* to produce spores that can be blown around, and increases the rate of stubble breakdown by soil microbes.

Although burning of infected residues will also significantly reduce the amount of infected residues on the soil surface, it will not guarantee freedom from BGM in the following season.

Burying or burning stubble can significantly increase the risk of soil erosion and reduce water infiltration.

Volunteer control (the green bridge)

Volunteer plants growing in or near paddocks where BGM was a significant problem are a likely method of carry-over and must be managed by application of herbicide or cultivation. This will also reduce carryover of ascochyta

Seed source and treatment

Obtain seed from a commercial supplier, or from a source known to have negligible levels of BGM. Irrespective of the source, all seed must be thoroughly treated with a registered fungicide seed dressing. Thiram based fungicide seed dressings are effective in significantly reducing, but not entirely eliminating, BGM from infected seed.

In areas where there may be a risk of BGM, sow varieties with higher resistance to the disease (see Table 1).

Seedling emergence

Research on harvested seed has shown a germination test does not accurately predict emergence. Accordingly, growers are advised to conduct their own emergence test, as follows:

- After grading and treatment, sow 100 seeds at least 5 cm deep in the paddock that you intend for sow for the season and water if necessary.
- Count the number of seedlings that have emerged after one, two and three weeks and note their appearance. Note if they look healthy or if they are stunted and distorted.
- To get an idea of variability in emergence and the paddock, replicate the test; i.e. sow 100 seeds in 3–4 different locations in the paddock. This will also help identify potential herbicide residue problems.

Paddock selection

Paddocks in which crops were affected by BGM should not be re-sown to pulses in the following season. Nor should vetch be sown beside paddocks where BGM was an issue the previous season.

Vetch should be grown as far away from paddocks in which BGM was a problem as is practically possible.

9 M Ryley, K Moore, G Cumming, L Jenkins (2015) Australian Pulse Bulletin – Chickpea: Managing Botrytis Grey Mould. Pulse Australia. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

However, under conducive conditions, this practice will not guarantee that crops will remain BGM free, because of the pathogen's wide host range, ability to colonise dead plant tissue, and the airborne nature of its spores.

Sowing time and row spacing

If long-term weather forecasts suggest a wetter-than-normal year (e.g. La Nina), consider sowing in the later part of the suggested sowing window for your district and on wider rows (e.g. 100 cm). Planting on wider rows results in increased air movement through the crop and reduced humidity within the canopy.

Fungicide application and timing

In seasons and situations favourable to the disease, a preventative spray of a registered fungicide immediately prior to canopy closure, followed by another application 2 weeks later, will assist in minimising BGM development in most years.

If BGM is detected in a district or in an individual crop, particularly during flowering or pod fill, a fungicide spray should be applied before the next rain event.

None of the fungicides currently registered for the management of BGM have eradicant activity, so their application will not eradicate established infections. Consequently, timely and thorough application is critical. [10]

Check the APVMA website for up to date chemical registrations and labels.

9.4 Rusts

Rust, caused by the pathogen *Uromyces viciae-fabae*, is a serious disease of vetch in New South Wales and Queensland. Rust is found most commonly from mid spring.

Rust is not usually a problem every year in the southern part of the Northern region, and often occurs in years with good spring rainfall and mild temperatures.

9.4.1 Varietal resistance or tolerance

Morava⦹, Rasina⦹, Volga⦹ and Timok⦹ are resistant to rust and are the preferred varieties for grain in areas prone to rust infections (see Table 1).

9.4.2 Damage caused by disease

Rust epidemics can significantly reduce vetch yields. Care must be taken when growing rust susceptible varieties as grazing or feeding hay/silage from rust infected plants may induce abortions in pregnant livestock.

9.4.3 Symptoms

On the leaves there are numerous small, orange- brown pustules each surrounded by a light-yellow halo (Photos 1 and 2). As the disease develops, severely infected leaves wither and may fall from the plant. On stems, the rust pustules are similar, but often larger, than those on the leaves. Isolated rust pustules may appear on the pods. Severe infection may cause premature defoliation, resulting in reduced seed size. [11]

10 M Ryley, K Moore, G Cumming, L Jenkins (2015) Australian Pulse Bulletin – Chickpea: Managing botrytis grey mould. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

11 CropPro (2014) Rust of Faba Beans. http://www.croppro.com.au/crop_disease_manual/ch06s06.php

Photo 1: *Rust spores on vetch leaves and stem.*

Photo: Stuart Nagel

Photo 2: *Visible rust infection on the underside of vetch leaves.*

Photo: Stuart Nagel

9.4.4 Conditions favouring development

The rust fungus survives on stubble and self-sown volunteer plants. The teliospores produced can infect volunteer plants directly without the need for an alternate host. Infection of volunteer plants is thought to be an important factor in the early development of rust epidemics. Rust spores from stubble and volunteers are blown onto new crops by the wind and infect plants. New spores form in rust pustules on infected plants. Secondary spread of the disease occurs when these spores become air-borne and then spread to other plants, (Figure 1).

Rust commonly occurs late in the growing season during podding, resulting in premature leaf drop which can reduce seed weight and size. Humid and warm conditions (more than 20°C) promote its spread. [12]

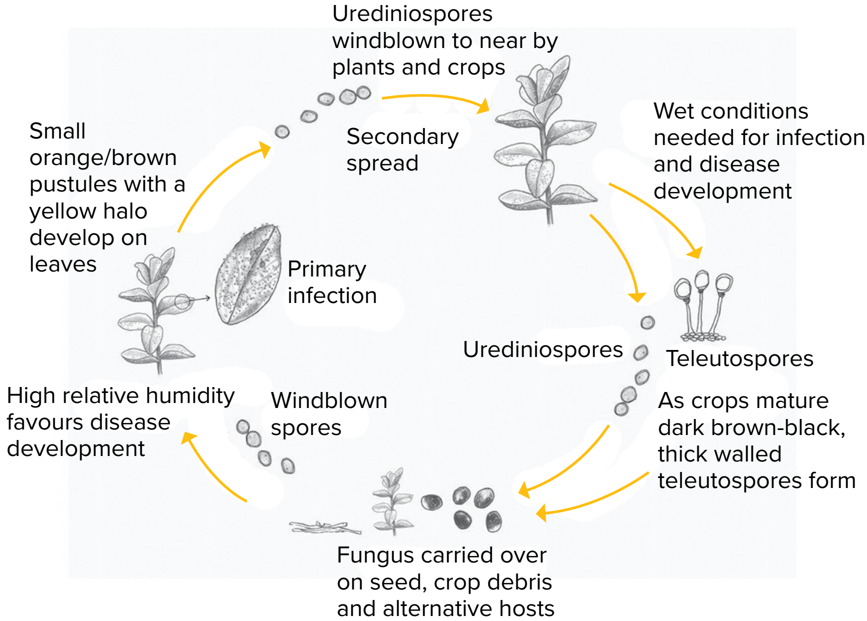

Figure 1: *Disease cycle of rust on legumes.*

Illustration by Kylie Fowler

9.4.5 Management of disease

Because the spores of the fungus can travel long distances to infect a new crop, disease prevention is difficult but awareness is key.

Paddock Selection

A break of at least three years between vetch crops is recommended. Aim for a separation of 250m from the previous year's vetch paddock. Do not sow adjacent to last year's vetch stubble.

Variety Selection

A number of vetch varieties are currently available with improved resistance to rust (see Table 1).

12 CropPro (2014) Rust of Faba Beans. http://www.croppro.com.au/crop_disease_manual/ch06s06.php

Fungicide control and timing

While it is usually not economically viable to use fungicides for rust on vetch, it may be necessary where rust susceptible varieties are to be used as feed.

Foliar fungicides can be used to control the disease and prevent a rust epidemic developing. Crops should be monitored closely if warm (around 20°C) temperatures and very high humidity occur.

Successful fungicide application relies on crop monitoring and timeliness of application with the right product effective against rust. Several products are registered for use against rust. [13]

For fungicides registered for control of rust in vetch, see Table 2.

Check the APVMA website for up to date chemical registrations and labels.

9.5 Viruses

MORE INFORMATION

PulseAaustralia - Managing viruses

Vetch can be a host to a number of aphid species, most commonly the cowpea and pea aphid. These aphids can spread viruses between and within different pulse crops. Viruses can be a problem in vetch, especially in years that favour aphid movement. All viruses that affect pulse crops in the Northern region have been found to affect common vetch varieties as well. Though there have not been trials dedicated to vetch varietal resistance and tolerance to viruses, there have been observation in the severity and incidence of viruses. [14]

9.5.1 Symptoms

Viruses differ from most fungal diseases in that they infect plants systematically and no curative treatment is available. Virus infections are spasmodic and levels depend heavily on seasonal conditions and differ greatly between years and locations. Early infection can lead to stunting, reduced tillering and plant death and losses can be high. Late infections have less impact, but can still affect seed quality.

Pulse viruses are transmitted either in a persistent or non-persistent manner by insects (mostly aphids). The mode of transmission has implications for the way a virus develops in the field and its management.

Plants grown from infected seed are stunted with pale, bunched, down-curled, faintly mottled leaves. Plants infected by aphids during the season exhibit similar symptoms on plant parts that emerge following infection, older leaves present before infection remain healthy. Pod set and seed size are both reduced in infected plants. [15]

9.5.2 Conditions favouring development

Rainfall in summer and autumn has a major effect on virus infections in crops. High rainfall during this period leads to a build up of weed hosts for viruses and the growth of self sown pulses. Aphids are also favoured by a wet summer and autumn. Aphid population development is strongly influenced by local conditions. Early breaks and summer rainfall favour early increases in aphids and volunteers that host viruses, resulting in a higher level of virus risk. These conditions can lead to an early infection which can then have a major impact on growth and yield. [16]

13 CropPro (2014) Rust of Faba Beans. http://www.croppro.com.au/crop_disease_manual/ch06s06.php

14 Joop van Leur (2017) NSW DPI. Personal Communication.

15 G Thomas, B Coutts (2016) Lupin foliar disease: diagnosis and management. DAFWA. https://www.agric.wa.gov.au/lupins/lupin-foliar-diseases-diagnosis-and-management

16 GRDC (2010) Aphids and viruses in pulse crops – Fact sheet. https://grdc.com.au/__data/assets/pdf_file/0019/205642/aphidsvirusesfactsheets.pdf.pdf

9.5.3 Management of viruses

Sow early at high seeding rates using narrow row spacing to promote early crop canopy coverage into standing stubble. This deters aphids from landing and shades over the seed-infected and early infected plants, denying aphids access to them.

Direct drill into retained stubble. Ground cover reduces aphid landing rates before a crop canopy develops, especially with wide row spacing.

Minimise the pool of potentially virus-infected plant material near crops by controlling the green bridge of weeds, pastures and volunteer pulses that can harbour viruses and aphids over summer or between crops. This includes weeds around dams, tracks and the margins of crops. Isolate from neighbouring crops that could be a source of infection.

Some species of aphids are attracted to areas of bare earth. Use minimal tillage and sow into retained stubble, ideally inter-row to discourage aphid landings.

Controlling aphids

Monitor crops and neighbouring areas regularly. Identify the species of aphid present and their numbers.

Beneficial insects – including hover flies, lacewings, ladybirds and parasitic wasps – will attack aphids and assist in preventing aphid levels from increasing. Beneficial insects can help reduce virus spread and spring feeding damage, but some virus spread will have occurred before aphid numbers subside. The risk of non-persistently transmitted viruses can be reduced by an integrated disease management approach applied prior to seeding that includes a range of crop hygiene and management measures.

Insecticide applied as seed dressings will help control aphid attack and the spread of viruses. Foliar insecticides applied soon after crop emergence can help control persistently transmitted viruses, but are of little benefit against non-persistently transmitted viruses. Preferably use a 'soft' insecticide, that targets the aphids and leaves beneficial insects unharmed. [17]

MORE INFORMATION

Aphids and viruses in pulse crops.

Managing viruses in pulse crops

Managing Viruses in Pulses

17 GRDC (2010) Aphids and viruses in pulse crops – Fact sheet. https://grdc.com.au/__data/assets/pdf_file/0019/205642/aphidsvirusesfactsheets.pdf.pdf

Plant growth regulators and canopy management

Not applicable for this crop.

Crop desiccation/spray out

Key messages

- Vetch is suited to crop-topping due to its early maturity. Desiccation is not recommended in vetch.
- Do not desiccate crops intended for seed.
- Timing of crop-topping is important to ensure good weed control and to limit yield losses to the crop.
- Check labels before application and adhere to necessary withholding periods.

Crop-topping and desiccation are well established techniques to improve the rotational fit, benefits and profitability of the pulse crop. While they are essentially the same physical operation of applying a desiccant herbicide close to final maturity of the pulse, they do achieve different objectives and must be applied with care.

Desiccation is not recommended in vetch, however, due to its early maturity, vetch can be crop-topped.

Crop-topping (for weed control) or desiccation can ensure a quicker and more uniform ripening of the crop. Plants growing in wheel tracks may ripen later and usually need to be desiccated for harvest. Timing of desiccation or crop-topping is critical for grain quality because premature desiccation of wheel tracks or later maturing areas in a paddock can lead to grain quality issues in the harvested sample (e.g. green kernel or stained seed coats). [1]

There are three reasons to apply non-selective herbicides late in the season:

1. just prior to harvest to manage late season weeds;
2. in-crop spray topping of annual ryegrass and other weed species to prevent seed set; and
3. for pre-harvest desiccation of the crop to accelerate or even up ripening to assist with harvest.

Pulse species differ in their time to maturity, making some unsuitable for crop-topping. Crop-topping is conducted before the target weed species mature, later maturing pulse species will be adversely affected.

The application of herbicides late in the season to prevent weeds setting seed or to desiccate crops must be carried out with caution and in line with herbicide label recommendations. It is essential to check if these practices are acceptable to buyers, as in some situations markets have extremely low or even zero tolerance to some pesticide and herbicide residues.

In-crop spray topping with paraquat or glyphosate in pulse crops and pastures is an effective strategy for controlling a range of annual grasses. it should be used as a tool with other integrated weed management (IWM) techniques such as cutting crops for hay, breakcrops and green and brown manuring. Timing of application and rates of product are crucial to maintaining crop yield while reducing ryegrass seeds.

The yield of most pulse crops is not reduced if crop topping is delayed until seeds in the top pods are 75% of their full size. However, given the goal of in-crop spray topping is to achieve effective ryegrass control, growers need to strike a balance between optimal timing for ryegrass control (which is often earlier) and yield loss. Of all legumes, early maturing peas are most suited to in-crop spray topping. [2]

MORE INFORMATION

Late season herbicide use factsheet.

1 Pulse Australia. (2015). Lentil production: Southern region. http://pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

2 GRDC (2010) Late season herbicide use Factsheet. http://www.goodfoodworld.com/wp-content/uploads/2017/09/GRDC_LateSeasonHerbicideUse_FS.pdf

11.1 Application

Timing is critical. If the crop is desiccated too early, seed size may be reduced and the sample quality impaired by the presence of green cotyledons.

The ideal timing for crop-topping occurs when the vetch seeds have reached 30% moisture, or when the lower 75% of pods are brown with firm seeds and leathery pods. It is also important to consider the maturity of weeds.

Spray the crop when the ryegrass is at the optimum stage, that is when the last ryegrass seed heads at the bottom of the plant have emerged and the majority are at or just past flowering (with anthers present or glumes open) but before haying off is evident (Photo 1).

Photo 1: *Preventing seed set on all ryegrass escapes is the aim when croptoping pulses.*

Source: Pulse Australia

Paraquat 360 g/L (Gramoxone®360 Pro) is registered for harvest aid or salvage spraying in vetch. A high water rate of 100Litres/ha or higher is essential for an effective spray out job.

Paraquat

Optimum timing for ryegrass control is approximately 10 days after flowering. Spray when as many pods as possible have fully developed seeds although pods may still be green. The higher rate of paraquat can give more reliable control of ryegrass, but can cause yield loss. [3]

Table 1: *Crop-topping to reduce the seed set of annual ryegrass. product registrations for pre-harvest weed control and desiccation Vary by crop type. always check product labels. Withholding period: DO NOT harvest for 7 days after application, DO NOT graze or cut for stock food for 1 day (7 days for horses).*

	Paraquat (e.g. Gramoxone)	
Active ingredient	250 g/L	200 g/L
Rate/ha	400–800 mL	0.5–1 L

3 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2008). Grain legume handbook. *GRDC: Canberra, ACT.*

Withholding period	Harvest	Grazing
	14 days	1 day (7 days for horses)

Source: Grain Legume Handbook

When spraying, use extreme caution and carefully consider the possibility of spray drift onto susceptible plants – e.g. cotton, canola, lucerne, grapevines, horticultural crops, belah and kurrajong trees.

11.2 Vetch termination timing

The optimum time to terminate vetch to achieve the greatest benefit for the following wheat crop is an important management decision. Finding the balance between early termination for soil water conservation as opposed to later termination for greater biomass production and nitrogen fixation for the benefit of the next crop is not always simple.

Seasonal conditions, crop growth, weed spectrum and livestock feed requirements are all factors that can influence the decision of when to terminate vetch growth.

Trials from 2012–2014 in southern Australia found that early termination of vetch resulted in higher soil N and soil water at sowing the following year compared with later termination timings of vetch. When vetch is established in March and is terminated 'early' (three to four months later, in June, July), soil water will be conserved for the subsequent wheat crop; the risk of haying off due to high nitrogen will be lower than if the vetch were terminated 'later' (August, September).

Wheat yield in the year following vetch was highest for the earlier termination timings of the vetch. Brown manure vetch had higher soil N and soil water compared to vetch taken through to harvest. Regardless of sowing time, approximate vetch biomass production of 2 t/ha (up to 120 kg N/ha of total plant N produced if no losses occur) may be a good target if a wheat crop is to follow and a dry season is forecast (Decile 3 or less). However, variation in seasonal conditions, soil type and livestock need to be considered. In dry seasons, residual mineral nitrogen from vetch brown manure can influence cereal crop growth in the following two years. However, this trial demonstrates that soil water is more critical than nitrogen in Decile 1 and 2 rainfall years. [4]

MORE INFORMATION

Vetch termination 2012–2014 end use treatment

Vetch termination: finding a compromise

4 D Ferrier, L Goward, M Peoples (2014) Vetch termination. Birchip Cropping Group. Online Farm Trials. http://www.farmtrials.com.au/trial/17638

Harvest

Key messages:

- Harvesting vetch is easily achieved by using cereal harvesters with crop lifters. [1]
- Grain quality and prices can suffer if there is mechanical damage, weathering and seed staining. Moisture levels at harvest also affect the quality of grain in storage.
- To reduce the risk of shattering and seed quality reduction, aim to harvest vetch within the optimum sowing window.
- Fire prevention is important when harvesting pulses. Ensure to regularly remove flammable material from the engine bay.
- Harvest weed seed control is an increasingly important Integrated Weed Management strategy in the Northern region.

12.1 Windrowing

Windrowing or swathing involves cutting the crop and placing it in rows held together by interlaced straws, supported above the ground by the remaining stubble. It can be considered as an option where:

- the crop is uneven in maturity, or the climate does not allow for rapid drying of the grain naturally
- there is a risk of crop losses from shedding and lodging

The long, twining stems of vetch can make it difficult to form into conventional windrows by raking, but a slasher/windrower can be used instead. [2]

Windrowing enables growers to:

- Avoid pod shatter and drop crops resulting in increased harvest yield
- Avoid problems where the header reel gets in the way of tall crops during harvest
- Avoid green material such as late weeds which can contaminate the grain and cause problems during storage due to high moisture.
- Manage very slow and unevenly ripening crops in mild seasons
- Increase header efficiency.

Windrowing should be used as an optional management tool rather than an essential crop practice.

Windrowing for weed management

Windrowing can be used to help reduce seed set of weeds such as annual ryegrass, saffron thistle and wild radish. Growers must be aware that some weed seed may be mature before the crop matures. Crops windrowed to maximize weed control generally incur a yield penalty.

Alternatively, an additional form of control following harvest can be used to effectively manage weeds. Options include use of a knockdown herbicide post-harvest, and the removal of straw spreaders from headers followed by burning header tracks with a hot burn (windrow burning). When windrowing a very weedy crop, windrowing should be delayed as long as possible to reduce the risk of regrowth causing problems in the windrows.

1 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

2 DPI NSW. Namoi Woolly pod vetch. http://www.dpi.nsw.gov.au/agriculture/pastures-and-rangelands/species-varieties/namoi-woolly-pod-vetch

12.1.1 Timing

Correct windrow timing is essential. If crops are windrowed too early, yield will be sacrificed and quality will be reduced due to a high number of shriveled seeds. Leaving it too late will result in a high risk of pod shattering and pods being knocked off during the windrowing operation.

To properly judge the crop maturity, sample from a number of sites within the paddock. In practice, the correct time can be difficult to determine.

Windrowing should occur when the pods are passed physiological maturity and are in the dry-down phase.

12.2 Harvesting issues

Key points:

- Harvesting at the optimum moisture content means fewer grain defects. Premium prices come from harvesting at the optimum moisture.
- Harvest early before summer weeds become a problem to reduce clogging, staining and sample contamination. Desiccating the crop will kill summer weeds and ensure even crop ripening.
- Vetch can be prone to shattering, so harvesting at the right time is important.
- Sowing the vetch with 15 kg oats/ha can help lift the vetch off the ground and aid harvesting. [3]
- Crops sown into standing stubble will be easier to harvest

12.2.1 Harvest timing

Timely harvest is critical to avoid yield and quality losses from severe weather events at or just before harvest. Some pulse crops and varieties within crops are more prone to lodging, shattering and/or pod drop at maturity particularly if rain or strong wind occurs once mature. This can result in grain loss and harvesting difficulties. Yield losses increase the longer harvest is delayed.

Timing can often coincide with cereal harvesting so priorities must be set with the most valuable commodity harvested first. Cereal crops can be left standing in the paddock when mature with little deterioration of quality if rainfall does not occur, vetch on the other hand will decline in quality and harvestability once their moisture content declines. Vetch, if ready, should also have precedent over windrowed canola

Harvesting vetch with a low moisture content in the middle of a hot day is a recipe for disaster. Not only can the grain crack once in the header or with subsequent handling there after, but grain can be lost at the front of the header as it can shatter when the knife hits it and not even get into the header.

Many late-harvested crops are often about 8% moisture, whereas the maximum moisture content for receival is 14% with market preference at 12%. [4]

12.2.2 Weathering and mould

Weathering of seed caused by delayed harvesting can increase mould infection. *Alternaria* mould species usually predominate, while *Aspergillus*, *Cladosporium* and *Penicillium* species may also be present.

Humid (above 70% relative humidity), wet conditions favour the development of a range of fungi in late-harvested crops.

Increased risk of late ascochyta infection can develop on dry, senescing pods under wet conditions, and can penetrate through to the seed in susceptible varieties.

MORE INFORMATION

Agriculture Victoria - Estimating Crop Yields And Crop Losses

GRDC - Careful Harvester Set Up

3 QLD DAFF (2011) Vetches in southern Queensland. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

4 T Weaver (2015) GroundCover Issue 118: Profitable pulses – it's all about the harvest window. GRDC. https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-118-sep-oct-2015/profitable-pulses-its-all-about-the-harvest-window

Darkening of the seed coat is caused by oxidation of polyphenol compounds (tannins). Conditions that accelerate seed-coat darkening include rainfall, cool-to-mild temperatures, high humidity and sunlight.

Native budworm can occasionally attack senescing pulses, particularly where rainfall has softened the pod. Insect-damaged seeds are classified as defective and cannot exceed the tolerance level of 3%. The current export receival standard for visible ascochyta lesions is a maximum of 1% on the seed cotyledon (kernel).

For more information on receival standards, see Section 12.5 Receival standards, below.

Grain quality deteriorates the longer mature pulses are exposed to weather.

Expansion of the seed as it absorbs moisture and then contraction as it dries weakens the seed coat, rendering seed more susceptible to mechanical damage during harvest.

Levels of cracked and damaged grain can be as high as 50% in extreme cases of weathering and prolonged rainfall. Vetch can be prone to shattering (Table 2). Harvesting grain at high moisture levels (up to 14%) minimises cracking.

Early harvested pulses are more resilient to breakage during harvesting and subsequent handling.

Table 1: *Vetch varietal risk of pod shattering.*

Variety	Pod shattering (%)
Common vetch	
Blanchefleur	5–10
Cummins	5–10
Morava⍉	0
Rasina⍉	0–2
Volga⍉	0–2
Timok⍉	0–2
Purple Vetch	
Popany	20–30
Woolly pod vetch	
Haymaker⍉	5–10
Capello⍉	5–10
RM4⍉	2–5

Source: SARDI

12.3 Harvester settings

Setting up header front and drum speeds correctly improves pulse quality. Pulses are easily threshed, so open the concave clearance and reduce the drum speed (Table 2).

Pulses are larger than wheat so a concave with many wires or blanked-off sections can stop grain separation. For best performance, remove alternate wires and blanking-off plates. A clean sample can be achieved with maximum wind settings and barley sieve settings.

Take extra care when harvesting pulses for seed to reduce grain cracking. Gentle harvesting will give the best seed quality. Rotary harvesters are gentler on the crop and will generally cause less grain damage than conventional harvesters.

Vetch threshes easily but can be prone to cracking so adjust thresher speed (400 to 600 revolutions per minute) and concave (10 to 30 millimetres) to suit. Removing alternate wires and blank-off plates from the concave will help reduce cracking. If possible cover the rasp bars with plate.

Table 2: *Harvester settings for vetch.*

Setting	Vetch
Reel speed	Slow
Spiral clearance	Low
Thresher speed	400 to 600rpm
Concave clearance	10 to 30 mm
Fan speed	Medium
Top sieve	25 mm
Bottom sieve	10 to 16 mm
Rotor speed	Slow

Source: GRDC

12.3.1 Modifications and aids

Early harvesting can solve many problems and losses are reduced as the pods are less prone to shattering or dropping. The crop is also easier to gather because it stands more erect, allowing the harvester front to operate at a greater height and reducing the dirt, rocks and sticks entering the harvester.

A straw chopper may be of value to chop up the stubble and spread it uniformly. Crop lifters are not required unless the crop is badly lodged or late-sown and drought-affected. Set the finger tyne reel to force material down onto the front. For example, moving the broad elevator auger forward can improve the feeding of light chickpea material.

Vibration due to cutter bar action, plant on plant, reel on crop impact and poor removal of cut material by the auger all cause shattering and grain loss. Grain loss can be reduced by harvesting in high humidity or at night to minimise pod shattering. Avoid harvesting in extreme heat.

Finger reels are less aggressive than bat reels and cause fewer pod losses. Double-acting cutter bars reduce cutter-bar vibration losses. Four finger guards with open second fingers also reduce vibrations (Photo 1).

Photo 1: *Finger tyne reel with four finger guards and pen second fingers to reduce vibrations.*

Source: GRDC

12.4 Fire prevention

Key points:

- Most harvester fires start in the engine or engine bay
- Others are caused by failed bearings, brakes and electricals and rock strikes
- Regular removal of flammable material from the engine bay is urged
- More regular clean downs with a high pressure air compressor are required. This may be as often as each stop at the chaser bin.

Harvesting season in Australian cropping areas is the most stressful time for farmers as they glean finished crops. Ideally, harvest occurs under hot dry conditions, but the risk of fire is extreme and a fire can damage crops, machinery and property, not to mention the lives of the community as well.

With research showing an average of 12 harvesters burnt to the ground every year in Australia (Photo 2), agricultural engineers encourage care in keeping headers clean to reduce the potential for crop and machinery losses. [5]

A review of the causes of header fires concluded that 75% of the fires started in the engine bay and others from failed bearings, electrical problems and rock strikes. [6]

Photo 2: *GRDC figures show that there are 1000 combine harvester fires in Australia each year.*

Source: Weekly Times

Many of the pulse crops come with an increased fire risk because of certain characteristics of the residues.

All of these pulse crop residues may well have much lower ignition temperatures than cereal crops. When harvesting, more regular clean downs with a high pressure air compressor is required.

The proximity of flammable material to heat sources such as exhaust manifolds and turbochargers with high ambient temperature, low humidity and windy conditions in the paddock make this an explosive situation, even under ideal conditions.

Heated ignition sources can be in different areas, including:

- around the engine bay of the header such as the exhaust manifold or the tubocharger where temperatures can get up to 650°C
- mechanical failures from bearings

5 GRDC (2012) A few steps to preventing header fires. GRDC Ground Cover Issue 101, http://www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-101/A-few-steps-to-preventing-header-fires

6 G Quick (2010) An investigation into combine harvester fires. http://pulseaus.com.au/storage/app/media/blog%20assets/HARVESTER%20FIRES%20-%20Graeme%20Quick%20-%20Final%20Report.pdf

- sparks from electrical short circuit
- striking metal fences or rocks to cause a spark
- static electricity from moving parts or operators clothing
- foreign objects that are taken into the header

Fuel sources can include:

- the dried standing crop itself
- crop residue that has been chopped finely to create an ideal fuel for instant ignition.
- flammable fuels and oils used in the header.
- dust that carries crop residue

Oxygen (air) is required for a fire to burn. Air is being blown around inside and out of the header throughout the harvesting process and is an important component of harvest fires.

Static electricity is often blamed, but the evidence shows that this is a minor risk, even though it is common to get a build up from many parts of a header. The energy to ignite crop residue is not enough in a static electrical discharge. [7]

Machinery failure is in many cases responsible for fires starting so it is critical that all growers undertake scheduled harvester operation checks and regular maintenance leading up to and throughout harvest in an effort to reduce the risk of fire. Many pre-harvest preventative maintenance checks tie into what growers already do on a regular basis, such as checking belts, hoses and wiring for damage.

Growers should also be regularly monitoring bearing operation temperatures with an infra-red thermometer to detect rapid increases in temperature, indicating imminent failure. Oil seals should also be inspected. A dripping line or weeping seal needs to be repaired prior to harvest, otherwise that could become a fire hazard.

Some growers use exhaust insulation blankets (such as those used in the mining and racing car industries), alumina-silica materials on exhausts and turbo chargers to reduce fire risk. This is an effective way of reducing fire ignition sources, but growers need to be careful with the impact such insulators could have on engine and turbo operation temperatures and any warranty implications.

Harvester hygiene is important; conduct regular clean-outs during harvest and exercise caution when harvesting leafy pulse crops, as these are renowned for dust build-up.

It is also important to have properly functioning fire extinguishers on harvesters. Machine-mounted fire suppression options on the market have come down in price so growers should consider having a fire suppression system fitted.

Abide by state-based grain harvesting codes of practice and declared harvest bans, and observe the Grassland Fire Danger Index (GFDI) protocol on high fire risk days. [8]

Harvester fire reduction checklist

1. Recognise the big four factors that contribute to fires: relative humidity, ambient temperature, wind and crop type and conditions. Stop harvest when the danger is extreme.
2. Focus on service, maintenance and machine hygiene at harvest on the days more hazardous for fire. Follow systematic preparation and prevention procedures.
3. Use every means possible to avoid the accumulation of flammable material on the manifold, turbocharger or the exhaust system. Be aware of side and tailwinds that can disrupt the radiator fan airblast that normally keeps the exhaust area clean.

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7 P Bowden (2016) Fire risk when harvesting pulses. Pulse Australia. http://pulseaus.com.au/blog/post/avoiding-harvester-fires

8 S Watt, B White. (2016). Growers focused on reducing harvester fire risk. https://grdc.com.au/Media-Centre/Media-News/South/2016/11/Growers-focused-on-reducing-harvester-fire-risk

4. Be on the lookout for places where chaffing can occur, such as fuel lines, battery cables, wiring looms, tyres and drive belts.
5. Avoid overloading electrical circuits. Do not replace a blown fuse with a higher amperage fuse. It is your only protection against wiring damage from shorts and overloading.
6. Periodically check bearings around the harvester front and the machine. Use a hand-held digital heat-measuring gun for temperature diagnostics on bearings and brakes.
7. Maintain fire extinguishers on the harvester and consider adding a water-type extinguisher for residue fires. Keep a well maintained fire fighting unit close-by to the harvesting operation ready to respond.
8. Static will not start a fire but may contribute to dust accumulation. Drag chains or cables may help dissipate electrical charge but are not universally successful in all conditions. There are some machine mounted fire-suppression options on the market.
9. If fitted, use the battery isolation switch when the harvester is parked. Use vermin deterrents in the cab and elsewhere, as vermin chew some types of electrical insulation.
10. Observe the Grassland Fire Danger Index (GFDI) protocol on high fire risk days.
11. Maintain two-way or mobile phone contact with base and others and establish a plan with the harvest team to respond to fires if one occurs. [9]

Using machinery

To preventing machinery fires, it is imperative that all headers, chaser bins, tractors and augers be regularly cleaned and maintained. All machinery and vehicles must have an effective spark arrester fitted to the exhaust system. To prevent overheating of tractors, motorcycles, off-road vehicles and other mechanical equipment, all machinery needs to be properly serviced and maintained. Fire-fighting equipment must be available and maintained—it is not just common sense; it is a legal requirement.

Take great care when using this equipment outdoors:

Be extremely careful when using cutters and welders to repair plant equipment; this includes angle grinders, welders and cutting equipment,

Ensure that machinery components including brakes and bearings do not overheat, as these components can drop hot metal onto the ground, starting a fire.

Use machinery correctly, as incorrect usage can cause it to overheat and ignite.

Be aware that when blades of slashers, mowers and similar equipment hit rocks or metal, they can cause sparks to ignite dry grass.

Avoid using machinery during inappropriate weather conditions of high temperatures, low humidity and high wind.

Do repairs and maintenance in a hazard-free, clean working area such as on bare ground, concrete or in a workshop, rather than in the field.

Keep machinery clean and as free from fine debris as possible, as this can reduce onboard ignitions. [10]

Use of fire suppression systems on the header

There are several systems that can be put on the header to prevent fires or to deal with fire if it starts.

Fire Knock Out will drench the engine bay in fire retardant using a self actuating switch.

9 Barr R. (2015). Plant of attack needed for harvester fires. https://grdc.com.au/Media-Centre/Media-News/South/2015/10/Plan-of-attack-needed-for-harvester-fires

10 NSW Rural fire Service. Farm firewise. NSW Government, http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=1161

PODCAST

LISTEN: GRDC Podcasts: Harvester Fires.

MORE INFORMATION

GRDC Reducing Harvester Fire Risk: The Back Pocket Guide

Avoiding harvester fires - pulses

An investigation into harvester fires

Plan of attack needed for harvester fires

A few steps to preventing header fires

Fire Prevention Shield reduces the temperature of the components in the engine bay by drawing air from the cooling fan through a heat exchanger, charging it to higher pressure to clean residues from around the muffler. This effectively reduces residues and temperature to lower the risk of fire. [11]

12.4.1 Harvesting in low-risk conditions

Growers can use the Grassland Fire Danger Index guide to assess the wind speed at which harvest must cease (a GFDI of 35), depending on the temperature and relative humidity (Figure 1).

Step 1: Read the temperature on the left hand side.

Step 2: Move across to the relative humidity.

Step 3: Read the wind speed at the intersection. In the worked example, the temperature is 35°C and the relative humidity is 10% so the wind speed limit is 26kph.

TEMP °C	5	10	15	20	25	30	40	50	60	65	RH%*
15	31	35	38	40	43	45	49	53	56	58	AVERAGE WIND SPEED (KPH)†
20	29	33	36	38	40	43	46	50	53	55	
25	27	30	33	36	38	40	44	47	50	52	
30	25	28	31	33	35	37	41	44	47	49	
35	23	26	28	31	33	35	38	41	44	46	
40	21	24	26	28	30	32	35	39	41	43	
45	19	22	24	26	28	30	33	36	39	40	
TEMP °C	5	10	15	20	25	30	40	50	60	65	RH%*

*RH% (Relative Humidity rounded down)
†Wind speed averaged over 10 minutes

Figure 1: *Grassland fire danger index guide.*

Source: CFS South Australia

12.5 Receival standards

Pulse receival and export standards are set nationally by the pulse industry to ensure that market requirements for major end-users are able to be achieved.

The Australia Pulse Standards Committee compiles trading Standards through extensive consultation with all sectors of the Australian pulse industry.

Vetch should be whole, sound, dry, fresh and colour typical of the variety of the season (Table 3).

All pulses must be free from animal excreta, rodents, live insect pests and any chemical not registered for use on stored pulses or in excess of legal tolerances. There is nil tolerances on pickling compounds/seed dressings or any fungicide added to the pulse as a seed dressing and any tainting agents and/or other contaminants imparting an odour not normally associated with that particular pulse.

There is nil acceptance of toxic and/or noxious weed seeds which are prohibited by state laws against inclusion in stock feed.

It is understood that as Minimum Standards they may not be tight enough for the requirement of some buyers. Suitable qualifications to any Standard can be made

11 P Bowden (2016) Fire risk when harvesting pulses. Pulse Australia. http://pulseaus.com.au/blog/post/avoiding-harvester-fires

MORE INFORMATION

Receival and trading standards

Australia Pulse Standards 2016/2017

as agreed between all parties concerned to represent the basis for better quality consignments.

It should also be understood that these are Australian Industry Standards and do not take into account specific overseas country quarantine restrictions (such as prohibited weed seeds, disease status or contaminant levels) or the requirements of the Export Control Act (1982) and its subordinate legislation.

Individual commodity traders are responsible for ensuring that specific country requirements and those pertaining to compliance with the Export Control Act (1982) are included as additional specifications on the contract.

Table 3: *Vetch receival standards.*

Receival standard	Value	Comments
Moisture content max	14%	Aerate if 12%
Purity minimum	97%	Includes whole Vetch, Defective Vetch, skins and de-coated Vetch.
Defective maximum	5%	Vetch not of the specified variety. Vetch kernels that are broken, chipped, diseased, frost damaged, insect damaged, sappy, shrivelled, split, sprouted, weather damaged, wrinkled. Includes pods that contain Vetch, whether broken or unbroken and loose seed coat. Vetch where whole or part of the seed coat only is damaged, is included as sound Vetch.
Mould	1 grain per 200 g	Mould (Field and / or Storage), Caked, Bin Burnt & Heat Damaged.
Poor Colour maximum	1%	Vetch whose seed coat or kernels are distinctly off colour from the characteristic colour of the predominating class.
Foreign material maximum	3% Max by weight, of which Max 2% by weight cereal grain and 0.5% Max by weight Unmillable Material	Includes unmillable material and all vegetable matter other than Vetch seed material. Includes cereal grain.
Unmillable material maximum	0.5% Max by weight (of which 0.3% Max by weight of soil)	Soil, stones and non-vegetable matter. Please read important note re soil contamination – see Point 14 of Procedures.
Snails maximum	1 per 200 g	Dead or alive. Whole or substantially whole (more than half) including bodies per 200 g sample.
Field insects per 200 g	15	Dead or alive per 200 g sample.
Objectionable material	Nil tolerance	Includes Objectionable Odour.
Ryegrass ergot	2 cm max.	Pieces laid end to end per 200 g sample.

Source: Australian Pulse Standards 2016/2017

12.6 Harvest weed seed management

There are several ways of utilising harvest to lessen the numbers of viable weed seeds, to prevent weed seed returning to the seedbank and then proliferate during the next season. Techniques include harvest weed-seed control (HWSC), windrow burning, and the use of chaff carts, direct baling the Harrington Seed Destructor. It has been shown that these systems have similar effectiveness. [12]

12.6.1 Harvest weed-seed control

Many Northern grain growers have been a little sceptical about introducing harvest weed-seed control (HWSC) as a tool for combating herbicide resistance. Nationally, HWSC is proven to reduce the weed seedbank, and some weeds of the northern grains region are suited to this method of control, particularly in a farming environment of increasing herbicide resistance.

Weed-seed capture and control at harvest can add to the effectiveness of other tactics to put the weed seedbank into decline. Up to 95% of annual ryegrass seeds that enter the harvester exit in the chaff fraction. If these can be captured, they can be destroyed or removed.

Western Australian farmers and researchers have developed several systems to effectively reduce the return of annual ryegrass and wild radish seed into the seed bank, and help put weed populations into decline.

A key tactic for all harvest weed-seed control operations is to maximise the percentage of weed seeds that enter the header. This means harvesting as early as possible before weed seed is shed, and harvesting as low as is practical, e.g. at 'beer-can height'.

Northern weeds suited to HWSC

- Definitely—turnip weed and African turnip weed are potentially very good candidates for HWSC, although these species are not yet resistant.
- Definitely in winter crops—annual ryegrass, wild radish and wild oats. Wild oats shed seed at about 2% per day and ryegrass at 1% a day, but it is still worth using HWSC at the start of harvest.
- Possibly in winter crops—barnyard grass and feathertop Rhodes grass are known to shed their seed in summer crops, but where they germinate in spring in winter crops they may be suitable candidates for HWSC.
- Possibly in summer crops—feathertop Rhodes grass provides an opportunity for HWSC in summer crops where there is a high percentage of seed retention at the start of harvest. [13]

MORE INFORMATION

GRDC's Tactics for managing weed populations

Section on narrow-windrow burning in GRDC's Tactics for managing weed populations

12.6.2 Burning in narrow windrows

During traditional whole-paddock stubble burning, the very high temperatures needed to destroy weed seeds are not sustained for long enough to kill most weed seeds. However, by concentrating harvest residues, which includes weed seeds, into a narrow windrow, the fuel load is increased and the period of high temperatures extends to several minutes, improving the kill of weed seeds.

12.6.3 Burning in narrow windrows

During traditional whole-paddock stubble burning, the very high temperatures needed to destroy weed seeds are not sustained for long enough to kill most weed seeds. However, by concentrating harvest residues, which includes weed seeds, into

12 M Street and G Shepherd (2013) Windrow burning for weed control: WA fad or a viable option for the east? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Windrow-burning-for-weed-control-WA-fad-or-viable-option-for-the-east

13 T Somes (2016) Can harvest weed-seed control work for the North? Ground Cover. Issue 124, September–October 2016. GRDC, https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-124-SeptemberOctober-2016/Can-harvest-weedseed-control-work-in-the-north

VIDEOS

WATCH: Windrow burning in Northern NSW

WATCH: Burning Barriers to windrow burning in NSW

MORE INFORMATION

Section on narrow-windrow burning in GRDC's Tactics for managing weed populations

Windrow burning for weed control: WA fad or a viable option for the east?

Section on chaff carts in GRDC's Tactics for managing weed populations

Setting up harvesters to capture weed seed in the chaff

a narrow windrow, the fuel load is increased and the period of high temperatures extends to several minutes, improving the kill of weed seeds (Photo 3).

Photo 3: *Narrow windrow burning the Northern region.*

Photo: P Heuston

12.6.4 Chaff carts and chaff decks

Chaff carts are towed behind headers during harvest to collect the chaff fraction (Photo 4). The chaff that is collected is dumped into piles and then burnt the following autumn or used as a source of stock feed.

Photo 4: *Chaff cart in action*

Photo: A. Storrie

12.6.5 Bale-direct system

The bale-direct system uses a baler attached to the harvester to collect all chaff and straw material (Photo 5). This system requires a large baler to be attached to the back of the harvester. As well as removing weed seeds, the baled material has an economic value as a livestock feed. Header-towed bailing systems were developed in Western Australia by the Shields family.

Photo 5: *Bale direct harvestor on a Northern region farm.*

Photo: P Heuston

MORE INFORMATION

Section on bale-direct systems in GRDC's Tactics for managing weed populations

Small and large baler projects of the Shields family

12.6.6 Integrated Harrington Seed Destructor

The integrated Harrington Seed Destructor (iHSD, Photo 6) is the invention of Ray Harrington, a progressive farmer from Darkan, WA. With funding from the GRDC and the Australian Herbicide Resistance Initiative (AHRI), the HSD was commercialised and made available to wider Australia. The iHSD comprises a chaff-processing cage mill, and chaff and straw delivery systems. The retention of all harvest residues in the field reduces the loss and/or banding of nutrients and maintains all organic matter to protect the soil from wind and water erosion, as well as reducing evaporation loss compared to the use of windrow burning, chaff carts and baling. [14]

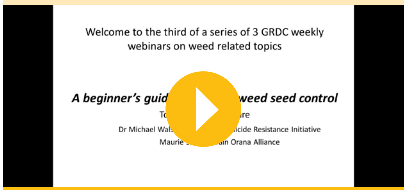
The chaff deck places the chaff exiting the sieves of the harvester on to permanent wheel tracks. Growers using chaff decks have observed that few weeds germinate from the chaff fraction and believe that many weed seeds rot in it. A permanent tramline farming system is necessary to be able to implement the chaff deck system. [15]

14 GRDC (n.d.) Section 6. Managing weeds at harvest. GRDC, https://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest

15 Roberts P. (2014). New systems broaden harvest weed control options. GRDC. https://grdc.com.au/Media-Centre/Media-News/West/2014/11/New-systems-broaden-harvest-weed-control-options

VIDEOS

WATCH: A beginner's guide to harvest weed seed control



MORE INFORMATION

Section on the Harrington Seed Destructor in GRDC's Tactics for managing weed populations

Chaff deck concentrates weeds in controlled traffic

Photo 6: *Integrated Harrington Seed Destructor.*

Source: Michael Walsh

Storage

Key messages

- Pulses stored above 12% moisture content require aeration cooling to maintain quality.
- Meticulous hygiene and aeration cooling are the first lines of defense against pest incursion.
- Fumigation is the only option available to control pests in stored pulses, which requires a gas-tight, sealable storage.
- Avoiding mechanical damage to pulse seeds will maintain market quality, seed viability and be less attractive to insect pests.
- Pea and Cowpea weevils are the most common insect pests affecting stored pulses.

Storing pulses successfully requires a balance between ideal harvest and storage conditions. Harvesting at 13–14% moisture content captures grain quality and reduces mechanical damage to the seed but requires careful management to avoid deterioration during storage.

MORE INFORMATION

Stored Grain website

Grain Storage GrowNotes

VIDEOS

WATCH: GCTV: Stored Grain: Oilseeds and Pulse storage.

13.1 How to store vetch on-farm

A recent trend has been increased use of on-farm storage. Much of Australia's grain production is now stored on-farm before delivery to bulk handling sites. The ABS estimates on-farm storage is growing by 4.8% p.a. In 2011, it was estimated that growers on the east coast had an average 11 million tonnes of on-farm storage. This allows farmers to maximise marketing opportunities and minimise storage and handling costs. [1]

To discourage mould growth and insect infestation, the moisture content of vetch seed stored on-farm for the next season should not be over 13%. If the moisture content of harvested grain is too high, aerated storage will prevent spoilage. Seed stored with high moisture content can deteriorate, particularly if stored at high temperatures.

13.1.1 Optimum moisture and temperature

Research has shown that harvesting pulses at higher moisture content (up to 14%) reduces field mould, mechanical damage to the seed, splitting and preserves seed viability. The challenge is to maintain this quality during storage as there is an increased risk of deterioration at these moisture levels (Figure 1). As a result, pulses stored above 12% moisture content require aeration cooling to maintain quality.

1 PricewaterhouseCoopers. (2011). The Australian Grains Industry: The Basics.

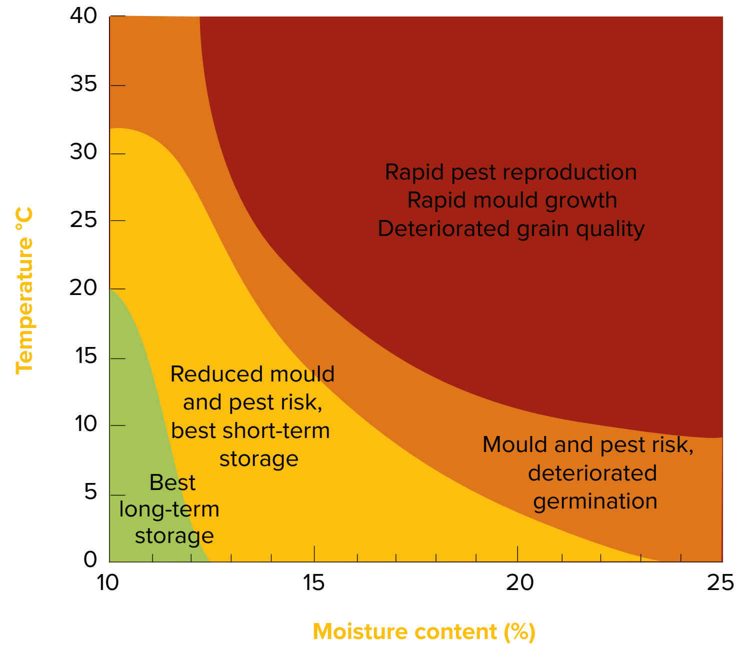


Figure 1: *Effects of temperature and moisture on stored grain.*

Source: CSIRO Ecosystems Sciences

Grain Trade Australia (GTA) sets a maximum moisture limit of 14% for most pulses but bulk handlers may have receival requirements as low as 12%. As a general rule of thumb, the higher the moisture content, the lower the temperature required to maintain seed quality (Table 1).

Without aeration, grain is an effective insulator and will maintain its warm harvest temperature for a long time.

Green pods and grains increase the risk of mould developing during storage — even at lower moisture content. Aeration cooling will help prevent mould and hot spots by creating uniform conditions throughout the grain bulk. [2]

Table 1: *Maximum recommended storage period.*

		Grain Temperature (°C)	
		20	30
Moisture Content (%)	14	3 months	N/A
	13	9 months	3 months
	12	> 9 months	9 months

Source: CSIRO

13.1.2 On-farm storage options

Grain storage systems come in a range of shapes and sizes to meet farm requirements and careful planning is needed to optimise an on-farm grain storage facility investment. According to the option selected, on-farm grain storage systems can provide a short-term or long-term storage facility. Depending on the goal of on-farm storage, whether it be access to improved markets or simply to maximise harvest efficiency, there are a number of options available.

2 GRDC. (2012). Grain storage factsheet: Storing Pulses.

Costs and storage flexibility can vary between grain storage options as can longevity of the investment. Table 2 identifies the major on-farm grain storage options, their advantages and disadvantages.

Table 2: *Advantages and disadvantages of grain-storage options.*

Storage type	Advantages	Disadvantages
Gas-tight, sealable silo	Gas-tight, sealable status allows phosphine and controlled atmospheres to control insects Easily aerated with fans Fabricated on-site, or off-site and transported Capacity from 15 t to 3,000 t 25 years or more of service life Simple in-loading and out-loading Easily administered hygiene (cone-based silos particularly) Can be used multiple times in a season	Requires foundation to be constructed Relatively high initial investment required Seals must be maintained regularly Access requires safety equipment and infrastructure Requires and annual test to check gas-tight sealing
Unsealed silo	Easily aerated with fans 7–10% cheaper than sealed silos Capacity from 15 t to 3,000 t Up to 25 year service life Can be used multiple times in a season	Requires foundation to be constructed Silo cannot be used for fumigation Insect control limited to protectants in eastern states and Dryacide® in WA Access requires safety equipment and infrastructure
Grain-storage bags	Low initial cost Can be laid on a prepared pad in the paddock Provide harvest logistics support Can provide segregation options Are ground operated	Requires purchase or lease of loader and unloader Increased risk of damage to grain beyond short-term storage (typically three months) Limited insect control options, with fumigation possible only under specific protocols Requires regular inspection and maintenance, which need to be budgeted for Aeration of grain bags currently limited to research trials only Must be fenced off Prone to attack by mice, birds, foxes, etc. Limited wet-weather access if stored in paddock Need to dispose of bag after use Single-use only

VIDEOS

WATCH: Over the Fence: On-farm storage delivers harvest flexibility and profit.

WATCH: Stay safe around grain storage.

MORE INFORMATION

Grain storage facilities

Grain storage cost–benefit analysis template

Saving weather-damaged grain for seed

Prepare on-farm storage early to protect your harvest

Storage checklist

Grain storage – invest today for the system of tomorrow

Economics of on-farm grain storage: cost–benefit analysis

Economics of on-farm grain storage: a grains industry guide

Storage type	Advantages	Disadvantages
Grain-storage sheds	Can be used for dual purposes 30 years or more of service life Low cost per stored tonne	Aeration systems require specific design Risk of contamination from dual purpose use Difficult to seal for fumigation Vermin control is difficult Limited insect control options without sealing Difficult to unload

Source: Kondinin Group

13.1.3 Silos

Silos are the most common method of storing grain in Australia, constituting 79% of all on-farm grain storage facilities nationally (Figure 2). Silos are the ideal storage option for pulses, especially if they are cone based for easy out-loading with minimal seed damage. For anything more than short-term storage (3 months) aeration cooling and gas-tight sealable storage suitable for fumigation are essential features for best management quality control.

Always fill and empty silos from the centre holes. This is especially important with pulses because most have a high bulk density. Loading or out-loading off-centre will put uneven weight on the structure and cause it to collapse.

Photo 1: *Storage silo with concrete slab underneath for easy cleaning.*

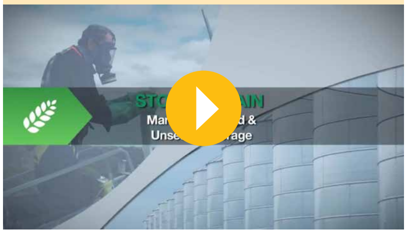
Source: GRDC

MORE INFORMATION

GRDC Silo buyer's guide

VIDEOS

WATCH: GCTV. Stored grain: Managing sealed and unsealed storage



Gas-tight sealable silos

A gas-tight sealable silo will ensure phosphine, or other fumigants and controlled atmospheres, are maintained at a sufficient concentration to kill insects through their complete life cycle of eggs, larvae, pupae and adult. Be aware of cunning marketing terminology such as 'fumigatable silos'. Although such a silo might be capable of sealing with modifications, a gas-tight sealable silo needs to be tested onsite to meet Australian Standard (AS 2628–2010) after installation. Gas-tight sealable silos also can be used for alternative methods of insect control including controlled atmospheres of inert gasses, such as carbon dioxide or nitrogen. Current costs of using these gases (between $5 and $12/tonne to treat stored grain compared with $0.30 per tonne using phosphine) carbon dioxide and nitrogen atmospheres will arguably be used solely by niche growers, such as organic growers, until gas is less expensive.

There is significant work being carried out in lower-cost nitrogen gas generation and if buying a silo, ensure it is gas-tight for future proofing of the investment. [3]

Pressure testing sealable silos

Key points:

- A silo sold as a 'sealed silo' needs to be pressure tested to be sure it's gas-tight.
- It is strongly recommended that growers ask the manufacturer or reseller to quote the AS2628 on the invoice as a means of legal reference to the quality of the silo being paid for.
- Pressure test sealed silos upon erection, annually and before fumigating with a five-minute half-life pressure test.
- Maintenance is the key to ensuring a silo purchased as sealable can be sealed and gas-tight.

Why do I need to do a pressure test?

In order to kill grain pests at all stages of their life cycle (egg, larvae, pupae, adult), phosphine gas concentration levels need to reach and remain at 300 parts per million (ppm) for seven days or 200ppm for 10 days.

Trials show that these levels of gas concentration are impossible to achieve in silos that are not pressure tested and gas-tight, so insects will not be killed at all life stages. The fumigation may appear successful when the adults die but the surviving eggs and pupae will continue to develop and re-infest the grain.

A pressure test is a measure of how well a silo will seal to contain fumigation gas.

When to perform a pressure test

If silos are properly maintained pressure testing does not take long and should be done at three distinct times.

1. When a new silo is erected on farm carry out a pressure test at a suitable time of day to make sure it's gas-tight before paying the invoice or filling with grain.
2. Importantly, a silo also needs to be pressure tested when full, before fumigating grain. If the silo has a slide plate outlet that has been tested empty, retest when full to make sure the pressure of the grain doesn't compromise the seal. The weight of grain can break the seal on the slide-plate outlet where it is not well supported by cams or bolts etc. For older, poorly-designed cone-bottom silos, gentle pressure from a jack may assist the seal. If the weight of grain on the slide plate stops it from sealing, some added pressure from a jack under the silo will assist the sealability.
3. Pressure testing silos needs to be part of the annual maintenance. It is much easier to replace seals and carry out repairs when silos are empty.

3 GRDC. (2016). Grain storage facilities: Planning for efficiency and quality. Stored grain hub. http://storedgrain.com.au/grain-storage-facilities/

VIDEOS

WATCH: GCTV2 - Carrying out a pressure test

MORE INFORMATION

Pressure testing sealable silos

Sealed silos – take the pressure test

Aerating stored grain: cooling or drying for quality grain

Carrying out a pressure test

1. Choose the right time to pressure test
2. Check seals
3. If there is no aeration fan, install an air valve
4. Check oil levels
5. Pressurise the silo
6. Time the half life
7. Look for leaks [4]

13.2 Aeration during storage

Grain that is over the standard safe storage moisture level of 12.5% moisture content can be dealt with in a number of ways.

- Blending — over-moist grain is mixed with low-moisture grain then aerated.
- Aeration cooling — grain of moderate moisture, up to 15% moisture content, can be held for a short term under aeration cooling until drying equipment is available.
- Aeration drying — large volumes of air force a drying front through the grain in storage and slowly remove moisture. Supplementary heating can be added.
- Continuous flow drying — grain is transferred through a dryer, which uses a high volume of heated air to pass through the continual flow of grain.
- Batch drying — usually a transportable trailer drying 10–20 tonnes of grain at a time with a high volume of heated air to pass through the grain and out through perforated walls. [5]

Without aeration, grain is an effective insulator and will maintain its warm harvest temperature for a long time. Like housing insulation, grain holds many tiny pockets of air within a stack. [6]

Why aerate grain?

Aeration cools grain and slows most quality deterioration processes:

- Germination and seed vigour is maintained for longer when cool and dry.
- When grain temperatures are below 15–20°C grain storage pests' life cycle slows or stops. Aeration can deliver these temperatures in winter and summer.
- Pulse grains maintain grain colour, reduce moulds risk.
- Mould development slows when grain moisture is uniform and below 13%.

Aeration capacity provides multiple benefits around harvest time:

- Ability to harvest early to reduce risk of weather damage causing quality and yield losses.
- Safely store grain at moisture levels a little above receival standards until blended with dryer grain.
- Hold high moisture grain safely for short periods prior to drying or blending.
- Return to harvesting earlier after rain delay.
- Gain extra harvesting hours each day. [7]

4 GRDC. (2014). Pressure testing sealable silos – Factsheet. http://storedgrain.com.au/pressure-testing/
5 GRDC. (2012). Grain storage factsheet: Storing Pulses.
6 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/
7 DAFF Qld. (2010). Aeration for cooling and drying. https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/grain-storage/aeration

13.2.1 Aeration cooling

Key points:

- Grain temperatures below 20°C significantly reduce mould and insect development.
- Reducing grain temperature with aeration cooling protects seed viability.
- Controlling aeration cooling is a three-stage process — continual, rapid and then maintenance.
- Stop aeration if ambient, relative humidity exceeds 85%.
- Automatic grain aeration controllers that select optimum fan run times provide the most reliable results.

Aeration cooling:

- Creates uniform conditions throughout the grain bulk.
- Prevents moisture migration.
- Maintains seed viability (germination and vigour).
- Reduces mould growth.
- Lengthens (and in some instances stops) insect reproduction cycles.
- Slows seed coat darkening and quality loss.

Aeration cooling allows for longer-term storage of low-moisture grain by creating desirable conditions for the grain and undesirable conditions for mould and pests. Unlike aeration drying, aeration cooling can be achieved with air-flow rates of as little as 2–3 litres per second per tonne of grain. At this rate, aeration cooling can be delivered from fans driven by a 0.37 kilowatt (0.5 horsepower) electric motor for silos around 100 t.

High-moisture grain can also be safely held for a short time with aeration cooling before blending or drying. Run fans continuously to prevent self-heating and quality damage.

Be aware that small seeds will reduce the aeration fan capacity as there is less space for air to flow between the grains. [8]

Research carried out by the Department of Agriculture, Fisheries and Forestry (DAFF), Queensland shows that with the support of an aeration controller, aeration can rapidly reduce stored grain temperatures to a level that helps maintain grain quality and inhibits insect development.

During trials where grain was harvested at 30°C and 15.5% moisture, grain temperatures rose to 40°C within hours of being put into storage.

An aeration controller was used to rapidly cool grain to 20°C and then hold the grain between 17–24°C during November through to March.

Before replicating similar results on farm, growers need to:

- Know the capacity of their existing aeration system.
- Determine whether grain requires drying before cooling can be carried out.
- Understand the effects of relative humidity and temperature when aerating stored grain.
- Determine the target conditions for the stored grain. [9]

Air used for cooling grain

Varying ambient conditions affect stored grain differently depending on the combination of temperature and relative humidity outside the silo and the temperature and moisture content of the stored grain (Table 3).

VIDEOS

WATCH: Grain Storage cooling aeration.

8 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

9 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

Table 3: *The relationship between air temperature and relative humidity and grain moisture content.*

Inlet Air		Resulting temperatures in wheat at varying moisture contents (°C)		
Temperature (°C)	RH (%)	10%MC	12%MC	14%MC
10°C	30	10.2	8.5	7.7
	60	14	11.6	10
20°C	30	18.7	16.1	14.2
	60	24.1	21	18.8
30°C	30	27.4	24.3	22
	60	34	30.4	27.9

Source: GRDC

Grain with a higher moisture content can be cooled quickly with low-humidity air due to the evaporative cooling effect that occurs inside the storage.

The relative humidity of the ambient air affects the efficiency of grain cooling.

In an ideal world, growers would select air for cooling that is low in temperature and relative humidity, but these conditions rarely occur.

Air movement within the stack

Grain at the top of the stack is the hottest, as heat rises through the grain and it is exposed to the head space in the silo (Figure 2).

As the air in the head space heats and cools each day, it creates ideal conditions for condensation to form and wet the grain on the top of the stack.

Be aware aeration drying requires specifically-designed equipment and the process is much slower than aeration cooling or hot-air drying.

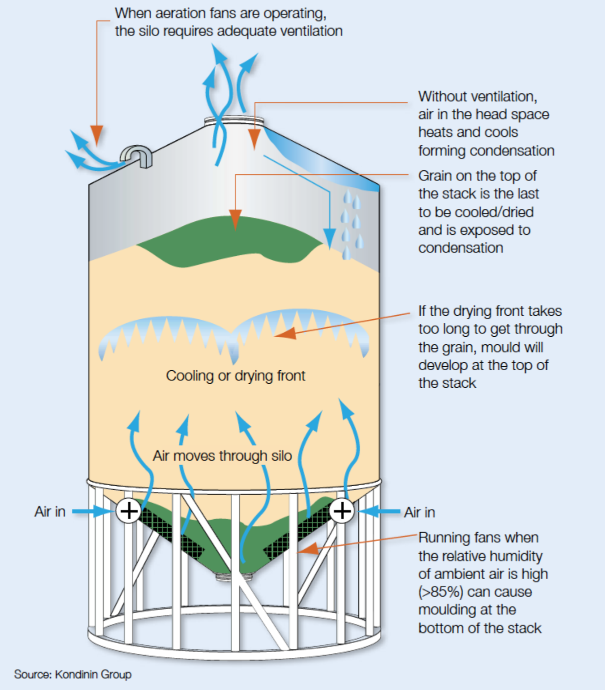


Figure 2: *Air movement within an aerated silo.*

Source: Kondinin Group

Operating an aeration fan for cooling requires a planned control program, which is best done with an automatic aeration controller. But even without an aeration controller growers need to aim for the same run time, following the same process.

For more information on automatic aeration controllers, see Section 13.3.4 Aeration controllers.

Without aeration, grain typically increases in temperature immediately after it enters the storage. The initial aim is to get maximum air-flow through the grain bulk as soon as it enters storage, to stop it from sweating and heating.

When first loading grain into storage, run the aeration fans continuously from the time the grain covers the aeration ducts for the next 1–3 days, until the cooling front reaches the top of the storage. However, do not operate the aeration fans on continuous mode if the ambient relative humidity is higher than 85% for extended periods of time as this will wet the grain.

After the aeration fans have been running continuously for 2–3 days to flush out any warm, humid air, reduce run time to 9–12 hours per day during the coolest period, for the next seven days. The goal is to quickly reduce the grain temperature from the mid 30s°C down to the low 20s°C.

An initial reduction in grain temperature of 10°C ensures grain is less prone to damage and insect attack, while further cooling becomes a more precise task. During this final stage, automated aeration controllers generally run fans during the coolest periods of the day, averaging 100 hours per month.

Grain temperature is gradually reduced as low as possible and then maintained throughout the storage period. [10]

The risks of getting it wrong

Running aeration fans on timers that are pre-set for the same time each day will not ensure the selection of the most appropriate air for grain quality maintenance.

The biggest risk with running aeration fans without a controller is forgetting or not being available to turn fans off if the relative humidity exceeds 85%.

Operating fans for extended periods of a few hours or days in humid conditions can increase grain moisture and cause moulding.

Aeration controllers are designed to automatically select the best time to run aeration fans. Fans on these systems only run when the conditions will benefit the stored grain.

13.2.2 Aeration drying

Grain growers are using silo aeration on their stored grain to gain harvest flexibility and more marketing options. Silo aeration can be used to cool grain and keep insect populations low. But it can also be used to dry the grain – allowing greater tolerance of moisture at harvest. Ambient air can also be used to dry grain. Here, high flow rates of air of at a temperature and humidity that will remove water from the grain (see grain equilibrium moistures) is pumped through the grain bulk.

Pulses stored for longer than three months at high moisture content (over 14%) will require drying or blending to maintain seed quality. Aeration drying has a lower risk of cracking and damaging pulses, which can occur with hot-air dryers.

Providing the air is of a quality that will dry and not re-wet the grain, the grain will dry from the bottom of the silo, with a drying front moving upwards through the grain stack. Aeration drying is a much slower process than aeration cooling or hot-air drying. The time it takes and the moisture content of grain after a drying front has reached the top of the grain stack is highly dependent on the quality of the air available and used for drying. Several drying fronts may be needed to dry grain to receival standards. If aeration is to be used for drying, check with your aeration

10 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

VIDEOS

WATCH: GCTV5: Aeration drying – getting it right

MORE INFORMATION

How aeration works

Aerating stored grain – Cooling or drying for quality control.

Aeration cooling for pest control

supplier that the fan and ducting have sufficient flow rate and pressure to force a moisture change front through the grain in your silo quickly enough to prevent mould development. It is also critical to ensure that flow fields are even and grain depth is not too deep. Air with greatest capacity to dry, occurs most during the day when temperatures are high and relative humidity low, but this is not always the case. Very hot dry air can overdry and crack grain. The average quality of the inlet air (note fan heat effects) determines the final grain moisture content. [11]

Unlike aeration cooling, drying requires high airflow rates of at least 15–25 l/s/t and careful management. [12]

Well designed - purpose built high flow rate aeration drying silos with air flow rates of 15–20 l/s/t and higher, can dry grain from higher moisture contents, provided air of suitable relative humidity (RH) and temperature is available. Aeration drying requires careful management over several days and sometimes weeks depending on starting grain moisture and ambient conditions.

Note: It is vital to understand that aeration cooling equipment with low airflow rates of 2–4 l/s/t will not reliably dry grain and if used for this purpose, places the grain at significant risk.

For all aeration systems, provide adequate venting to ensure fan performance and air flow rates are not unnecessarily restricted. [13]

13.2.3 Cooling or drying — making a choice

Knowing whether grain needs to be dried or cooled can be confusing but there are some simple rules of thumb. For longer-term storage grain must be lowered to the correct moisture content.

Grain that is dry enough to meet specifications for sale can be cooled, without drying, to slow insect development and maintain quality.

Grain of moderate moisture can be either cooled for short periods to slow mould and insect development or, dried providing the right equipment and conditions are available.

After drying to the required moisture content, grain can be cooled to maintain quality. High-moisture grain will require immediate moisture reduction before cooling for maintenance. [14]

13.2.4 Aeration controllers

Running aeration fans on timers that are pre-set for the same time each day will not ensure the selection of the most appropriate air for grain quality maintenance. The biggest risk with running aeration fans without a controller is forgetting or not being available to turn fans off if the relative humidity exceeds 85%.

Operating fans for extended periods of a few hours or days in humid conditions can increase grain moisture and cause moulding. Aeration controllers are designed to automatically select the best time to run aeration fans (Photo 2). Fans on these systems only run when the conditions will benefit the stored grain. [15]

11 GRDC. (2004). How aeration works. http://www.customvac.com.au/downloads/GRDC_How_Aeration_Works.pdf

12 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

13 C Warrick. (2013). GRDC Factsheet: Aerating stored grain – Cooling or drying for quality control.

14 GRDC. (2016). Aeration cooling for pest control. Stored grain hub. http://storedgrain.com.au/aeration-cooling/

15 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

Photo 2: *Automatic aeration controllers are the most effective way to cool grain and are designed to manage many storages from one central control unit.*

Source: GRDC

Controllers for cooling

For the purposes of aeration cooling, automatic controllers are by far the most effective and most efficient method of control. Not only will they cool grain quickly and efficiently, they all have trigger points to turn fans off if ambient conditions exceed 85% relative humidity, which can wet grain. Automatic aeration controllers for cooling are available in four main variations:

- Set-point controllers
- Time Proportioning Controllers (TPCs)
- Adaptive Discounting Controllers (ADCs)
- Internal sensing controllers.

Controllers for drying

Most aeration controllers are now available with a drying function, which is generally performed using the manual, set-point method, the adaptive discounting method, or the internal sensing method of control. However, drying depends completely on the airflow through the grain and even with the addition of a drying function does not mean it will dry grain without appropriate quantity and quality of airflow. An aeration controller will greatly assist the drying process, but they are not a set-and-forget tool, as the grain requires regular monitoring and in most cases the controller requires regular adjustments.

Operating in drying mode, aeration controllers select for air with low relative humidity. They also provide the added benefit of ensuring fans are not left running when the ambient conditions exceed 85% relative humidity and grain could be re-wet. [16]

13.2.5 Installation and maintenance tips

When retrofitting an aeration system, avoid splitting air-flow from one fan to more than one storage. Each storage will provide a different amount of back-pressure on the fan resulting in uneven air-flow and inefficient or even ineffective cooling.

If buying an aeration controller be aware that most controllers need to be installed by an electrician.

The preferred mounting location for aeration controllers is outside where the sensors can get ambient condition readings but are sheltered from the direct elements of the

VIDEOS

WATCH: Using aeration controllers – Philip Burrill.

16 C Warrick. (2013). GRDC Factsheet: Aerating stored grain – Cooling or drying for quality control.

weather. To avoid the chance of a dust explosion, avoid installing aeration controllers in a confined space.

Ensure your electrician installs wiring properly insulated and protected from potentially-damaging equipment, such as augers. [17]

13.2.6 Monitoring

Regular monitoring of stored grain is essential. Grain should be checked for, temperature, moisture content, quality, germination and for insect pests.

Aeration controllers reduce the amount of time operators need to physically monitor grain storages and turn fans on and off, but units and storage facilities still need to be checked regularly (Photo 3).

Most controllers have hour meters fitted so run times can be checked to ensure they are within range of the expected total average hours per month. Check fans to ensure they are connected and operating correctly. The smell of the air leaving the storage is one of the most reliable indicators if the system is working or not.

The exhausted air should change from a humid, warm smell to a fresh smell after the initial cooling front has passed through the grain. Animals can damage power leads and automatic controller sensors and fan blades or bearings can fail, so check these components regularly. Check for suction in and feel for air-flow out of the storage vents when the fans are running.

Keeping grain at the right moisture and temperature levels will reduce the likelihood of insect infestations, but stored grain still needs to be sampled regularly and monitored for any changes. If possible, safely check the moisture and temperature of the grain at the bottom and top of the stack regularly. [18]

Photo 3: *Monitor the effectiveness of the aeration cooling process by checking grain temperature with a temperature probe or a thermometer taped to a rod.*

Photo: Chris Warrick, Kondinin Group

13.2.7 Sampling grain for pests

Damage by grain insect pests often goes unnoticed until the grain is removed from the storage. Regular monitoring will help to ensure that grain quality is maintained.

17 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

18 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

Sample each grain storage at least monthly. During warmer periods of the year fortnightly sampling is recommended.

Take samples from the top and bottom of grain stores and sieve (using 2 mm mesh) onto a white tray to separate any insects (Photo 4).

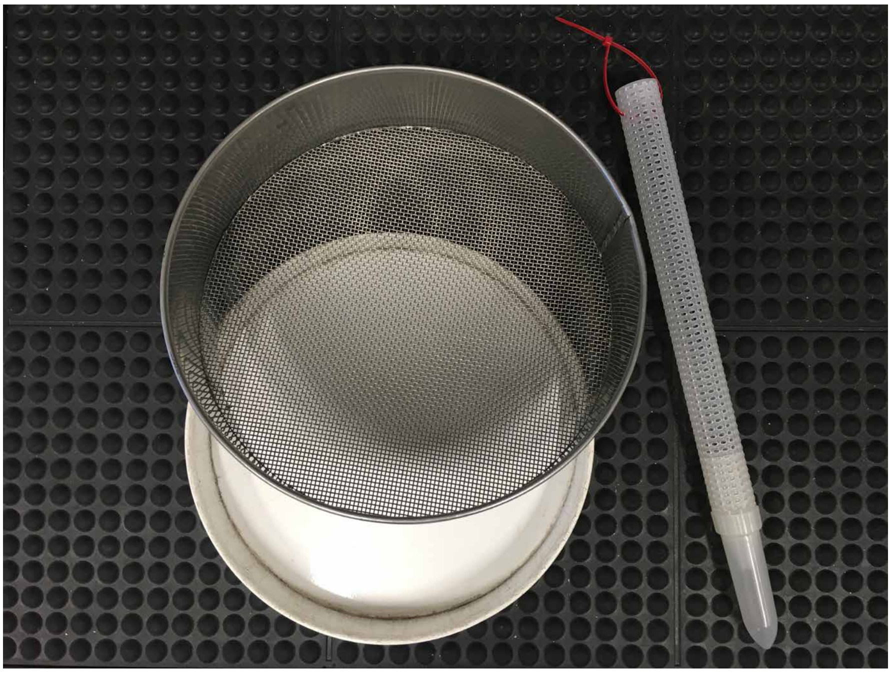


Photo 4: *Use a 2 mm mesh sieve to separate insects from grain.*

Source: GRDC

Hold tray in the sunlight for 10–20 seconds to trigger movement of any insects, making them easier to see. Use a magnifying glass to identify pests.

Grain probes or pitfall traps should also be used to check for insects. These traps are left in the grain during storage and are often able to detect the start of an infestation.

Push probe/trap into the grain surface and pull up for inspection fortnightly/monthly. Place 1–2 traps in the top of a silo or several traps in a grain shed (Photo 5).

Photo 5: *Probe traps pushed at the top of silos or bulk grain storages help detect the first signs of an infestation.*

Source: ProAdvice

MORE INFORMATION

Monitoring stored grain on-farm

Vigilant monitoring protects grain assets

Be sure to check grain three weeks prior to sale to allow time for treatment if required. [19]

Monitoring grain temperature and moisture content

Pests and grain moulds thrive in warm, moist conditions. Monitor grain moisture content and temperature to prevent storage problems. Use a grain temperature probe to check storage conditions and aeration performance. When checking grain, smell air at the top of storages for signs of high grain moisture or mould problems. Check germination and vigour of planting seed in storage. Aeration fans can be used to cool and dry grain to reduce storage environment problems. It is vital to monitor grain moisture content and temperature to prevent pests and grain moulds from thriving. [20]

13.3 Stored grain pests

Key points:

- The most common pulse pests are the cowpea weevil (*Callosobruchus* spp.) and pea weevil (*Bruchids pisorum*).
- Only treat grain when insects are found. Grain markets have limitations on levels of chemical residues that must be adhered to. The demand for freedom from insecticide residues is increasing.
- The only control options are phosphine, an alternative fumigant or controlled atmosphere, all of which require a gas-tight, sealable storage to control the insects at all life stages.
- Chemical sprays are not registered for pulses in any State.
- Weevil development ceases at temperatures below 20°C. This is a strong incentive for aeration cooling, especially if gas-tight storage is not available. [21]

The most common pulse pests are the cowpea weevil (*Callosobruchus* spp.) and pea weevil (*Bruchids pisorum*). The cowpea weevil has a short life span of 10–12 days while the pea weevil only breeds one generation per year. Though weevils are not usually a problem during short-term storage, they can damage grain that is cracked, has split seeds or has been damaged by seed borers.

Weevil development ceases at temperatures below 20°C. This is a strong incentive for aeration cooling, especially if gas-tight storage is not available. [22]

Insect control options are limited for stored pulses and oilseeds. Grain protectants are not registered for use on these grains. Chemical sprays are not registered for pulses in any State. The only control options are phosphine, an alternative fumigant or controlled atmosphere, all of which require a gas-tight, sealable storage to control the insects at all life stages.

The effectiveness of phosphine fumigation on oilseeds can be reduced due to phosphine sorption during treatment. Use sound grain hygiene in combination with aeration cooling to reduce insect activity. Small-seed grains, may need larger capacity aeration fans on stores. Always store pulses at their recommended grain moisture content level. [23]

Grain markets demand that delivered grain is free of live insects. If insects are detected as grain is out-loaded for sale, treatment is likely to delay the delivery by 2–4 weeks. To maintain pest-free stored grain of good quality and value, growers need to:

19 Plant health Australia. (2015). Monitoring stored grain on-farm. http://www.planthealthaustralia.com.au/wp-content/uploads/2018/03/Monitoring-stored-grain-on-farm-2018.pdf

20 Plant health Australia. (2015). Monitoring stored grain on-farm. http://www.planthealthaustralia.com.au/wp-content/uploads/2018/03/Monitoring-stored-grain-on-farm-2018.pdf

21 GRDC. (2016). Stored grain information hub: Storing pulses. http://storedgrain.com.au/storing-pulses/

22 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

23 GRDC. (2016). Northern and Southern regions grains storage pest control guide. http://storedgrain.com.au/pest-control-guide-ns/

- Make full use of good hygiene and aeration cooling – this can overcome 70% of pest problems.
- Identify pest incursions early through monthly monitoring (Figure 3). Early detection of pests gives the best chance of effectively treating the grain, preventing loss of grain quality and market access.
- Select the right storage treatments and apply them correctly.

The first grain harvested is often at the greatest risk of pest infestation due to contamination with grain left over from the previous season. It is good practice to separate the first few tonnes of grain that pass through headers and grain handling equipment at the start of harvest. Use it quickly for stock feed, or plan to aeration cool, then fumigate this grain within four weeks.

When it comes to controlling pests in stored grain — prevention is better than cure. Grain residues in storages or older grain stocks held over from last season provide ideal breeding sites.

Figure 3: *Common stored grain pests.*

Source: Kondindin Group

MORE INFORMATION

Grain storage pest control options and storage systems.

Finding storage pests early

13.3.1 Stored grain pest identification

The tolerance for live storage pests in grain either for domestic animal feed, human consumption or export markets is nil. Furthermore, an increasing number of grain markets are requesting low chemical residues on grain. It is important to accurately identify any pests to ensure use of the most appropriate control options. Correct identification and treatment choice helps prevent pest treatment failures due to chemical resistance. Follow the pest identification chart to work out which pest you have (Figure 4).

Keep a good magnifying glass handy to see the key features of these small insects. A piece of sticky tape may be helpful to hold insects still. To assist identification, place live insects into a glass container and check if they can climb up the glass. If it is cold, warm the jar in the sun briefly to encourage the insects to move.

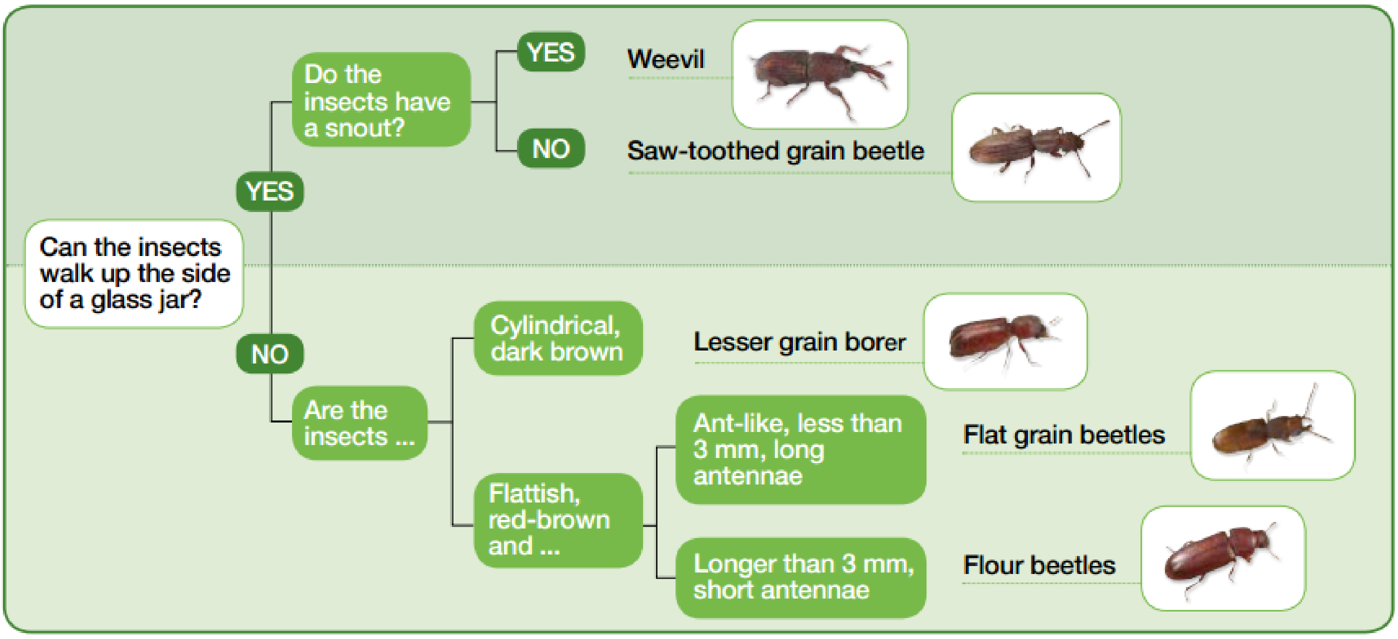


Figure 4: *Stored grain pest identification chart.*

Source: DAFF, Qld

The most common pulse pests are the cowpea weevil (Bruchids) and pea weevil.

Pea weevil

- Adults have globular shaped body (4–5 mm long) with long legs and antennae (Figure 11).
- Does not have a long snout like true weevils.
- Wings are patterned with white/cream spots.
- One generation per year and only breed in standing pea crops before harvest. Eggs laid and glued onto pods.
- Adult is long-lived and overwinters, but does not feed on field peas.
- Cream coloured and C-shaped larvae bore into the seed.
- Adults are strong fliers and reappear in spring to visit flowers to feed on the nectar, then seek out new field pea crops to lay eggs.
- Sieve and check seed for neat round holes (evidence adults have emerged).

Figure 5: *Adult Pea weevil and an example of damaged grain.*

Source: CSIRO

Cowpea weevil or Bruchids

- Adults (up to 4 mm long) have long antennae, climb vertical surfaces (e.g. glass jar) and are strong flyers.
- Globular, tear-shaped body is reddish brown with black and grey markings (Photo 6).
- Does not have a long snout like true weevils.
- Adults have a short lifespan (10–12 days).
- Adults do not feed, but lay about 100 white eggs on the outside of seed.
- Larvae feed and develop within individual seeds and emerge as adults leaving a neat round hole.
- Common problem in warmer months.
- Fortnightly sampling and sieving is important to prevent serious losses. [24]

24 Plant health Australia. (2015). Monitoring stored grain on-farm. http://www.planthealthaustralia.com.au/wp-content/uploads/2018/03/Monitoring-stored-grain-on-farm-2018.pdf

VIDEOS

WATCH: GCTV2: Grain storage insect ID

MORE INFORMATION

Identification of insect pests in stored grain

Stored grain pests identification: the back-pocket guide

Monitoring stored grain on-farm

Photo 6: *Adult Cowpea weevil and an example of infestation in seed.*

Source: DAFF Qld

Why identify stored insect grain pests?

Most insect-control methods for stored grain work against all species, so you don't need to identify the storage pests to make decisions about most control methods. But if you intend to spray grain with insecticides you may need to know which species are present if:

- A previous application has failed, and you want to know whether resistance was the reason—if more than one species survived, resistance is unlikely to be the cause.
- You intend to use a residual protectant to treat infested grain—pyrimiphos-methyl, fenitrothion and chlorpyrifos-methyl are ineffective against lesser grain borer, and pyrimiphos-methyl and fenitrothion are generally ineffective against saw-toothed grain beetles.
- You intend using dichlorvos to treat infested grain—if lesser grain borers are present you need to apply the higher dose rate, which increases the withholding period before grain can be marketed from seven days to 28 days. [25]

13.3.2 Hygiene

The first line of defence against grain pests is before the pulses enter storage — meticulous grain hygiene. Because pest control options are limited, it's critical to remove pests from the storage site before harvest.

Cleaning silos and storages thoroughly and removing spilt and leftover grain removes the feed source and harbour for insect pests.

25 DAFF. Identification of insects in stored grain. https://www.daf.qld.gov.au/business-priorities/plants/field-crops-and-pastures/broadacre-field-crops/grain-storage

Clean the following areas thoroughly:

- Empty silos and grain storages
- Augers and conveyers
- Harvesters
- Field and chaser bins
- Spilt grain around grain storages
- Leftover bags of grain [26]

When to clean

Straight after harvest is the best time to clean grain handling equipment and storages, before they become infested with pests. A trial carried out in Queensland revealed more than 1000 lesser grain borers in the first 40 litres of grain through a harvester at the start of harvest, which was considered reasonably clean at the end of the previous season. Discarding the first few bags of grain at the start of the next harvest is also a good idea. Further studies in Queensland revealed insects are least mobile during the colder months of the year. Cleaning around silos in July – August can reduce insect numbers before they become mobile.

How to clean

The better the cleaning job, the less chance of pests harbouring. The best ways to get rid of all grain residues use a combination of:

- Sweeping
- Vacuuming
- Compressed air
- Blow/vacuum guns
- Pressure washers
- Fire-fighting hoses

Using a broom or compressed air gets rid of most grain residues, a follow-up wash-down removes grain and dust left in crevices and hard-to-reach spots (Photo 7). Choose a warm, dry day to wash storages and equipment so it dries out quickly to prevent rusting. When inspecting empty storages, look for ways to make the structures easier to keep clean. Seal or fill any cracks and crevices to prevent grain lodging and insects harbouring. Bags of left-over grain lying around storages and in sheds create a perfect harbour and breeding ground for storage pests. After collecting spilt grain and residues, dispose of them well away from any grain storage areas. [27]

VIDEOS

WATCH: GCTV2: Grain Silo Hygiene.

Photo 7: *TIPS: An extended broom handle makes sweeping out silos easier (left). A concrete slab underneath silos makes cleaning easier. (right).*

Source: Kondinin Group

26 GRDC Storing Pulses. http://storedgrain.com.au/storing-pulses/

27 GRDC. (2013). Hygiene and structural treatments for grain storage – GRDC Factsheet. http://storedgrain.com.au/hygiene-structural-treatments/

13.3.3 Aeration cooling for pest control

While adult insects can still survive at low temperatures, most young storage pests stop developing at temperatures below 18–20°C (Table 4).

At temperatures below 15°C the common rice weevil stops developing.

At low temperatures insect pest life cycles (egg, larvae, pupae and adult) are lengthened from the typical four weeks at warm temperatures (30–35°C) to 12–17 weeks at cooler temperatures (20–23°C). [28]

Table 4: *The effect of grain temperature on insects and mould.*

Grain Temperature (°C)	Insect and Mould Development
40–55	Seed damage occurs, reducing viability
30–40	Mould and insects are prolific
25–30	Mould and insects are active
20–25	Mould development is limited
18–20	Young insects stop developing
<15	Most insects stop reproducing, mould stops developing

Source: Kondinin Group)

For more information on Aeration cooling, see Section 13.4.1 Aeration cooling below.

VIDEOS

WATCH: GCTV7: Applying Diatomaceous Earth demonstration

MORE INFORMATION

Hygiene and structural treatments for grain storage

13.3.4 Structural treatments

While most grain buyers accept small amounts of residue on cereal grains from chemical structural treatments, avoid using them or wash the storage out before storing oilseeds and pulses. After cleaning grain storages and handling equipment treat them with a structural treatment.

It is always safer to check with the grain buyer's delivery standards for maximum residue level (MRL) allowances before using grain protectants. Diatomaceous earth (DE) (amorphous silica), commonly known as Dryacide®, can be applied either as a dust or a slurry to treat storages and handling equipment for residual control. DE acts by absorbing the insect's cuticle (protective exterior), causing death by desiccation (drying out). If applied correctly with complete coverage in a dry environment, DE can provide up to 12 months protection — killing most species of grain insects and with no risk of building resistance. [29]

13.3.5 Chemical treatment

Key points:

- Chemicals used for structural treatments do not list the specific use before storing pulses on their labels and MRLs in pulses for those products are either extremely low or nil.
- Using chemicals even as structural treatments risks exceeding the MRL so is not recommended.
- Using diatomaceous earth (DE) as a structural treatment is possible but wash and dry the storage and equipment before using for pulses. This will ensure the DE doesn't discolour the grain surface.
- If unsure, check with the grain buyer before using any product that will come in contact with the stored grain. [30]

28 GRDC Aeration cooling for pest control. http://storedgrain.com.au/aeration-cooling/

29 GRDC. (2013). Hygiene and structural treatments for grain storage – GRDC Factsheet. http://storedgrain.com.au/hygiene-structural-treatments/

30 GRDC. (2016). Stored grain information hub: Storing pulses. http://storedgrain.com.au/storing-pulses/

Phosphine

In order to kill grain pests at all stages of their life cycle (egg, larva, pupa, adult), including pests with strong resistance, phosphine gas concentration levels need to reach and be maintained at 300 parts per million (ppm) for seven days (when grain is above 25°C) or 200ppm for 10 days (between 15–25°C).

Phosphine is available in two different forms for on-farm use (bag chains and tablets) and there are various ways to apply each option effectively in a gas-tight, sealed silo.

Bag chains are the safest form and the best way to guarantee no residue is spilt on the grain or will harm the operator. The other form is the traditional and most recognised — tablets — which can be bought in tins of 100. A third form — phosphine blankets — is available, but is designed for bulk storages larger than 600 tonnes.

Phosphine application rates are based on the internal volume of the gas-tight, sealable silo to be fumigated. Regardless of how much grain is in the silo whether it is full or empty, the rate is the same — based on the volume of the silo (Photo 8). [31]

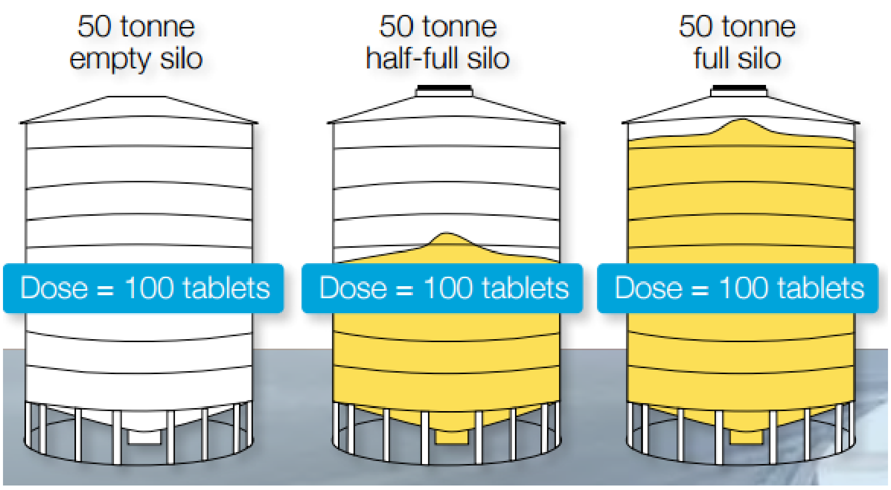


Photo 8: *Treat the silo volume, not the grain.*

Source: CBH

Using bag chains

The application rate for fumigating with a standard bag chain is one bag chain per 75m3 or 60 t of storage capacity. Always refer to the label. Do not cut a bag chain to save extra phosphine for use at a later date. The phosphine will start evolving as soon as it is exposed to air, so will be less effective if it's stored for use at a later date. Storing phosphine after it has already been opened also poses a danger when re-opened, as the gas has been dissipating in a confined space, potentially reaching explosive levels. For larger bulk storage silos, phosphine can be obtained in blanket form. Like bag chains, blankets must not be cut or separated so the minimum size storage for fumigation using a single blanket is 750m3 or 600 t of storage capacity.

Using tablets

The application rate for phosphine is 1.5 grams per cubic metre, which in tablet form equates to three tablets per 2m3. Always read the product label to confirm recommended application rates.

Application from the top

Hang bag chains in the head space or roll out flat in the top of a gas-tight, sealed silo so air can freely pass around them as the gas dissipates. Always spread out phosphine tablets evenly on trays, before hanging them in the head space or placing

VIDEOS

WATCH: GCTV Stored Grain: Phosphine Dose Rates.

31 GRDC. (2016). Fumigating with phosphine, other fumigants and controlled atmospheres. http://storedgrain.com.au/wp-content/uploads/2016/10/GRDC-PHOSP-Booklet_2016_R2_Reduced.pdf

them level on the grain surface inside a gas-tight, sealed silo. The aim is to place the tablets where as much surface area as possible is exposed to air so the gas can disperse freely. Prevent trays from sitting on an angle to avoid tablets piling up to one side and creating more than one layer in the tray.

Application from the bottom

Some silos are fitted with purpose-built facilities for applying phosphine from the bottom. This method of application carries a safety advantage as the operator doesn't have to leave the ground to apply the phosphine. However, ensuring top lids or vent openings on silos are in sound condition and correctly sealed before fumigation, will usually require a climb to the top. Bottom-application facilities must have a passive or active air circulation system to carry the phosphine gas out of the confined space as it evolves. Without air movement, phosphine can reach explosive levels if it's left to evolve in a confined space.

VIDEOS

WATCH: GCTV: Stored grain: Fumigation recirculation

Fumigation period

A gas-tight, sealed silo (one that satisfies a half-life pressure test) must remain sealed for the full 7–10 days to achieve a successful fumigation using phosphine tablets or bag-chains. In a gas-tight, sealed silo the required fumigation period is seven days if the grain temperature is above 25°C or 10 days if the grain temperature is between 15–25°C. If the temperature inside the silo is below 15°C, insect pests will not be active and phosphine is not reliably effective — avoid its use.

Opening the silo during fumigation is potentially harmful to the operator if they are not wearing the appropriate PPE, but also compromises the fumigation as gas concentration levels will quickly fall below the lethal level required to kill insect pests. Phosphine label recommendations have been developed as a result of thorough industry testing so using phosphine as the label specifies will achieve the best result.

Phosphine resistance

Poor fumigations may appear successful when some dead adults are found but many of the eggs, pupae and larvae are likely to survive and will continue to develop and re-infest the grain. These partial kills are often worse than no kill at all because the surviving insects, (adults, pupae, larvae and eggs) are likely to be those that carry increased phosphine resistance genes as a consequence. Underdosing risks increasing the number of insect populations carrying the genes for phosphine resistance and this has serious consequences for the industry.

Phosphine remains the single-most relied upon fumigant to control stored grain pests in Australian grain production systems, but continued misuse is resulting in poor insect control and developing resistance in key pest species. In the same way that repeated herbicide use of the same mode of action leads to resistant weeds, repeated phosphine use leads to resistant grain pests (Figure 6). Unlike herbicides, where resistance can be avoided by rotating chemical group from year to year, there are few alternative stored grain fumigation options other than phosphine. Alternative fumigants and controlled atmospheres that are available for stored grain pests are in most cases more expensive. The best way to prevent resistance is to use phosphine correctly — in a gas-tight, sealed silo.

MORE INFORMATION

[Fumigating with phosphine, other fumigants and controlled atmospheres]

[Grain fumigation – a guide.]

[Fumigation to control insects in stored grain]

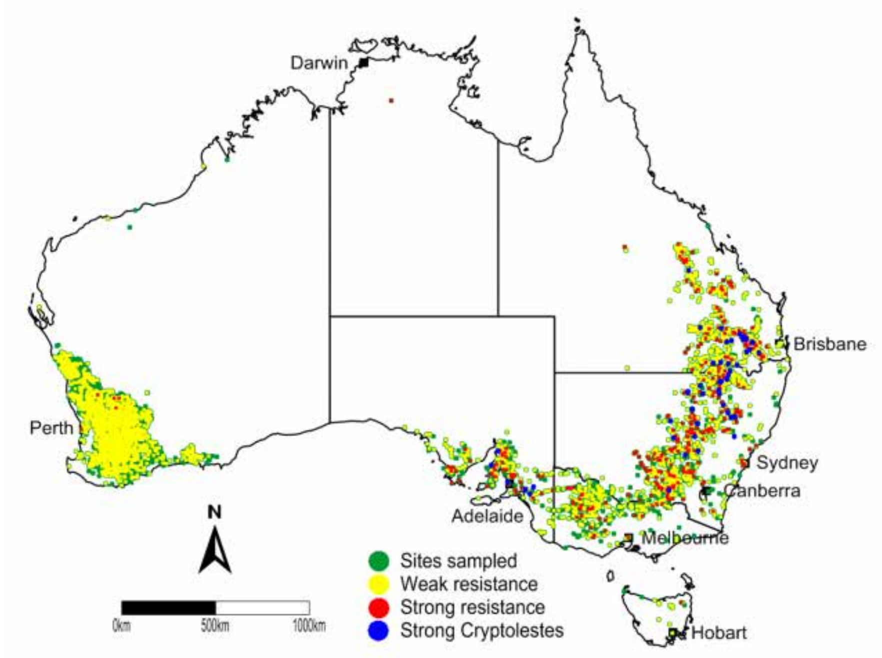


Figure 6: *Instances of phosphine resistance 1986 – 2014.*

Source: DAFWA

Phosphine safety

Caution should always be used when dealing with phosphine gas, it is not only toxic but also highly explosive. Observe all withholding periods for handling and grain use. Phosphine released from aluminium phosphide tablets, pellets or sachets has a characteristic smell which can usually be detected at concentrations within the safe level. Unless fumigating in a well-ventilated situation gas respirators suitable for protection against phosphine should be worn. Masks should fit properly for protection – this may be difficult for those with bearded faces – but is essential to avoid poisoning. Proper mask maintenance is also essential. For safety reasons, it is best not to work alone when applying phosphine tablets or in a structures that have been fumigated. Warning signs should be clearly displayed during fumigation. Always open containers of phosphine preparations in the open air or near open windows. If possible use the contents of a tin in one operation. If any is left over the tin lid should be replaced and sealed with PVC tape. [32]

Withholding period

After fumigating with phosphine, hold grain for a further two days after ventilation before delivering or using for human consumption or animal feed. This is a legal requirement as instructed by the label. The total time required for fumigation ranges from 10–17 days accounting for the minimum exposure period, ventilation and withholding period. It is important to monitor grain regularly and at least 17 days before out-loading to allow sufficient time for the fumigation process when required. [33]

Controlled atmospheres

Although phosphine is still the most commonly-used gas fumigant for controlling pests in stored grain, there are other options. Each of the alternatives still requires a gas-tight, sealable silo and are currently more expensive than using phosphine, but they offer an alternative for resistant pest species. Nitrogen and CO_2 carry the

32 Day, T., Day, H., Hawthorne, W., Mayfield, A., McMurray, L., Rethus, G., & Turner, C. (2006). Grain legume handbook. *GRDC: Canberra, ACT.* https://grdc.com.au/__data/assets/pdf_file/0032/208886/chapter-3-seeding.pdf.pdf

33 GRDC. (2016). Fumigating with phosphine, other fumigants and controlled atmospheres. http://storedgrain.com.au/wp-content/uploads/2016/10/GRDC-PHOSP-Booklet_2016_R2_Reduced.pdf

advantage of being nonchemical control alternatives. Both nitrogen and CO_2 methods of control are sometimes referred to as controlled atmosphere (CA) because they change the balance of natural atmospheric gases to produce a toxic atmosphere.

Carbon dioxide

Treatment with CO_2 involves displacing the air inside a gas-tight silo with a concentration level of CO_2 high enough to be toxic to grain pests. This requires a gas-tight seal, measured by a half-life pressure-test of no less than five minutes. To achieve a complete kill of all the main grain pests at all life stages CO_2 must be retained at a minimum concentration of 35% for 15 days. The amount of CO_2 required to reach 35% concentration for 15 days is one 30 kg (size G) cylinder per 15 t of storage capacity, plus one extra cylinder. CO_2 is a non-flammable, colourless, odourless gas that is approximately 1.5 times heavier than air. Food grade CO_2 comes as a liquid in pressurized cylinders and changes to a gas when released from the cylinder.

The basic process is to open the storage's top lid to let oxygen out as CO_2 is introduced. Regulate the CO_2 gas into the bottom of the silo via a high pressure tube ideally 1 metre long (no longer than 2m). One kilogram of liquid CO_2 will produce approximately half a cubic metre of gas. Each cylinder could take three hours to dispense. In cooler conditions this process will take longer as the gas will tend to freeze if released from the bottle too quickly. This method of fumigation is not recommended when temperatures are below 15°C. Once the concentration at the top of the storage reaches 80%, stop adding CO_2 and seal the top lid.

Even in a silo that meets the five-minute, half-life pressure test, an initial CO_2 concentration of 80% or more is required to retain an atmosphere of 35% for the full 15 days, because the CO_2 is absorbed by the grain, reducing the atmospheric concentration over time. If the storage does leak, CO_2 can be added periodically over the 15 days if required. The key is to maintain the CO_2 concentration above 35% for 15 consecutive days, which will require suitable electronic instruments or a gas tube detector kit for monitoring. At temperatures below 20°C carbon dioxide is less effective because insects are less active so the concentration must be maintained for an extended period.

Nitrogen

Grain stored under nitrogen provides insect control and quality preservation without chemicals. It is safe to use, environmentally acceptable and the main operating cost is electricity. It also produces no residues so grains can be traded at any time, unlike chemical fumigants that have withholding periods. Insect control with nitrogen involves a process using Pressure Swinging Adsorption (PSA) technology, modifying the atmosphere within the grain storage to remove everything except nitrogen, starving the pests of oxygen.

The application technique is to purge the silo by blowing nitrogen-rich air into the base of the silo, forcing the existing, oxygen-rich atmosphere out the top. PSA takes several hours of operation to generate 99.5% pure nitrogen and before the exhaust air has a reduced concentration of 2% oxygen. At 2% oxygen adult insects cannot survive, providing this concentration is maintained for 21 days with a grain temperature above 25°C. Anything less will not control all life stages — eggs, larvae and pupae. For grain below 25°C this period is extended to 28 days. The silo must be checked the day after fumigation and may need further purging to remove oxygen that has diffused from the grain. Nitrogen storage will also maintain the quality of canola and pulses by inhibiting the respiration process that causes oxidation, which leads to seed deterioration, increased free fatty acids and loss of colour. [34]

For further information on controlled atmosphere fumigation with CO_2 or nitrogen, contact the commercial suppliers of appropriate gas and equipment; BOC Gases Australia Ltd, on 13 12 62 or visit www.boc.com.au

34 GRDC. (2016). Fumigating with phosphine, other fumigants and controlled atmospheres. http://storedgrain.com.au/wp-content/uploads/2016/10/GRDC-PHOSP-Booklet_2016_R2_Reduced.pdf

13.3.6 Maximum Residue Limits

Key points:

- Grain samples are tested for pesticide residues in Australia and when export shipments leave the port to ensure they are within maximum residue limits (MRLs).
- A single violation of an importing country's MRL can lead to punitive measures on all Australian grain exported to that country and undermine Australian grains' reputation internationally.
- Consequences may include costs awarded against the exporter and/or grower. If repeated violations are detected with the same chemical, that chemical may be banned.
- It is essential that growers ensure both pre-harvest and post-harvest chemical applications adhere to the Australian Grain Industry Code of Practice.
- Use only registered products and observe all label recommendations including label rates and withholding periods.
- Trucks or augers that have been used to transport treated seed or fertiliser can be a source of contamination. Pay particular attention to storage and transport hygiene.
- Silos that have held treated fertiliser or pickled grain will have dust remnants that require particular attention. These silos either need to be cleaned or designated as non-food-grade storage.
- Compliance with Australian MRLs does not guarantee the grain will meet an importing country's MRL (which may be nil).
- Know the destination of your grain. When signing contracts, check the importing countries' MRLs to determine what pesticides are permitted on that crop.

By observing several precautions, growers can ensure that grain coming off their farm is compliant with the maximum pesticide residue limits that apply to Australian exports. Violations of maximum residue limits (MRLs) affect the marketability of Australian grain exports, and consequences may include costs being imposed on exporters and/or growers.

It is essential that both pre-harvest and post-harvest chemical applications adhere to the Australian Grain Industry Code of Practice, only registered products are used and all label recommendations, including rates and withholding periods, must be observed. Other key points include:

- Trucks or augers that have been used to transport treated seed or fertiliser can be a source of contamination – pay particular attention to storage and transport hygiene;
- Silos that have held treated fertiliser or pickled grain will have dust remnants – these silos either need to be cleaned or designated as non-food grade storage;
- Know the destination of your grain. When signing contracts, check the importing countries' MRLs to determine what pesticides are permitted on a particular crop. [35]

MORE INFORMATION

Managing MRLs factsheet

35 GRDC. (2014). Managing maximum residue limits in export grain - Factsheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/07/grain-marketing-and-pesticide-residues

Environmental issues

MORE INFORMATION

Frost - Frequently Asked Questions booklet

Key messages

- All vetch varieties are moderately sensitive to frost damage.
- Knowing the frost risk in each paddock, altering sowing times and variety choice are the best ways to management for frost.
- Vetch is not well-adapted to waterlogging.
- Reduce the impact of waterlogging through the choice of crop, seeding, fertiliser and weed control.
- Though vetch is drought-tolerant, under sever moisture stress plants will defoliate.

14.1 Frost issues for Vetch

Key points:

- Frost doesn't cause extensive damage every year, but some areas are more prone to it and can cause frequent damage.
- All the vetches are moderately frost sensitive and seedlings can be cut back severely by heavy frosts. [1]
- However, trials in Tasmania have shown that vetch crops have considerable potential as a means of avoiding the problem of grain losses due to late frosts. [2]
- Minor agronomic tweaks might be necessary in some frost prone areas.
- In the event of severe frost, monitoring needs to occur up to two weeks after the event to detect the full extent of the damage. [3]

Spring radiation frost is of significant importance in Australia, as it causes large yield and revenue losses to the national economy: it is estimated to cost about $360 million a year in unfulfilled or lost yield potential. [4]

14.1.1 Conditions that lead to frost

Clear, calm and dry nights following cold days are the precursor conditions for a radiation frost (or hoar frost). These conditions are most often met during winter and spring where high pressures follow a cold front, bringing cold air from the Southern Ocean and settled, cloudless weather (Figure 1). [5] When the loss of heat from the earth during the night decreases the temperature at ground level to zero, a frost occurs. Wind and cloud reduce the likelihood of frost by decreasing the loss of heat to the atmosphere. The extent of frost damage is determined by how quickly the temperature gets to zero, how long its stays below zero, and the how far below zero it falls.

1 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

2 G Dean (2001) Production of legume forage crops in frost-prone areas of Tasmania. Agronomy Australia Proceedings. http://agronomyaustraliaproceedings.org/images/sampledata/2001/3/a/dean.pdf

3 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

4 R Barr (2016) Diversity the key to balancing frost heat risks. GRDC, https://grdc.com.au/Media-Centre/Media-News/South/2016/01/Diversity-the-key-to-balancing-frost-heat-risks

5 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

VIDEOS

WATCH: GCTV15: Frost ratings

WATCH: GCTV15: The frost ranking challenge

WATCH: GCTV12: Frost susceptibility ranked

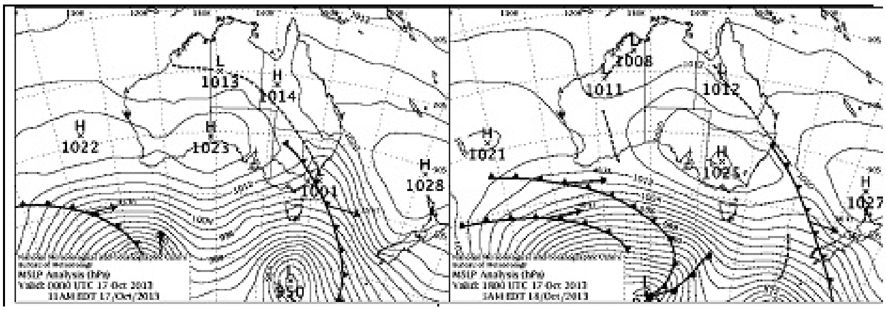


Figure 1: *A cold front passes through, injecting cold air in from the Southern Ocean the day before a frost (left). Overnight, the high-pressure system stabilises over south-east Australia, meaning clear skies and no wind leading to a frost event (right).*

Source: GRDC

Though temperatures (particularly in winter and spring) are getting warmer, frost is still a major issue, and likely to remain so. CSIRO researchers found that in some areas of Australia the number of frost events is increasing (with the greatest increase in August), and that central western NSW, the Eyre Peninsula, Esperance and the northern Victorian Mallee were the only major crop growing areas to be less affected by frost from 1961 to 2010 (Figure 2). [6] This increase is thought to be caused by the latitude of the subtropical ridge of high pressure drifting south (causing more stable pressure systems) and the existence of more El Niño conditions during this period. [7]

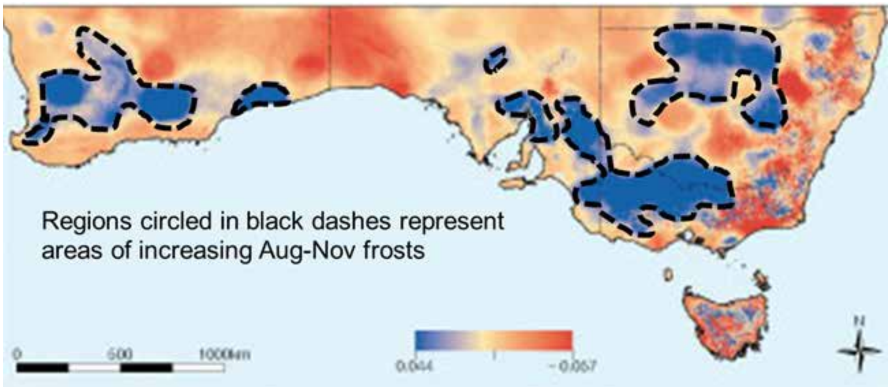


Figure 2: *Region of increasing August–November frost events.*

Source: GRDC

14.1.2 Frost damage

It is difficult to accurately assess the amount of frost damage in a crop because of its patchy nature and the difficulty in predicting compensation that may occur. To diagnose frost damage in pulse and canola crops, inspect between bud formation and during pod growth if night air temperature (recorded 1.2 m above ground) falls below 2°C and there was a frost (Photo 1). Check low-lying, light-coloured soil types and known frost-prone areas first. Then check other areas. Symptoms may not be obvious for five to seven days after the frost. [8]

6 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

7 D Grey (2014) Frost damage in crops: where to from here? GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Frost-damage-in-crops-where-to-from-here

8 B Biddulph (2016) Frost: Diagnosing the problem. DAFWA. https://www.agric.wa.gov.au/frost/frost-diagnosing-problem?nopaging=1

Photo 1: *A frosted vetch crop.*

Photo: Grant Alday

Impact and cost of frost

The real cost of frost is a combination of the actual cost due to both reduced yield and quality, along with the hidden cost of managment tactics used to try and minimise frost risk. The hidden costs associated with conservative management to minimise frost risk includes:

- delayed sowing and its associated yield reduction
- sowing less profitable crops (i.e. tolerant crops) in an attempt to reduce the impacts of frost
- avoiding cropping on the valley floors which also contain some of the most productive parts of the landscape.

Frosts can also have quite a large social impact as it happens so suddenly, unlike drought which one can adapt to mentally and financially by reducing further inputs as it unfolds. [9]

14.1.3 Managing frost

Frost risk is difficult to manage in pulses, however some key management strategies may reduce the risk or extent of damage. These strategies include:

- Know the topography, and map areas of greatest risk so that they can be managed to minimise frost damage.
- Choosing the right crop type, crop variety and sowing time can help reduce exposure or impact at vulnerable growth stages.
- Carefully assess the soil type, condition and soil moisture levels, along with stubble and canopy management.
- Correct crop nutrition and minimised crop stress can influence the degree of frost damage.

Modifications to conditions over large areas are required to reduce frost risk. Small changes in management can have a big impact because frost damage occurs at specific 'trigger' temperatures. Keeping the air temperature even 0.1°C above the critical 'trigger' point will avoid frost damage. Air flow through the canopy can also

VIDEOS

WATCH: GCTV20: Frost's emotional impact—is it greater than its economic impact?

9 B Biddulph (2017) Frost and cropping. DAFWA. https://www.agric.wa.gov.au/frost/frost-and-cropping?page=0%2C0

have a positive impact towards avoiding frost damage. If the frost is severe, below the 'trigger temperature', damage occurs regardless of management, so then avoidance becomes important.

The soil is the heat bank, and it is desirable to have warm soil so that warm air can rise at night to minimize frost risk. The crop canopy will trap cold air on top, so a dense canopy is not necessarily desirable.

Problem areas and timings

Mapping or marking areas identified as frost-prone will enable growers to target frost and crop management strategies to these high-risk areas. Knowing when the period of greatest probability of frost risk occurs is also important for crop management. After a frost event, make note of the location and severity, as this will help to inform future crop choice and post frost decisions. Check low lying, light coloured soil types and known frost prone areas first.

Crop choice and time of sowing

Strategies to minimise frost damage in pulses work in combinations of either: growing a more tolerant species; trying to avoid having peak flowering and early podding during the period of most risk; extended flowering to compensate for losses to frost; or ensuring that most grain is sufficiently filled to avoid damage when frost occurs (Table 1). Time of flowering affects tolerance and the ability to compensate after the frost has occurred. Targeting flowering and early podding to periods of least frost risk (lowest probability) is achieved through combinations of sowing date and variety choice based on flowering time and flowering duration. Local experience will indicate the best choices.

Late flowering targets avoidance of early frosts, but in the absence of frost may also reduce yield potential due to moisture deficiency or high temperatures. Very early flowering can allow pods to be sufficiently developed to escape frost damage, and ensure some grain yield at least before a frost occurs. Increased disease risk needs to be considered with early sowing.

Frost damage risk can be reduced by not sowing varieties earlier than the recommended sowing window and so avoid flowering in July to early August.

Spread the risk

Match different pulses to risk areas by sowing a different variety or species into targeted areas within the same paddock. Matching the crop, variety, sowing date and subsequent inputs to the frost risk location spreads the risk.

Have forage as an optional use. Designating hay or forage as a possible optional use for the pulse in high frost-risk paddocks provides flexibility (Photo 2).

Photo 2: *Frosted pulses make excellent quality forage.*

Source: Pulse Australia

Reduce frost damage

Minimise input costs to reduce financial risk exposure in frost-prone paddocks. Bear in mind though, that reducing inputs may reduce financial exposure and assist grain gross margins when crops are hit by frost, but can lessen the chance of a successful hay cut or jeopardise the crop if no frost occurs.

Manage nodulation and nutrition. Ensure pulse crops are adequately nodulated and fixing nitrogen. Ensure pulses have an adequate supply of trace elements and macro-nutrients – (supplying high levels is unlikely to increase frost tolerance). Crops deficient or marginal in potassium and copper are likely to be more susceptible to frost damage, and this may also be the case for molybdenum. Foliar application of copper, zinc or manganese may assist, but only if the crop is deficient in the element applied.

Canopy management. A bulky crop canopy, and exposure of the upper pods may increase frost damage. The pulse canopy can be managed. Semi-leafless, erect peas may be more vulnerable than conventional, lodging types because their pods are more exposed

Sow in wider rows, so that frost is allowed to get to ground level, and the inter-row soil is more exposed. An open canopy does not trap cold air. Wide rows require the soil to be moist to trap the heat in the soil during the day. With wide or paired rows and a wide gap, the heat can radiate up.

Channel cold air flow away from the susceptible crop by using wide rows aligned up and down the hill or slope. A sacrifice area may be required where the cold air settles.

Cereal stubble presence provides a cooler soil and root zone, worsening the frost effect compared with bare soil. Standing stubble is considered less harmful than slashed stubble as less light is reflected and the soil is more exposed to the sun. Dark coloured stubble will be more beneficial than light coloured.

Rolling can help keep soils warm by preventing soil moisture loss, but not necessarily on self-mulching or cracking soils. Note that press wheels roll only in the seed row, but not the inter-row. With no-till practice, avoid having bare, firm moist soil as it will lose some of its stored heat.

Claying or delving sandy soils increase the ability of the soil to absorb and hold heat by making the soil colour darker, and retaining moisture nearer the surface.

Higher carbohydrate level in the plant during frost leads to is less leakage during thawing. Biological farmers measure sugars in the plant sap ('Brix' reading). A higher sugar content (high Brix) will also have a lower freezing point, and associated protection against frost damage. The effectiveness of various products applied to soil and plant to increase plant carbohydrates is unknown.

Better varieties coming. The GRDC is investing through Pulse Breeding Australia in germplasm enhancement and pulse variety breeding for frost tolerance, including altered flowering time and duration to avoid frost; and screening of pulse varieties for relative levels of frost tolerance in the field. New varieties will be released when available. [10]

What to do with a frosted crop

A frosted vetch crop has a number of management options due to the fact that it is so often grown as a forage and as such is not always harvested so frosted grain is not an issue.

There are a number of options to make use of a frosted crop, each with advantages and disadvantages (Table 1).

VIDEOS

WATCH: Frost initiative: Do micronutrients reduce frost risk?

WATCH: MPCN: Copper and frost relationship investigated

10 Pulse Australia. (2015). Australian Pulse Bulletin. Minimising frost damage in pulses. http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

Table 1: *Management options for frost-damaged crops, with advantages and disadvantages.*

Options	Advantages	Disadvantages
Harvest	Salvage remaining grain More time for stubble to break down before sowing Machinery available	Cost may be greater than return Need to control weeds Threshing problems Removal of organic matter
Hay, silage	Stubble removed Additional weed control	Costs $35–50/t to make hay Quality may be poor Nutrient removal
Graze	Feed value	Inadequate stock to use feed Remaining grain may cause acidosis Stubble may be difficult to sow into
Spray	Stops weeds seeding Preserves feed quality for grazing Gives time for final decisions Retains feed Retains organic matter	With a thick crop, difficulty getting chemicals onto all of the weeds May not be as effective as burning Boom height limitation Costs $5/ha plus cost of herbicide Some grain still in crop
Plough	Recycles nutrients and retains organic matter Stops weed seedset Green manure effect	Requires offset disc to cut straw Soil moisture needed for breakdown and incorporation of stubble
Swathe	Stops weed seedset Windrow can be baled Regrowth can be grazed Weed regrowth can be sprayed	Relocation of nutrients to windrow Low market value for straw Poor weed control under windrow Costs to windrow Costs per herbicide to spray

Source: GRDC

Useful tools

There are numerous useful tools that can help growers decisions about aspects of cropping to maximise yields in frost-prone areas. Among them are:

- Bureau of Meteorology's BOM Weather app
- Plant development and yield apps—MyCrop and Flower Power (both from DAFWA), Yield Prophet
- Temperature monitors such as Tinytag

National Frost Initiative

Frost has been estimated to cost Australian growers around $360 million in direct and indirect yield losses every year. To help the grains industry minimise the damage frost causes, the GRDC has invested about $13.5 million in more than 60 frost-related projects since 1999. In 2014, it began the National Frost Initiative, to provide the Australian grains industry with targeted research, development and extension solutions to manage the impact of frost and maximise seasonal profit. [11]

MORE INFORMATION

Tips and tactics: Managing frost risk

An analysis of frost impact plus guidelines to reduce frost risk and assess frost damage

Frost and cropping

11 T March, S Knights, B Biddulph, F Ogbonnaya, R Maccallum and R Belford (2015) The GRDC National Frost Initiative. GRDC Update Paper. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/The-GRDC-National-Frost-Initiative

VIDEOS

WATCH: GCTV3: Frost R&D

WATCH: GCTV16: National Frost Initiative

MORE INFORMATION

Managing frost risk: northern, southern and western regions

The initiative is addressing frost management through multidisciplinary research projects in the following programs:

1. Genetics—developing more frost-tolerant wheat and barley germplasm and ranking current wheat and barley varieties for susceptibility to frost.
2. Management—developing best-practise strategies for crop canopy, stubble, nutrition and agronomic management so growers can minimise the effects of frost; and searching for innovative products that may minimise the impact of frost.
3. Environment—predicting the occurrence, severity and impact of frost events on crop yields and mapping frost events at the farm scale to enable better risk management. [12]

14.2 Waterlogging/flooding issues for this crop

Waterlogging occurs when there is insufficient oxygen in the soil pore space for plant roots to adequately respire. Waterlogging causes low soil oxygen concentrations, which limit root and shoot growth, function and survival. Root harming gases such as carbon dioxide and ethylene also accumulate in the root zone and affect the plants. Waterlogging symptoms include yellowing, stunting, or generally weak appearance in the low-lying areas or patches (Photo 3).

Transient (hours to days) and longer term waterlogging (days to weeks) can cause substantial crop loss depending on the growth stage where waterlogging occurs. This problem occurs in low-lying areas in uneven fields either in irrigated lands or rainfed conditions during rainy season. Waterlogging can reduce root growth, and consequently reduce shoot extension and branching resulting in reduced plant biomass.

The risk of yield reduction and crop failure from waterlogging limit the range of soils where susceptible crops can be grown and even in better soils, that do not suffer prolonged waterlogging, short periods of transient waterlogging can have devastating effects when waterlogging occurs during reproductive growth.

Photo 3: *A patch in a pulse crop that is damaged and dying due to prolonged waterlogging.*

Photo: David Jochinke

12 GRDC (2016) Managing frost risk: northern, southern and western regions. Tips and Tactics. GRDC, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2016/02/managingfrostrisk

Vetch is more tolerant than lentil or chickpea to waterlogging but is still considered sensitive. [13] Some anecdotal reports state that vetch shows a similar response to waterlogging as narrow-leafed lupin. [14]

14.2.1 Hardpans and waterlogging in southern NSW

Many pulse crops in southern NSW and northern Victoria had symptoms of waterlogging in 2016. Throughout spring, many plant samples were received at the diagnostic laboratory at Wagga Wagga with evidence of waterlogging, leading to premature death.

Waterlogging can have a three stage effect on pulse crops. Firstly, plants standing in free water can effectively 'drown' if the waterlogged conditions occur over an extended period and the pulse crop will die prematurely. Secondly, waterlogged conditions can promote root pathogens to infect and cause injury, such as Phytophthora, which are expressed later in the season. Thirdly, observations in northern NSW pulse trials and crops since 2010 have consistently shown that resistance to foliar disease is reduced if plants are waterlogged.

Hardpans (or ploughpans) can lead to waterlogging issues, in particular the development of perched watertables in the root zone. Hardpans often form just below the depth of cultivation. This can result in root disease development, poor nodulation or poor root growth. In the 1990s, a survey of pulse crops in southern NSW found 50% of paddocks to have soil bulk densities high enough to limit water movement and root development in pulse crops.

Check paddocks to be sown to pulses for hardpan layers. It may be necessary to cultivate paddocks at a deeper level or use ripping tynes to break up layers. [15]

14.2.2 How can waterlogging be monitored?

Waterlogging occurs:

- Where water accumulates in poorly drained areas such as valleys, at the change of slope or below rocks.
- In duplex soils, particularly sandy duplexes with less than 30 cm sand over clay.
- In deeper-sown crops.
- in crops with low levels of nitrogen.
- In very warm conditions when oxygen is more rapidly depleted in the soil. [16]
- In compacted soils

As well, waterlogging greatly increases crop damage from salinity. Germination and early growth can be much worse on marginally saline areas after waterlogging events.

Identifying problem areas

- Plants can be waterlogged if there is a water table within 30 cm of the surface. There may be no indication at the surface that water is lying in the root zone. Observe plant symptoms and paddock clues, and verify by digging a hole to test for water seepage. [17]

The best way to identify problem areas is to dig holes about 40 cm deep in winter, and see if water seeps or flows into them (Photo 4). If it does, the soil is waterlogged. Some farmers put slotted PVC pipe into augered holes. They can then monitor

13 R Matic, S Nagel, G Kirby (2008) Common Vetch. Pastures Australia. http://keys.lucidcentral.org/keys/v3/pastures/Html/Common_vetch.htm

14 French, B., & White, P. (2005). Soil and environmental factors affecting pulse adaptation in Western Australia. *Australian Journal of Agricultural Research*, *50*, 375–387.

15 K Lindbeck (2017) GRDC Update Papers: The watch outs for pulse disease in 2017. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/02/the-watch-outs-for-pulse-diseases-in-2017

16 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

17 DAFWA (2015) Diagnosing waterlogging in cereals. DAFWA, https://www.agric.wa.gov.au/mycrop/diagnosing-waterlogging-cereals

the water levels in their paddocks. Digging holes for fence posts often reveals waterlogging.

Symptoms in the crop of waterlogging include:

- Yellowing of crops and pastures.
- The presence of weeds such as toad rush, cotula, dock and Yorkshire fog grass. [18]

Photo 4: *Water fills a hole that has been dug in waterlogged soil.*

Source: Soilquality)

Other impacts of waterlogging and floods

Heat from stagnant water

Stagnant water, particularly if it is shallow, can heat up in hot, sunny weather and may kill plants in a few hours. Remove excess water as soon as possible after flooding to give plants the best chance of survival.

Chemical and biological contaminants

Floodwater may carry contaminants, particularly from off-farm run-off. You should discard all produce, particularly leafy crops, that have been exposed to run-off from beyond the farm.

Make sure you take food-safety precautions, and test soils before replanting, even if crops look healthy. Contaminants will reduce over time with follow-up rainfall and sunny weather.

Iron chlorosis or nitrogen deficiency

Floods and high rainfall can leach essential nutrients from the soil, which can affect plant health. Nutrients such as iron and nitrogen can be replaced by fertilising.

Soils with high clay content

Soils with a high clay content can become compacted and form a crust after heavy rain and flooding. Floodwater also deposits a fine clay layer or crust on top of the soil, and this can prevent oxygen penetrating into the soil (aeration).

18 Soilquality (2016) Waterlogging. Fact sheet. Soilquality, http://soilquality.org.au/factsheets/waterlogging

VIDEOS

WATCH: [GCTV3: Big wet—management strategies after flooding]

Pests and diseases

Many diseases are more active in wet, humid conditions, and pests can also cause problems. Remove dying or dead plants that may become an entry point for disease organisms or insect pests. Apply suitable disease-control measures as soon as possible, and monitor for pests. [19]

14.2.3 Managing waterlogging

Key points:

- Reduce the impact of waterlogging through the choice of crop, seeding, fertiliser and weed control.
- Avoid growing vetch on regularly waterlogged soils.
- Sow waterlogging-tolerant crops such as oats and faba beans.
- Sow as early as possible with a higher seeding rate.
- Drainage may be appropriate on sandy duplex soils on sloping sites.
- For paddocks susceptible to waterlogging, plant them first with the best crop choice for vigorous early growth.
- Raised beds are more effective on relatively flat areas and on heavier textured soils, but areas need to be large enough to justify machinery costs.
- Employ practices that reduce or prevent compaction

Drainage is usually the best way of reducing waterlogging. Drain waterlogged soils as quickly as possible, and cultivate between rows to aerate the soil.

Good drainage is essential for maintaining crop health. Wet weather provides a good opportunity to improve the drainage of your crop land, as it allows you to identify and address problem areas.

There are several things you can do to improve crop drainage, immediately and in the longer term.

Drainage problems after flooding

After significant rain or flooding, inspect the crops when it is safe to do so and mark areas (e.g. with coloured pegs) that are affected by poor drainage. If possible, take immediate steps (e.g. by digging drains) to improve the drainage of these areas so that the water can get away.

Irrigation after waterlogging

To avoid recurrence of waterlogging, time irrigation by applying small amounts often until the crop's root system has recovered.

Ways to improve drainage

In the longer term, look for ways to improve the drainage of the affected areas. Options include:

- reshaping the layout of the field
- improving surface drainage
- installing subsurface drainage

If the drainage can't be improved, consider using the area for some other purpose (e.g. as a silt trap). [20]

MORE INFORMATION

[Cropping on raised beds in southern NSW]

19 Queensland Government Business and Industry Portal (2016). Managing risks to waterlogged crops. Queensland Government, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/managing-risks-waterlogged-crops

20 Queensland Government Business and Industry Portal (2016) Improving drainage of crop land. Queensland Government, https://www.business.qld.gov.au/industry/agriculture/crop-growing/disaster-recovery-for-crop-farming/saving-crops-floods/improving-drainage-crop-land

MORE INFORMATION

Nitrogen management in waterlogged crops

Should waterlogged crops be topdressed with N fertiliser?

Choice of crop species

Some species of grains crop are more tolerant to waterlogging and being flooded than others. Grain legumes and canola are generally more susceptible to waterlogging than cereals.

Seeding crops early and using long-season varieties help to avoid crop damage from waterlogging. Damage will be particularly severe if plants are waterlogged between germination and emergence. Plant first those paddocks that are susceptible to waterlogging. However, if waterlogging delays emergence and reduces plant, resow the crop.

Seeding rates

Increase sowing rates in areas susceptible to waterlogging to give some insurance against uneven germination. High sowing rates will also increase the competitiveness of the crop against weeds, which take advantage of stressed crops. Seeding crops early and using long-season varieties help to avoid crop damage from waterlogging. Crop damage is particularly severe if plants are waterlogged between germination and emergence. Plant first those paddocks that are susceptible to waterlogging.

Raised beds

Raised beds are the only long-term option for preventing waterlogging and increasing crop yield on target areas (Photo 5). Crop yields are more reliable and yield and profit are increased.

Photo 5: *Waterlogged crop without raised beds (left) while the crop on raised beds remains healthy (right).*

Source: DAFWA

Raised beds are an option when:

- The probability of waterlogging is 50% or more in the wettest months (usually June to August) when the emerging crops are most susceptible and on susceptible soils.
- Shallow water tables and large gravel contents in the soil reduce the soil's capacity to absorb rainfall, resulting in a high frequency of waterlogging.
- Where hill slopes are greater than 3%, waterlogging may not be a problem. In shallow or gravelly soils, however, waterlogging can occur on land with slopes greater than 3%.

Susceptible soils are:

MORE INFORMATION

Cropping on raised beds in southern NSW

Raised bed cropping

Innovative management techniques to reduce waterlogging

- Shallow sand, high gravel content soils and loam-over-clay soils situated in areas where the waterlogging frequency is greater than 50%.
- Soils in areas with a shallow water table will also be susceptible but that land is likely to be salt-affected and reclamation of the salinity is likely to be difficult, even with the use of raised beds.

Raised beds may be an option in many situations and professional advice should be obtained before installing them. [21]

14.3 Other environmental issues

For information on salinity, sodicity and other soil constraints, see Section 1: Planning and Paddock preparation.

14.3.1 Drought stress

Key points:

- Drought stress is a key yield-limiting factor in crop production.
- Though vetch is considered drought tolerant, it is most sensitive to drought stress in the early stages of establishment. [22] Vetch can defoliate under severe moisture stress. [23]
- There are few strategies to manage for drought conditions.

Vetch has been adopted by Australian farmers as a legume rotation crop where drought is the major environmental stress. Its substantial root system and its ability to flower quickly and set seed in a dry spring give it good drought tolerance. Vetch is better adapted to these regions than field peas, chickpeas, lentils, faba beans or lupins. [24]

Drought is one of the major environmental factors that reduces grain production in the rain-fed and semi-arid regions of Australia (Photo 6).

Photo 6: *Drought conditions in 2015 left a dry landscape prone to dust storms.*

Photo: Brad Collis, Source: GRDC

21 D Bakker. (2015). Raised beds to alleviate waterlogging. https://www.agric.wa.gov.au/waterlogging/raised-beds-alleviate-waterlogging

22 J Frame. Vicia sativa L. FAO. http://ecocrop.fao.org/ecocrop/srv/en/cropView?id=238003

23 DAF (2011) Vetches in southern Queensland. DAF QLD. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/pastures/vetches

24 R Matic (2015) GRDC Final Reports: DAS00013 – Vetch variety improvement for Australian field crop farming systems. https://grdc.com.au/research/reports/report?id=268

14.3.2 Managing drought stress

Drought can be unpredictable and can last for extended periods of unknown length, therefore it is difficult to prepare for it. Best management practices in farming revolve around conserving soil moisture. Modern day practices such as zero tillage and stubble retention help conserve this water. Sound summer weed management will prevent weeds robbing the paddock of moisture. All these things can help grow a better crop in low rainfall years. Consider carefully your starting moisture in a predicted low rainfall or El Nino year, if the starting moisture is not adequate, don't sow.

In drought, it is important to not ignore the signs and to have a plan, act early, review and then plan again, and revise the plan with each action as you play out your strategy.

Step One: Check the most limiting farm resources:

- funds available;
- surface/subsoil moisture for crop leaf and root growth;
- need to service machinery – breakdowns cost time, money and frustration.

Step Two: Set action strategies, considering:

- breakeven position of each strategy chosen;
- windows of opportunity to adopt management practices that will be profitable during drought;
- available resources and the implications for ground cover, chemical residues, etc., of carrying out each strategy;
- when situations are changing, conditional and timely fall-back options.

Step Three: Monitor and review performance, position and outlook by:

- using your established network to stay informed about key factors that affect your drought strategies;
- being proactive about the decisions made;
- being prepared for change;
- remembering that the impact falls very heavily not only on the decision makers but on the whole farm family. [25]

MORE INFORMATION

Make sure to consider the impacts of herbicide residues following drought.

Winter cropping following drought

Soil management following drought

DPI NSW Drought Hub

Drought planning

Managing drought

Soil management following drought

The principal aim after rain should be to establish either pasture or crop as a groundcover on your bare paddocks as quickly as possible. This is especially important on the red soils, but is also important for the clays. After drought, many soils will be in a different condition to what is considered to be their 'normal' condition. Some will be bare and powdery on the surface, some will be further eroded by wind or water, and some will have higher levels of nitrogen (N) and phosphorus (P) than expected. Loss of effective ground cover (due to grazing or cultivation) leaves the soil highly prone to erosion by wind and water. Research by the former Department of Land and Water Conservation's Soil Services showed that erosion due to drought-breaking rain can make up 90% of the total soil loss in a 20–30 year cycle. Following a drought, available N and P levels in the soil are generally higher than in a normal season. However, most of the N and P is in the topsoil, so if erosion strips the topsoil much of this benefit is lost. [26]

25 Meaker G, McCormick L, Blackwood I. (2007). Primefacts: Drought planning. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/96236/drought-planning.pdf

26 Jenkins A. (2007). Primefacts: Soil management following drought. NSW DPI. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0012/104007/soil-management-following-drought.pdf

Marketing

The final step in generating farm income is converting the tonnes produced into dollars at the farm gate. This section provides best in class marketing guidelines for managing price variability to protect income and cash-flow.

15.1 Price determinants for feed grains in northern markets.

Stock feed markets are the biggest consumers of grain domestically in Australia.

Domestic stock feed grain consumption in Northern Australia is equivalent to approximately 45% of the total winter crop produced in NSW and Qld. Furthermore the domestic market in Victoria traditionally will draw grain in from NSW to support domestic stock feed markets as well as bulk and container export programs. Further drawing on stocks in Northern markets.

The biggest stock feed market in northern Australia is the beef industry representing 45% of all stock feed demand in these markets, followed by the poultry industry at 30%.

Whilst the poultry industry remains a strong source of demand for feed grains in northern markets intensive livestock industries such as poultry and pig meat continue to experience geographic relocation. Whilst to some extend Qld has been able to benefit from a shift in pig meat production away from NSW, the stronger trend across both these industries is a move away from East Coast markets to South Australia and Western Australia.

This geographic shift is being driven by the availability of land, of feed grains and a more favourable regulatory environment.

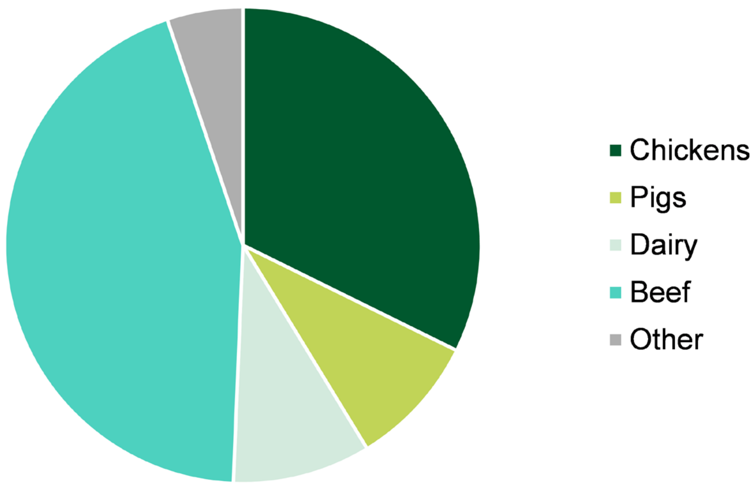


Figure 1: *Sources of demand for stock feed in Northern Australia*

The key drivers of prices for feed grains in Northern markets include;

- Rate of exports and remaining supply of feed grains for domestic markets.
- Commodity prices in the consuming industry (ie meat prices – especially for beef)
- Consumption trends in domestic livestock markets.
- Livestock health
- Seasonality / supply of pasture and fodder vs grains.

- Imports of alternate feed sources (ie soy bean meal)
- Prices of competing feed grains.
- Regulatory changes

15.2 Executing tonnes into cash

When it comes to accessing domestic stock feed markets there are several ways this can be approached.

1. Sale to a feed miller or manufacturer
2. Sale direct to farm or end user.
3. Sale to a trader or merchant who on sells this grain to the stockfeed market.

Each organisation will differ in terms of how they manage grain purchases, the professionalism of the enterprise and management around grain requirements and grain purchases, documentation and record keeping.

Hence it is particularly prudent when making sales into these markets to be vigilant in maintaining records of contracts, even when they are executed by phone. It is strongly advised that the seller keeps a written record of the particulars of the contract including price, quantity, quality, delivery and payment terms to protect yourself in the event of a dispute with your counterparty as to the details of the sale agreement.

It is even better practice to send a contract confirmation to the buyer in the event they don't provide one to you, or even as well as. Grain Trade Australia provide standard form contract documents which can be completed by either party and returned to the buyer by email as confirmation of the verbal contract. This way, any mis-understandings that may have taken place on the phone can be quickly identified and rectified immediately whilst the conversation is still fresh in both your minds rather than waiting until delivery to identify a problem.

15.2.1 How to sell for cash

Like any market transaction, a Cash grain transaction occurs when a bid by the buyer is matched by an offer from the seller. Cash contracts are made up of the following components with each component requiring a level of risk management:

Price

Future price is largely unpredictable hence devising a selling plan to put current prices into the context of the farm business is critical to manage price risk.

Quantity and Quality

When entering a cash contract you are committing to delivery of the nominated amount of grain at the quality specified. Hence production and quality risk must be managed.

Delivery terms

Timing of title transfer from the grower to the buyer is agreed at time of contracting. If this requires delivery direct to end users it relies on prudent execution management to ensure delivery within the contracted period.

Payment terms

In Australia the traditional method of contracting requires title of grain to be transferred ahead of payment; hence counterparty risk must be managed.

Grain Trade Australia is the industry body ensuring the efficient facilitation of commercial activities across the grain supply chain. This includes contract trade and dispute resolution rules. All wheat contracts in Australia should refer to GTA trade and dispute resolution rules.

Quantity (tonnage) and quality (bin grade) determine the actuals of your commitment. Production and execution risk must be managed.

Price is negotiable at time of contracting.
Price basis or price point is important as it determines where in the supply chain the transaction will occur and so what costs will come out of the price before the growers net return.

Timing of delivery (title transfer) is agreed upon at time of contracting. Hence growers negotiate execution and storage risk they may have to manage.

Whilst the majority of transactions are on the premise that title of grain is transferred ahead of payment this is negotiable. Managing counterparty risk is critical.

GTA Contract No.3

CONTRACT CONFIRMATION

GTA Trade Rules and Dispute Resolution Rules apply to this contract

GRAIN TRADE AUSTRALIA

This Contract is confirmation between:

BUYER	SELLER
Contract No:	Contract No:
Name:	Name:
Company:	Company:
Address:	Address:
Buyer ABN:	Seller ABN:
NGR No:	NGR No:

The Buyer and Seller agree to transact this Contract subject to the following Terms and Conditions:

Commodity:	GTA Commodity Reference:
Grade:	Inspection: (Origin – Destination)
Quantity:	Tolerance: (Refer over)
Packaging:	Weights: (Origin – Destination)
Price:	Excl/Inc/Free GST
Price Basis:	

Delivery/Shipment Period:
(Delivered, Shipped, Free In Store, Free On Board, Ex-Farm, etc.)

Delivery Point and Conveyance:
(Road, Rail, Delivered Container Terminal, Freight, Rated Basing Point, Loading Weight requirements if applicable)

Payment Terms: The buyer agrees to pay the seller within . In the absence of a declaration, payment will be 30 days end of week of delivery.

Levies and Statutory Charges: Any industry, statutory or government levies which are not included in the price shall be deducted as required by law.

Disclosures: Is any of the crop referred to in this contract subject to a mortgage, Encumbrance or lien and/or Plant Breeders Rights and/or EPR liabilities and/or registered or unregistered Security Interest? ◯NO ◯YES (Please ☐ appropriate box) If "yes" please provide details:

Other Special Terms and Conditions:

All Contract Terms and Conditions as set out above and on the reverse of this page form part of this Contract. Terms and Conditions written on the face of this Contract Confirmation shall overrule all printed Terms and Conditions on the reverse with which they conflict to the extent of the inconsistency. This Contract comprises the entire agreement between Buyer and Seller with respect to the subject matter of this Contract.

Recipient Created Tax Invoice (RCTI).
To assist with the processing of the Goods and Services Tax compliance, the buyer may prepare, for the seller, a Recipient Created Tax Invoice (RCTI). If the seller requires this service they are required to sign this authorisation.

☐ Please issue a RCTI (Please ☐)

Incorporation of GTA Trade & Dispute Resolution Rules:
This contract expressly incorporates the GTA Trade Rules in force at the time of this contract and Dispute Resolution Rules in force at the commencement of the arbitration, under which any dispute, controversy or claim arising out of, relating to or in connection with this contract, including any question regarding its existence, validity or termination, shall be resolved by arbitration.

Buyer's Name: PRINT NAME	Seller's Name: PRINT NAME
Buyer's Signature:	Seller's Signature:
Date:	Date:

This Contract has been executed and this form serves as confirmation and should be signed and a copy returned to the buyer/seller immediately. 2014 Edition

Figure 2: *Typical cash contracting as per Grain Trade Australia standards.*

15.2.2 Counterparty risk

Most sales involve transferring title of grain prior to being paid. The risk of a counterparty defaulting when selling grain is very real and must be managed. Conducting business in a commercial and professional manner minimises this risk.

Principle: "Seller beware" – There is not much point selling for an extra $5/t if you don't get paid.

Counterparty risk management includes:

1. Dealing only with known and trusted counterparties.
2. Conduct a credit check (banks will do this) before dealing with a buyer they are unsure of.
3. Only sell a small amount of grain to unknown counterparties.
4. Consider credit insurance or letter of credit from the buyer.
5. Never deliver a second load of grain if payment has not been received for the first.

If possible, do not part with title of grain before payment or request a cash deposit of part of the value ahead of delivery. Payment terms are negotiable at time of contracting,

Above all, act commercially to ensure the time invested in a selling strategy is not wasted by poor counterparty risk management. Achieving $5/t more and not getting paid is a disastrous outcome.

15.2.3 Read market signals

The appetite of buyers to buy a particular commodity will differ over time depending on market circumstances. Ideally growers should aim to sell their commodity when buyer appetite is strong and stand aside from the market when buyers are not that interested in buying the commodity.

Principle: "Sell when there is buyer appetite" – When buyers are chasing grain, growers have more market power to demand a price when selling.

Buyer appetite can be monitored by:

1. The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate buyer appetite is strong. However if there is one buyer $5/t above the next best bid, it may mean cash prices are susceptible to falling $5/t if that buyer satisfies their buying appetite.
2. Monitoring actual trades against public indicative bids. When trades are occurring above indicative public bids it may indicate strong appetite from merchants and the ability for growers to offer their grain at price premiums to public bids.

15.2.4 Know the specifications of your grain

Feed 'grades' of grain as defined by bulk handler receival standards can have very broad quality specifications. For the lowest grades there is often no minimum tolerances on screenings or protein hence no two parcels are the same.

The important factor for the stock feed market however is not what 'grade' the grain is but its energy and protein components which ultimately determine conversion in to meat or other animal products. Hence by having your grain tested and knowing your specifications helps the buyer to know exactly what the value of the grain will be in the production system.

Without this information the buyer may base their pricing on the 'minimum' specification or likely worst case scenario, to protect themselves in the event they receive grain of the lowest quality allowable in the grade specifications. However knowing why your grain was downgraded and the specifications of the load, the buyer may be able to pay premiums for the exact quality you are offering, above the minimum specification.

15.3 Ensuring access to markets for Northern Australian feed grains

Planning on where to store the commodity is important in ensuring access to the market that is likely to yield the highest return.

Animal industries such as pigs and poultry are highly intensive and tend to be geographically concentrated. Hence proximity to these markets can be an important determinant of market access. Some growers may not have access to these markets at all due to large distances between production and demand making the cost of transport prohibitive to profitably accessing these markets.

In Northern Australia some of the largest delivered markets include Brisbane (Qld), Darling Downs (Qld), Texas / North Star (NSW), Riverina (NSW). Hence once again proximity to these markets must be considered as party of any marketing plan to access demand from the stock feed industry.

15.3.1 Storage and Logistics

Return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access to maximise returns as well as harvest logistics.

Storage alternatives include variations around the bulk handling system, private off farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity.

Commodities destined for the domestic end user market, (e.g feed lot, processor, or container packer), may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on-farm requires prudent quality management to ensure delivery at agreed specifications and can expose the business to high risk if this aspect is not well planned. Penalties for out-of-specification grain on arrival at a buyer's weighbridge can be expensive. The buyer has no obligation to accept delivery of an out-of-specification load. This means the grower may have to incur the cost of taking the load elsewhere whilst also potentially finding a new buyer. Hence there is potential for a distressed sale which can be costly.

On-farm storage also requires prudent delivery management to ensure commodities are received by the buyer on time with appropriate weighbridge and sampling tickets.

Principle: "Storage is all about market access" – Storage decisions depend on quality management and expected markets.

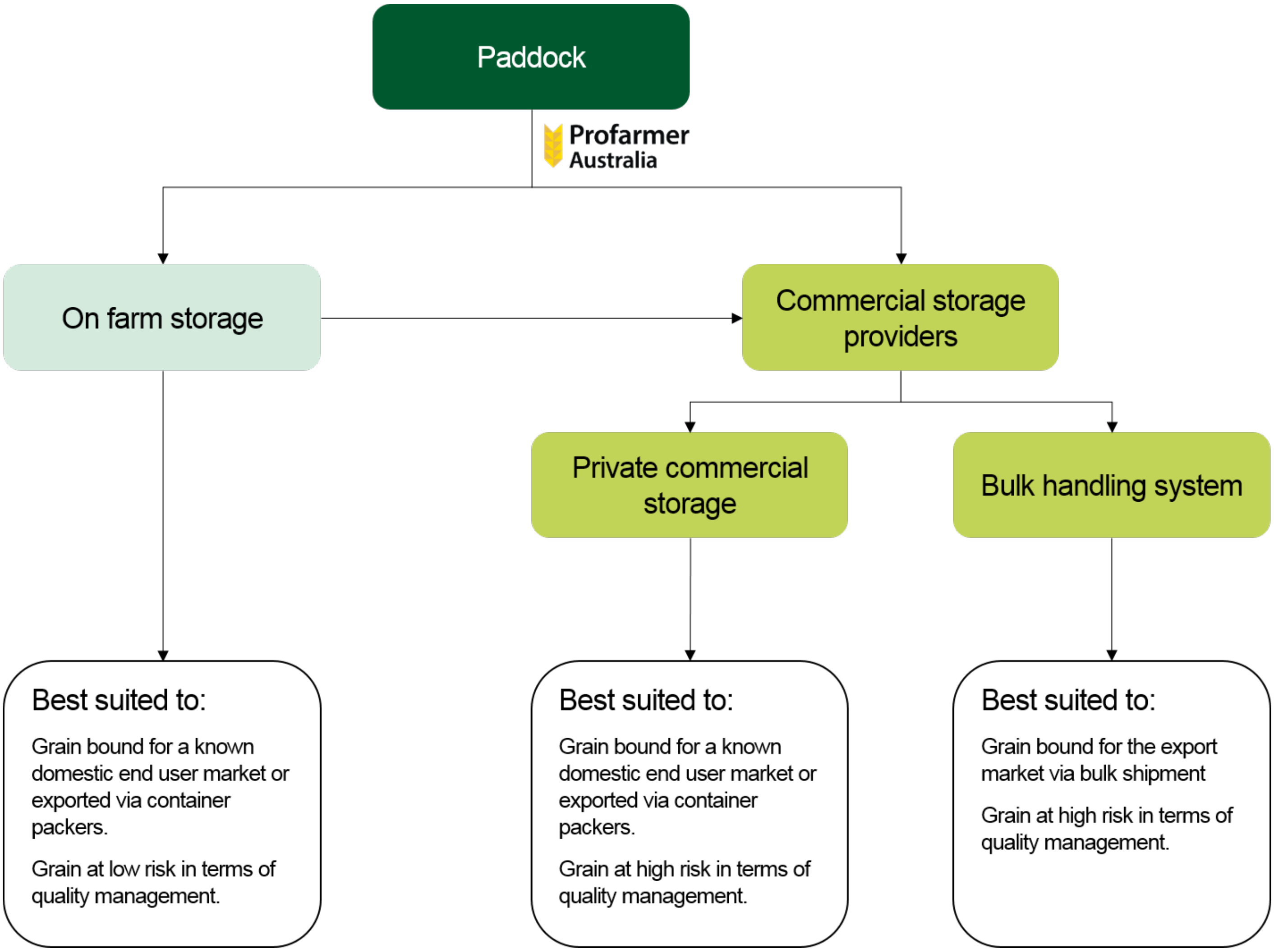


Figure 3: *Grain storage decision making*

Decisions around storage alternatives of harvested commodities depend on market access and quality management requirements.

15.3.2 Separate the delivery decision from the pricing decision

Organised stock feed buyers, with a clear out look as to what their grain requirements will be across the season may seek to purchase their grain in advance of delivery. That is they may purchase grain in March for delivery between May and July. This provides the seller the opportunity to obtain price certainty immediately whilst delivery may not take place until some point in the future.

The benefit of this is that a seller can capture strong value when it presents, even though it may not be a convenient time to arrange delivery. Or you can create cash flow certainty for a known future commitment at today's price.

15.3.3 Cost of carrying grain

Storing grain to access sales opportunities post-harvest invokes a cost to "carry" grain. Price targets for carried grain need to account for the cost of carry.

Carry costs for canola are typically $4-5/t per month consisting of:

1. monthly storage fee charged by a commercial provider (typically ~$1.50-2.00/t per month)

2. the interest associated with having wealth tied up in grain rather than cash or against debt (~$2.50-$3.00/t per month depending on the price of the commodity and interest rates.

The price of carried grain therefore needs to be $4-5/t per month higher than what was offered at harvest.

The cost of carry applies to storing grain on farm as there is a cost of capital invested in the farm storage plus the interest component. $4-5/t per month is a reasonable assumption for on farm storage.

Principle: "Carrying grain is not free" – The cost of carrying grain needs to be accounted for if holding grain and selling it after harvest is part of the selling strategy.

Principles revised

"Always keep written records" – thorough record keeping is everyone's responsibility not just the buyers.

"Seller beware" – Know your counterparty

"Know your specs" – grades don't always convey quality

"Separate the delivery decision from the pricing decision"

"Sell when there is buyer appetite" – When buyers are chasing grain, growers have more market power to demand a price when selling.

"Storage is all about market access" – Storage decisions depend on quality management and expected markets.

"Carrying grain is not free" – The cost of carrying grain needs to be accounted for if holding grain and selling it after harvest is part of the selling strategy.

Current and past research

Project Summaries
www.grdc.com.au/ProjectSummaries

As part of a continuous investment cycle each year the Grains Research and Development Corporation (GRDC) invests in several hundred research, development and extension and capacity building projects. To raise awareness of these investments the GRDC has made available summaries of these projects.

These project summaries have been compiled by GRDC's research partners with the aim of raising awareness of the research activities each project investment.

The GRDC's project summaries portfolio is dynamic: presenting information on current projects, projects that have concluded and new projects which have commenced. It is updated on a regular basis.

The search function allows project summaries to be searched by keywords, project title, project number, theme or by GRDC region (i.e. Northern, Southern or Western Region).

Where a project has been completed and a final report has been submitted and approved a link to a summary of the project's final report appears at the top of the page.

The link to Project Summaries is www.grdc.com.au/ProjectSummaries

Final Report Summaries
http://finalreports.grdc.com.au/final_reports

In the interests of raising awareness of GRDC's investments among growers, advisers and other stakeholders, the GRDC has available final reports summaries of projects.

These reports are written by GRDC research partners and are intended to communicate a useful summary as well as present findings of the research activities from each project investment.

The GRDC's project portfolio is dynamic with projects concluding on a regular basis.

In the final report summaries there is a search function that allows the summaries to be searched by keywords, project title, project number, theme or GRDC Regions. The advanced options also enables a report to be searched by recently added, most popular, map or just browse by agro-ecological zones.

The link to the Final Report Summaries is http://finalreports.grdc.com.au/final_reports

Online Farm Trials
http://www.farmtrials.com.au/

The Online Farm Trials project brings national grains research data and information directly to the grower, agronomist, researcher and grain industry community through innovative online technology. Online Farm Trials is designed to provide growers with the information they need to improve the productivity and sustainability of their farming enterprises.

Using specifically developed research applications, users are able to search the Online Farm Trials database to find a wide range of individual trial reports, project summary reports and other relevant trial research documents produced and supplied by Online Farm Trials contributors.

The Online Farm Trials website collaborates closely with grower groups, regional farming networks, research organisations and industry to bring a wide range of crop research datasets and literature into a fully accessible and open online digital repository.

Individual trial reports can also be accessed in the trial project information via the Trial Explorer.

The link to the Online Farm Trials is http://www.farmtrials.com.au/

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Section 15: Marketing

GRDC Stored Grain Project http://storedgrain.com.au/

The Stock Feed Manufacturers Council of Australia http://sfmca.com.au/

The Australian Fodder Industry Association http://www.afia.org.au/

The link below provides current financial members of Grain Trade Australia http://www.graintrade.org.au/membership

A guide to grain contracts https://www.graintrade.org.au/sites/default/files/file/Guide%20to%20taking%20out%20contracts%20to%20supply%20grain%20Nov%202013.pdf

Grain trade Australia contracts: http://www.graintrade.org.au/contracts

Grain trade Australia commodity standards http://www.graintrade.org.au/commodity_standards

GTA managing counterparty risk 14/7/2014 http://www.graintrade.org.au/sites/default/files/Grain%20Contracts%20-%20Counterparty%20Risk.pdf

GrainGrowers Guide to Managing Contract Risk www.graingrowers.com.au/policy/resources

Counterparty risk: A producer perspective, Leo Delahunty http://www.graintrade.org.au/sites/default/files/GTA_Presentations/Counterparty%20risk%20-%20a%20producer%27s%20perspective%20-%20Leo%20Delahunty_0.pdf