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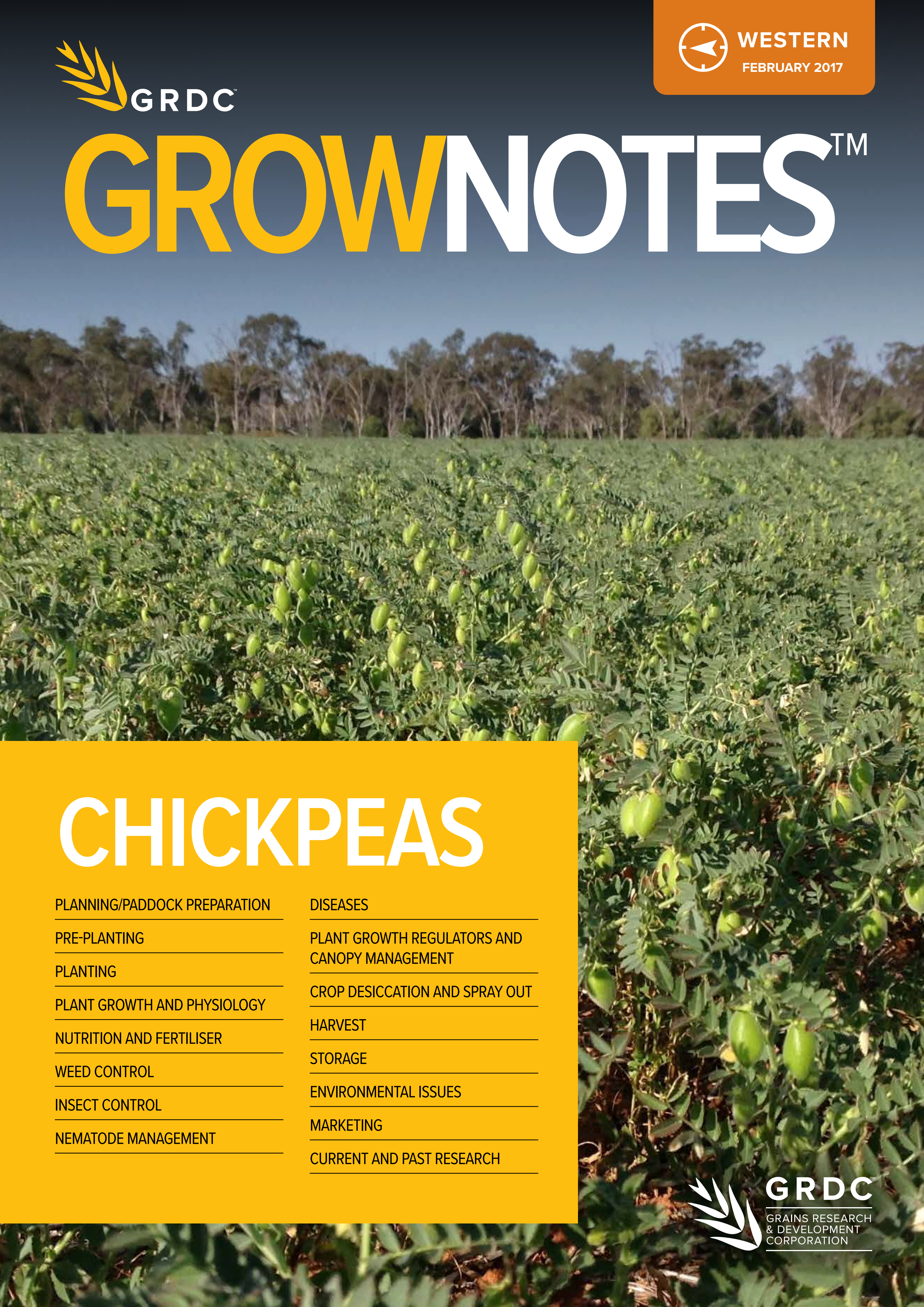

CHICKPEAS

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

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Start here for answers to your immediate chickpeas crop management issues

When should I sow chickpea in my area?

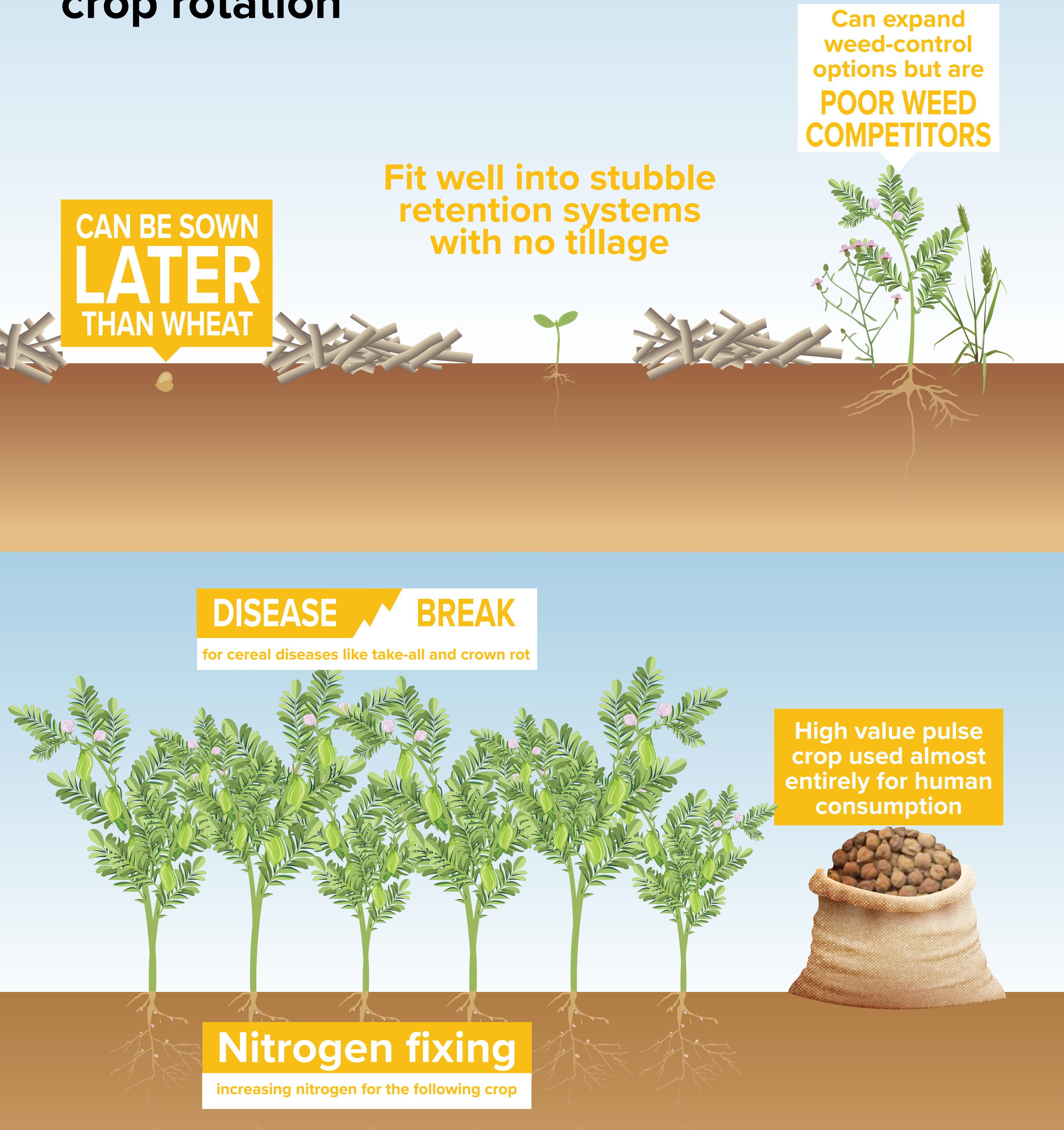
Do I need to apply any nitrogen to a chickpea crop?

What weed control options are there for chickpea crops?

What can I do to minimise the impact of Ascochyta blight?

Can chickpeas be susceptible to nematodes?

Benefits of including chickpeas in crop rotation



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Introduction

Key messages

- Chickpeas are an annual leguminous crop, used for human and animal consumption.
- There are two groups of chickpeas grown in Australia: Desi and Kabuli.
- In Western Australia (WA), chickpeas are mainly grown in the northern and eastern parts of the cropping region.
- Pulse crops, including chickpeas, tend to be grown in areas of medium to low rainfall (350–250 millimetres (mm)).
- Chickpeas are a very good source of carbohydrates and proteins, which together constitute about 80% of the total dry seed weight.
- New higher yielding varieties with improved resistance to Ascochyta blight have now been developed and should help to stimulate chickpea plantings in WA.

A.1 Crop overview

Chickpea (*Cicer arietinum*) is the second most important cool-season food legume worldwide. It is also the largest pulse crop in Australia (after lupin) in terms of planting area and production. On average, chickpeas are sown on 411,000 ha annually to produce 448,000 t, with an average yield of 1.15 t/ha (ABARE 2012). [1]

Chickpeas are an annual leguminous crop, and the grain is used for human and animal consumption. There are two groups of chickpeas grown in Australia, Desi and Kabuli, mainly distinguished by seed size, shape and colour. They also have different growth requirements, markets and end-users. In Western Australia, chickpeas are mainly grown in the northern and eastern parts of the cropping region (although a small industry also exists for a specialty large-seeded kabuli chickpea, grown under irrigation in the Ord River irrigation area). [2]

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

2 https://www.agric.wa.gov.au/pulses/western-australian-pulse-industry

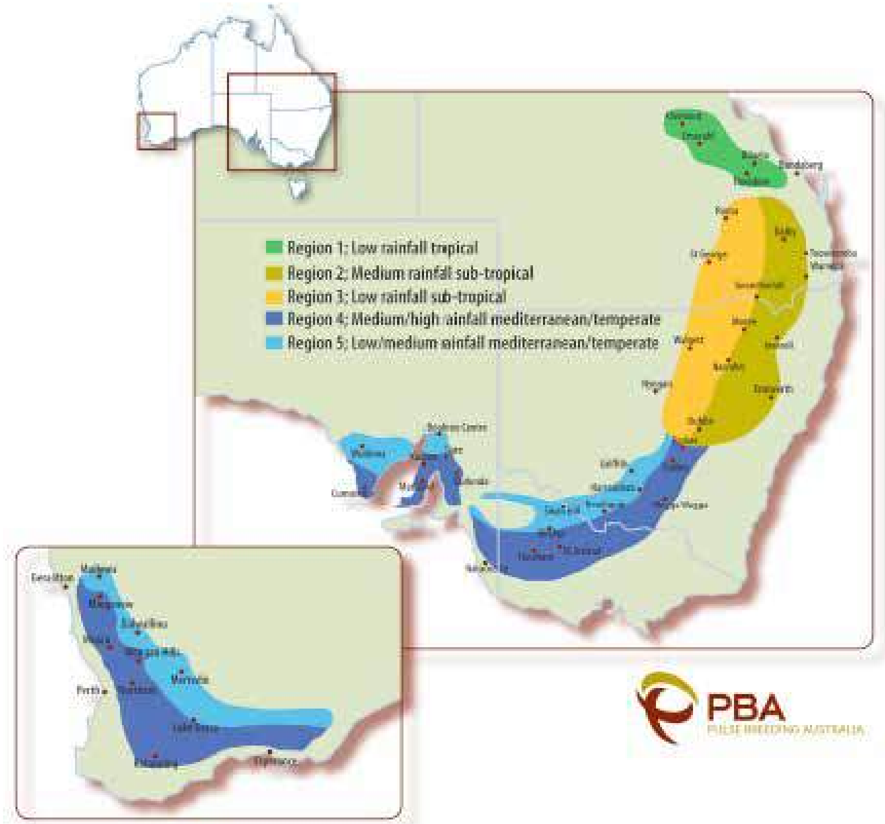

Figure 1: *Main growing areas for chickpeas in Australia. Pulse Breeding Australia (PBA) categorises chickpea production areas into five regions, based on rainfall and geographic location.*

Source: http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/northern-guide

Desi

Desi types of chickpea have small angular seeds weighing about 120 mg, are wrinkled at the beak, and range in colour from brown to light brown and fawn. They are normally dehulled and split to obtain dhal (Figure 2), and are favoured in the Asian sub-continent. Desi types are generally earlier maturing and higher yielding than the kabuli types, particularly the larger seeded kabulis. There is an increasing use of large, whole-seeded desi types in a range of food preparations in Bangladesh. A small premium has been paid for desi types (e.g. Kyabra⒟) fitting this use. Desi chickpeas have traditionally made up about 90–95% of Australian production. [3]

3 http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

Figure 2: *Desi Chickpeas are split to make dhal, a very important dish in India.*

Kabuli

Kabuli have larger, rounder seeds, weighing about 400 mg. They are white-cream in colour, and are almost exclusively used whole. They are preferred through the Mediterranean region. They are sold whole, so seed size and appearance are critically important. Yields are generally lower and more variable than desi varieties, although premiums for larger chickpeas can offset the yield disadvantage. Advances through plant breeding are giving more consistent results from kabuli varieties. Kabuli seed sizes of 7–8 mm can command price premiums of over $100 per tonne (t) over desi types, and sizes >8 mm considerably more.

The plant is erect and freestanding, ranging in height from 40–60 cm, although well-grown plants may reach 80 cm. They have a fibrous taproot system, a number of woody stems forming from the base, upper secondary branches, and fine, frond-like leaves. Each leaflet has a thick covering of glandular hairs that secrete a strong acid (malic), particularly during pod-set, and this provides some protection from insects. The plant can derive >70% of its nitrogen from symbiotic nitrogen fixation. Yields are best in areas with reliable seasonal rainfall and mild spring conditions during seed filling. Chickpeas are suited to well-drained, non-acidic soils of a medium-to-heavy texture. [4]

Chickpeas are prepared and eaten in a variety of ways (Figure 3). Chickpeas are a staple food in the Middle East and the Indian subcontinent. The consumption of pulses in the western world is increasing, as diets are becoming more diverse and people are recognising pulses' nutritional value. However, this is still a very small percentage of global consumption. Only 1% of Australian chickpeas is consumed locally, and the rest is exported.

4 Pulse Australia. Chickpea, (*Cicer arietinum*). http://www.pulseaus.com.au/growing-pulses/bmp/chickpea

Figure 3: *Chickpeas are exported for human consumption.*

Photo: Flickr

A.1.1 Pulses

Chickpeas are pulses, which are annual legume crops that fix nitrogen from the atmosphere and produce high-protein grain for human consumption. [5] Pulses do not include green beans and peas; these are considered vegetable crops. Crops grown mainly for oil extraction (such as peanuts and soybeans) are also excluded. Pulses are a minor part of the cropping system in WA, accounting for about 1% of the total value of all broadacre grain production. The major pulses grown in WA are field pea, faba bean and chickpea, with smaller amounts of lentils also grown in some seasons. Pulse crops tend to be grown in the medium-to-low rainfall environments (350–250 mm). They are generally sown in winter and harvested in late spring or summer; chickpeas are sown at the start of the growing season in May. [6]

Chickpeas are grown in Western Australia, South Australia, Victoria, New South Wales and Queensland. The majority of Australian-produced chickpeas are exported, with India, Pakistan and Bangladesh taking nearly 80% of all exported chickpeas. Chickpeas are suitable for both ruminant and non-ruminant feeds but are not commonly used for these purposes because of the higher prices obtained from human consumption markets. [7]

A.1.2 Quality attributes

Australian chickpeas are exported to more than 40 countries. The industry is committed to supplying chickpeas with quality attributes tailored to these markets (Figure 4). Important quality traits targeted by chickpea breeders include:

- large and uniform seed size
- lighter coloured seed coat
- splitting quality of desi chickpea
- hydration and cooking characteristics of desi and kabuli chickpeas [8]

5 E Armstrong (2013) The role of pulses and their management in southern NSW. GRDC Update Papers 31 July 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/The-role-of-pulses-and-their-management-in-southern-NSW

6 https://www.agric.wa.gov.au/pulses/western-australian-pulse-industry

7 P Chudleigh (2012) An economic analysis of GRDC investment in the National Chickpea Breeding Program. GRDC Impact Assessment Report Series, December 2012, https://www.grdc.com.au/Research-and-Development/~/media/2FE8D5C5C0FE42B8BC7985647002FD70.pdf

8 Pulse Australia (2010) A snapshot of Australian pulses. Poster reprint from CICILS/IPTIC Convention, http://www.pulseaus.com.au/pdf/CICILS-IPTIC%202010%20Poster%20Booklet.pdf

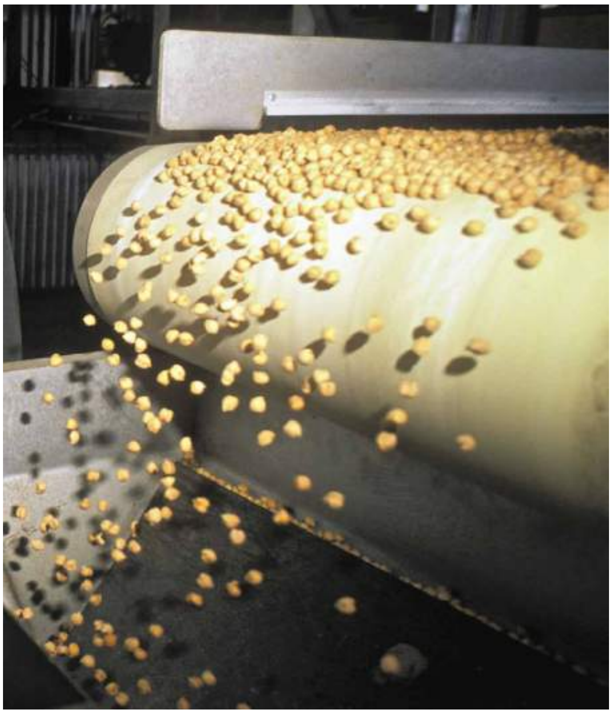

Figure 4: *Chickpea being graded. Because chickpea is traded for human consumption, samples must be of high quality.*

Photo: B Collis, Source: GRDC

A.1.3 Nutritional information

Chickpeas are a very good source of carbohydrates and proteins, which together constitute about 80% of the total dry seed weight. Pulses are the major source of protein in vegetarian diets, with a protein percentage of 20–25%; wheat has only half this amount, and rice only has a third of the protein of pulses. [9] Starch, which is the principal carbohydrate component, varies in content from 41–50%, and is lower in desi varieties than kabuli varieties. Total seed carbohydrates vary from 52–71%. The crude protein content of chickpea varieties ranges from 16-24%. Crude fibre, an important constituent of chickpeas, is mostly located within the seed coat. Based on amino acid composition, the proteins of chickpea seed were found, on average, to be of higher nutritive value than those of other grain legumes. Chickpeas meet adult human requirements for all essential amino acids except methionine and cysteine, and have a low level of tryptophan. Chickpeas have a high protein digestibility and are richer in phosphorus and calcium than other pulses.

Table 1: *Nutritional information for pulses per 100 g raw. These values should be taken as guidelines only; values can vary with variety, conditions of growth and age of pulse.*

	Chickpea	Field pea	Lupin	Lentil (red)	Lentil (green)	Faba bean	Mungbean
Energy (kJ)	986	886	1840	968	1550	1680	1800
Protein (g)	13	18	32	14	27	25	26
Fat (g)	3.8	0.8	5	0.4	2.5	1.3	2
Carbohydrate	41	40	26	44	58	57	72
Fibre (g)	17	19	15	7	10	8	12

Source: Pulse Australia

9 DAFF (2012) Chickpea—overview. Department of Agriculture Fisheries and Forestry Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/overview

A.1.4 Agronomy at a glance

- Measure stored soil moisture depth
- Avoid saline or sodic soils
- Assess the Phytophthora risk
- Avoid waterlogged areas.
- Control broadleaf weeds
- Ensure there are no damaging levels of herbicide residue
- Avoid planting near old chickpea stubble
- research variety choice and specific variety management packages
- Ensure seed quality and seed fungicide dressing is adequate
- Ensure inoculation procedures are adequate
- Sow in an up-and-back row formation
- Ensure fertiliser requirements are met
- Assess crop establishment conditions
- Monitor crops at critical stages
- Respond to crop management needs in timely way
- Set up boom spray for fungicides
- Consider desiccation as harvest aide
- Prepare storage infrastructure for grain at 14–16% moisture [10]

A.2 Brief history

The first grain legumes to be introduced into Australia were most likely field pea and chickpea in the late 19th century. Field pea has been grown ever since, albeit on a limited scale until its resurgence in the 1980s, but chickpea remained ignored for almost 80 years. Market demand was low, with limited consumption of grain legumes as food in Australia at that time and a restricted knowledge of trade opportunities. With a humble beginning of <0.08 million ha in 1971, winter grain legumes reached >2.3 million ha in the 2012 season (Figure 4). [11]

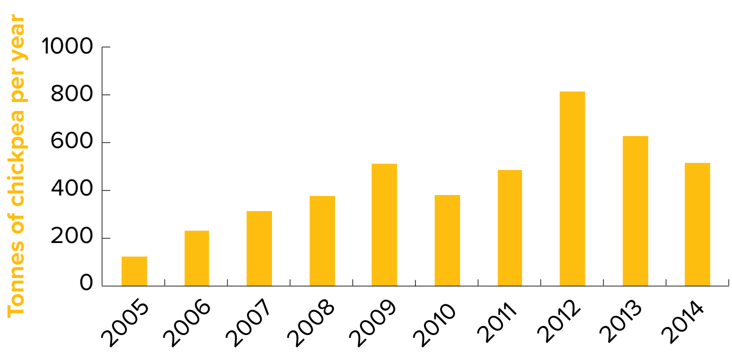

Figure 5: *Australia chickpea production (desi and kabuli), tonnes of chickpeas per year.*

Source: ABARES and Pulse Australia

Chickpeas were first grown in Australia as a commercial crop in Goondiwindi, Queensland, during the early 1970s. In the mid-1990s, chickpea was the most rapidly

10 Pulse Australia, Checklist for Northern Growers http://www.pulseaus.com.au/storage/app/media/crops/2010_NPB-Chickpea-checklist-north.pdf

11 Siddique, K. H. M., Erskine, W., Hobson, K., Knights, E. J., Leonforte, A., Khan, T. N., ... & Materne, M. (2013). Cool-season grain legume improvement in Australia—use of genetic resources. *Crop and Pasture Science*, *64*(4), 347–360.

expanding pulse industry in south-western Australia. WA's chickpea industry rose to be a significant 70,000 hectare grain legume crop until the arrival of the fungal disease Ascochyta blight in 1999 devastated the industry. Currently production is less than 10,000 tonnes (see Tables 2 and 3). New higher yielding varieties with improved resistance to Ascochyta blight have now been developed and should help to stimulate chickpea plantings in WA. [12]

Table 2: *Production (tonnes) of chickpea crops in Western Australia, 2011–2015.*

2011	2012	2013	2014	2015	5-year average
6,000	4,000	6,000	4,000	3,000	4600

Source: DAFWA

Table 3: *Adjusted trial yields in t/ha and expressed as percentage of site mean.*

Region/Nearest town	Agzone 2 Wongan Hills		Agzone 4 Mullewa		NVT long-term yield potential
Variety name	Average yield (t/ha)	% Site mean	Average yield (t/ha)	% Site mean	2009–2013
Ambar⚙	0.53	99	.71	111	1.207
Genesis™ 079	0.63	116	.59	92	1.189
Genesis™ 090	0.38	70	.37	58	1.089
Genesis™ 836	0.53	97	.74	116	1.155
Neelam⚙	0.64	119	.62	98	1.247
PBA Maiden⚙	0.59	110	.68	106	1.169
PBA Slasher⚙	0.54	99	.73	114	1.195
PBA Striker⚙	0.56	104	.78	122	1.257
Site mean (t/ha)	0.54		.64		
LSD (t/ha)	0.11		.08		
CV%	13.92		8.32		
Sowing date	15 May 2014		12 May 2014		

Source: Ian Pritchard, DAFWA and NVT

A.3 GRDC chickpea breeding investment

The chickpea breeding program has so far relied on conventional breeding techniques. However, the amount of genetic and genomic resources is increasing, and in the near future, marker-assisted breeding methods will be deployed, or traits such as pyramiding minor genes for Ascochyta blight resistance and combining these with high levels of PRR resistance. It is anticipated that the use of such technologies will be more economical and allow faster delivery of varieties to Australian growers than current methodologies. [13]

The principal outputs of GRDC chickpea breeding investments have been improved varieties. Important traits from these improved varieties have been disease and pest resistance, and traits that influence yield. Improvements in these traits were delivered in the new varieties released between 2005 and 2012. Higher yields and increased disease resistance can translate into higher profits from the chickpea crop; in turn, potentially increasing the attractiveness of chickpeas in a cereal rotation and benefiting the next cereal crop.

12 https://www.agric.wa.gov.au/pulses/western-australian-pulse-industry

13 Siddique, K. H. M., Erskine, W., Hobson, K., Knights, E. J., Leonforte, A., Khan, T. N., ... & Materne, M. (2013). Cool-season grain legume improvement in Australia—use of genetic resources. *Crop and Pasture Science*, *64*(4), 347–360.

Figure 6: *The GRDC-funded chickpea breeding program has resulted in improved varieties with better disease and pest resistance.*

GRDC's investment in three projects (DAN00065, DAN00094, DAN00151) is expected to produce a number of benefits. The total investment of $43 million has been estimated to produce total gross benefits of $123 million, providing a net present value of $80 million, a benefit-cost ratio of just under 3:1 (over 30 years, using a 5% discount rate), and an internal rate of return of over 15%. [14]

Pulse Breeding Australia (PBA) is a world-class Australian breeding program for chickpeas, field peas, faba beans, lentils and lupins. PBA has operated since 2006, with a vision to see pulses expand to more than 15% of the cropping area, thereby underpinning the productivity, profitability and sustainability of Australian grain farming systems. PBA is developing a pipeline of improved varieties for Australian growers that achieve higher yields, have resistance to major diseases and stresses, and have grain qualities that enhance market competitiveness.

PBA is an unincorporated joint venture between:

- Department of Primary Industries, Victoria (DPI Vic)
- South Australian Research and Development Institute (SARDI)
- Department of Agriculture, Fisheries and Forestry, Queensland (DAFF Qld)
- New South Wales Department of Primary Industries (NSW DPI)
- Department of Agriculture and Food Western Australia (DAFWA)
- University of Adelaide
- University of Sydney
- Pulse Australia
- Grains Research and Development Corporation (GRDC)

A.4 Keywords

Chickpeas, desi, kabuli, pulse, nitrogen fixation, rotation, breeding, farming systems, Western Australia.

14 P Chudleigh (2012) An economic analysis of GRDC investment in the National Chickpea Breeding Program. GRDC Impact Assessment Report Series, December 2012, https://www.grdc.com.au/Research-and-Development/~/media/2FE8D5C5C0FE42B8BC7985647002FD70.pdf

Planning/Paddock preparation

Key messages

- To reduce disease risk, chickpea crops should be separated from the previous year's chickpea crop by at least 500 m and up to 1 km in areas where old stubble is prone to movement; i.e. downslope and on flood plains.
- Avoid paddocks with high weed burdens, as chickpeas provide poor competition for weeds.
- Chickpeas are not as well suited to low rainfall areas (less than 350 mm) (Figure 1). Kabuli types are less tolerant than desi types to dry conditions, as they require more moisture to achieve a satisfactory grain size and yield. Desi types require above 350 mm annual rainfall and kabuli types need more than 400 mm.
- Chickpea is an advantageous crop rotation because of its nitrogen-fixing ability, however, it can be susceptible to nematodes.
- Consider herbicide residual and plant-back effects before sowing.
- Prior to sowing it is important to consider disease, nematode and pest management by knowing paddock history and testing soils for these issues.

Figure 1: *Ideal conditions for chickpea growth.*

Source: Pulse Australia

WATCH: Growing profitable pulses

1.1 Paddock selection

Key points

- Well-drained soils with a pH above 5.5 in calcium chloride ($CaCl_2$), heavy deep clays, heavy loam, sandy loam and Salmon Gum soils. Avoid soils with a pH below 5.5 ($CaCl_2$), saline soils, high boron soils and Wodjil soils. Chickpea has poor tolerance of low pH where aluminium toxicity can be a problem.
- Check soil tests to determine if the soil type is suitable for chickpea production; i.e. pH 5.2–8.0, loams to self-mulching clays, sufficient stored soil moisture, absence of herbicide residues and absence of constraints such as sodicity, salinity/chloride, high bulk density and potential for waterlogging.
- A soil structure and slope which allows good drainage—avoid shallow soils.
- Little or no risk of sulfonylurea carry-over.
- A low broadleaf weed burden.
- Remove rocks from paddocks. The paddock surface needs to be left relatively even and flat after sowing for easy harvest.
- To minimise the risk of diseases, do not grow chickpeas more often than one year in four in the same paddock and at least 500 m from last season's chickpea stubble. [1]
- Chickpea crops should be separated from previous year's crop by at least 500 m and up to 1 km in areas where old stubble is prone to movement; i.e. downslope and on flood plains. This helps to reduce the spread of ascochyta blight, a foliar/stubble-borne disease.

Aim to direct-drill chickpeas into standing cereal stubble. Crops reliably yield 10% higher when established this way. Uniformity of soil type, paddock topography, and surface condition of the paddock are all important criteria in assessing whether country is suitable for chickpea production. Harvest losses are much higher in rough or uneven paddocks, particularly in dry seasons when crop height is reduced. Sticks or rocks, eroded gullies or gilgais ('melon' or 'crab' holes) will prevent headers operating at low cutting height. This is particularly important when using headers with wide fronts. Small variations in paddock topography can lead to big variations in cutting height across a wide front and a subsequent increase in harvest losses.

Moisture supply can significantly affect crop maturity. Changes in soil type and moisture-holding capacity across a paddock can lead to uneven crop maturation, delayed harvesting and increased risk of weather damage or high harvest losses.

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

Paddocks that have even soil types are relatively easier to manage, and are preferred for chickpeas. [2]

Selecting a paddock with minimal variation in soil type will often help to provide even maturity and ripening of the crop. This will enable harvesting at the earliest possible time, increase quality, and minimise harvest losses. The overall result is usually a more profitable crop.

1.1.1 Avoid deep gilgai or heavily contoured country

Contours and undulating country ('melon holes' or 'crab holes') present two problems:

- Uneven crop maturity due to variation in soil water supply. Melon-holes usually store more water than the mounds, and the crop in wetter areas will often continue to flower and pod when the rest of the crop is already drying down. Similarly, contour banks retain more moisture after rain, and prolong crop maturity relative to the rest of the crop late in the crop.
- High harvest losses and increased risk of dirt contamination in the header sample. Many dryland chickpea crops require the header front to be set close to ground level, and even small variations in paddock topography can lead to large variations in cutting height across the header front, and a significant increase in harvest losses.

Contamination of the harvested sample with dirt and clods is difficult to avoid in undulating, gilgai country, and can cause a significant increase in grading losses and costs.

Foreign material must not exceed 3% by weight, of which no more than 0.3% must be unmillable material (soil, stones and non-vegetable matter). If a farmer delivers chickpeas that do not meet this export standard, they will need to be graded at a cost of $15–25/t.

1.1.2 Soil

Desi chickpea is well suited to many of the calcareous red-brown earths, duplex soils, and shallow red earth soils that constitute about 60% of the agricultural land in the low rainfall regions of south-western Australia. [3]

Prior to planting, review soil tests and records, paying particular attention to the following soil characteristics:

- soil type: loams to self-mulching clays
- pH 5.2–8.0
- saline soils: ECe >1.5 ds/m will cause a yield reduction
- sodicity: >1.0 surface or >5.0 in subsoil can limit yield
- high boron and soil chloride levels >600 mg/kg in subsoil layers severely limit root growth, depth and water extraction from the soil
- potential waterlogging problems—avoid compacted soils or areas where free water does not drain away and/or remains saturated. Spring sowing may be an option in higher rainfall areas [4]
- amount of stored soil moisture and received rainfall
- note potential impacts of herbicide residues [5]

For more information on causes and management of waterlogging, salinity, sodicity and chloride issues, see Section 14: Environmental issues.

2 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

3 Jettner, R. J., Loss, S. P., Siddique, K. H. M., & French, R. J. (1999). Optimum plant density of Desi chickpea (*Cicer arietinum L.*) increases with increasing yield potential in south-western Australia. Crop and Pasture Science, 50(6), 1017-1026.

4 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

5 G Cumming (2014) Chickpea varieties selecting horses for courses. GRDC Update Papers 5 March 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Chickpea-varieties-selecting-horses-for-courses

Chickpeas will not grow in light acid soils and areas prone to waterlogging should be avoided. Chickpea crops must be harvested close to the ground so stony paddocks or fields with uneven soil surface (e.g. gilgai) should be avoided.

Chickpea are susceptible to hostile subsoils, with boron toxicity, sodicity and salinity causing patchiness in affected paddocks. Chickpea will not tolerate soils with any exchangeable aluminium present. Tolerance to sodicity in the root zone (to 90 cm) is less than 1% exchangeable sodium (ESP) on the surface and less than 5% ESP in the subsoil. [6]

WATCH: Novel approaches to tackling soil acidity in the west.

IN FOCUS

Adaptation and seed yield of cool-season grain legumes in Mediterranean environments of south-western Australia.

A range of cool-season grain legume species have shown considerable potential for soils unsuitable for the production of narrow-leafed lupin (*Lupinus angustifolius* L.) at limited sites in the Mediterranean-type environments of south-western Australia. In one study the adaptation of these grain legume species was compared by measuring crop phenology, growth, and yield in field experiments at 36 sites over three seasons, with the aim of identifying species with suitable adaptation and seed yield for specific environments. Soil pH and clay content and rainfall were the environmental factors identified as the most important in determining seed yields. Soil pH and clay content appeared to be especially important in the adaptation of kabuli chickpea, performing best in soils with pH >6.0 and clay contents >15%. [7]

6 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

7 SiddiqueABD, K. H. M., LossAB, S. P., ReganA, K. L., & JettnerC, R. L. (1999). Adaptation and seed yield of cool season grain legumes in Mediterranean environments of south-western Australia. Aust. J. Agric. Res, 50(375), 87.

Subsoil

Chickpeas are suited to soils with a surface pH($CaCl_2$) of greater than 5.0, particularly if pH rises to above 5.5 within 10-15 cm of the surface. [8]

Subsurface pH is of importance to the break crop in the rotation. Knowing the pH at depth is vital for an effective break crop, particularly if the surface soil is testing at or above the target of pH 5.5. Subsurface soil pH results in WA have not been favourable and many growers are deciding the best way to invest is to repair it. This may be through applying more lime than initially planned and mechanical incorporation of the lime. Recent surface-applied lime has yet to impact on the subsurface soils without mechanical incorporation in many soil types.

In a sample of 184 paddocks across the WA growing region, 38% of all paddocks had satisfactory surface pH of 5.5 or above, and 40% of these had subsurface pH values below target (Less than pH 4.8.). Overall, 23% of the 184 paddocks had satisfactory surface and sub surface soil for growing chickpeas.

The break crops chickpea, field pea and canola are all sensitive to acidity. These crops will not be productive in spite of a hospitable surface soil (pH greater than 5), as the acid subsurface will prevent root growth and nutrient adsorption. Testing the subsurface soil pH will help make better decisions of crop type and variety for rotation. [9]

WATCH: Over the Fence West: Spading pays off for Moora grower.

1.1.3 Soil pH

Key points:

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

Hydrogen ion concentration in the soil is called pH and is influenced by chemical reactions between soil components and water. Soil pH is affected by the varied combinations of positively charged ions (sodium, potassium, magnesium, calcium, aluminum, manganese, and iron) and negatively charged ions (sulfate, chloride,

8 Parker W. DAFWA (2014). Crop Updates – Break crops being sown onto unsuitable soils, unsuspectingly.

9 Parker W. DAFWA (2013). Profitable crop and pasture sequencing 2013 trial report. https://www.agric.wa.gov.au/grains-research-development/profitable-crop-and-pasture-sequencing-2013-trial-report?page=0%2C0

bicarbonate, and carbonate). Soil pH directly affects the concentration of major nutrients and the forms of microelements available for plant uptake and can result in deficiencies or toxicities (Figure 2).

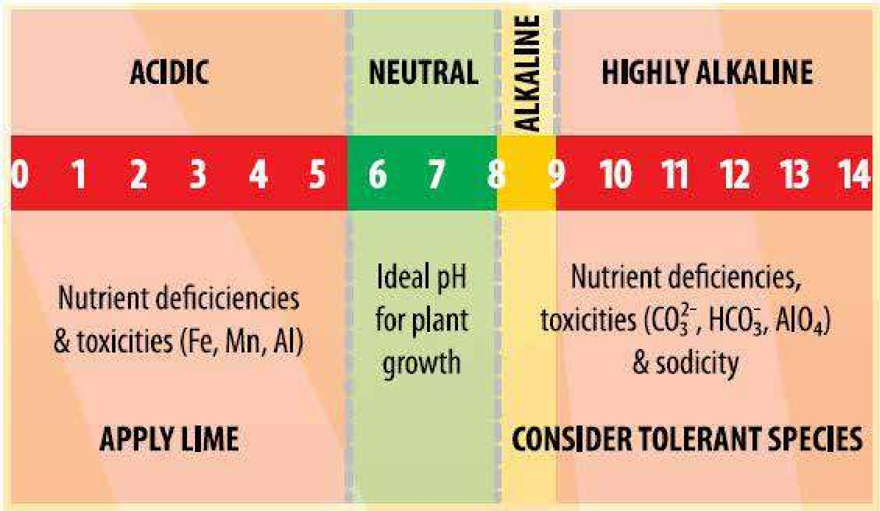

Figure 2: *Classification of soils on the basis of pH (1:5 soil:water), the implications for plant growth and some management options.*

Source: Soilquality.org

MORE INFORMATION

Soil acidity Western Australia

Soil acidity is a major constraint to farming in Western Australia. Extensive surveys of soil pH profiles across the south-west show that more than 70% of surface soils and almost half of subsurface soils are below appropriate pH levels. The majority of growers now place soil acidity in their top three management priorities. Managing soil acidity is both achievable and profitable.

Managing soil pH

Acid soils

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

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

Alkaline soils

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

MORE INFORMATION

DAFWA - Soil pH

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

In high pH soils, using alkalinity tolerant varieties of crops and pasture can reduce the impact of high pH. [10]

1.1.4 Rainfall

Chickpeas are not well suited to the lower rainfall, hotter areas, although the plants will set seed under warmer conditions where other pulse crops are likely to fail. Cool wet conditions are more likely to stimulate foliar diseases and these can adversely affect seed set and yield. Desi varieties should only be grown in areas where the annual rainfall is greater than 350 mm. Sowing is best carried out from early May

10 Soiquality.org. Soil pH- South Australia. http://www.soilquality.org.au/factsheets/soil-ph-south-austral

to early June with early sowing recommended for the lower rainfall areas. Kabuli varieties are later maturing and should only be grown in areas where the annual rainfall is over 450 mm. As a higher value crop, kabuli types are often grown on fallow where extra moisture can mean larger seed. [11] When grain prices are high, growing chickpeas on fallow as a cash crop rather than a break crop could be considered.

1.1.5 Physical constraints

Physical constraints decrease oxygen and water movement in soils. Compacted soils and those with high physical strength (bulk density >1.5 g/cm3) impede root growth. Subsoil compaction can be caused by heavy traffic or tillage on wet soils. Compacted layers may be visible, measured by high penetration resistance (> 2 MPa), or indicated by distorted root growth. Deep ripping of soils and use of controlled traffic can help to overcome compaction, but in some soils, amelioration with organic matter, gypsum or lime, for example, may be required as well. Chickpeas are particularly prone to hard pans and compacted soils, and suffer more from waterlogging if compaction layers exist.

WATCH: De-compacting and stabilising compacted soils in WA.

See Section 14: Environmental issues for more information on waterlogging.

1.1.6 Nutrient constraints

Crop management can affect nutrient deficiencies. Iron deficiency in pulses is more likely to occur in wheel tracks and compacted areas. Manganese deficiency is more likely in light, fluffy soil.

In pulses, cobalt and molybdenum are required for nodulation and N fixation, so deficiency of these trace elements can lead to poor nodulation. In higher pH soils, Zinc deficiency is also possible. Ensure good Zinc supply in granular fertiliser or by foliar spray.

1.1.7 Biological constraints

Problems can occur when there is a lack of beneficial organisms such as earthworms and *Arbuscular mycorrhizae* fungi (AMF) in soils. Their build-up can be encouraged by use of stubble retention and direct drilling or no tillage as well as appropriate crop rotations.

11 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

1.1.8 Problematic paddocks

Stones and sticks are a concern in poorly or recently cleared country. Harvest losses increase dramatically if the header front needs to be raised to avoid serious mechanical damage to the header. Small stones and wood fragments can also contaminate the seed sample and downgrade quality.

Cloddy or badly ridged paddocks are likely to cause contamination of the chickpea sample during harvest. Level the soil surface as much as possible, either during ground preparation or at sowing. A land-roller can be helpful after sowing, in cultivated situations, to level the soil surface and push clods of soil and small stones back down to level with the surface.

1.1.9 Stubble retention

Chickpeas fit well into stubble retention systems with no tillage, and serve their wider role in crop rotations and farming systems. Retention of adequate plant residues on the surface is important to protect the soil from erosion both during growth and after harvest. This will not affect chickpea germination or growth, and can improve establishment on hard-setting, surface-crusting soils. Sowing into cereal stubble reduces soil moisture losses from evaporation. [12]

Chickpeas established by direct drilling into standing cereal stubble reliably yield 10% higher than when using other planting techniques (Figure 3). [13]

Figure 3: *Better chickpea yields are achieved by sowing into cereal stubble.*

Photo: Gordon Cumming, Pulse Breeding Australia

There are advantages and disadvantage to stubble retention, with high stubble loads potentially causing problems for growers in the following year (Table 1).

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

13 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Table 1: *Advantages and disadvantages in retaining stubble.*

Advantages of stubble retention	Potential disadvantages of stubble retention
Retained stubble provides excellent ground cover (>2.5 t/ha), thus reducing wind and water erosion;	Seeder blockages impact on plant establishment;
increases rainfall infiltration;	Stubble provides ideal habitat for pests to survive;
reduces moisture evaporation (>4.5 t/ha);	physically intercepts herbicides;
eliminates the need to burn, bale or incorporate; and	increases frost risk;
recycles nutrients back into the soil.	carries over diseases; and
	increases potential for nitrogen tie-up.

Based on information from the GRDC

WATCH: Stubble Management.

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

WATCH: GCTV4: Burning for stubble retention.

Stubble and its impact on temperature in chickpea crops

Key points:

- Chickpea sown into flattened residue had lower (av. 1.00C) minimum temperatures compared to standing residue.
- Chickpea sown into flattened residue had higher (av. 3.40C) maximum temperatures compared to standing residue.
- Stubble thresholds are unknown at this stage.

Stubble affects soil physical properties such as temperature and moisture. The effect on temperature is due to landscape features such as whether a paddock was on top of a hill, on a hill slope, or at the lower end of a slope because cold air (due to its higher density) tends to flow downhill and settle in the lower parts of the landscape, leading to colder pockets where temperatures decline the most.

Stubble cover also affects air and soil temperature. During the day, the stubble reflects radiation due to its 'albedo'. A bare, darker soil absorbs more solar radiation than a stubble-covered soil and warms up more readily. The stubble also acts as insulation—it contains a lot of air which is a poor conductor of heat.

Finally, the stubble affects the moisture content of the soil. It takes more heat to warm up moist, stubble-covered soil than dry, bare soil. This causes soil temperature of a bare soil to be higher than stubble-covered soil during the day (especially in the afternoon). At night, however, the bare soil loses more heat than stubble-covered soil due to the lack of insulation (the air-filled mulch being a poorer heat conductor). This is especially noticeable when skies are clear. The air above the bare soil is therefore warmer during the night than the stubble-covered surface. This can affect canopy temperature profiles in crops.

In a recent trial, the temperature of stubble and the subsequent impacts on chickpea crops in NSW were explored.

In this trial, PBA HatTrick⒟ was sown at 30 plants/m² into paired 0.50 m rows with a skip row configuration leaving a gap of 1.0 m between skip rows.

Tiny tag™ temperature sensors were placed in mini Stevenson screens within chickpea experimental plots to measure temporal changes in temperature at ground level. Temperature sensors were placed between 1.0 m wide rows in:

1. plots sown into standing stubble with bare soil between chickpea rows
2. plots sown into flattened stubble with surface stubble between chickpea rows

The sensors recorded temperature every 15 minutes and were left in the plots right through to harvest in mid-December.

Chickpeas were sown into 5.84 t/ha of wheat stubble, either standing or flattened.

Standing stubble plots with bare soil between rows:

- had minimum temperatures 1°C warmer at the base of the canopy than surface-stubble plots during vegetative period
- had maximum temperatures -3.4°C cooler at the base of the canopy than surface-stubble plots during flowering and grain fill period
- recorded five days with maximum temperatures >35°C compared to 27 days of maximum temperatures >35°C where stubble was flattened.

Plant components for the stubble treatments are shown in Table 2. Plants sown into bare soil between standing wheat rows had higher grain yields which were achieved through more pods being set and more seeds being produced per square metre.

Table 2: *Effect of stubble treatment on selected plant components.*

Stubble	DM/m² (g)	Grain/m² (g)	Seeds/m²	Pod No/m²	Seeds/pod	HI
Bare soil	706	270	1072	815	1.3	0.38
Straw	526	226	908	538	1.7	0.43

Source: GRDC

Conclusions

- Flattened surface residue led to lower minimum temperatures in crop than standing residue.
- Flattened residue had higher maximum temperatures during flowering and grain fill than standing residue.
- Flattening and spreading residue can increase crown rot infection in the following wheat crop.
- Keep wheat stubble standing in defined rows and sow chickpeas between wheat rows. [14]

Bunching and clumping of stubble

Stubble bunching or clumping can occur when sowing into retained stubble as a result of blockages during sowing. These mounds of stubble are often picked up in the header front, causing mechanical blockages and contamination of the sample if they contain excessive amounts of soil.

14 Verrell, A. (2016). GRDC Update Papers - Stubble and its impact on temperature in chickpea crops. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Stubble-and-its-impact-on-temperature-in-chickpea-crops

MORE INFORMATION

Wide rows and stubble retention

Determining best stubble management

Management options for dealing with stubble clumping include:

- use of a no-till (disc) seeder or other seeder capable of handling heavy stubble
- modification of existing air-seeders (tyne shape and lifting some tynes)
- sowing before soil and stubble becomes too wet
- use of rotary harrows to spread and level stubble and sow between old plant rows, aiming to leave stubble standing

Standing stubble can be slashed or burnt if sowing equipment with good trash flow is not available. [15]

1.1.10 Soil testing guide

Accurate soil tests allow small landholders to maximise the health of their soils and make sound decisions about fertiliser management to ensure crops and pastures are as productive as possible (Figure 4).

Identifying potential soil limitations enables landholders to develop an action plan (such as an appropriate fertiliser program) to reduce the potential of 'problem' paddocks.

Figure 4: *Terrier automatic soil sampler.*

Source: DAFWA

Soil health looks at all aspects of the soil together, including the physical, chemical and biological components, rather than each component separately.

Healthy soil requires a balance between inputs and outputs and regular soil tests provide a valuable monitoring tool to keep an eye on soil nutrient levels and other key characteristics such as pH and salinity.

A soil imbalance can affect the ability of plants to absorb any applied fertiliser, wasting time and money. A combination of soil tests, on-farm observations and historical records will assist in determining soil health.

Soil testing is a useful tool to provide information to support decisions about fertiliser application, however it is important to combine test results with other information, such as specific crop or pasture requirements, available funds and fertiliser cost, methods of application and potential income from the crop or pasture being grown.

15 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. PulseAustralia Limited.

Accurate results

Soil test results are only as accurate as the samples taken from the paddock and how they are handled leading up to laboratory analysis. If the samples do not truly reflect the soils in a certain paddock the test results are likely to suggest an inaccurate picture of soil fertility.

Sampling not only depends on how the sample is taken but when and where.

There are four main steps in soil sampling:

- collecting representative samples
- laboratory analysis
- interpretation of test results on which to make decisions
- recording the results and actions taken for future reference

Taking the test

There is more to soil testing than analysing the soil's nutrient status. The process incorporates the sampling procedure, soil analysis and interpretation of the results leading to a sound recommendation.

Before collecting soil samples, consult a local agronomist to discuss the need for additional tests such as deep soil nitrogen tests. In most soils the nutrients are concentrated in the top 10 cm of soil, so ensure samples are consistently taken to this depth.

When to collect samples

Changes in soil moisture, plant growth stage and decomposition of organic matter all affect soil nutrient levels. For example, available nutrients can be low in soil samples collected during spring as nutrients are still in the plant and are not returned to the soil until after decomposition.

Check with your local agronomist as to the best time to collect soil samples in your area. Most comparisons are based on mid–summer (January to March) sampling when the soil is dry.

Regular tests build better profile

Because many factors influence soil test results, soil analysis for one season is not conclusive. Subtle differences in soil type can impact significantly on the availability and exchange of nutrients between the soil and plants so it is important to test soil regularly.

Testing the soil at the same time each year improves the comparison of results between years and builds a clear profile of soil health over time. It's also to take tests from the same site to monitor change of nutrients over time.

Collect enough samples to make up a representative picture of a paddock. It is better to over-sample, as this will provide a more accurate picture of the soil and will help reduce unnecessary fertiliser application.

Selecting your samples

Sampling often limits the success of soil testing. One hectare of soil to a depth of 10 cm contains about 1300 t of soil. A 10 g subsample sent to a laboratory represents only one part in 1300 million. So ensure your samples are representative.

To increase test result accuracy, avoid sampling soil near fences, trees, troughs, headlands, dams, stock tracks and clumps of manure, fertiliser dumps, fertiliser bands from the previous year, burnt heaps, areas of abnormally good or poor growth, or poorly drained areas.

Also avoid collecting samples from areas where fertiliser, gypsum or lime have been applied during the preceding three months. Wet soil can alter test results due to microbial activity and mineralisation.

Account for variability

Variability of soil is often overlooked.

Most soils in Western Australia (WA) are not uniform and comprise different soil types and slopes. Even individual paddocks often have variations in soil surface depth, soil type and nutrient levels, which can be significant over relatively short distances.

Many soil types can be found in a single paddock. This, combined with management practices, can lead to varying nutrient levels within and across paddocks. Even if the paddock has a uniform single soil type, stock can spread nutrients unevenly through urine and dung. Management can concentrate or spread nutrients through clearing, burning, grazing or hay production.

Where soil differences within a paddock are obvious and areas can be treated differently, take separate samples from each area.

Where there is more than one soil type, take about 20 cores from each major soil type. Ensure each soil type is sampled and labelled separately to allow for individual analysis.

To increase productivity on larger properties it is worthwhile classifying the land and soil types and ensuring samples are only collected from within a specific land and soil type.

Sampling sites

Take samples from across a paddock using a dedicated soil sampling tube or 'pogo'. Take at least five (preferably more) samples per hectare, covering the entire area.

Keep in mind that a hectare is 100 m × 100 m and to take five samples diagonally will involve taking samples about 30 m apart in a zig-zag pattern.

If the paddock is predominantly of one soil type, take at least 40 cores, each to a depth of 10 cm. For each soil type, bulk all samples together, thoroughly mix and take a 500 g subsample to be sent to the laboratory with clear labels.

Note in your records the pattern that you used to collect samples. Following the same pattern in future years will provide a clearer picture of soil fertility trends.

Handle with care

Collect cores in a clean plastic bag and label clearly. Do not use second-hand containers or touch soil samples with bare hands as this will contaminate the sample and affect the test results.

Air-dry samples by leaving the top of the bag open to the air if there is a delay between sampling and posting. Send samples to the laboratory early in the week if possible to avoid postal delays over weekends.

Prepared soil sampling kits are available from most rural supply stores. If using an off-the shelf kit read the instructions carefully as they may have specific instructions.

Interpreting the results

A number of laboratories are available to test and analyse your soil samples. Some services offer recommendations relating to the test results.

Contact your local agricultural consultant, agronomist or rural supply store for the contact details of available soil testing and support services in your region.

How to take a soil sample

To obtain an accurate soil analysis, the sample cores need to be taken correctly. Before taking samples, plan how many samples are required and from where they will be collected in the paddock.

Ensure the stainless steel sampling tube and collection bags (use new bags for each sample) are clean before taking samples, including inside the steel tube. If using oils on clay soils, ensure they are free of nitrates and carbon.

Most soil samples are taken from the top 100 mm of surface soil. Adjustable soil sampling probes often will have marks at 100 mm intervals.

If no mark exists set the depth stop at 100 mm using a ruler. It is vital all samples are taken from the same depth.

Zone the paddock based on soil type or yield potential and then take a representative sample from those areas (Figure 5).

Agronomist's view

For large paddocks, plan to take at least 25 cores in a grid or zig-zag pattern (Figure 5). Paddocks of more than 50 ha will require more core samples (minimum of 30 cores).

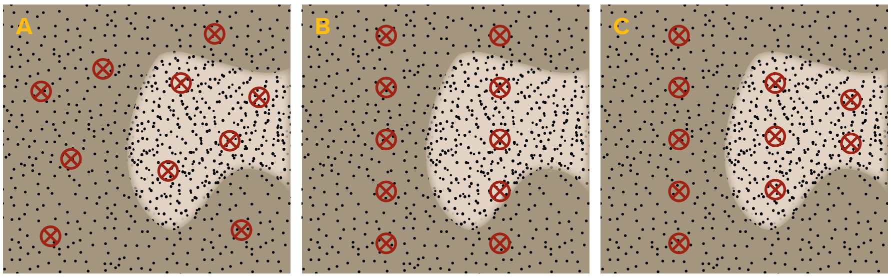

Figure 5: *Sampling strategies used to create a composite sample that integrates variation across different soil types (A and B); and a strategy to describe variation by sampling zones and analysing samples separately (C). A: haphazard samples strategically located to approximate the relative representation of different soil types. B: samples taken along transects intersecting different soil types. C: equal numbers of samples from each zone.*

Source: Soilquality.org

If there are two or three distinct soil types in a paddock of more than 100 ha, treat them as separate paddocks. In WA, it is recommended to take 4–8 samples within a paddock (each sample being at least 12–15 cores), each taken from within a land management unit in the paddock.

Before sampling, remove any debris from the soil surface, without disturbing the soil. Do not scuff away any plant material from the surface as this will lead to a loss of surface soil. Push in the sample tube straight until the depth stop contacts the ground.

Half-turn the sample tube and then remove it from the ground, taking care not to lose any soil from the end of the tube.

In light soils, the whole tube might need to be pushed toward the ground and a finger placed over the end of the core while the tube is parallel to the ground to ensure the soil does not fall out.

Place a sample bag over the upper end of the tube and invert, emptying the core into the bag. Tap the tube with the palm of a hand to loosen the core if required.

Soil tests can be a great tool in determining the health of your soils and in turn, maximise their productivity. [16]

16 DAFWA (2016). Soil sampling and testing on a small property. https://www.agric.wa.gov.au/soil-productivity/soil-sampling-and-testing-small-property?page=0%2C2

1.2 Paddock rotation and history

1.2.1 Break cropping

- A break crop is any crop sown to provide diversity to help reduce disease, weed and pest levels in a paddock.
- Choice of break crop type is determined by soil type and regional climate; crop sequence is determined by market and agronomic factors.
- Sourcing regional information from research organisations, agronomists, consultants, other farmers and industry bodies is essential when selecting the most suitable crop type and varieties.

Break crops generally refer to a pulse or oilseed crop grown instead of cereals. The decision not to grow wheat but to grow and choose a break crop is based on many factors including the relative profitability of the crops, yield by price, the cereal disease pressure, herbicide resistance and personal preference.

MORE INFORMATION

GRDC Break crop benefits Fact Sheet.

1.2.2 Chickpea as a rotation crop

Chickpea is well-suited to rotation with cereal and canola crops. Determining the most suitable cereal–pulse–oilseed rotation requires careful planning. There are no set rules and it is best to plan a separate rotation for each cropping paddock.

The major aim should be to achieve sustainability and the highest possible overall profit, but to achieve this, the rotation must be flexible enough to cope with key management strategies such as; maintaining soil fertility and structure, controlling crop diseases, exploiting plant available water, managing farm business risk and controlling weeds and their seed-set (Table 3). The same pulse should not be grown in succession, and extreme care must be taken if growing the same crop in the same paddock without a spell of at least three years. For disease management, it is recommended to aim for a break of at least four years between chickpea crops. [17] Successive cropping with the same pulse is likely to result in a rapid build-up of root and foliar diseases as well as weeds. Where possible, alternate the type of pulse crop being grown in a continuous rotation with cereals. Following dunfield pea or faba bean, leave two years before sowing chickpea. It is almost impossible to grade volunteer peas out of chickpea.

Table 3: *Advantages and disadvantages of including chickpeas as a crop rotation.*

Advantages	Disadvantages
Chickpea is a break crop that can be used successfully in rotations to effectively break the lifecycle of cereal root diseases like take-all and crown rot. Chickpea plants fix their own nitrogen. They have an extensive and deep root system. Chickpea can be sown relatively late compared to wheat, which can spread the demand for machinery and labour. Chickpeas can improve soil friability. Can expand weed-control options Don't require much additional equipment. Can be sown as an opportunity crop if seasonal conditions (full profile after summer rain) allow in lower rainfall districts. Assist in snail control as chickpeas are not attractive for snail multiplication.	Chickpea is less competitive against weeds than some other crops. Crop-topping to prevent weed seed set is not recommended in chickpea. Chickpea is not known to break up hard pans or compacted layers in the soil profile. Nematodes are a major drawback to planting chickpeas before wheat.

17 Pulse Australia. Southern Pulse Bulletin PA 2012 #08. Chickpea disease management strategy. http://pulseaus.com.au/storage/app/media/crops/2012_SPB-Chickpea-disease-management.pdf

In most situations, chickpeas can increase soil N by up to 35 kg nitrate-N/ha and yields of following wheat crops by up to 1 t/ ha, with an additional 1% of protein. Well-grown chickpea crops have been found to contribute up to 51 kg N/ha to the subsequent cereal crop. [18] In one study, the benefit of chickpea was equivalent to the application of 60 kg N/ha as fertiliser. [19]

It is often better to follow chickpea with barley rather than wheat. While older chickpea varieties were a host for the root lesion nematode *(Pratylenchus neglectus, P. thornei)*, newer varieties are not as susceptible to root lesion nematode multiplication. [20] Note that it is important to test soil for nematodes numbers if following chickpeas with a cereal other than barley, that may be more susceptible to yield loss.

Double-cropping pulses after cereals has been encouraged, except when stored soil moisture contents are low. The disadvantages of including pulses in the rotation are possible soil erosion losses due to the lower stubble levels produced and the chance of a greater volatility in prices associated with pulses. [21]

NOTE: Do not sow on to a field pea or faba bean stubble. Do not sow for two years after a dun field pea type or after faba bean. It is almost impossible to grade volunteer peas out. [22]

WATCH: Over the Fence: Chickpea redeemed as 'soil conditioner'.

1.2.3 Pulse effects on cereal yield

Pulses and cereal crops are complementary in a cropping rotation. This means crops benefit subsequent crops through processes related to disease, weeds, rhizosphere microorganisms, herbicide residues, residual soil water and mineral N. They may also include two recently discovered processes. One is growth stimulation following hydrogen gas released into the soil by the legume–rhizobia symbiosis. The other is a drain on assimilates when the roots are strongly colonised by the hyphae of *Arbuscular mycorrhizal* fungi built up by a previous colonised host crop.

Pulses fix their own N, leaving available N in the soil for the following cereal crop. Pulses also play a vital role in helping manage major cereal root diseases,

18 Cox, H. W., Strong, W. M., Lack, D. W., & Kelly, R. M. Profitable double-cropping rotations involving cereals and pulses in central Queensland.

19 Marcellos, H., Felton, W. L., & Herridge, D. F. (1993). Crop productivity in a chickpea-wheat rotation. In Proceedings 7th Australian Agronomy Conference (pp. 276–278).

20 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

21 Cox, H. W., Strong, W. M., Lack, D. W., & Kelly, R. M. Profitable double-cropping rotations involving cereals and pulses in central Queensland.

22 Pulse Australia. Chickpeas in South Australia and Victoria. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpeas-SA-Vic.pdf

particularly crown rot, by allowing more time for the cereal stubble to break down between host crops.

The combination of higher soil N and reduced root diseases is cumulative and can result in a dramatic increase in subsequent cereal yields. However, it is important to remember that the benefits of N fixation from pulses is not guaranteed. The amount of N fixed is determined by how well the pulse crop grows, reflecting the effectiveness of nodulation, seasonal conditions, crop management, and the level of nitrate in the soil at sowing. Soil nitrate suppresses nodulation and N fixation, hence high soil nitrate means low N fixation (Figure 6).

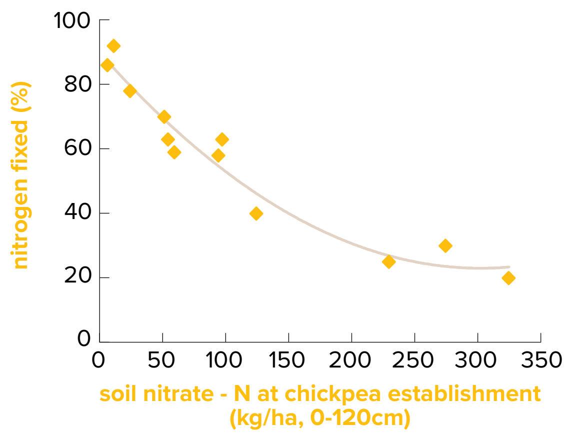

Figure 6: *Effect of soil nitrate nitrogen on nitrogen fixation by chickpea*

Source: J.A. Doughton et al 1993

Nitrate – N benefit for following cereals

The nitrate-N benefit from chickpea over a range of grain yields has been calculated from trials in northern Australia and is shown in Table 4. The terminology is important to an understanding of N budgets for chickpea and faba bean:

- 'Total N fixed'—the N fixed in both aboveground (shoots) and belowground (roots and nodules) biomass. With chickpea, 50% of total crop N is below ground.
- 'Nitrogen balance'—the difference between N inputs to the pulse crop (N fixation + N applied) and N outputs (N harvested in grain or hay + N lost (volatilised) from the crop and soil).
- 'Nitrate-N benefit'—the extra nitrate-N available at sowing in soil that grew a pulse crop in the previous season, compared with soil that grew a cereal crop.
- 'Harvest index' (HI)—for different crops, the relationship between shoot dry matter and grain yield (i.e. HI) may vary according to season and management.

By understanding the development and measurement of crop biomass and the factors that influence HI, better N and rotation management decisions can be made. [23]

23 Peoples, M. B., Schwenke, G. D., Felton, W. L., Chen, D., & Herridge, D. F. (2003). Effects of below-ground nitrogen on N balances of field-grown fababean, chickpea, and barley. *Crop and Pasture Science*, *54*(4), 333-340.

Table 4: *Nitrate-N benefit from chickpea, over a range of grain yields (all values are kg/ha).*

Grain yield (t/ha)	Shoot dry matter (t/ha)	Low soil nitrate at sowing (50 kg N/ha)			Mod soil nitrate at sowing (100 kg N/ha)		
		N fixed	N balance	Nitrate-N benefit	N fixed	N balance	Nitrate-N benefit
1.0	2.4	31	–3	16	13	–21	4
1.5	3.6	74	22	28	47	–5	13
2.0	4.8	120	49	44	84	12	24
2.5	6.0	157	66	48	111	21	38
3.0	7.1	198	88	52	141	31	52
3.5	8.3	231	102	57	164	35	64
4.0	9.6	264	116	61	188	39	69

Source: Grain Legume Handbook (2008)

Crown rot

Crown rot (caused by *Fusarium pseudograminearum*) is a major constraint to winter cereal production in Australia. The disease effectively blocks the base of infected tillers, preventing water movement from the roots through the stems and producing prematurely ripened heads (whiteheads) that contain no grain or lightweight shrivelled seed. Crown rot is a stubble-borne pathogen and survives as mycelium (cottony growth) inside cereal and grass weed residues.

Rotations to non-host winter pulses, oilseeds or summer crops are the most important component of an integrated disease management system. The effectiveness of a break crop in reducing yield loss to crown rot is a function of both inoculum survival (decomposition) and water-use pattern of the break crop. Chickpeas tend to use less water during the season than canola and generally do not root as deeply. Cereal crops following chickpea may experience reduced moisture stress through this water saving, thus reducing the development of whiteheads in infected tillers.

Yield response in a following cereal crop as a result of the benefit of reducing crown rot is a function of a break crop's effect on inoculum survival, soil water and Nitrogen (Figure 6). [24]

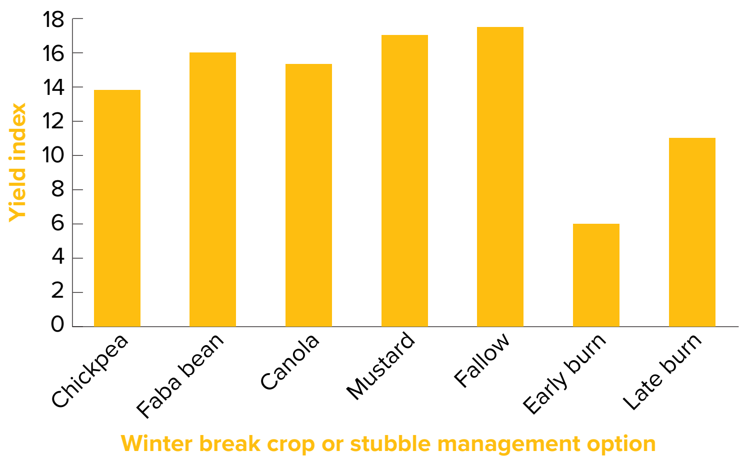

Figure 7: *Yield index of wheat after various break crops of management options compared with continuous wheat*

Source: NSW DPI, 2006

24 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

WATCH: Over the Fence West: VRT and legume rotations deliver yield boost and input cost cut.

1.2.4 Understanding soils and pulse crop constraints

If poor crop growth and yield are occurring in a paddock, despite good rainfall and soil moisture, the factor constraining yield needs to be determined (Figure 8).

Figure 8: *Aerial shot of chickpea crops showing wide-scale crop loss due to sodic/saline conditions.*

Understanding growth constraints will influence crop choice and management. Constraints may be soil related or biological (e.g. disease, an insect pest, or a nematode). Some guidelines are provided in Table 5 and 6 below to assist in testing and diagnosis.

Table 5: *Indicative signs and likely causes of constraints to plant growth.*

Likely constraint	Indicative signs of a constraint	Possible solution
Biological	Roots may show dark lesions, knotting or discoloration (e.g. honey or brown coloured)	Identify the problem. Use crop rotations and farm hygiene and grow more resistant crops or varieties. Use fungicide or insecticide seed treatment, appropriate disease or pest control. Encourage the build-up of beneficial organisms through supplying organic substrate (e.g. stubble retention). Use direct drilling or no-till
Nutrient deficiency	Leaves or stems show characteristic symptoms of nutrient imbalance	Identify the nutrient disorder (soil or plant test). Apply appropriate fertiliser as granular, liquid injection or foliar application. Improve agronomy practices to build a healthier soil
Soil surface sodicity	Soil surface shows waterlogging, hard setting or crusting. Water ponds for several days after rain	Applying gypsum can improve soil surface sodicity by flocculating soil and so improving infiltration and exchange of sodium for calcium
Physical	Roots are deformed or may grow at a right angle. Rooting depth is restricted by presence of stones or rock, by a dense clay layer, hardpan, a plough layer or traffic compaction	Deep ripping may benefit some hardpans or compacted layers. Some ameliorant may need to be incorporated at the same time (e.g. organic matter, gypsum, lime). Controlled traffic will be needed afterwards. Growing plants with a taproot that is deep rooting can help
Chemical	There is an absence of fresh roots in the rooting zone (e.g. top 1 m of soil). The subsoil remains wet after a dry finish	Salinity: avoid sensitive crops such as chickpea and lentil, and grow more tolerant crops and varieties. If subsoil drainage is improved, then this can help to leach salts from the upper soil layers Acidity: use lime to as an ameliorant on acidic soils Sodicity: apply gypsum Alkalinity: elemental sulfur can help acidify highly alkaline soils, but large quantities will be required on heavy clay soils
Subsoil sodicity	Subsoil is lacking drainage. Structure of subsoil is coarse or dense	Sodicity: apply high rates of gypsum, but incorporation is needed, otherwise adequate rainfall and time are needed for gypsum to be effective in subsoils

Source: Grain Legume Handbook 2008

Table 6: *Testing and decision process to follow in determining which soil constraints apply.*

<table>
<tr><th colspan="6">Electrical conductivity (EC, 1:5 water) (dS/m)</th></tr>
<tr><th colspan="6">Check soil for EC in surface and subsoil</th></tr>
<tr><td colspan="3">Low EC <0.3 dS/m in top 10 cm
Low EC <0.7 dS/m in subsoil
Plant growth is not affected by salinity:</td><td colspan="3">High EC >0.3 dS/m in top 10 cm
High EC >0.7 dS/m in subsoil
Plant growth is affected by salinity:</td></tr>
<tr><td colspan="3">Check soil for exchangeable sodium percentage (ESP) and/or dispersion</td><td colspan="3">Check soil for sodium and chloride concentration</td></tr>
<tr><td colspan="2">No dispersion
(ESP <6)</td><td>Dispersion
(ESP >6)</td><td>Cl >300 mg/kg in top 10 cm soil
Cl >600 mg/kg in subsoil</td><td colspan="2">Cl <300 mg/kg in top 10 cm soil
Cl <600 mg/kg in subsoil</td></tr>
<tr><td colspan="2">Check soil pH
(1:5 soil:water)</td><td></td><td></td><td colspan="2">Check for gypsum crystals and sulfur concentration</td></tr>
<tr><td>pH <5.5</td><td>pH >8.0</td><td></td><td></td><td>S >100 mg/kg</td><td>S <100 mg/kg</td></tr>
<tr><td>Acidity constraint</td><td>Alkalinity constraint</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Sodicity constraint</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>Osmotic effect due to high salt and Na/Cl toxicity,</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>High EC due to gypsum; no constraint to crop growth</td><td>No gypsum; other salts are causing the problem</td></tr>
</table>

Source: Qld Natural Resources and Water Bulletin

For more information on soil constraints on chickpeas, see Section 14: Environmental issues.

1.3 Fallow weed control

Chickpeas are slow to emerge and initially grow slowly. They are notoriously poor competitors with weeds. Even moderate weed infestation can result in severe yield losses and harvesting problems. The best form of weed control is rotation and careful selection of paddocks largely free from winter weeds, for example in areas with a sequence of clean winter fallows (Figure 8).

Figure 9: *Fallow paddock.*

Source: Farmers Weekly Photo: Tim Scrivener

Uncontrolled heavy weed growth during the summer fallow period can reduce the yield of the subsequent crop by:

- robbing subsequent crops of available soil nitrogen
- decreasing the amount of stored soil moisture
- reducing crop emergence due to the physical and/or chemical (allelopathic) interference at seeding time.

A study by the Cooperative Research Centre (CRC) for Australian Weed Management found that summer weeds can lock away large amounts of nitrogen in the weedy biomass, rendering it unavailable for crop growth. Weed burdens of 2.5 tonnes per hectare can cause a net loss of available soil nitrogen and burdens of more than 3 t/ha can reduce subsequent wheat yields by as much as 40%.

In another Grains Research and Development Corporation (GRDC) funded study in South Australia, it was found that the major impact of summer weeds was on soil moisture. Complete weed control increased available soil moisture at one site by over 11 millimetres. The CRC study also found that as weed biomass increased, water losses increased. The magnitude of the water loss and its importance to the subsequent grain yields however, varied from site to site.

Summer weeds can also impede crop emergence. Moderate to heavy uncontrolled weed growth can result in reduced crop emergence in minimum tillage systems due to the impenetrable layer left on the soil surface. Wireweed for example, has long tough and wiry stems which can get caught in the tynes at seeding. [25]

Paddocks generally have multiple weed species present at the same time, making weed control decisions more difficult and often involving a compromise after assessment of the prevalence of key weed species. Knowledge of your paddock and early control of weeds are important for good control of fallow weeds. Information is included for the most common of the problem weeds; however, for advice on individual paddocks you should contact your agronomist.

Benefits of fallow weed control are significant:

- Conservation of summer rain and fallow moisture (this can include moisture stored from last winter or the summer before in a long fallow) is integral to winter cropping in the northern region, particularly so as the climate moves towards summer-dominant rainfall.
- Modelling studies show that the highest return on investment in summer weed control is for lighter soils, or where soil water is present that would support continued weed growth. [26]

Trials exploring methods for summer grass control have found:

- Glyphosate-resistant and -tolerant weeds are a major threat to our reduced-tillage cropping systems.
- Although residual herbicides will limit re-cropping options and will not provide complete control, they are key to successful fallow management.
- Double-knock herbicide strategies (sequential application of two different weed control tactics) are useful tools but the herbicide choices and optimal timings will vary with weed species.
- Other weed management tactics can be incorporated, e.g. crop competition, to assist herbicide control.
- Cultivation may need to be considered as a salvage option to avoid weed seed-bank increase.

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25 S Peltzer. (2016). Summer Weeds. DAFWA. https://www.agric.wa.gov.au/postharvest/summer-weeds

26 GRDC (2012) Make summer weed control a priority—Southern region. Summer Fallow Management, GRDC Fact Sheet January 2012, https://www.grdc.com.au/~/media/8F16BE33A0DC4460B17317AA266F3FF4.pdf

WATCH: Fallow spray techniques explored for WA's low rainfall zones.

1.3.1 Management strategies

Controlling summer weeds early will conserve valuable soil nitrogen and moisture for use by the crop during the following season. A Western Australian grower at Salmon Gums can demonstrate an average farm crop yield increase of 400 kilograms per hectare since the adoption of consistent summer weed control.

Herbicide application

Broadleaf weeds and herbicide resistant grasses can cause major problems and a careful management strategy must be designed well in advance. If possible, control weeds in the year prior to sowing chickpea or avoid paddocks with specific weeds that cannot be controlled by available herbicides. [27]

Summer weed control can be expensive but is necessary to prevent problems with excessive growth and/or moisture and nitrogen loss from the soil. When using herbicides:

- Water rates should be kept high (at least 60 litres per hectare).
- Add a surfactant and/or spraying oil to all post-emergent treatments unless otherwise directed on the label.
- Do not spray stressed plants.
- Spray grazing can be effective at high stocking rates.
- Glyphosate, 2,4-D, metsulfuron, atrazine and triclopyr are the most common herbicides used for summer weed control.
- Where summer grasses are present, glyphosate at rates around 2 L/ha are generally required.
- Metsulfuron provides cheap control of wireweed, triclopyr is generally preferred for melon control and atrazine for small crumbweed (also known as mintweed or goosefoot).
- 2,4-D controls a wide range of broadleaved weeds and is preferred if stock are available for spray grazing. The ester formulations are usually more effective for summer weed control because they are oil soluble and more able to penetrate the waxy surfaces or stubble.
- Moisture stress in weeds is common in summer and reduces the effectiveness on most herbicides. This can be partially overcome by spraying early in the

27 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

morning. However, at this time of day, inversions may be present which could lead to excessive drift. Avoid spraying during still conditions. [28]

Herbicide options for broad-leaved weed control are very limited. If the standard treatment of post-sow pre-emergent simazine is unlikely to provide adequate control, growers need to consider alternative control strategies:

- the use of Balance®
- use of trifluralin
- inter-row cultivation is only an option in wide row systems
- inter-row shielded sprayer (glyphosate) is only an option in wide row systems
- post emergent Broadstrike® may be damaging (refer to label)
- directed post-emergence sprays of Broadstrike® and/or simazine

Herbicide options for grassy weeds may be very limited if herbicide resistant ryegrass is present. If the standard trifluralin pre-sowing treatment and post-sow pre-emergent simazine are unlikely to provide adequate control, growers will need to consider alternative control strategies:

- the use of Balance®
- use of group A herbicides post-emergent if herbicide resistance not present
- inter-row cultivation is only an option in wide row systems
- inter-row shielded sprayer (glyphosate) is only an option in wide row systems
- crop topping or weed wiping are not options to prevent seed set of escape weeds

Avoid paddocks with high numbers of herbicide resistant weeds unless a programmed strategy is in place. [29]

Double-knock strategies

Double-knock refers to the sequential application of two different weed-control tactics applied in such a way that the second tactic controls any survivors of the first. Most commonly used for pre-sowing weed control, this concept can also be applied in-crop. [30]

Consider the species present, interval timing and water rate. Double-knock herbicide strategies are useful tools for managing difficult-to-control weeds, but there is no 'one size fits all' treatment. The interval between double-knock applications is a major management issue for growers and contractors. Shorter intervals can be consistently used for weeds where herbicides appear to be translocated rapidly (e.g. Awnless barnyard grass, ABYG) or when growing conditions are very favourable. Longer intervals are needed for weeds where translocation appears slower (e.g. fleabane, feathertop Rhodes grass and windmill grass) or where environmental conditions like temperature and soil moisture have affected weed growth. Critical factors for successful double-knock approaches are for the first application to be on small weeds and to ensure good coverage and adequate water volumes, particularly when using products containing paraquat. Double-knock strategies are not fail-proof and rarely effective for salvage weed-control situations unless environmental conditions are exceptionally favourable.

Grazing summer weeds

Summer weeds can provide quality feed for sheep, especially when there is no other green feed around. Windmill grass for example has a moderate forage value and has a digestibility of 35-68%. Perennial grasses such as windmill grass maintain some quality feed into summer especially with summer rainfall and when the flowering stage is delayed. Annual grasses such as soft brome (*Bromus hordeaceus*) and

28 S Peltzer. (2016). Summer Weeds. DAFWA. https://www.agric.wa.gov.au/postharvest/summer-weeds

29 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

30 C Borger, V Stewart, A Storrie. Double knockdown or 'double knock'. Department of Agriculture and Food Western Australia, http://www.agric.wa.gov.au/objtwr/imported_assets/content/pw/weed/iwm/tactic%202.2doubleknock.pdf

MORE INFORMATION

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

Summer weeds

barley grass have moderate digestibility but quickly lose quality as they become reproductive.

Be wary, however, that some summer weeds create grazing problems. Caltrop is toxic to sheep and can cause photosensitization (abnormal sensitivity to sunlight) leading to inflammation of exposed skin and sometimes death. If seed set is not prevented, the spiny burrs from infestations can cause lameness and infection, particularly in young lambs because their hoofs are soft.

Crumbweed (*Chenopodium pumilio*) can also be toxic to sheep causing cyanide poisoning, profuse scouring and sudden death. It emerges in spring and summer and can also reduce crop establishment in the following season (allelopathic). It is native to Western Australia.

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

1.4 Fallow chemical plant-back effects

Plant-back periods are the obligatory times between the herbicide spraying date and safe planting date of a subsequent crop. Some herbicides have a long residual persistence. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods, e.g. sulfonylureas (chlorsulfuron). This is shown in Table 7 where known. The rate of decay is influenced by soil pH and moisture levels.

Check the AVPMA website for more details.

Table 7: *Residual persistence of common pre-emergent herbicides, and noted residual persistence in broadacre trials and paddock experiences.* [31]

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

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

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

Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the 'Protection of crops etc.' heading in the 'General Instructions' section of the label. [32]

In wheat-chickpea rotations avoid the use of fallow and in-crop residual herbicides such as Broadstrike®, Eclipse®, Flame® Grazon®DS, Lontrel® and metsulfuron (Ally®, Associate®, Lynx®,, Harmony®M, particularly during the summer fallow or weed control period (after November).

The use of long-term residual sulfonylurea herbicides such as Monza®, chlorsulfuron (Glean®, Lusta®) and Logran® in wheat should be avoided when re-cropping to chickpeas.

MORE INFORMATION

Herbicide residues in pulses

1.4.1 Herbicide residues in soil

Residues from herbicides used in the current or previous crop could impact on subsequent crop choice in rotations (Figure 10). Crop damage could occur if this is ignored, particularly where rainfall has been minimal. Pulse and other crop types differ in their sensitivity to residual herbicides so check each herbicide used against each crop type. Check herbicide history in paddocks for any chemical that may cause any detrimental effect to chickpeas. Herbicide choice in crops may have to accommodate the planning of a pulse crop next in the rotation sequence. For example, it could be

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

10 months before a chickpea crop can be grown after use of an imidazolinone ('imi') herbicide, and likewise over 24 months after chlorsulfuron has been applied on high pH soils. [33]

Figure 10: *Herbicide residue affected plants appear pale and stunted.*

Source: DAFWA

Herbicides such as Group B (Logran®, Glean®, Hussar® and Ally®) typically pose the greatest threat if they are persistent in the soil when chickpeas are planted. Typical symptoms are stunting and yellowing of the plants if affected. Other herbicides to be wary of are LontrelTM, AmineTM (used over summer) and dicamba (used prior to cropping). These herbicides (in Group I) can cause twisting and growth distortions of plants. [34]

WATCH: GCTV16: Desi Chickpea – considering herbicide residuals.

33 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

34 M Witney, (2012). GRDC. Update Papers. Chickpea management and agronomy. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2012/07/Chickpea-management-and-agronomy

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. [35]

For more information, see Section 6: Weed control.

1.5 Seedbed requirements

Chickpea seeds are larger than peas or lentils, so they are less sensitive to seed placement than some other crops. However, a firm, yet friable, moist seedbed is still essential.

No-till

Under no-till conditions, avoid excessive amounts of surface residue in order to promote proper seed placement and early warm-up of the soil. Potential production fields must have a history of limited weed pressure since weeds can negatively impact seed yield and are strong competitors with chickpea plants. [36]

Chickpea and faba bean yields have been found to be higher after no-till than after cultivated fallows, also leading to better yield and protein responses in subsequent cereal crops. Growing chickpea under no-tillage rather than a cultivated fallow increases yields by an average of 11% and increases the following wheat crop by 0.9 tonnes per ha. [37]

Tillage

A smooth seedbed with most of the previous crop residue incorporated is good for chickpea growth (Figure 11). This will allow proper depth of planting as well as good seed-soil contact, which is essential for rapid germination and emergence. If moisture is short keep deep preplant tillage to a minimum to prevent excessive drying in the top 5–8 cm of soil. [38]

One study in Spain found that conventional tillage practices lead to better chickpea root development than no-tillage practices. [39] Another study in Pakistan found that conventional tillage reduced weed biomass in chickpea crops by 20% and increased yield by 2% compared to no-till practices. [40]

35 Dow AgroSciences. Rotational Crop plant-back intervals. http://msdssearch.dow.com/PublishedLiteratureDAS/dh_0931/0901b80380931d5a.pdf?filepath=au&fromPage=GetDoc

36 Chickpea production in the high plains. South Dakota State University Extension, University of Wyoming, University of Nebraska. http://www.agmrc.org/media/cms/ec183_435DBB048F8C5.pdf

37 W Felton. (2003). Chickpea increases no-till farming yields. Farming ahead No. 134.

38 E S Oplinger, L L Hardman, E A Oelke, A R Kaminski, E E Schulte, J D Doll. (1990). Chickpea (garbanzo bean). Alternative field crops manual. https://hort.purdue.edu/newcrop/afcm/chickpea.html

39 Muñoz-Romero, V., López-Bellido, L., & López-Bellido, R. J. (2012). The effects of the tillage system on chickpea root growth. Field Crops Research, 128, 76-81.

40 Jan, A., Amanullah, Akbar, H., & Blaser, B. C. (2012). Chickpea response to tillage system and phosphorus management under dryland conditions. *Journal of plant nutrition*, *35*(1), 64-70.

MORE INFORMATION

GRDC Strategic Tillage Tips and Tactics fact sheet.

Figure 11: *Strategic tillage can provide control for herbicide-resistant weeds and those that continue to shed seed throughout the year. Here it has been used for control of barnyard grass in fallow.*

Source: https://grdc.com.au/Resources/Factsheets/2014/07/Strategic-tillage

1.6 Soil moisture

1.6.1 Dryland

Australia is the world's driest continent, yet only around 7% of Australia's grain crops are grown on irrigated soil, with the remainder produced under dryland conditions. [41] The majority of soils in the cropping region of WA are relatively low in clay and soil organic matter. Consequently, their inherent soil quality is naturally low. Sustainable management of the soil resource is therefore essential to the continued viability of the Western Australian agricultural industry. The State's main dryland cropping region extends from Geraldton in the mid-west to Esperance in the south. Dryland crops are typically grown on a broad hectare scale and rely on seasonal rainfall rather than irrigation. The climate in south-western Australia is Mediterranean, with hot dry summers where growers rely heavily on winter rain.

Chickpeas require greater than 350 mm annual rainfall, but there are opportunities to grow them in lower rainfall areas if adequate soil moisture is present at sowing (e.g. >20 mm of stored soil water at 0-60 cm depth). The best guide to assessing soil water storage is to put down several soil cores. [42]

Preserving dryland fertility

The Western Australian No-Tillage Farmers Association (WANTFA) is driving adoption of sustainable and profitable broad acre cropping systems by sharing farmer experiences and innovations from their research and field trials. Here are some of their key recommendations for preserving soil's biological fertility.

- Minimise soil erosion.
- Try to maintain/increase organic matter contents.
- Use diverse rotations.
- Select nitrogen fixing bacteria to match the host plant and soil characteristics.
- Calculate fertiliser applications to account for soil nutrient supply.

41 Agribusiness review. (2014) Finding new ways for dryland farmers to stay profitable. http://business.nab.com.au/finding-new-ways-for-dryland-farmers-to-stay-profitable-6689/

42 Pulse Australia. Southern Pulse Bulletin PA 2010 #05–Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

MORE INFORMATION

Surface water management

Subsurface water management

Water Quality Improvement Plans

Dryland crops near sensitive water resources

- Consider whether any addition to soil will change the physical and chemical environment.
- Remove practices that promote plant pathogens.
- Consider management practices and commercial products for their capacity to enhance soil fertility.
- Be patient. Soil biological processes take time to develop. [43]

1.6.2 Irrigation

Key points:

- Select fields with good layout and tail water drainage (Figure 12).
- Avoid high bulk density or high clay content soils that do not internally drain quickly.
- Avoid acid, saline or sodic soils (see levels below).
- Pre-irrigate or water-up to fill the soil profile wherever possible.
- Irrigate early at 60–70% of field capacity to avoid crop stress and soil cracking open.

Key tips for success:

- **Drainage**: Ensure the layout allows irrigation and drainage within eight hours.
- **Soil structure**: Good soil structure ensures good water infiltration, root penetration and internal drainage.
- **Subsoil moisture**: Pre-irrigate or water-up to achieve adequate soil moisture for uniform emergence and during the vegetative stage. Irrigate prior to flowering to ensure a good profile of moisture during flowering and pod fill.
- **Sown on time**: Sow recommended varieties within the preferred sowing window for your location.
- **Crop establishment**: Use good quality seed and germination-test retained seed (Figure 13). Aim for a plant population of 35 to 40 plants per square metre.
- **Adequate nutrition**: While chickpeas are efficient at extracting soil phosphorus it is wise to apply adequate phosphorus relative to the paddock history and soil-test results. Approximately 40 kg of P per hectare is required for a 4 tonne crop. Good inoculation procedures with the appropriate rhizobium should meet the N requirements of chickpeas, however low zinc and sulfur levels should also be addressed.
- **Soil moisture**: Check soil moisture regularly to ensure timely irrigations to avoid stress or possible crop damage. Moisture monitoring equipment is now available at reasonable prices and can assist in more precise measuring, particularly at depth. Ensure plants do not stress during the reproductive stage and have adequate available soil water for the entire growing season. [44]

43 Agribusiness review. (2014) Finding new ways for dryland farmers to stay profitable. http://business.nab.com.au/finding-new-ways-for-dryland-farmers-to-stay-profitable-6689/

44 Pulse Australia. Southern Pulse bulletin PA 2010 #17 – Irrigated chickpea management. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-irrigation.pdf

Figure 12: *Irrigated beds with damage from water remaining in the tail drain.*

Source: Pulse Australia

Figure 13: *Poor quality seed on the left – all seed was sown on the same day.*

Source: Pulse Australia

Irrigated chickpea crops can be very profitable and rewarding with well-managed crops yielding in excess of 3.5 t/ha. High yields have occurred across a wide range of soil types and irrigation layouts through a combination of correct paddock selection, precise irrigation scheduling and close attention to chickpea agronomy. In addition, chickpeas can contribute to crop rotations because of their ability to fix nitrogen and provide a disease and weed break for following cereal crops.

Full or supplementary irrigation of chickpea is common in districts where chickpea is grown in rotation with other irrigated crops, such as cotton. Management requirements for irrigated chickpea are the same as for dryland, but their sensitivity to waterlogging, for even a short time, can result in severe losses, particularly if the crop is also under stress from herbicides or disease.

Using sprinkler irrigation equipment reduces the risk of waterlogging, even during flowering and pod-fill, however there may be a higher risk of foliar disease, e.g.

botrytis grey mould and ascochyta blight, due to the increased irrigation frequency and leaf wetness. [45]

Factors to consider when planning for irrigated chickpea production:

- Avoid heavy clay or dense soil types (bulk density >1.5) that do not drain freely and are subject to waterlogging.
- Select fields with an effective irrigation layout, such as beds or hills, and relatively good grades.
- A border-check layout that is steeper than 1:800 grade is suitable provided there are short runs on free draining soils that can be irrigated quickly and do not remain saturated.
- Rolling may be required to flatten the ridges left by press-wheel furrows or to flatten clods.
- Irrigation can be used to activate and incorporate a number of pre-emergent herbicides.
- Pre-irrigate to fill the moisture profile prior to planting chickpea crops, unless there has already been sufficient rainfall. Watering-up is most effective in bed, row and sprinkler systems, but is not recommended for border-check layout unless soil moisture is insufficient to achieve a uniform germination.
- As a general rule, irrigation of the emerged crop should start early when there is a deficit of 30–40 mm and around 60–70% field capacity. Schedule irrigation using soil moisture indicators rather than the crop growth stage.
- Time irrigation application to prevent moisture stress during flowering and podding and to reduce the impact of high temperatures on yield, quality and grain size. This is particularly important with large kabuli types. Chickpea is very sensitive to waterlogging during flowering and podding so great care is required to provide adequate soil moisture without waterlogging.
- In furrow irrigation systems, water every second row to avoid waterlogging. Doubling up the number of siphons can increase water flow and reduce irrigation time.
- Aim to have watering completed in less than eight hours, and have good tail water drainage to avoid any waterlogging in the crop area.
- Avoid irrigating if rain is forecast for the near future.
- In border-check layouts and paddocks with heavy soil types or long runs: **if in doubt, do not water.** [46]

It is important for growers and agronomists to base yield expectations on the total water supply available. This includes a combination of the amount of soil water in the profile, likely in-crop rainfall and irrigation water supply. A general rule of thumb for chickpeas can be based on 1 tonne grain per megalitre water supply (per hectare).

To offset the good performances there are growers who have only achieved yields of 1.0–1.5 t/ha and some of the common causes have been:

- problems with poor crop establishment and vigour (seed quality, seedbed, herbicides)
- unsuitable soils limiting water extraction (sodic or saline subsoils)
- poor scheduling of in-crop irrigation
- restricted water supply limiting yield

Chickpeas are very sensitive to waterlogging and even if waterlogged for a short period of time, crop losses can be severe. This has particularly occurred where crops have been moisture stressed allowing soils to dry out to depth and often crack open (Figure 14). Waterlogging is a stress on a chickpea crop and when combined with

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

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

other stresses such as moisture stress, damaged root systems, disease, herbicide injury, or sodic and saline soils can be a disaster. Watering during flowering or podfill when the crop is more sensitive further increases the risk of yield loss. [47]

Figure 14: *Chickpea on the left received a very late irrigation.*

Irrigation techniques to reduce the period of waterlogging:

- for furrow irrigation, water every second row
- double-up siphons to speed up water flow.
- do not irrigate if rain is likely
- ensure that tail water drains away quickly

Spray irrigation

The risk of waterlogging is significantly reduced when using lateral move or centre-pivot irrigators compared to flood, as the amount and timing of water application can be better controlled. However, wet foliage from more frequent irrigations can increase the risk of fungal diseases particularly ascochyta blight and botrytis grey mould. Greater attention to disease management, monitoring the variety chosen in relation to disease resistance, is important. [48]

Irrigation management strategy for chickpea

- Pre-irrigate to fill the moisture profile before planting chickpea crops, unless there has already been sufficient rainfall. Watering-up is most effective in bed, row and sprinkler systems, but is not recommended for border-check layout unless soil moisture is insufficient to achieve a uniform germination. Ensure that seed placement allows at least 7 cm of soil above the seed if using Balance® or simazine and the soil surface is left flat to prevent herbicide leaching into the plant furrow.
- As a general rule, irrigation of the emerged crop should start early when there is a deficit of 30–40 mm and around 60–70% field capacity. Schedule irrigation using soil moisture indicators rather than the crop growth stage.
- Time irrigation application to prevent moisture stress during flowering and podding and to reduce the impact of high temperatures on yield, quality and grain size. This is particularly important with large kabuli types. Chickpea is very

47 Pulse Australia. Southern Pulse bulletin PA 2010 #17 – Irrigated chickpea management. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-irrigation.pdf

48 Pulse Australia. Southern Pulse bulletin PA 2010 #17 – Irrigated chickpea management. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-irrigation.pdf

MORE INFORMATION

Irrigated Chickpeas – Best Practice Guide.

sensitive to waterlogging during flowering and podding so great care is required to provide adequate soil moisture without waterlogging.

- In furrow irrigation systems, water every second row to avoid waterlogging. Doubling up the number of siphons can increase water flow and reduce irrigation time.
- Aim to have watering completed in less than eight hours, and have good tail water drainage to avoid any waterlogging in the crop area.
- Avoid irrigating if rain is forecast for the near future.
- In border-check layouts and paddocks with heavy soil types or long runs: **if in doubt, do not water.** [49]

IN FOCUS

High value kabuli chickpea production in the Ord River Irrigation Area

In the Ord River Irrigation Area (ORIA) kabuli chickpea is a high-value industry producing large seeded, high quality grain for domestic and export markets (Figure 15). The area sown to chickpea in the ORIA varies from 400 to 1000 ha per year.

Figure 15: *Irrigated chickpea crop in the Ord River Irrigation Area, WA.*

Source: DAFWA

Fertiliser

Soils in the ORIA are generally deficient in phosphorus (P), nitrogen (N) and zinc (Zn), therefore fertilisers are applied to compensate. Grower practice is to apply approximately 40 kg of P/ha, 3 kg Zn/ha, 10 kg sulfur (S)/ha and 45 kg N/ha However, these levels may be too high or unnecessary in some instances, particularly N.

There are indications that N might provide some benefit to the crop prior to nodulation. Inspection of nodulation in commercial crops in 1999–2000 indicated that active nodulation does not start until about five weeks after sowing. However, high levels of N could also adversely affect nodulation and care should be taken if applying higher rates.

Chickpeas are very efficient at utilising soil P. They secrete organic acids from their roots, which dissolve insoluble sources of P to provide water-soluble P for plant uptake. Hence, sites that have been cropped for several years may have adequate levels of residual P. Studies conducted in the ORIA have indicated that a soil P level of 24mg/kg is sufficient for chickpea production.

It is common practice in the ORIA to apply diammonium phosphate (DAP) at 200–300 kg/ha, as it is generally the least expensive form of P fertiliser available. However excess N is applied at this rate. It is now suggested that growers use 3:1 superphosphate/potash at 150–250 kg/ha.

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

Zinc deficiencies have been recorded on crops in the ORIA. The practice of applying Zn (3 kg/ha) in the form of zinc monohydrate has been common in recent years. However, build-up in soil Zn levels does occur and annual application may not be necessary. Soil levels above 2 ppm are generally adequate for most field crops grown on Kununurra clay soils in the ORIA.

Irrigation

The scheduling of crop irrigation is a critical management strategy affecting kabuli chickpea yield and quality. For Kimberley, Large and Macarena during the cropping season, eight irrigations are usually required with an inundation period of 8–12 hours. It is suggested that irrigations be timed to coincide with the following stages of growth:

- pre-sowing irrigation
- post-emergent
- early growth/vegetative
- 50% flowering
- start of podding
- early podding
- mid-podding
- end of podding.

Soil type and seasonal conditions may affect crop growth and development, and consequently, the timing of irrigation at each growth stage. For instance, irrigation may need to be more frequent if temperatures are warmer and when grown on Ord sandy loam, which has a lower water-holding capacity when compared to the Cununurra clay.

The development of root and seedling diseases is promoted by waterlogged conditions at sowing, due to watering too early or excessively following sowing. Therefore, sowing must be delayed until the soil moisture conditions are optimum after the pre-sowing irrigation (14–18 days). Generally, the first post-sowing irrigation is required about 14–18 days after sowing (post-emergence).

Diseases

Seedling diseases and root rots are the most damaging diseases. It is likely that a complex of *Pythium, Fusarium, Phytophthora* and *Rhizoctonia* species causes most diseases. The development of disease can be more severe where the soil remains wet for prolonged periods. Hence, soil moisture at sowing and during crop establishment needs to be monitored to minimise the possibility of waterlogging at this time. It is recommended that seed be treated with P-Pickle T to reduce the risk and impact of disease (see section on Seed Treatment). P-Pickle T is not effective against *Phytophthora* spp.

Crop rotation is important in managing crop disease. Ideally, chickpea rotation needs to be limited to one year in three to minimise the persistence of fungal pathogens in the soil infecting subsequent chickpea crops. Other crops may act as a host for some fungal pathogens (for example other legumes and possibly some other dicotyledons such as cotton), which needs to be considered when selecting paddocks for chickpea. Chickpea following cereal crops such as maize and sorghum produce the best seed yield and quality.

Insects

The main insect pest in the ORIA is heliothis (*Helicoverpa* spp.), which can cause severe damage to crops. If present at flowering and early podding, larvae may feed on flowers and developing pods. Once punctured, seed development ceases in young pods and results in yield loss. During mid to late podding, larvae feed on the developing seeds, causing reduced yields and unmarketable seeds.

Generally, it is not recommended to spray for budworm during the vegetative stage, unless significant damage to the crop is evident (Table 8). Crops need to be checked for budworm twice weekly from the time the crop emerges.

Table 8: *Threshold levels for each developmental stage.*

Growth stage	Threshold (larvae per m of crop)
Vegetative	20–30
Flowering	5
Podding	3 (small-medium) to 5 (very small)

Source: DAFWA

Inter-row cultivation is a cheap and effective method of reducing Helicoverpa levels in chickpea crops, however care is needed to avoid root pruning of the chickpea crop. Cultivation collapses pupal tunnels and prevents the emergence of Helicoverpa moths. Inter-row cultivation can also be useful by reducing weed burden, however pre-sowing weed management is preferred.

Harvest

Approximately two weeks after the final irrigation the crop can be undercut about 2.5 cm below the soil surface. The soil requires some residual moisture to allow effective undercutting. The crop can be harvested between 7 and 14 days after undercutting, depending on weather conditions, crop biomass and crop moisture. The crop is ready to harvest when the stems and pods are light brown and the seed feels hard and rattles within the pod. At this stage, the seed moisture content should be around 15%. Harvesting at lower seed moisture content (13%) increases the susceptibility of the seed to physical damage during and after harvest.

Markets

The Ord River District Co-operative Ltd. markets kabuli chickpea produced in the ORIA. The product mainly supplies domestic markets in Australian capital cities where it is sold as whole seed in specialty shops and, in larger volumes, to hommus, falafel and dip manufacturers. The processing market requires varieties with specific 'after cooking' flavour. Macarena and Kimberley Large varieties provides these quality attributes and are also sold to high value international markets in Italy and surrounding Mediterranean countries. [50]

50 Pritchard I. DAFWA (2014). High value kabuli chickpea production in the Ord River Irrigation Area - post planting guide. https://www.agric.wa.gov.au/chickpeas/high-value-Kabuli-chickpea-production-ord-river-irrigation-area-post-planting-guide

1.7 Yield and targets

Seed yields of chickpea are low (world average 623 kg/ha^{-1}), compared to many other crops. Early field trials in Merredin, south-western Australia, indicate that seed yield in chickpea is controlled by the Harvest Index of branches and that seed yields might be raised by restricting branches in high density stands to no more than two, each with a high harvest index. [51] Starting soil water can also have a strong influence on the yield expectation of chickpea as well as the riskiness of production.

Yield results from Pulse Breeding Australia (PBA) and National Variety Trials (NVT) are available from the NVT website as well as from the specific Pulse Variety Management Package (VMP) brochure. Long term yields can be represented in several different ways but are typically displayed as either site specific, averaged over multiple years (Figure 15), or for each year averaged over multiple sites for a region. All trial sites are disease free.

Results lists are estimates for the following varieties (ordered from highest t/ha to lowest) (Figure 16).

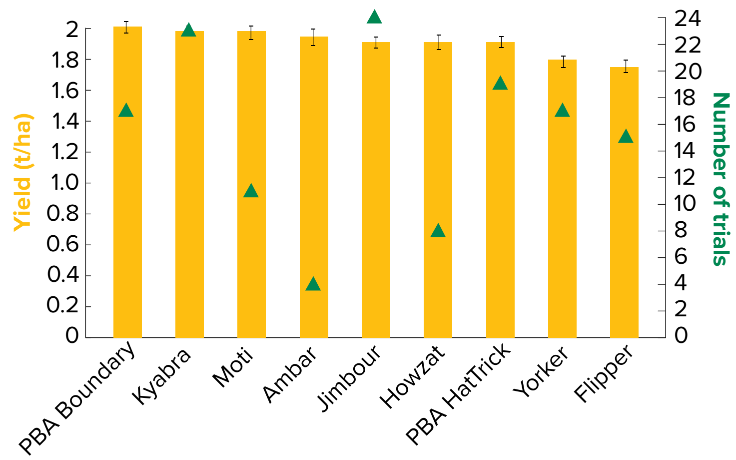

Figure 16: *NVT Long term yield report for desi chickpeas (2005 to 2012).*

Source: GRDC

IN FOCUS

Critical period for chickpea yield

To determine the critical window for chickpea yield, the South Australian Research and Development Institute (SARDI) set up trials at Roseworthy (sowing date 7 June) and Turretfield (sowing dates 14 June and 9 July, 2014) in SA.

Crops of PBA Boundary⦸ and PBA Slasher⦸ were shaded for two weeks at different stages during the growing season. Untreated controls yielded three tonnes per hectare and Figure 19 shows yields achieved by the shade-stressed crops.

The trials showed that the critical window for chickpeas starts at about 300 'degree-days' before flowering and the most vulnerable stage for yield was found to be 200 'degree-days' after flowering (Figure 17).

51 K.H.M. Siddique and A.M. Sedgley. An ideotype for chickpea (Cicer Arietinum L.) in a dry mediterranean environment. 2nd Aust. Agron Conf.©,Uni of WA.

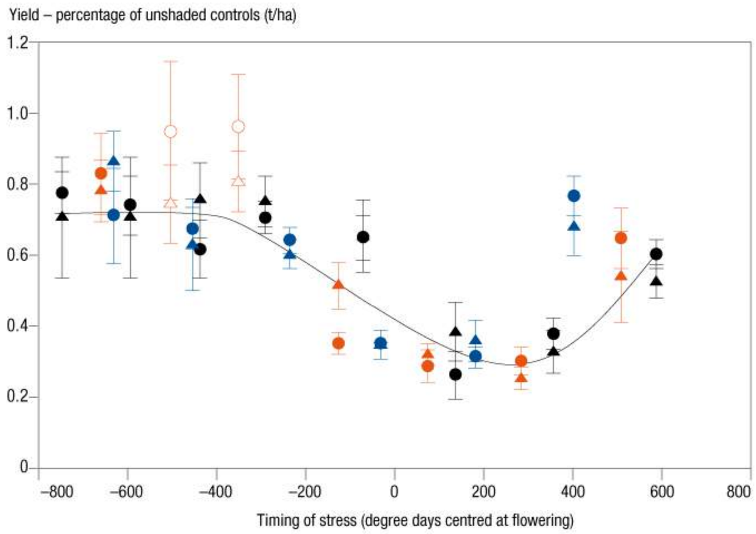

Figure 17: *Yield (percentage of unshaded controls t/ha) of chickpeas in response to timing of stress. PBA Boundary⍉ is represented with circles and PBA Slasher⍉ with triangles. Crops at Roseworthy are shown with black symbols, early-sowing crops at Turretfield are shown in red and late-sowing crops at Turretfield are shown in blue. (Hollow red circles and triangles are not significantly different from the control.) Note: the yield is most severely reduced with stress about 200 to 300 degree days after flowering.*

Source: GRDC

Degree-days are a calculation of time based on daily temperature and are necessary to account for the fact that crops develop faster at high temperatures. For the crop, one day at 15°C is not the same as a day at 10°C.

For example, if chickpeas are grown in conditions where the daily mean temperature is 15°C, the critical stage of 200-degree-days will be reached 13 days after flowering (200 ÷ 15 = 13). If chickpeas are grown in a warmer region or the crop was sown late with, for example, a daily mean temperature of 20°C, the crop will reach the 200-degree-days mark 10 days after flowering (200 ÷ 20 = 10).

Ensuring good growing conditions (sufficient supply of water and nutrients) and avoiding stress (such as frost and heat) during the critical window are essential for high-yielding chickpea crops. [52]

Several tools are available to help growers maximise yields.

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

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

52 L Lake, V Sandras. SARDI. (Nov – Dec 2014). Ground Cover issue 113: Critical period for chickpea yield. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-113-NovDec-2014/Critical-period-for-chickpea-yield

Avoiding a failed crop saves money now and saves stored water for future crops. [53]

Estimating crop yields

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

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

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

Estimation methods

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

1. Select an area that is representative of the paddock. Using a measuring rod or tape, measure out an area 1 m^2 and count the number of heads or pods.
2. Do this five times to get an average of the crop.
3. Count the number of grains in at least 20 heads or pods, and average.
4. Use a table of grain weights to ascertain the weight you can expect per 100 g for the crop you will plant, the then calculate potential yield.

The accuracy of yield estimates depends on taking an adequate number of counts so as to get a representative average for the paddock. The yield estimate will only be a guide and assumptions made from the estimates contain a degree of uncertainty. This type of yield estimation is one of the easiest and quickest to complete and should be able to be used in a number of situations on a grain-growing property. As grain losses before and during harvest can be significant, factor in an allowance for 5–10% loss in your final calculations. [54]

Yield Prophet

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

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

The simulations provide a framework for farmers and advisers to:

- forecast yield
- manage climate and soil water risk
- make informed decisions about N and irrigation applications
- match inputs with the yield potential of their crop

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

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

- assess the effect of changed sowing dates or varieties
- assess the possible effects of climate change

How does it work?

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

- a soil test sampled prior to planting
- a soil classification selected from the Yield Prophet library of ~1,000 soils, chosen as representative of the production area
- historical and current climate data taken from the nearest Bureau of Meteorology (BOM) weather station
- paddock-specific rainfall data recorded by the user (optional)
- individual crop details
- fertiliser and irrigation applications during the growing season

MORE INFORMATION

Yield Prophet

1.7.1 Seasonal outlook

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

Mobile applications (apps) are available for decision support, providing tools for ground-truthing precision agriculture data. Apps and mobile devices are making it easier to collect and record data on-farm. The app market for agriculture is evolving rapidly, with new apps becoming available on a regular basis. [55]

The Department of Agriculture and Food, Western Australia (DAFWA) provides up-to-date information about the coming season and its potential impacts on cropping and agriculture. To help make informed on-farm decisions, the DAFWA Seasonal climate information website provides statistical seasonal rainfall forecasts, modelled plant-available soil water at the start of the growing season and risk of frost occurring at different locations.

DAFWA's Season Climate Outlook (SCO) is a monthly newsletter that summarises climate outlooks for the next three months produced by DAFWA's Statistical Seasonal Forecast (SSF) system specifically for the Western Australian wheatbelt, and by the Australian Bureau of Meteorology. It provides a review of recent climate indicators, including ENSO (El Niño Southern Oscillation), the Indian Ocean Dipole, the Southern Annular Mode, as well as local sea surface temperature and pressure systems. At appropriate times of year it also includes an overview of the rainfall outlook for the growing season produced by the SSF. [56]

Australian 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, as well as El Nino Southern Oscillation status. It is designed for decision makers such as farmers whose businesses rely on the weather. Download from the Apple iTunes store or Australian CliMate.

One of the CliMate tools, *Season's progress?* uses long-term (1949 to present) weather records to assess progress of the current season (rainfall, temperature, heat sums and radiation) compared with the average and with all years. It explores the readily available weather data, compares the current season with the long-term average, and graphically presents the spread of experience from previous seasons. Crop progress and expectations are influenced by rainfall, temperature and radiation

55 http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Managing-data-on-the-modern-farm

56 DAFWA. Seasonal Climate outlook. https://www.agric.wa.gov.au/newsletters/sco

MORE INFORMATION

GRDC Update paper, Managing data on the modern farm.

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, 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.

1.7.2 Fallow moisture

For a growing crop there are two sources of water: first, the water stored in the soil during the fallow; and second, the water that falls as rain while the crop is growing. As a farmer, you have some control over the stored soil water; you can measure how much you have before planting the crop. Long-range forecasts and tools such as the SOI can indicate the likelihood of the season being wet or dry; however, they cannot guarantee that rain will fall when you need it. [57]

HowWet/N?

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

HowWet/N?:

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

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

The questions this tool answers are:

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

Inputs

- A selected soil type and the weather station.
- An estimate of soil cover and starting soil moisture.
- Rainfall data input by the user for the stand-alone version of How Often?

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

Outputs

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

Reliability

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

Soil descriptions are based on generic soil types with standard organic carbon (C) and C:N ratios, and as such should be regarded as indicative only. They are best used as a measure of relative water accumulation and nitrate mineralisation. [58]

MORE INFORMATION

How Wet/N?

1.7.3 Water Use Efficiency

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

Water Use Efficiency 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). [59]

The strongest determinant of chickpea grain yield and its water use under rainfed conditions is rainfall and its distribution. Water availability is a major constraint for production of grain in Australia and improving WUE is a primary target for growers, breeders and agronomists. WUE benchmarks can be used to derive attainable yield for a location and season (Table 8).

Table 9: *Effect of planting date on total water use (E,) and Water Use Efficiency of chickpea at Merredin, WA.* [60]

Planting date	Total water sue (E_t mm)	WUE (kg dry matter ha^{-1} mm^{-1})	GWUF. (kg seed ha^{-1} mm^{-1})	Planting date	Total water use (E_t mm)	WUE (kg dry matter ha^{-1} mm^{-1})	GWUE (kg seed ha^{-1} mm^{-1})
(a) 1982				(b) 1983			
11 May (D1)	213.2	23.2	6.81	17 May (D1)	191.8	35.2	6.52
26 May (D2)	214.1	19.5	5.94	31 May (D2)	182.8	29.2	6.18
17 June (D3)	229.6	18.8	5.55	14 June (D3)	182.1	26.6	6.15
30 June (D4)	227.2	16.9	4.86	30 June (D4)	188.3	21.1	5.88
				20 July (D5)	182.1	17.7	5.15
Mean	221.0	19.5	5.79	Mean	185.4	26.2	5.98
l.s.d. (P<0.5)	24.8	2.5	1.09	l.s.d. (P<0.5)	17.8	5.8	1.04
C.V. (%)	7.0	10.2	11.7	C.V. (%)	6.2	12.8	11.3

Seasonality and size of rainfall events also influence crop WUE. In the western and southern growing regions, rainfall is winter-dominant, falling during the crop's growing season and rainfall events are mostly small (< 5 mm). These features of rainfall mean that soil evaporation, favoured by winter rainfall and small events, is the main unproductive source of water loss in western and southern regions. Collectively,

58 Australian CliMate. How Wet/N, http://www.australianclimate.net.au/About/HowWetN

59 GRDC. (2009). Water Use Efficiency – Fact Sheet. Northern Region.

60 Siddique, K. H. M., & Sedgley, R. H. (1987). Canopy development modifies the water economy of chickpea (Cicer arietinum L.) in south-western Australia. Crop and Pasture Science, 37(6), 599–610.

vapour pressure deficit and rainfall patterns are the main climate determinants of location-specific WUE. [61]

Large inter-seasonal fluctuations in weather can result in larger inter-seasonal fluctuations in water use, and therefore in production of legumes. Seasonal evapotranspiration (ET) has been found to significantly correlate with seasonal rainfall for chickpeas.

Potential transpiration efficiencies (TE) of 15 kg/ha–1 mm–1 together with soil evaporation (Es) values of 100–125 mm can be used as benchmark values to assess the yield potential of cool season grain legume crops in low rainfall Mediterranean-type environments. [62]

One study found that a 2/3 supplemental irrigation level gives the optimum WUE for chickpea. [63]

Chickpeas have a relatively short growing season and use less water than many other broadleaf crops such as sunflower or safflower. Chickpeas use less water and thereby leave more water available for succeeding crops. Chickpea has an adaptive root system to drier conditions and large root surface area per unit root weight so can be more tolerant of water deficit stress. [64]

Nitrogen-deficient soils will also reduce WUE, leading to impaired photosynthesis and a drop in above-ground dry matter per unit transpiration.

IN FOCUS

Chickpea Water Use Efficiency in relation to cropping system, cultivar, soil nitrogen and Rhizobial inoculation in semiarid environments

Crops grown in semiarid rainfed conditions are prone to water stress which could be alleviated by improving cultural practices. This study determined the effect of cropping system, cultivar, soil nitrogen status and *Rhizobium* inoculation (*Rz*) on water use and Water Use Efficiency (WUE) of chickpea (*Cicer arietinum* L.) in semi-arid environments. Four varieties were grown in no-till barley, no-till wheat, and tilled-fallow systems and under various rates of N fertiliser (0, 28, 56, 84, and 112 kg N ha–1) coupled with or without *Rz*. On average, chickpea used about 10 mm of water from the top 0–15 cm soil depth. In the tilled-fallow system, chickpea extracted 20% more water in the 15–30 cm depth, 70% more in the 30–60 cm depth, and 156% more in the 60–120 cm depth than when it was grown in the no-till systems. Water Use Efficiency increased from 4.7 to 6.8 kg ha–1 mm–1 as N fertiliser rate was increased from 0 to 112 kg N ha–1 when chickpea was grown in the no-till barley or wheat systems, but chickpea grown in the tilled-fallow system did not respond to changes in the fertiliser N rates averaging WUE of 6.5 kg ha–1 mm–1. In the absence of N fertiliser, the application of *Rz* increased WUE by 33% for chickpea grown in the no-till barley system, 30% in the no-till wheat system, and 9% in the tilled-fallow system. Chickpea inoculated with *Rhizobium* achieved a WUE value similar to the crop fertilised at 84 kg N ha–1. Without the use of *Rz*, chickpea increased WUE in a linear fashion with increasing fertiliser N rates from 0 to 84 kg N ha–1.

61 V Sandras, G McDonald. GRDC. (2012). Water Use Efficiency of grain crops in Australia: principles, benchmarks and management.

62 Siddique, K. H. M., Regan, K. L., Tennant, D., & Thomson, B. D. (2001). Water use and Water Use Efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. European Journal of Agronomy, 15(4), 267–280.

63 Oweis, T., Hachum, A., & Pala, M. (2004). Water Use Efficiency of winter-sown chickpea under supplemental irrigation in a Mediterranean environment. Agricultural water management, 66(2), 163–179.

64 Benjamin, J. G., & Nielsen, D. C. (2006). Water deficit effects on root distribution of soybean, field pea and chickpea. Field Crops Research, 97(2), 248–253.

Cropping system, cultivar, and inoculation all had greater impact on WUE than on the amount of water extracted by the crop from the soil. The improvement of cultural practices to promote general plant health along with the development of cultivars with improved crop yields will be keys for improving Water Use Efficiency of chickpea in semiarid environments. [65]

Crop biomass and grain yield depend on photosynthesis. Photosynthesis involves the uptake of carbon dioxide (CO_2) through stomata, which are pore-like, specialised cells in the surface of leaves. However, open stomata required for CO_2 uptake are an open gate for water loss. Therefore, there is a tight trade-off between uptake of CO_2 and water loss, and this explains the close link between crop production and water use. [66]

Managing to optimise Water Use Efficiency

Measures to improve WUE should aim to reduce soil evaporation during winter both directly – e.g. by increasing soil cover, by mulches or earlier-developing canopies – and indirectly, by increasing infiltration. In spring, measures to increase WUE should aim to reduce transpiration by minimising canopy development to what is required by the crop to maximize harvest index. [67]

Although farmers have no control over rainfall, by using different management practices they can affect how much of the rainfall is used by the crop and how efficiently it is used.

Fallowing captures out-of-season rainfall and can increase the amount of water available for crop growth. However, the proportion of rainfall retained by fallowing (also referred to as fallow efficiency) can be small, typically in the order of 20% but often less.

Retaining stubbles on the fallow and controlling summer weeds may help to reduce water loss from the fallow and improve fallow efficiency, although the value of stubble retention appears to vary with soil texture and rainfall. On sandy soils, there may be little benefit from stubble retention on water capture over summer, and in some cases standing stubble may increase evaporative losses. In contrast, on clay soils in southern Australia, fallow efficiencies up to 40% have been measured with retained stubbles.

Crop choice: There are differences in WUE between crops, with wheat having higher WUE than grain legumes or canola. Chickpeas in WA have been estimated to have a WUE based on total biomass of 16.0 (11.1–18.3) kg/ha.mm and based on grain yield of 6.2 (4.7–8.9) kg/ha.mm. [68]

Arguably, time of sowing is the most important management practice determining WUE and yield. Many studies in a range of crops have shown that 'late' sowing will reduce yields, although for short-season varieties, sowing very early may have little benefit or may reduce yields. Time of sowing generally has only a small effect on total crop water use but can have a marked effect on WUE. The highest water use efficiencies are consistently achieved when the crop is sown at the optimum time. Late sowing reduces WUE for a number of reasons: sowing into colder soil delays crop establishment and early vigour, which increases the proportion of crop evapotranspiration lost as soil evaporation; there is a higher likelihood of heat stress around flowering and during grain growth; and there are reductions in biomass per unit water use associated with increasing vapour pressure deficit.

65 Gan, Y. T., Warkentin, T. D., Bing, D. J., Stevenson, F. C., & McDonald, C. L. (2010). Chickpea Water Use Efficiency in relation to cropping system, cultivar, soil nitrogen and Rhizobial inoculation in semiarid environments. Agricultural water management, 97(9), 1375–1381.

66 V Sandras, G McDonald. GRDC. (2012). Water Use Efficiency of grain crops in Australia: principles, benchmarks and management.

67 Siddique, K. H. M., & Sedgley, R. H. (1987). Canopy development modifies the water economy of chickpea (Cicer arietinum L.) in south-western Australia. Crop and Pasture Science, 37(6), 599–610.

68 Siddique, K. H. M., Regan, K. L., Tennant, D., & Thomson, B. D. (2001). Water use and Water Use Efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. European Journal of Agronomy, 15(4), 267–280.

The spatial arrangement of plants in crops, the result of the chosen row spacing and sowing rate, affects crop water use in two main ways: first, it affects the rate of early growth and the degree and timing of canopy closure, and thus the proportion of crop water use lost as soil evaporation; and second, it influences the partitioning of water use between the pre-anthesis and post-anthesis periods. The amount and distribution of rainfall will largely influence the optimum sowing rate. Nevertheless, grain yields (and WUE) are quite stable over a wide range of sowing rates, which affords a degree of flexibility when deciding on the most appropriate sowing rate. Increased sowing rates increase early crop growth rate and potentially reduce evaporation from the soil surface thus 'saving' water for use later in the season.

On the other hand, high sowing rates will lead to vigorous early crop growth and water use which may cause early depletion of soil moisture if rainfall is low. In general, using low plant densities in low-rainfall regions, or in regions where crops depend on soil moisture reserves at sowing, helps to partition water use between the pre-flowering and post-flowering periods more effectively. Row spacing may have relatively little effect on WUE. The potential gains in WUE from altering row spacing will depend on how it affects the proportion of moisture lost from bare soil evaporation and how it influences the pattern of water use during the growing season. Increased row spacing can lead to increased exposure of the soil surface and raised soil evaporation, but where the maximum leaf area of the crop is small, or where the soil surface is not moist for long periods of time, altering row width has little effect on bare soil evaporation. Present evidence suggests that using wide rows in non-cereal crops may have limited benefit to the efficient use of seasonal rainfall or may cause reductions in efficiency. [69]

WATCH: Over the Fence West: Max soil water with plastic.

69 V Sandras, G McDonald. GRDC. (2012). Water Use Efficiency of grain crops in Australia: principles, benchmarks and management.

MORE INFORMATION

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

WATCH: GCTV12: Water Use Efficiency Initiative

1.7.4 Nitrogen use efficiency

Over 40 years, the amount of mineral N fertilisers applied to agricultural crops increased 7.4 fold, whereas the overall yield increase was only 2.4 fold. This means that N use efficiency, (NUE) which may be defined as the yield obtained per unit of available N in the soil (supplied by the soil + N fertiliser) has declined sharply. NUE is the product of absorption efficiency (amount of absorbed N/quantity of available N) and the utilisation efficiency (yield/absorbed N). For a large number of crops, there is a genetic variability for both N absorption efficiency and for N utilisation efficiency. [70]

Breeding for more efficient symbioses with *Rhizobia* and *Arbuscular micorrhizal* (AM) fungi can be an alternative for increasing plant productivity using the same amount of synthetic N fertiliser. Conservation tillage using no-till and continuous cover cropping cultures are also known to increase significantly the potentiality and diversity of plant colonisation by AM fungi in comparison to conventional tillage. Thus, these new alternative farming techniques can increase NUE for a number of crops through the beneficial action of AM.

Under both, humid conditions and dry weather chickpea has been found to maintain a constant partial factor N use efficiency (PFNUE: grain yield per unit fertiliser N) and a consistently high N utilisation efficiency (NUE: grain yield per unit N in the above-ground dry matter) for grain production. [71]

Whatever the mode of N fertilisation, an increased knowledge of the mechanisms controlling plant N economy is essential for improving NUE and for reducing excessive input of fertilisers, while maintaining an acceptable yield and sufficient profit margin for farmers.

1.7.5 Double crop options

Double cropping is growing a winter and summer crop following one another. Chickpeas are a very good crop to double crop out of an early sorghum crop straight back into chickpea, avoiding the need for long fallow in wet summers. This is possible because chickpea needs less water than wheat, depending on what yield a grower is targeting.

70 Hirel, B., Tétu, T., Lea, P. J., & Dubois, F. (2011). Improving nitrogen use efficiency in crops for sustainable agriculture. Sustainability, 3(9), 1452–1485.

71 Neugschwandtner, R. W., Wagentristl, H., & Kaul, H. P. (2015). Nitrogen yield and nitrogen use of chickpea compared to pea, barley and oat in Central Europe. International Journal of Plant Production, 9(2), 291–304.

IN FOCUS

Strategic double cropping on Vertisols: A viable rainfed cropping option in India to increase productivity and reduce risk

A long-term (15 year) experiment in India demonstrated that cropping during the rainy season is feasible, and that grain productivity of double cropped sorghum + chickpea (SCP–SCP) and mung bean + sorghum (MS–MS) sequential systems were higher than their conventional counterparts with rainy season fallow; i.e. fallow + post-rainy sorghum (FS–FS) and fallow + post-rainy chickpea (FS–FCP). In the SCP–SCP system the additional grain yield of rainy sorghum (3400 kg ha–1 per two-year rotation) ensured that the total productivity of this system was greater than all other systems. Double cropping MS–MS and SCP–SCP sequential systems had significantly higher crop N uptake compared to traditional fallow systems at all rates of applied nitrogen(N). The intensified MS–MS and SCP–SCP sequential systems without any N fertiliser applied recorded a much higher median gross profit. Applying 120 kg of N ha–1 considerably increased the profitability of all systems. The gross profit margin analysis showed that nitrogen is a key input for improving productivity, particularly for the double cropping systems. However, traditional systems are unviable and risky without N application in the variable climates of the semi-arid tropics. Together, our results show that on Vertisols in semi-arid India, double cropping systems increase systems' productivity, and are financially more profitability and less risky than traditional fallow post-rainy systems while further benefits can be achieved through fertiliser application. [72]

1.8 Disease status of paddock

Three pre-planting practices are paramount for managing chickpea diseases: stubble management, controlling volunteers and weeds, and paddock selection.

Floods and surface water flows can distribute inoculum of *Phoma rabiei* (formerly *Ascochyta rabiei*, causing ascochyta blight) and *Botrytis cinerea* (causing botrytis grey mould) as well as *Sclerotinia*, *Phytophthora root rot* and root-lesion nematodes across large areas of the northern region cropping belt. Some diseases such as ascochyta blight are considered 'community diseases', so what happens in a neighbouring paddock or even several kilometres away can affect crops. [73]

Ascochyta blight in chickpeas is now manageable, but can still loom as the biggest potential issue in Australian chickpea production unless it is managed by a combination of variety choice, strategic use of fungicides and crop hygiene (seed source, rotation, proximity of chickpea stubbles).

Chickpea crops in southern Australia and isolated parts of northern Australia are being hit by a more virulent strain of the damaging ascochyta blight. Pulse pathologists in Victoria and South Australia have noted a marked decline in the resistance of several varieties of chickpeas, with varieties previously rated as

72 Rao, V. N., Meinke, H., Craufurd, P. Q., Parsons, D., Kropff, M. J., Anten, N. P., ... & Rego, T. J. (2015). Strategic double cropping on Vertisols: A viable rainfed cropping option in the Indian SAT to increase productivity and reduce risk. European Journal of Agronomy, 62, 26-37.

73 GRDC (2011) What to consider before planting chickpeas. GRDC Media Centre 6 June 2011, http://grdc.com.au/Media-Centre/Media-News/North/2011/06/What-to-consider-before-planting-chickpeas

moderately resistant performing like susceptible lines. [74] There have been no reported cases of this new Ascochyta blight strain in Western Australia.

Ascochyta resistant varieties are not immune to ascochyta blight, particularly at pod fill, but do make it easier to control with reduced risk, inputs and expense. Lower rainfall areas must be considered as being at least medium risk for ascochyta, but could be high risk on an individual paddock basis. Know the ascochyta blight disease rating of the variety grown; assess the individual paddock risk and manage the crop appropriately. Be aware of the specific management needs for the variety chosen through its variety management package (VMP).

Avoid sowing chickpeas into paddocks that have a recent and prolonged history of predominantly legume (e.g. medic, lentil, and field pea) or broadleaf crops (e.g. canola). *Phoma, Fusarium, Pythium or Sclerotinia* may be present.

Seed treatment should be considered mandatory for protection, especially with kabuli types. Resistance to PRR may perhaps provide slightly better tolerance to waterlogging or common root rots. [75]

1.8.1 Cropping history effects

Paddocks closer than 1 km to last year's chickpea stubble should be considered as a higher risk from ascochyta blight infection and need to be managed as such. Varieties with higher ascochyta resistance such as PBA Slasher⦿, GenesisTM090 or GenesisTM509 should be considered, otherwise there is the need for programmed ascochyta spraying through the season. Where possible, place as great a distance as practicable between this year and last year's chickpea paddocks and be mindful of common wind direction. [76]

For more information, see Section 9: Diseases.

1.9 Nematode status of paddock

Root lesion nematodes (RLN) are widespread in cropping soils through WA. Although mainly considered an issue in wheat crops, RLN also infects chickpeas, with yield losses of 20–30% previously recorded in intolerant varieties. Chickpeas are susceptible to RLN which means that this nematode colonises the root systems and builds up numbers in the soil. However, chickpea varieties can vary in their levels of resistance to RLN; this is related to the extent to which they build up RLN populations in the soil, which then dictates the effect on subsequent crops in the rotation. Varieties that are more susceptible allow greater multiplication of RLN in their root systems over a season. The higher the resulting RLN population left in the soil following chickpeas, the greater is the potential for a negative impact on the yield of subsequent crops.

1.9.1 Effects of cropping history on nematode status

Root-lesion nematode numbers build up steadily under susceptible crops and cause decreasing yields over several years. Yield losses >50% can occur in some wheat varieties, and up to 20% in some chickpea varieties. The amount of damage caused will depend on:

- the numbers of nematodes in the soil at sowing
- the tolerance of the variety of the crop being grown
- the environmental conditions

Generally, a population density of 2000 RLN/kg soil anywhere in the soil profile has the potential to reduce the grain yield of intolerant wheat varieties. A tolerant crop

74 Heard G. (2016). Ascochyta pressure on chickpeas http://www.stockandland.com.au/story/4085979/ascochyta-pressure-on-chickpeas/

75 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

76 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

yields well when high populations of RLN are present (the opposite is intolerance). A resistant crop does not allow RLN to reproduce and increase in number (the opposite is susceptibility).

Growing resistant crops is the main tool for managing nematodes. In the case of crops such as chickpea, choose the most tolerant variety available and rotate with resistant crops to keep nematode numbers at low levels. Information on the responses of crop varieties to RLN is regularly updated in grower and planting guides. Note that crops and varieties have different levels of tolerance and resistance to different nematode species.

Summer crops have an important role in management of RLN. Research shows when RLN is present in high numbers, two or more resistant crops in sequence are needed to reduce populations to low enough levels to avoid yield loss in the following intolerant, susceptible crops. [77]

For more information, see Section 8: Nematodes.

1.10 Testing soil for disease and nematodes

MORE INFORMATION

Root lesion nematode has a picnic in 2013, 2014 Crop Updates paper

Pratylenchus teres - WA's home grown Root Lesion Nematode, 2013 Crop Updates paper

Root lesion and burrowing nematodes: diagnosis and management.

Diseases and nematodes that occur underground can be difficult to detect and diagnose but they must be identified correctly to enable appropriate control measures to be implemented. It is important to have paddocks diagnosed for plant parasitic nematodes and disease so that optimal management strategies can be implemented. Testing your farm will tell you if nematodes or disease are present in your paddocks and at what density as well as which species are present.

It is important to know which species are present because some crop-management options are species-specific. If a particular species is present in high numbers, immediate decisions must be made to avoid losses in the next crop to be grown. With low numbers, it is important to take decisions to safeguard future crops. Learning that a paddock is free of these nematodes is valuable information because steps may be taken to avoid its future contamination.

Testing of soil samples taken either before a crop is sown or while the crop is in the ground provides valuable information. There is a great deal of spatial variation in nematode populations within paddocks. It is critical to follow sampling guidelines to ensure accurate results. [78]

It is crucial that diseases are correctly diagnosed to enable the right control measures to be employed for the benefit of crop yields.

1.10.1 Soil and plant testing services for diagnosing root diseases

MORE INFORMATION

MyCrop app

First, look at the distribution of symptomatic plants throughout the whole crop

To determine whether a fungal or nematode root disease is present in a crop, look for patchy areas of poor crop development associated with localised disease build-up. Some root disease may be more evenly scattered or distributed throughout the crop.

Next, carefully dig up samples of apparently diseased as well as healthy plants.

Thoroughly wash the soil from the roots and examine them for indicative symptoms which vary to some extent depending on the disease. Unthrifty plants may have smaller root mass, fewer root branches, root browning, root clumping or damaged root tips (spear tips) compared to thrifty or well-grown plants nearby.

77 K Owen, T Clewett, J Thompson (2013) Summer crop decisions and root-lesion nematodes. GRDC Update Papers 16 July 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Summer-crop-decisions-and-root-lesion-nematodes

78 S Simpfendorfer, M Gardner, G McMullen (2013) Desi chickpea varieties differ in their resistance to the root lesion nematode Pratylenchus thornei—Come-by-Chance 2010. Northern Grains Region Trial Results, autumn 2013. pp. 114–116. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/468328/Northern-grains-region-trial-results-autumn-2013.pdf

Confirmation of diagnosis

Suspected root disease or nematode problems in-crop can be confirmed by laboratory analysis of soil and/or roots. For patch diseases, sample from the edge of the patch rather than the centre.

Do not send washed plants to the laboratory. Follow sampling guidelines from DDLS Seed Testing and Certification.

Growing season tests are carried out on affected plants and associated soil. Although little can be done during the growing season to correct a fungal or nematode root disease, it is important to identify the cause of the problem so that decisions on appropriate management strategies can be taken leading up to and during the following seasons. Test kits are available from DDLS and participating distributors. To obtain submission forms and full sampling instructions, contact your local DAFWA office. Information can also be found online or by phoning +61 (0)8 9368 3721.

Pre-season assessment: the risk of root diseases being present in a paddock at a yield-limiting level next season can be determined by paddock history, paddock monitoring in spring or soil tests. A review of paddock history will identify the diseases likely to be present in each paddock. The level of disease likely to develop can be determined by digging up plants in spring from areas of poor growth and examining the roots for symptoms.

An informed decision can be made about the future use of each paddock based on the presence or absence of a disease and the conduciveness of the current season and crop to further develop that disease.

Pre-season soil tests can be used where the paddock history is not adequate for planning future use. Soil tests are conducted on representative soil samples. PreDicta-B™ uses DNA assessment to determine the root diseases or nematode species present and the likely risk of crop damage. Test kits are available through accredited agronomists and resellers. [79]

PreDicta B (B = broadacre) is a DNA-based soil testing service to identify which soilborne pathogens pose a significant risk to broadacre crops prior to seeding (Figure 17).

It has been developed for cropping regions in Australia and includes tests for:

- cereal cyst nematode (CCN)
- take-all (*Gaeumannomyces graminis* var. *tritici* (Ggt) and G. *graminis* var. *avenae* (Gga))
- rhizoctonia barepatch (Rhizoctonia solani AG8)
- crown rot (*Fusarium pseudograminearum*) * Note that oats are not very susceptible to crown rot – but does host it.
- root lesion nematode (*Pratylenchus neglectus* and *P. thornei*)
- stem nematode (*Ditylenchus dipsaci*)

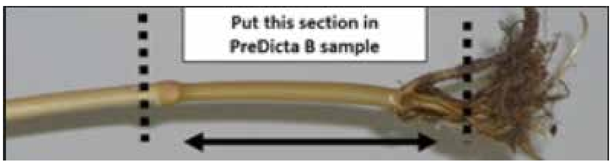

Figure 18: *Correct sampling strategy.*

Source: GRDC

PreDicta B samples are processed weekly from February to mid-May (prior to crops being sown) to assist with planning the cropping program. PreDicta B is not intended for in-crop diagnosis. That is best achieved by sending samples of affected plants to your local plant pathology laboratory.

79 DAFWA (2016). Root disease under intensive cereal production systems. https://www.agric.wa.gov.au/barley/root-disease-under-intensive-cereal-production-systems

See the PIR SA Predicta B website for more information.

1.11 Insect status of paddock

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

Pest outbreaks occur often in response to natural conditions, but sometimes in response to management practices. Minimum tillage and stubble retention have resulted in greater diversity of invertebrate species seen in crops. Cultural control methods such as burning, rolling or cultivating stubbles are sometimes needed to compliment chemical and biological controls. [80]

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

Soil insects include:

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

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

- Weedy fallows and volunteer crops encourage soil insect build-up.
- Insect numbers decline during a clean long fallow due to lack of food.
- Summer cereals followed by volunteer winter crops promote the build-up of earwigs and crickets.
- High levels of stubble on the soil surface can 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-tillage 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. Since 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.

1.11.1 Insect sampling of soil

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

The majority of crop monitoring for insect pests is done with a sweep net, or visually. Using a shake/beating tray is another technique. Sampling pastures mostly relies on visual assessment of the sward or the soil below it. The sweep net is the most convenient sampling technique for many insects. The net should be about 38 cm in

80 https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests

diameter, and swept in a 180 arc from one side of the sweepers body to the other. The net should pass through the crop on such an angle that it is tilted so that the lower lip travels through the crop marginally before the upper lip. The standard sample is 10 sweeps, taken over 10 paces. This sampling set should be repeated as many times as practicable across the crop, and at no less than five locations. After completing the sets of sweeps, counts should be averaged to give an overall estimate of abundance. Sweep nets tend to under-estimate the size of the pest population. Sweep net efficiency is significantly affected by temperature, relative humidity, crop height, wind speed, plant density and the operator's vigour. [81]

Soil sampling by spade

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 dessert spoon of the seed under 1 cm of soil at each corner of a 5 × 5 m square at five widely spaced sites per 100ha.
3. Mark the position of the seed baits, as large populations of soil insects can destroy the baits.
4. One day after seedling emergence, dig up the plants and count the insects.

Trials have shown no difference in the type of seed used for attracting soil-dwelling insects. However, use of the type of seed 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. [82]

The South Australian Research and Development Institute (SARDI) Entomology Unit provides an insect identification and advisory service. The unit identifies insects to the highest taxonomic level for species where this is possible and can also give farmers biological information and guidelines for control. [83]

Insect ID: The Ute Guide

The Insect ID Ute Guide is a comprehensive reference guide for insect pests commonly affecting broadacre crops and growers across Australia, and includes the beneficial insects that may help to control them. Photos have been provided for multiple life-cycle stages, and each insect is described in detail, with information on

81 http://ipmguidelinesforgrains.com.au/insectopedia/introduction/sampling.htm

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

83 http://pir.sa.gov.au/research/research_specialties/sustainable_systems/entomology/insect_diagnostic_service

MORE INFORMATION

Pest Genie Australia

APVMA.

the crops they attack, how they can be monitored and other pests that they may be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [84]

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're aware of the latest pests affecting crops for each region
- Ensure awareness of international bio-security pests

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

For more information see Section 7: Insect control

1.11.2 Effect of cropping history

It is important to consider paddock history when planning for pest management. Resident pests can be easier to predict by using paddock history, and agronomic and weather data to determine the likely presence (and numbers) of certain pests within a paddock. This will point towards the likely pest issues and allow growers to implement preventive options. [85] Reduced tillage and increased stubble retention have changed the cropping landscape with respect to soil moisture retention, groundcover and soil biology and this has also affected the abundance and types of invertebrate species being seen in crops. These systems increase invertebrate biodiversity but also create more favourable conditions for many pests such as slugs, earwigs, weevils, beetles and many caterpillars. In turn they have also influenced beneficial species such as carabid and lady beetles, hoverflies and parasitic wasps. [86]

See Section 7: Insect control for more information.

84 https://grdc.com.au/Resources/Apps

85 https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-117-July-August-2015/Growers-chase-pest-control-answers

86 https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Emerging-insect-pests

Pre-planting

Key messages

- In variety choice, consider yield and adaptation to the area, disease resistance, grain quality, marketability and proximity to receival point.
- Be aware of the specific management needs for the variety chosen through its variety management package (VMP). [1]
- Kabuli chickpea provides a very profitable cropping option to Western Australian grain growers when produced under the right conditions and management.
- Test for seed quality in terms of germination and vigour prior to sowing. Only sow the highest quality seed.
- If using grower-retained seed, ensure it has been stored correctly; i.e. at the right moisture and temperature, and for no longer than 12 months. This is because rapid deterioration of grain quality occurs under conditions of high temperature/moisture and with poor seed quality including weathered, cracked and diseased seed.

Agronomist's tip: It is recommended that any seed stored longer than 12 months be tested for viability, especially if storage facilities may not be up to recommended storage standards.

2.1.1 Choosing a variety

Choosing a variety that has been bred for, and proven in, the western grains region is the first step in successful chickpea production (Figure 1). Understanding varietal ratings with respect to diseases and their control is a key part of risk management.

Figure 1: *Chickpea trials test for varietal differences.*

Source: Flickr

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

The availability of varieties resistant to Ascochyta blight now provides growers with low disease-risk options for growing chickpeas in Western Australia (WA). Ascochyta blight of chickpeas has been a widespread and devastating disease in all Australian grain regions, and unless resistant varieties are used, it can be a major limitation when growing this crop.

Chickpea crops in southern Australia and isolated parts of northern Australia are being hit by a more virulent strain of the damaging ascochyta blight. Pulse pathologists in Victoria and South Australia have noted a marked decline in the resistance of several varieties of chickpeas, with varieties previously rated as moderately resistant performing like susceptible lines. [2] There have been no reported cases of this new Ascochyta blight strain in WA.

Some varieties with Ascochyta blight resistance that are available to growers may have other agronomic, disease or marketability limitations and will not suit all areas or situations.

When choosing varieties to grow, it is essential to consider their susceptibility to Ascochyta blight along with yield potential, price potential, marketing opportunities, flowering cold tolerance, maturity timing, lodging resistance and other agronomic features relevant to your growing region.

When comparing yields between varieties, growers need to be aware that where Ascochyta blight pressure is high, varieties with moderate resistance, or less, are more likely to suffer greater yield losses than the resistant lines, even with regular applications of foliar fungicides.

Area of adaptation

Chickpea varieties are bred for and selected in a range of environments. Hence, individual varieties have specific adaptations to help maximise yield and reliability under particular conditions. These conditions include rainfall, geography, temperatures, disease pressure and soil type.

The national chickpea area has been categorised by Pulse Breeding Australia (PBA) into five regions based on rainfall and geographic location. The Western Australia growing region includes:

- Region 4: medium/high rainfall; Mediterranean/temperate
- Region 5: low/medium rainfall; Mediterranean/temperate

These regions cross state borders and are target zones for national breeding programs and variety evaluation. Breeding trials and National Variety Trial (NVT) results help indicate specific adaptation, even within a region. The area of adaptation is specified for each variety so potential users are aware of their best fit. [3]

Evaluation of yield potential

When choosing a variety, many factors must be considered, including disease susceptibility, paddock suitability, seed availability, seed size and sowing rate (with reference to sowing machinery), seed cost, harvesting ease and marketing options.

The most accurate predictor of a variety's performance is a stable yield in many locations over several years. Yield results from Pulse Breeding Australia (PBA) and National Variety Trials (NVT) are available from the NVT website, as well as from the specific Pulse Variety Management Package (VMP) brochure. [4]

Long-term yields can be represented in several different ways but are typically displayed either as site-specific, averaged over multiple years, or for each year averaged over multiple sites for a region.

2 Heard G. (2016). Ascochyta pressure on chickpeas http://www.stockandland.com.au/story/4085979/ascochyta-pressure-on-chickpeas/

3 G Cumming (2014) Chickpea varieties selecting horses for courses. GRDC Update Papers 5 March 2014, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Chickpea-varieties-selecting-horses-for-courses

4 G Cumming (2014) Chickpea varieties selecting horses for courses. GRDC Update Papers 5 March 2014, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Chickpea-varieties-selecting-horses-for-courses

In association with Pulse Australia and its commercial seed partners, PBA launches its new varieties at targeted pulse field days during the spring field-day circuit. This gives growers and advisors the opportunity to view and assess the varieties in their growing regions prior to their availability.

A Variety Management Package (VMP) is released with each new PBA variety. The brochures provide information about appropriate agronomic and disease management and disease ratings for each variety.

The information in the brochures is compiled from agronomic and disease management projects funded by the Grains Research and Development Corporation (GRDC) in conjunction with the PBA partner agencies, combined with yield data from variety trials conducted by both PBA and NVT. [5]

2.2 Varietal performance and ratings yield

Table 1: *Varieties and varietal traits for chickpeas in WA*

Variety	Yield ability	Quality traits	Maturity	Other varietal traits
Desi				
PBA Striker⌀ 	Highest yielding desi chickpea variety across all chickpea-growing areas of Western Australia, and produces high yields in the low-to-medium rainfall areas of southern Australia. Yields of PBA Striker⌀ are substantially higher (7–13%) than PBA Slasher⌀ and Genesis™ 836 in Western Australia	Suitable for both splitting and direct consumption use by traders in India and the Middle East. Medium-sized desi seed with excellent milling quality, larger seed size than PBA Slasher⌀ and Genesis™ 836	Improved early vigour compared to PBA Slasher⌀, with early flowering and early maturity. PBA Striker⌀ flowers 5–7 days earlier than PBA Slasher⌀ and is earlier maturing than PBA Slasher⌀ and Genesis™ 836	Moderately Resistant (MR) to Ascochyta blight, it is a semi-spreading plant type similar to PBA Slasher⌀. Plant height and lowest pod height is similar to PBA Slasher⌀, but lower than Genesis™ 836
PBA Slasher⌀ 	Excellent adaptation to all areas of southern and western Australia. Yields of PBA Slasher⌀ are 5–7% higher than Genesis™ 836 in Western Australia	Assessed as suitable for both splitting and direct consumption use by traders in India and the Middle East. Medium-sized desi seed with good milling quality, with higher dehulling efficiency and dhal (splits) yield than Genesis™ 836	Mid-flowering and mid-maturity. PBA Slasher⌀ flowers 3–7 days earlier than Genesis™ 836, and is earlier maturing than Genesis™ 836	Combines Aschochyta blight resistance, rated as Resistant (R) to Ascochyta blight, high yield and good seed quality. Semi-spreading plant type. Plant height and lowest pod height is lower than Genesis™ 836

5 Pulse Breeding Australia. PBA Varieties and brochures. GRDC Major Initiatives, http://www.grdc.com.au/Research-and-Development/Major-Initiatives/PBA/PBA-Varieties-and-Brochures

Variety	Yield ability	Quality traits	Maturity	Other varietal traits
Neelamⓓ 	Highest yielding Resistant (R) Ascochyta blight rated desi chickpea variety. Yields of Neelamⓓ are 2–5% higher than PBA Slasherⓓ in Western Australia	Desi type chickpea suitable for the whole and splitting human food markets. Seed size is 17 grams/100 grams (g), marginally larger than Genesis™ 836, similar to PBA Slasherⓓ. However, its seed coat colour is lighter than PBA Slasherⓓ	Mid-flowering and mid-maturity variety similar to Genesis™ 836	Resistant (R) Ascochyta blight rated. Medium/tall plant height, taller than PBA Slasherⓓ and similar to Genesis™ 836
Ambarⓓ 	Well-adapted to most of southern Australia, particularly suited to the northern wheatbelt of Western Australia. Ambarⓓ yields are similar to PBA Slasherⓓ	Desi type chickpea suitable for the whole and splitting human food markets. Seed size is similar to Genesis™ 836 at 16 g/100 g. However, its seed coat colour is lighter than PBA Slasherⓓ	Earliest flowering and earliest maturing of all current desi chickpea varieties, making it particularly well-suited to shorter growing season (low rainfall) environments	Rated as Resistant (R) to Ascochyta blight. Bushy growth habit with profuse branching, it has a short/medium plant height, slightly shorter than PBA Slasherⓓ
PBA Maidenⓓ 	It is broadly adapted to WA regions and has shown similar yields to PBA Slasherⓓ	Largest seed size of current southern desi chickpea varieties (28% larger than PBA Slasherⓓ). Targeted for whole seed markets	Moderate early vigour. Early to mid-flowering and maturity. Semi spreading plant type	Moderately Resistant (MR) to Ascochyta blight

Variety	Yield ability	Quality traits	Maturity	Other varietal traits
Genesis™ 510 	Highest yielding desi under strong Ascochyta disease pressure	A desi type with small sized grain	Broadly adapted, mid to early flowering variety with medium plant height and good harvestability. It suits many farming systems, including inter-row sowing into standing stubbles and wider (>30 cm) row spacings	Ascochyta resistant desi chickpea release in Western Australia only. Requires one fungicide application for control of Ascochyta blight
Genesis™ 836 	A tall, erect and high yielding variety in WA, under moderate Ascochyta blight	Small sized desi grain is produced	Broadly adapted, mid to late flowering variety with good plant height and harvestability. It suits many farming systems including inter-row sowing into standing stubbles and wider (>30 cm) row spacings	A desi chickpea with moderately resistance to Ascochyta blight released for WA only. Requires two fungicide applications to control Ascochyta blight
Kabuli				
Genesis™ 079 	Highest yields in short season environments than current varieties	Budget for grain prices at lowest end of small kabuli range, due to 6–7 mm seed	A small seeded kabuli (predominantly 6–7 mm) with smaller seed than Genesis™ 090. Early maturity and uniform short plant height offers improved potential for agronomic weed control options under some conditions	Resistant to foliar Ascochyta blight. A small seeded kabuli (predominantly 6-7 mm) with smaller seed than Genesis™ 090 (predominantly 6-7 mm). Susceptible to Phytophthora

Sources: Pulse Australia, DAFWA

2.3 Planting seed quality

High quality seed is essential to ensure the best start for your crop. Grower-retained seed may be of poor quality with reduced germination and vigour, as well as potentially being infected with seed-borne pathogens. No matter whether chickpea seed is acquired commercially or grower retained on-farm, it is important to use the highest possible quality. Poor quality seed can result in low plant establishment due to poor germination, vigour and/or seed-borne diseases such as Ascochyta blight and Botrytis grey mould (BGM).

- All seed should be tested for quality including germination (high germination—above 80%) and vigour (AA test). Use large, graded seed.
- Use seed at low risk of Ascocytha blight infection.
- If grower-retained seed is of low quality, consider purchasing registered or certified seed from a commercial supplier. Always ask for a copy of the germination report.
- Regardless of the source, evenly treat seed with a thiram-based fungicide.
- 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).

High quality seed is vital (Figure 2). Check seed labels for germination percentage and purity, and ask for the germination certificate. The results of a germination test must be supplied with all seed for sale. Take the additional precaution of having the seed tested for both Ascochyta and Botrytis grey mould. Harvesting on time minimises the development of disease on seed. [6]

Figure 2: *Poor quality seed (left) all sown on the same day.*

Source: Pulse Australia

Effect of poor quality seed on yield

Seed quality problems often emerge only if the crop is not harvested under ideal moisture or seasonal finishing conditions. A sharp seasonal finish, a wet harvest or delayed harvest can have a big impact on seed quality.

Using severely weather damaged or mechanically damaged seed will result in:

- poor establishment and poor crop performance
- reduced plant vigour (increased susceptibility to soil-borne pathogens during establishment and increased susceptibility to foliar pathogens)
- patchy, uneven plant stands (increased susceptibility to weed competition, aphids and viruses)
- uneven plant development complicating in-crop management (e.g. herbicide applications)
- uneven and delayed crop maturity (e.g. making desiccation timing difficult and leading to a mixed grain sample)

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

- lower yields from a combination of all of the above

As a general guide, weather damaged seed with lower than normal germination and vigour levels should only be sown under very good conditions (for rapid establishment) and at a higher seeding rate. Such seed is not recommended for deep sowing or moisture seeking. [7]

The large size or fragile nature of pulse seed, particularly lupin, kabuli chickpea and faba bean, makes them more vulnerable to mechanical damage during harvest and handling. This damage is not always visually apparent and can be reduced by operations such as slowing header drum speed and opening the concave, or by reducing auger speed and lowering the flight angle and fall of grain. A rotary header and a belt elevator are ideally suited to pulse grain and can reduce seed damage, which can result in abnormal seedlings that germinate but do not develop further.

MORE INFORMATION

Chickpea: High Quality Seed

Under ideal conditions, abnormal seedlings may emerge but lack vigour, making them vulnerable to other rigours of field establishment. Factors such as low temperature, disease, insects, seeding depth, and soil crusting and compaction are more likely to affect the establishment of weak seedlings. Those that do emerge are unlikely to survive for long, will produce little biomass and make little or no contribution to final yield. [8]

Grower-retained seed

Grower-retained sowing seed should always be harvested from the best part of the crop where weeds and diseases are absent and the crop has matured evenly. Seed should be harvested first to avoid low-moisture grain, which is more susceptible to cracking. Seed moisture of 11–13% is ideal. Weeds, other grains, or disease contamination from other pulse crops should be avoided when selecting parts of the paddock for seed harvest.

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 *Helicoverpa* (Native budworm or heliothis) damage, mould infection, and risk of late Ascochyta seed infection
- harvesting at a moisture content >15% can lead to problems with moulds and fungal pathogens colonising on the seed coat during storage
- harvesting at a moisture content <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
- using chickpea seed which was 'shot and sprung' when harvested is not recommended. The chickpea is a relatively large seed that requires considerable moisture for germination to begin. Unlike cereal grains with higher starch content, once the chemical process has started and an embryo formed, the seed will continue to germinate, use up its energy reserves and die due to lack of follow-up moisture while in storage

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

8 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013, Pulse Australia Limited.

- seed-borne diseases such as Ascochyta blight and Botrytis grey mould (and/or in contamination with sclerotinia) 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 [9]

NOTE: Do not use any seed that has come from 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.

WATCH: GCTV16: Extension Files – Retained Pulse Seed

Grading

Chickpea seed for sowing should be professionally graded (preferably using a gravity grader) to provide a uniform seed lot and remove all small or split seeds, trash and weed seeds. A gravity grader is more efficient at removing lighter seeds, which are often disease infected. A higher proportion of small, shrivelled and light-weight grain can be expected in crops that have experienced high incidences of Ascochyta and or Botrytis grey mould.

Handling seed

The large size, awkward shape and fragile nature of many pulses mean that they need careful handling to prevent seed damage. The bigger the grain, the easier it is to damage. Seed grain, in particular, should be handled carefully to ensure good germination.

- Plan ahead so that handling can be kept to a minimum, to reduce damage between harvest and seeding.
- Augers with screen flighting can damage pulses, especially to larger seeded crops. This problem can be partly overcome by slowing down the auger.
- Tubulators or belt elevators are excellent for handling pulses, as little or no damage occurs. Cup elevators are less expensive than tubulators and cause less damage than augers. They have the advantage of being able to work at a steeper angle than tubulators. However, cup elevators generally have lower capacities.
- Augering from the header should be treated with as much care as later during handling and storage because it has the same potential for grain damage.
- Combine loaders that throw or sling, rather than carry the grain, can cause severe damage to germination.

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

2.3.1 Testing for seed quality

The only way to accurately know the seed's germination rate, vigour, and disease level is to have it tested. Seed-borne diseases can lower germination levels, and testing for presence in seed can be conducted by specialist laboratories for a number of diseases such as Ascochyta blight in chickpeas. Seed with poor germination potential or high levels of seed-borne disease should not be sown. Cheaper costs of this seed will be offset by higher sowing rates needed to make up for the lower germination and there is potential to introduce further disease on to the property.

For more information, see Section 2.3.3 Seed germination and vigour, below.

2.3.2 Seed size

Seed size can affect the seedling vigour in grain legumes where large seed produce more vigorous plants and may affect yield. [10]

Seed size can be quickly calculated at home by counting out 200 seeds and weighing—multiply the weight (grams) by five to get a 1000-seed weight. Or divide 200,000 by the weight (grams) to get number of seeds per kilogram (depending on your preferred method of calculating seeding rates).

Conducting both the germination test and seed size test on several batches of seed (i.e. at least twice) is recommended, to get a more accurate assessment of the sample.

2.3.3 Seed germination and vigour

Grain legumes often have poor seedling vigour which may reduce their competitiveness with weeds and pests. Low seedling vigour can also cause low Water Use Efficiency because of the long time to full canopy closure. Efforts that lead to improved seedling vigour among grain legumes may therefore be useful to improve yield and Water Use Efficiency. It has been suggested that there are inherent genetic differences in seedling vigour both between species and between varieties. [11]

A laboratory seed test for germination should be carried out before seeding to calculate seeding rates. However, a simple preliminary test on-farm can be done in soil after harvest or during storage. Results from a laboratory germination and vigour test should be used in seeding rate calculations.

Grower retained seed should be tested for germination and vigour at least twice:

- Immediately post-harvest, to assess if the seed is worth retaining or better sold for grain or fed to livestock.
- Just before sowing, after grading and treatment with fungicide seed dressing, so seeding rates can be adjusted to compensate for any decline in quality during storage over summer.

Weather-damaged seed deteriorates quicker than usual in storage and a third test in mid-storage is advised. This will indicate if the seed is still suitable for sowing and if not, allows time to consider other options.

Pulse seed should have a minimum germination of 80% to be kept for sowing. Seeds that do germinate from a tested batch with only a 50% germination rate will have low vigour. Avoid using seed with such low rates of germination.

Whilst increasing the seeding rate of poor quality seed may seem reasonable, it carries a high risk of seedling disease. If the poor quality is caused by seed-borne pathogens, the seed will be a source of infection for healthy seed and seedlings.

Simple germination tests can be done at home at any time over summer as temperature does not affect the results. For beans, chickpea, lupins, peas and vetch,

10 J Kamboozia, G McDonald, H Reimers. (1993). The effect of seed size, seed protein and genotype on seedling vigour in some grain legumes. 7th Aust. Agron. Conf.©, SARDI.

11 J Kamboozia, G McDonald, H Reimers. (1993). The effect of seed size, seed protein and genotype on seedling vigour in some grain legumes. 7th Aust. Agron. Conf.©, SARDI.

the sample size required is 1 kg for each 25 t of seed. There are two quick methods that both require 100 seeds for the test:

- Method 1: Place 100 seeds between at least four sheets of paper towel, roll up, fold the ends over and soak in fresh water for 30 minutes. Drain, put the 'seed doll' in a tray and place on the kitchen bench or workshop table. Ensure 'seed doll' does not dry out. After three, four, and five days unwrap 'doll', remove germinated seeds, taking a note of their vigour and re-wrap the 'doll'. After the fifth day, count the non-germinated and mouldy seeds.
- Method 2: Fill a flat shallow (5 cm deep) garden tray or non-rusty baking tray with clean sand, potting mix or freely draining soil. On the soil surface arrange your 100 sends in 10 rows and push the seeds into the soil with a pencil marked to a depth of 3 cm (Figure 1—right). Cover with a little more sand/soil and water gently. Keep soil moist but not wet as overwatering will result in fungal growth and possible rotting.

A germination test does not always accurately predict emergence. For a valuable crop like chickpeas a laboratory test should be used. Growers can also conduct their own emergence test, as per method 2. If this is conducted in the intended paddock this will also help to identify potential herbicide residue problems.

After 7–10 days the majority of viable seeds will have emerged (Figure 3—left). Count only the normal and healthy seedlings. If left for another few days you will also be able to assess how many of the germinated seeds are actually deformed (e.g. missing cotyledons or mould/disease affected), which will also give some indication of vigour. [12]

Figure 3: *Doing your own germination test (left) Seedling growth after 12 days and after 5 days (right)*

Photo: E. Leonard, Kevin Moore. Source: Pulse Australia

Sampling should be random and numerous subsamples should be taken to give best results. Sample either while seed is being moved out of the seed cleaner, storage or truck, or otherwise from numerous bags. Do not sample from within a silo or a bagging chute, as it is difficult to obtain a representative sample and is dangerous. Failure to sample correctly or test your seed could result in poor establishment in the field.

If an issue is suspected with kept grain, then it is better to get a sample tested early to avoid the cost of grading and time lost to procure suitable seed.

Testing seed vigour

Seed vigour is more accurately assessed by commercial laboratories as the assessment method is both temperature and time based. The seedling vigour test will also provide a better indication of the number of abnormal seeds present in addition to the germination percentage.

In years of drought or a wet harvest, seed germination can be affected, but also more importantly, seedling vigour can be reduced. Poor seedling vigour can heavily affect establishment and early seedling growth. This can often occur under more difficult

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

establishment conditions such as deep sowing, crusting, compaction, wet soils, or when seed treatments have been applied. Some laboratories also offer a seed vigour test when doing their germination testing. Vigour represents the rapid, uniform emergence and development of normal seedlings under a wide range of conditions. Several tests are used by seed laboratories to establish seed and seedling vigour.

Cool germination and cold tests

A cool or cold test is done to evaluate the emergence of a seed lot in cold wet soils, which can cause poor field performance. The cold test simulates adverse field conditions and measures the ability of seeds to emerge. It is the most widely used vigour test for many crops. It is also one of the oldest vigour tests.

This test is used to:

- evaluate fungicide efficacy
- evaluate physiological deterioration resulting from prolonged or adverse storage, freezing injury, immaturity, injury from drying or other causes
- measure the effect of mechanical damage on germination in cold, wet soil
- provide a basis for adjusting seeding rates.

This test usually places the seed in cold temperatures (5–10°C, with variations between laboratories) for a period, which is then followed by a period of growth. Then the seed is evaluated relative to normal seedlings according to a germination test. Some laboratories also categorise the seedlings further into vigour categories and report both of these numbers.

Accelerated ageing vigour test

Accelerated ageing estimates longevity of seed in storage. It is now also used as an indicator of seed vigour and has been successfully related to field emergence and stand establishment. This tests seed under conditions of high moisture and humidity. Seeds with high vigour withstand these stresses and deteriorate at a slower rate than those with poorer vigour. Results are reported as a percentage, and the closer the accelerated ageing number is to the germination result, the better the vigour. Results are expressed as a percentage of normal germination after ageing (vigorous seedlings).

Conductivity vigour test

The conductivity test measures electrolyte leakage from plant tissues and is one of two ISTA-recommended vigour tests. Conductivity test results are used to rank vigour lots by vigour level. It is important to have a germination test done too, because a conductivity test cannot always pick up all chemical and pathogen scenarios, which may be seed-borne.

Tetrazolium test (TZ) as a vigour test

The tetrazolium test is used to test seed viability, but is also useful as a rapid estimation of vigour of viable seeds. It is done in the same way as a germination test, but viable seeds are evaluated more critically into categories of:

- High Vigour—staining is uniform and even, tissue is firm and bright.
- Medium Vigour—embryo is completely stained or embryonic axis stained in dicots. Extremities may be unstained. Some over-stained or less firm areas exist.
- Low Vigour—large areas of non-essential structures unstained. Extreme tip of radicle unstained in dicots. Tissue is milky, flaccid, and over-stained.

Results have shown good relationships with field performance, and the test is useful for pulses.

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 seed sample can be conducted if requested, including the amount of weed seed contamination. Do not plant seed contaminated with weed seeds.

Disease testing

Seed-borne diseases such as ascochyta blight 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 be treated with a fungicide before sowing or a clean seed source may be used.

2.3.4 Seed purity

Seed should only be purchased from reliable sources. If growers have any doubts about a seed source then do not use seed. If growers decide to store their own seed they should ensure to keep good records and abide to seed storing recommendations for their area.

Agronomist's view

Accurate identification of chickpea varieties is critical to Ascochyta blight management in commercial crops.

Australian chickpea varieties differ in their reaction to Ascochyta blight. Varieties released before 2005 are susceptible to Ascochyta blight, and (in seasons conducive to disease) require intensive management with foliar fungicides. Most cultivars released in 2005 and later have improved Ascochyta blight resistance, and require fewer fungicide sprays.

Contamination between seed varieties has been found to lead to higher than expected disease susceptibility in moderately resistant crops. Contamination or a mix-up in source of planting seed might account for the observed differences in Ascochyta blight levels in chickpea crops grown from grower-retained seed. This is part of the large issue of maintaining genetic purity in Australian chickpea varieties after their release.

Key findings from chickpea seed purity research:

- DNA evidence has identified genetic contamination in commercial chickpea crops going back to at least 2011.
- Crop inspections have revealed obvious differences among plantings believed by growers to be the one variety.
- Minimise the risk of contamination of your 2014 planting seed by obtaining seed from a registered seed merchant.
- When retaining your own seed, put in place a quality control system to avoid accidental contamination.

The extent of purity contamination is not yet determined however, testing results from 36 seed lots suggest that the seed purity problem is far bigger than currently thought. Although the problem first surfaced in 2011, pathologists say it appears to be getting worse (Figure 4).

Figure 4: *As the issue of seed purity increases, growers should treat crops from suspect seed as a susceptible variety.*

Photo: Rachel Bowman, Seedbed Media

Accurate identification of chickpea variety is essential for:

- implementing appropriate disease-management strategies
- minimising the risk to resistance genes in moderately resistant varieties from increased inoculum generated on contaminant plants or 'mix up' crops of susceptible varieties
- maximising marketing opportunities by producing pure seed of one variety
- supporting grower's legal rights (e.g. if the seed you purchased is not what you paid for)
- assessing compliance with plant breeder's rights legislation, thus ensuring breeding programs receive the appropriate royalties
- prolonging the commercial life of new varieties
- providing confidence in the chickpea seed industry
- providing technical support to research programs (e.g. knowing the genotype of a plant from which an isolate is obtained is critical to the current GRDC project on the variability of the Australian population of the chickpea Ascochyta blight pathogen). [13]

13 K Moore, K Hobson, A Rehman, J Thelander (2014) Chickpea varietal purity and implications for disease management. GRDC Update Papers 5 March 2014, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Chickpea-varietal-purity-and-implications-for-disease-management

WATCH: Chickpea seed quality – Kevin Moore, 2013.

2.3.5 Seed storage

Storing pulses successfully requires a balance between ideal harvest and storage conditions. Harvesting at 14% moisture content captures grain quality and reduces mechanical damage to the seed but requires careful management to avoid deterioration during storage.

Tips for storing pulses:

- Pulses stored at >12% moisture content require aeration cooling to maintain quality.
- Meticulous hygiene and aeration cooling are the first lines of defence against pest incursion.
- Fumigation is the only option available to control pests in stored pulses, and requires gas-tight, sealable storage.
- Avoiding mechanical damage to pulse seeds will maintain market quality, seed viability and be less attractive to insect pests. [14]

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.

Ideally, chickpea needs to be stored at 13% moisture content and at temperatures below 30°C. Storage at very low moisture contents (< 10%) may make chickpeas (particularly kabuli types) more susceptible to damage during subsequent handling, as the seed shrinks away from the seed coat.

Like other grain, chickpea seed quality deteriorates in storage. Most rapid deterioration occurs under conditions of high temperature and moisture. Crops grown from seed that has been stored under such conditions may have poor germination and emergence.

Reducing temperature in storage facilities (to below 30°C) is the easiest method of increasing seed longevity. Temperatures can be reduced in grain silos by painting the outside of the silo white (temperatures reduced by 4–5°C), and/or aerating silos with dry, ambient air.

14 GRDC (2012) Storing pulses. GRDC Grain Storage Fact Sheet July 2014, http://grdc.com.au/Resources/Factsheets/2014/07/Grain-Storage-Fact-Sheet-Storing-Pulses

Reducing temperature in grain silos:

- Paint the outside of the silo with white paint. This reduces storage temperature by as much as 4–5°C, and can double safe storage life of grains.
- Aerate silos with dry, ambient air. This option is more expensive, but in addition to reducing storage temperatures, is also effective in reducing moisture of seed harvested at high moisture content.
- Heat drying of chickpea sowing seed should be limited to temperatures ≤40°C. [15]

WATCH: Over the Fence: Ensure seed viability with aerated storage.

Insect pests in storage

Insects are generally not considered to be a major problem in stored chickpea seed. However, where a prior infestation exists in the storage structure (most commonly as a result of cereal grain residue) then the infestation can develop and spread in the chickpeas. Ensure all handling equipment and storages are cleaned of old cereal grain before they are used to handle chickpeas. Good hygiene, combined with aeration cooling, should prevent infestations developing. If insect pests are found in stored chickpeas, the only registered treatment is phosphine fumigation.

For more information, see Section 13: Storage.

MORE INFORMATION

Storing pulses

2.3.6 Safe rates of fertiliser sown with the seed

All pulses can be affected by fertiliser toxicity. Higher rates of phosphorus (P) fertiliser can be toxic to establishment and nodulation if drilled in direct contact with the seed at sowing. Practices involving drilling 10 kg/ha of P with the seed at 18-cm row spacing through 10 cm points rarely caused any problems. However, with the changes in sowing techniques to narrow sowing points, minimal soil disturbance, wider row spacing, and increased rates of fertiliser (all of which concentrate the fertiliser near the seed in the seeding furrow), the risk of toxicity is higher. Agronomists, however, can present anecdotal reports where toxicity has not been a problem.

The effects are also increased in highly acidic soils, sandy soils, and where moisture conditions at sowing are marginal. Drilling concentrated fertilisers to reduce the product rate per hectare does not reduce the risk.

The use of starter nitrogen (N), such as DAP, banded with the seed when sowing pulse crops has the potential to reduce establishment and nodulation if higher rates are used. On sands, up to 10 kg/ha of N at 18-cm row spacing can be safely used. On clay soils, do not exceed 20 kg/ha of N at 18-cm row spacing. [16]

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

16 GRDC (2008) Grain Legume Handbook update 7 Feb 2008. Grain Legume Handbook Committee, supported by the Grains Research and Development Corporation (GRDC), https://grdc.com.au/uploads/documents/3%20Seeding.pdf

Banded potassium has been shown to be twice as accessible to the crop as top-dressed potassium. This is thought to be related to improved availability for the emerging crop, and decreased availability for weeds. Growers should not band high rates (i.e. >15 kg/ha) particularly with sensitive crops (e.g. chickpea, lupins) and should try to place potassium fertilisers away from the seed. Furthermore, growers should be aware that nutrient auditing requires fertiliser applications to cover potassium export during harvest, and are encouraged to account for variations in yield where possible. If a paddock is severely deficient then potassium needs to be applied early in the season to maximise response to the application. At seeding or up to 4 weeks after will optimise the benefits of potassium application. [17]

2.4 Future breeding directions

The current PBA program continues to focus on regional adaptation, higher grain yields and greater levels of varietal resistance to the main two chickpea diseases of Ascochyta blight and Phytophthora root rot.

Additional valuable traits that the breeding program is working with include:

- resistance to Botrytis grey mould
- virus resistance
- improved resistance to root-lesion nematodes (*Pratylenchus thornei* and *P. neglectus*)
- improved tolerance to soil salt levels
- improved reproductive cold tolerance [18]

17 Quinlan R, Wherrett A. (2016). Potassium – Factsheet. Soilquality.org. http://soilquality.org.au/factsheets/potassium

18 G Cumming (2014) Chickpea varieties selecting horses for courses. GRDC Update Papers 5 March 2014 http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Chickpea-varieties-selecting-horses-for-courses

Planting

Key messages

- The strain of rhizobia used for inoculating chickpeas is highly specific (Group N, CC1192). Inoculation is essential for effective nodulation and will result in a crop that is self-sufficient for N and provide soil health benefits in subsequent seasons.
- All seed, regardless of source, should be treated with a registered thiram-based fungicide seed dressing prior to sowing.
- The chickpea sowing window for low rainfall is April 20–May 25, and in medium rainfall from May 15–June 15.
- In WA, the greatest seed yields have been produced by sowing from mid to late June at southern sites, and early May at central and northern sites.
- While yields are relatively stable within the range of 35–50 plants/m^2, higher seeding rates (50 plants/m^2) produce the highest yields in western and southern areas.
- Sowing at 30–50 cm spacing is becoming common. Some innovators are sowing in 50–100 cm row spacing and using inter-row spraying for weed control. Understand the advantages and disadvantages of row spacing.
- Sow chickpeas 5–7 cm deep into good moisture. The seedlings are robust, provided high quality seed is used. There are also benefits to deep planting chickpea.

3.1 Inoculation

Pulses have the ability to 'fix' their own N from the air via nodules on their roots if specific nitrogen-fixing bacteria (rhizobia) are available. Grain legume crops (such as pulses) and pasture legumes initiate a symbiotic relationship with rhizobia bacteria, to form nitrogen-fixing root nodules. The chickpea is an introduced crop to Australia and, as such, seeds must be treated (inoculated) with the correct strain of rhizobia (symbiotic N-fixing bacteria) before planting.

The strain of rhizobia used for chickpeas is highly specific (Group N, CC1192). Inoculation is essential for effective nodulation and will result in a crop that is self-sufficient for N and provide soil health benefits in subsequent seasons. This N fixation process has a national benefit of close to $4 billion annually in Australian cropping systems. Growers can treat seed before sowing with inoculants containing live bacteria to stimulate nodulation and the N-fixation capacity of legumes. It is important to match the correct inoculant group to each legume. [1] The Group N bacteria are regarded as an 'aggressive nodulator'. This effectively means that nodulation will be successful in meeting the crop's N requirements provided the inoculants are handled and stored in a manner that will ensure bacterial survival and that growers adopt effective inoculation practices on-farm.

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

WATCH: GCTV13: Legumes – Sowing preparation.

WATCH: GCTV13: Legumes – Inoculant compatibility.

The most common method of inoculating chickpea is to coat the seed with a slurry of peat based inoculum immediately before planting (Figure 1). It is important to treat only the seed that can be planted the same day. Exposure to drying winds, high temperatures or direct sunlight will rapidly kill the bacteria. [2]

Figure 1: *Forms of rhizobia (left to right): Easyrihiz freeze-dried, Nodulator granules, Alosca granules, N-Prove granules and peat inoculant.*

Photo: M. Denton, DPI Vic

2 DAFF (2012) Planting chickpeas. Department of Agriculture, Fisheries and Forestry August 2012, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/planting

Only purchase refrigerated (but not frozen) inoculum from a reputable supplier and then store it in a cool, dry place. For maximum survival, peat inoculant should be stored in a refrigerator at ~4°C until used. If refrigeration is not possible, store in a cool, dry place away from direct sunlight. Granules and other forms also need to be stored in a cool place out of direct sunlight. Do not store an opened inoculum packet, as it will deteriorate rapidly. Discard the inoculant after the expiry date, because the rhizobia population may have dropped to an unacceptable level. Treat seed within 24 hours of sowing and sow into moist soil. Consider new technologies that are now also available and may suit your operations, e.g. freeze-dried inoculums, water liquid injection, granular inoculums. Dry sowing of chickpeas is now possible if using granular inoculums that enable rhizobia survival until rain arrives to germinate seed. [3]

MORE INFORMATION

Inoculating pulse crops

Inoculated seed must be planted into moisture within 12 hours of treatment. The sooner the better, as fungicide seed dressings can affect survival of the bacteria. Inoculated seed and acidic fertilisers should not be sown down the same tube. The acidity of some fertilisers will kill a high proportion of the rhizobia and render inoculation ineffective. Neutralised (e.g. Super lime) and alkaline fertilisers (e.g. DAP, Starter NP, lime) can be safely used. [4]

IN FOCUS

Nutrient uptake and yield of chickpea (Cicer arietinum L.) inoculated with plant growth- promoting rhizobacteria

Plant growth promoting rhizobacteria (PGPR) represent a wide variety of soil bacteria which, when grown in association with a host plant, result in stimulation of growth of their host plant. Several mechanisms have been suggested by which PGPR can promote plant growth, including phytohormone production, N_2 fixation, stimulation of nutrient uptake and biocontrol of pathogenic microorganisms.

One study evaluated the effects of single and combined inoculation with plant growth-promoting rhizobacteria from four genera including Azospirillum, Azotobacter, Mesorhizobium and Pseudomonas on nutrient uptake, growth and yield of chickpea plants under field conditions. Nodulation and nutrient concentration in shoots were significantly affected by the treatments at the beginning of flowering stage. The maximum dry weight of root nodules was recorded by applying the combined inoculation with Azospirillum spp. + Azotobacter chroococcum 5 + Mesorhizobium ciceri SWRI7 + Pseudomonas fluorescens P21. All inoculants were statistically superior over uninoculated control with respect to nitrogen concentration of shoots. The treatments containing Azospirillum + Azotobacter significantly improved phosphorus concentration in shoots. Grain yield, biomass dry weight and nitrogen & phosphorus uptake of grains were statistically improved by applying every inoculation treatment in comparison with control plants. Group comparisons between treatments showed that the occurrence of Azospirillum or Azotobacter inoculants in the treatment composition caused an expressive improvement in grain yield and plant biomass. In conclusion, application of every inoculation treatment studied here, especially treatments which contained Azospirillum or Azotobacter may stimulate growth and yield of chickpea as compared with uninoculated plants. [5]

3 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

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

5 Rokhzadi, A., & Toashih, V. (2011). Nutrient uptake and yield of chickpea (Cicer arietinum L.) inoculated with plant growth-promoting rhizobacteria. Australian Journal of Crop Science, 5(1), 44.

3.1.1 Inoculation checklist

Important points when purchasing and using inoculants:

- Check the expiry date on packet.
- Packets should be stored at around 4°C.
- Do not freeze (below 0°C) or exceed 15°C.
- Use Group N chickpea inoculum
- Prepare slurry and apply in the shade, avoiding exposure to high temperatures (>30°C), direct sunlight, and hot winds.
- Accurately meter adhesive slurry onto the seed. Too much water means sticky seeds and blockages in the seeder.
- Avoid high-speed mixing in augers and inoculate at the top of the auger not the bottom.
- Sow inoculated seed immediately. Never delay more than 12 h.
- Check air-seeders for excessively high temperatures in the air stream. Temperatures >50°C will kill the rhizobia. [6]

3.1.2 Inoculant types

Peat inoculum

The traditional method of supplying rhizobia to seed is with peat inoculum. Read the label and apply the inoculant according to the directions. Most pulse crop inoculums for application to seed contain a pre-mixed sticker which helps adhesion to the seed. Be cautious and read the inoculant label regarding adding any approved insecticides, fungicides, herbicides, detergents or fertilisers into the slurry as these may be toxic to the rhizobia. Inoculated seed should be used within 24 hours when applied alone, and within four hours is applied in conjunction with a fungicide.

In-furrow water injection

Water or fluid injection of inoculants into the seed row is becoming more common as it has been adapted to pulse growing and modern machinery. It can be used where machines are set up for liquid N on cereals, and where fungicides are used to treat seeds before sowing. Water injection of inoculant requires at least 40-50 litres of water per hectare and is better with more.

The slurry-water solution is sprayed under low pressure into the soil in the seed row during seeding. Benefits of the new inoculant carrier types over peat are that they are convenient, 'dissolve' more readily, and do not have the requirement for filtering out peat hairs etc. Read the label before mixing any fungicides.

Granular forms

Granular inoculants are applied like fertiliser as a solid in the seed furrow or near to the seed and avoid many of the compatibility problems that rhizobia have with fertilisers and fungicides. They also eliminate the application procedures needed with peat inoculum. Granular inoculants also offer some advantages when dry sowing.

Granules contain fewer rhizobia per gram than peat-based inoculants, so they must be applied at higher application rates. The size, form, uniformity, moisture content and rate of application of granules differ between products. Depending on the product or row spacing sown, application rates can vary from 4 kg/ha to 10 kg/ha to deliver adequate levels of nodulation.

Several granular inoculant formulations are now available, and they are not all the same in composition, practicalities of use and performance. Seek independent trial information for your area when making comparisons between products.

6 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

ALOSCA is a dry clay (Bentonite) granule now used in significant areas of Western Australia. BASF produces moist clay granules (Nodulator), while Novozymes Australia also produces a moist granular product.

Even application is best achieved through a dedicated third box on the seeder (Figure 2). Maintaining an even application rate when mixed with the seed is difficult as the granules shake down in the seed lot. Achieving an even distribution rate in the fertiliser box is also difficult, and rhizobia survival becomes an important consideration. Only ALOSCA claim compatibility when mixed with fertiliser. [7]

Figure 2: *An 'after-market' third box fitted to a Flexicoil box to enable application of granular inoculums. Note that granular inoculums cannot be applied mixed with the seed (uneven distribution of seed and/or inoculums occurs). Rhizobial survival is severely jeopardised if granular inoculums are applied mixed with fertiliser.*

Source: Grain Legume Handbook, 2008

3.1.3 Choosing an inoculant type

All types of inoculants will result in a well-nodulated crop in good conditions (Table 1). The choice of inoculant type by growers will depend on:

- experience
- paddock history; i.e. the need for added rhizobium
- product availability
- relative cost
- perceived efficacy
- ease of use
- the suitability of machinery to deliver the inoculum.

Granules can vary and, depending on the product, may be dry or moist, uniform, variable, powdery, coarse or fine.

When conditions are less than ideal, making the right choice becomes more critical.

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

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 to the seed without causing a reduction in rhizobia numbers. [8]

Table 1: *Inoculant types available.*

Inoculant product	Application method
BASF (NODULAID™NT)	Peat inoculant, applied as a slurry/powder/ liquid to the seed or in furrow to the soil
BASF (NODULATOR™)	Clay granular inoculant to be applied in furrow to the soil
New-Edge Microbials (EasyRhiz™)	Freeze-dried inoculant, made up into a liquid and applied to the seed or in furrow by water injection into the soil
New-Edge Microbials (Nodule N)	Peat inoculant, applied as a slurry to the seed
ALOSCA Technologies	Dry clay (bentonite) granular inoculant, applied in furrow to the soil
Novozymes Australia (Cell-Tech™)	Peat inoculant. Applied as a slurry/powder/ liquid to the seed or in furrow to the soil
Novozymes Australia (Tag-Team™)	Peat inoculant with phosphate-mobilising soil fungi *Penicillium bilaii.*

Source: Pulse Australia

3.1.4 When to inoculate

If crops within an inoculum group have not previously been grown in the paddock to be sown, then seed of the crop should be inoculated immediately prior to sowing; otherwise, a nodulation failure may occur (Figure 3).

If conditions for nodulation are likely to be adverse; i.e. waterlogged, acid soils, or lighter soils, then it may help to use some starter N, e.g. mono- or di-ammonium phosphate (MAP or DAP). This will stimulate early root growth until the numbers of naturally occurring rhizobia build up and begin fixing N. [9]

The current recommendation is to inoculate chickpea every time it is grown due to poor rhizobium survival on alkaline soils.

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

9 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

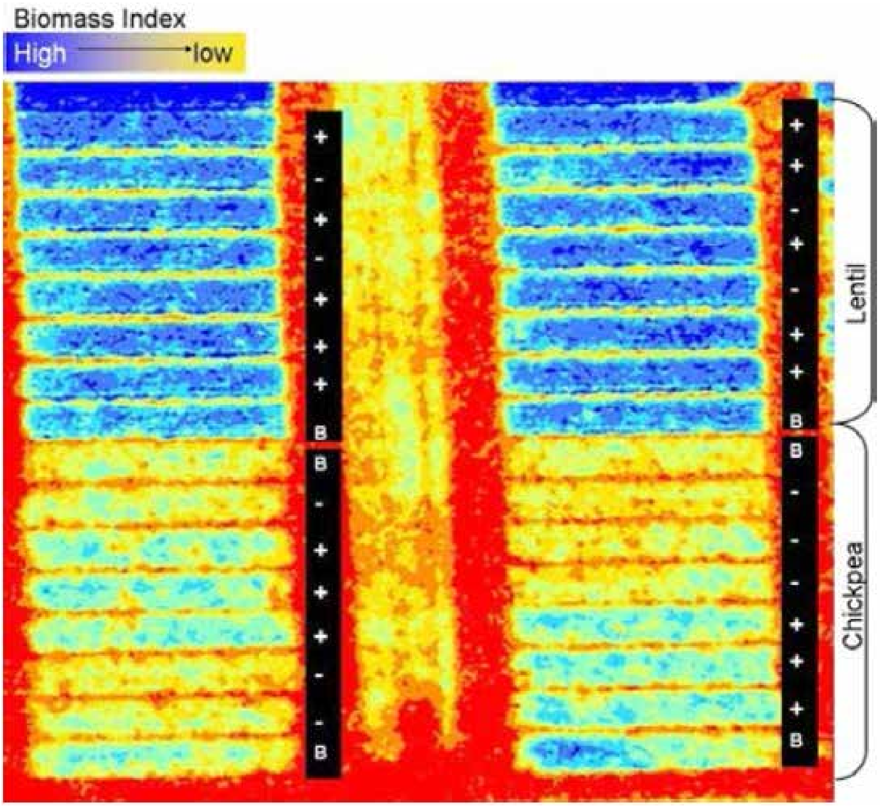


Figure 3: *Biomass image of lentil (top) and chickpea (bottom) inoculant plots at Paskeville SA 2009. Blue represents high biomass, yellow represents low biomass and red is bare earth. Note the responsiveness of chickpea but not lentil, plots to inoculation and inoculant type. B, buffer; +, inoculated; –, uninoculated.*

Photo: National Rhizobium Program trial by J. Heap, SARDI

Rhizobia will persist in the soil and, depending on a range of conditions, can inoculate a subsequent pulse. If the paddock has previously grown the same pulse, the number of rhizobia remaining in the soil will be affected by the:

- time since the pulse was last grown
- health of the crop
- type of rhizobia
- soil pH and texture.

Rhizobia types vary in their ability to persist in the soil until the host pulse crop is regrown. Lupin rhizobia (Group G) are most resilient and survive very well in low pH (down to pH 5) sandy soils. Pea and bean rhizobia (Groups E & F) survive well in neutral to alkaline soils with good texture (loams or clays).

If a well-nodulated lupin or pea crop has been grown in the previous four years, a response to inoculation is less likely. However, pea and bean rhizobia survive poorly in low pH or sandy soils. The safest and least risk option is to inoculate the crop, especially on light textured soils.

Less is known of the survivability of chickpea rhizobia (Group N). Inoculating at sowing is recommended regardless of other considerations.

The cost of inoculation is low and worth the effort if there is any doubt about the viability of residual soil rhizobia.

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. [10]

3.1.5 Inoculum survival

Moist peat provides protection and energy while the unopened packet is being stored. Inoculated seed should be sown directly into moist soil. Rhizobia can dry out and lose viability once applied to seed and not in moist soil. Granular inoculant forms may not dry out as quickly.

Most peat inoculants now contain an adhesive, which delays drying and increases survival of the rhizobia. Use a peat slurry mixture within 24 hours. Sow seed inoculated with peat slurry as soon as possible, but certainly within 12 hours, being sure to keep the seed in a cool place, away from sunlight.

With non-peat based inoculants, such as freeze-dried rhizobia, it is recommended that treated seed be sown within 5 hours of inoculation. The rhizobia survive for longer in granules than when applied on seed. Hence, when drysowing pulses, granular inoculant is preferred over peat and liquid injection methods.

Dry-dusting the peat inoculant into the seed box is not an effective means of distributing or retaining rhizobia uniformly on seed. Under some conditions, rhizobial death is so rapid where dry dusting is used that no rhizobia remain alive by the time the seed reaches the soil. [11]

3.1.6 Inoculant quality assurance

Legume inoculants sold to Australian farmers must pass a rigorous quality assurance (QA) program. Cultures of inoculant are tested by the Australian Legume Inoculants Research Unit (ALIRU) to establish that the correct rhizobial strain is present and the viable cell number exceeds a minimum value (Table 2).

Table 2: *ALIRU Quality Assurance rhizobia minimum numbers.*

Product	Viable rhizobia (no./g)	Rate per ha	Rhizobia (no./ha)	Expiry (months)
Peat	1 × 109	250 g	3 × 1011	12–18
Liquid	5 × 109	300 mL	2 × 1012	6
Granular	1 × 107	10 kg	1 × 1011	6
Freeze-dried	1 × 1012	0.15 g	2 × 1011	24

Source: Grain Legume Handbook, 2008

3.1.7 Inoculation methods

Pulses have historically been inoculated with rhizobia slurry onto the seed, but now rhizobia can be purchased in a form suitable to be applied with water injection into the soil, or as granules that are sown with the seed from a separate box. For water injection, the inoculant is mixed with water and applied at low pressure through tubes into each seed furrow. Using granules usually requires a third seed box as granules will shake out if mixed with seed and can lose viability if mixed with fertiliser (Table 3).

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

11 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Table 3: *Survival of different inoculant types with various application methods.*

Inoculant type	Where inoculant is applied	Survival in dry or drying soil*	Compatibility with seed-applied fungicide
Peat	Seed	Low	Some (check label)
Freeze-dried	Seed or in-furrow (water injection)	Very Low	Very Low
Granular	Seeding furrow of below seed	Yes	Yes
In-furrow water injection	Seeding furrow or below seed	Very low	Yes

*Survival will depend on duration of dry conditions and soil pH

Source: Pulse Australia, 2013

For chickpeas:

- Peat formulation: as slurry to seed (most common) or in furrow
- Freeze-dried formulation: as slurry to seed or liquid in furrow
- Granular formulation: in furrow at sowing [12]

3.1.8 Inoculum slurry

Most inoculants now contain a pre-mixed sticker. When mixing the slurry do not use hot or chlorinated water. Add the appropriate amount of the inoculant group to the solution and stir quickly. Mix into a heavy paste with a small amount of water prior to adding to the main solution. Add the inoculant suspension (slurry) to the seed and mix thoroughly until all seeds are evenly covered.

How to apply slurry to the seed:

- in a cement mixer (practical for small lots only unless a cement truck is used)
- through an auger (Figure 4)
- through a tubulator

When applying via an auger, make sure the auger is turning as slowly as possible. Reduce the height of the auger to minimise the height of seed fall. Perhaps add a slide, e.g. tin, to the outlet end of the auger to stop seed falling and cracking. Meter the slurry in, according to the flow rate of the auger (remember 250 g packet per 100 kg seed). Too much water means sticky seed and blockage problems in the planter.

12 GRDC. (2013). Inoculating legumes: The Back Pocket Guide. https://grdc.com.au/GRDC-BPG-InoculatingLegumes

Figure 4: *Pumping a slurry of rhizobia inoculant into the auger to coat seed before sowing.*

Source: GRDC

Applying the slurry through a tubulator is similar to applying through an auger, except that the tubulator reduces the risk of damaging the seed (Figure 5). Its mixing ability is not as effective as an auger.

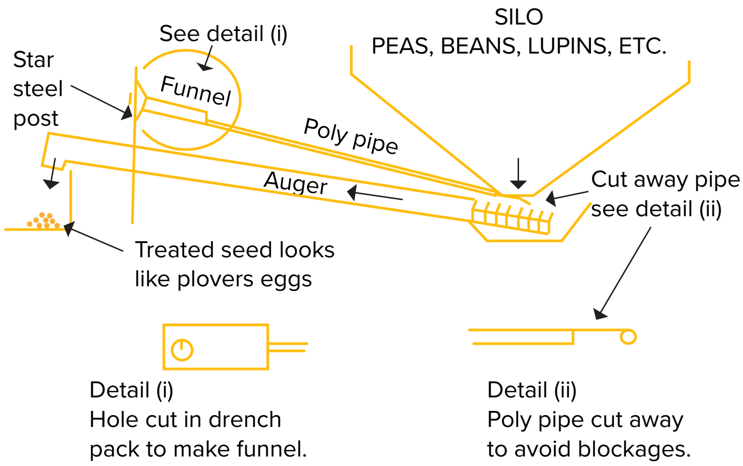


Figure 5: *Application of inoculum to seed through a tubulator.*

3.1.9 In-furrow water injection

Injection of inoculants mixed in water is becoming more common. It can be used where machines are set up to apply other liquids at seeding, such as liquid N or phosphorus (P). Water injection of inoculant requires at least 40–50 L/ha of water, and is better with more water. The slurry–water solution is applied under low pressure into the soil in the seed row during seeding. Benefits of the new inoculants over peat are that they mix more readily, and do not have the requirement for filtering out peat. Compatibility of the inoculant with trace elements is not yet known, but extreme caution is advised because water pH is critical, and trace element types, forms and products behave differently between products and inoculants groups.

Trials have consistently shown superior nodulation from water injection of inoculum (Figures 6 and 7). This is likely to be due to the larger numbers of live bacteria being delivered into the soil in close proximity to the seed.

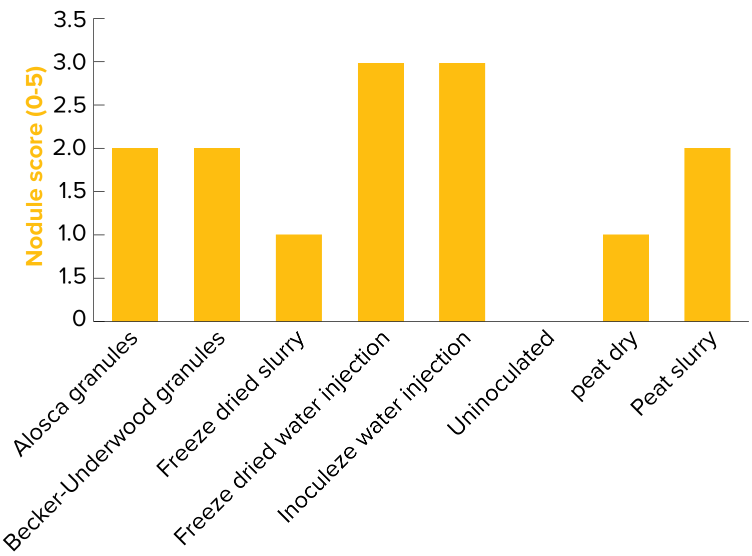


Figure 6: *Inoculation trial with nodule scores assessed at 4 weeks after planting.* [13]

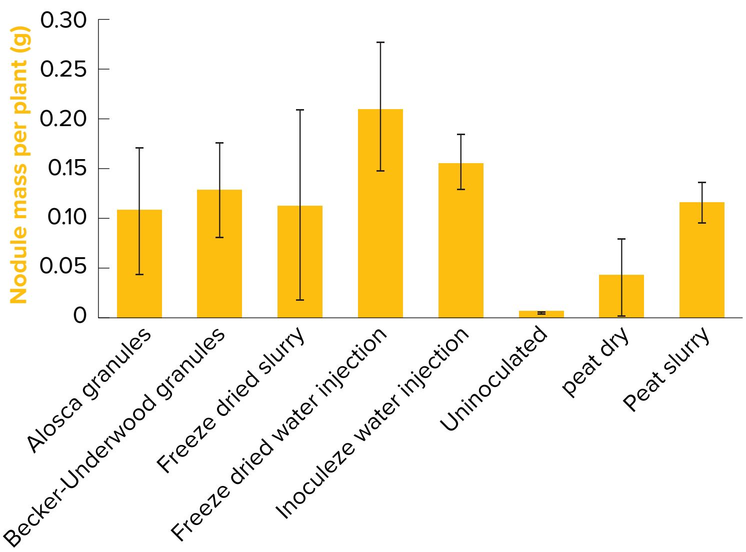


Figure 7: *Inoculation trial at Emerald (2005), nodule biomass at flowering.* [14]

13 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

14 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

3.1.10 Inoculant application trials

Inoculation of chickpea seed with Group N rhizobia is recommended regardless of paddock history. The standard method of mixing slurry and applying direct to seed still appears adequate; however, recent research has shown potential improvements by injecting the rhizobia into the seed furrow with water as a carrier. Peat granules have on average performed as well as the standard slurry method, whereas attapulgite clay granules and bentonite clay granules have generally resulted in nodulation levels higher than the untreated control, but equal to or less than the standard slurry method.

Trials from 2008 to 2010 have compared the use of the available inoculant treatments. Figure 8 presents trial results in terms of nodule score by product type.

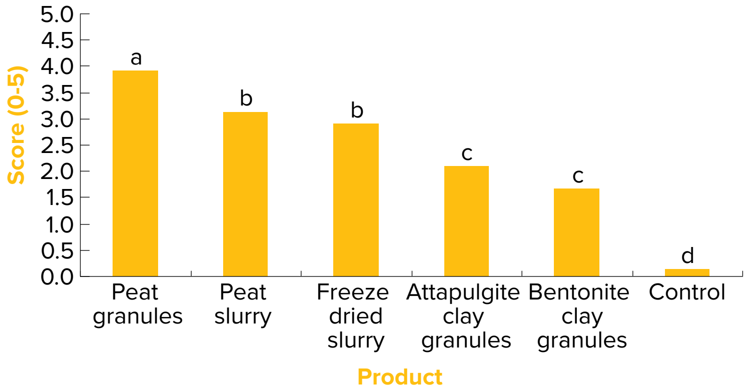


Figure 8: *Effect of inoculant treatment on nodulation of chickpea roots.* [15]

Limited trial data show that the most effective of the new technologies appears to be the application of rhizobia in-furrow with water (water-inject). This reduces the need to mix and apply slurry to the seed, but requires large volumes of water at sowing, as well as a liquid tank and plumbing to be incorporated into the seeder. Clay granules (attapulgite and bentonite) have often resulted in less nodulation than the standard slurry treatments.

However, where chickpeas are a regular crop in the rotation, the reduced efficacy provided by the clay granules compared with the standard slurry treatment is likely to be less pronounced. Granules can reduce labour and downtime at sowing, so would only be recommended where real efficiency gains can be made. Peat granules resulted in nodulation levels greater than the clay granules in one of two trials. The use of standard slurry treatment (peat slurry) still appears to be a reliable method of application. In some cases, nodulation may be less than with the 'water inject', but this needs to be balanced with the extra machinery cost of liquid injection.

In one trial, nodulation from the slurry applied to seed method was significantly affected by fungicide (thiram + thiabendazole), where the fungicide and slurry were applied within one hour of each other. In the trials where the fungicide did not affect nodulation, the seed had been treated with fungicide at least several days before inoculation. In the fungicide-affected trial, the freeze-dried slurry treatment showed a greater reduction in nodulation from fungicide than what was seen from the peat slurry treatment.

For growers planting small areas of chickpeas, or who are content with current treatments methods, the traditional method of peat slurry application still appears

15 R Brill, G Price (2011) Chickpea inoculation trials 2008–10. GRDC Update Papers March 2011, http://www.nga.org.au/results-and-publications/download/67/grdc-update-papers-general-/rhizobia-innoculation-methods-inchickpeas/grdc-adviser-update-paper-goondiwindi-march-2011.pdf

reliable. Where the requirement for N fixation is high (e.g. chickpeas cropped straight into sorghum stubble), liquid injection may improve outcomes. Liquid injection (once set up on a machine) may also provide logistical benefits.

Where chickpeas have been a regular crop in the rotation, granules may provide adequate nodulation and give logistical benefits such as reduced labour requirement.

Note: These results present only one year of data. To gain a full understanding of the individual treatments used, the trials need to be replicated over several seasons and as part of different farming systems. [16]

3.1.11 Compatibility with other major factors

Pesticides

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. BASF claims compatibility between its peat inoculum and Rovral®. However, the seed must be sown within several hours into moist soil to avoid reducing rhizobia viability.

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. [17]

Fungicides

Caution should be used when treating pulse seed with a fungicide. Some insecticide and seed treatments can also cause problems. Check the inoculant and chemical labels for compatibility of the inoculant and fungicide or insecticide seed treatments.

Effect of fungicidal seed dressings on inoculum survival

While fungicide seed dressings reduce the longevity of the N-fixing bacteria applied to the seed, the effect can be minimised by keeping the contact period to as short as possible (Table 4).

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

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

16 R Brill, G Price (2011) Chickpea inoculation trials 2008–10. GRDC Update Papers March 2011, http://www.nga.org.au/results-and-publications/download/67/grdc-update-papers-general-/rhizobia-innoculation-methods-inchickpeas/grdc-adviser-update-paper-goondiwindi-march-2011.pdf

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

Table 4: *Effects of fungicide seed dressings on plant growth and nodulation in chickpeas.*

Treatment	Fresh weight (g)			Height (cm)	Nodulation score
	Shoot	Root	Total		
Nil	106	142	248	47	1.0
Inoculum only	130	244	374	57	4.5
Inoculum + Thiram	103	182	285	55	1.8
Inoculum then Thiram	119	208	327	58	3.2
Thiram then inoculum	117	212	329	55	3.8
Inoculum + Apron	106	173	279	54	1.8
Inoculum then Arpon	114	207	321	59	3.3
Apron then inoculum	113	206	319	55	3.6
l.s.d (P = 0.05)	19	33	31	9	0.6

Source: Trevor Bretag, formerly DPI Victoria

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.

3.1.12 Nodulation and nitrogen fixation

Different pulses need different strains of rhizobia, so are grouped into inoculation groups. Unless the right strain is present in the soil or has been supplied by adding a commercial inoculant at seeding time, effective root nodulation will not take place and little if any N will be fixed. These effects are not always immediately obvious above ground.

Where the host legume plant is grown infrequently in the cropping rotation, re-inoculation can be beneficial. Use of a commercial inoculant will ensure that nodulation is prompt, that nodules are abundant and that the strain of rhizobia forming the nodules is effective at fixing N (Figure 9).

MORE INFORMATION

Inoculating legumes: a practical guide (GRDC)

Inoculating legumes: the back pocket guide (GRDC)

Rhizobia inoculants fact sheet (GRDC)

Figure 9: *Well-nodulated chickpea plants.*

Photo: G. Cumming, Pulse Australia

When the legume germinates, the rhizobia enter the plant's roots, multiply rapidly and form a nodule. Effective nodule formation and function for the all-important N fix requires good growing conditions, the appropriate rhizobia and a host plant. Rotation lengths of 3–4 years are recommended between successive chickpea crops as a disease management strategy (i.e. ascochyta blight). At this re-cropping interval, sufficient levels of surviving Group N rhizobia are unlikely for effective nodulation.

Nodules remain inactive until the soil nitrate supply is exhausted (ineffective nodules remain white inside due to the absence of leghaemoglobin). Effective N-fixing nodules on the other hand, are rusty red or pink colour inside (Figure 10).

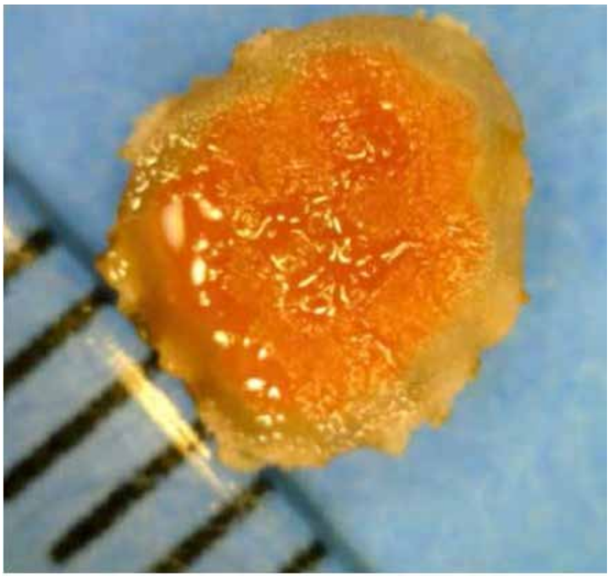


Figure 10: *Active nodules have a rusty red or pink centre.*

Photo: G. Cumming, Pulse Australia

IN FOCUS

Chickpea Water Use Efficiency in relation to cropping system, cultivar, soil nitrogen and Rhizobial inoculation in semiarid environments

Crops grown in semiarid rainfed conditions are prone to water stress which could be alleviated by improving cultural practices. One study determined the effect of cropping system, cultivar, soil nitrogen status and *rhizobium* inoculation (*Rz*) on water use and Water Use Efficiency (WUE) of chickpea in semiarid environments. Four varieties were grown in no-till barley, no-till wheat, and tilled-fallow systems and under various rates of N fertiliser (0, 28, 56, 84, and 112 kg N ha−1) coupled with or without *Rz*. On average, chickpea used about 10 mm of water from the top 0–15 cm soil depth. In the tilled-fallow system, chickpea extracted 20% more water in the 15–30 cm depth, 70% more in the 30–60 cm depth, and 156% more in the 60–120 cm depth than when it was grown in the no-till systems. Water Use Efficiency increased from 4.7 to 6.8 kg ha−1 mm−1 as N fertiliser rate was increased from 0 to 112 kg N ha−1 when chickpea was grown in the no-till barley or wheat systems, but chickpea grown in the tilled-fallow system did not respond to changes in the fertiliser N rates averaging WUE of 6.5 kg ha−1 mm−1. In the absence of N fertiliser, the application of *Rz* increased WUE by 33% for chickpea grown in the no-till barley system, 30% in the no-till wheat system, and 9% in the tilled-fallow system. Chickpea inoculated with *rhizobium* achieved a WUE value similar to the crop fertilised at 84 kg N ha−1. Without the use of *Rz*, chickpea increased WUE in a linear fashion with increasing fertiliser N rates from 0 to 84 kg N ha−1. Cropping system, cultivar, and inoculation all had greater impact on WUE than on the amount of water extracted by the crop from the soil. The improvement of cultural practices to promote general plant health along with the development of cultivars with improved crop yields will be keys for improving Water Use Efficiency of chickpea in semiarid environments. [18]

3.1.13 Monitoring nodulation

Grain growers are encouraged to assess their legume crops for nodulation levels. Late winter and early spring is the best time to sample crops. It's important that growers who have used inoculants and also those who have not, check crops to see whether adequate nodulation is occurring. For farming systems to derive maximum benefits from legume N-fixation, optimal nodulation is necessary.

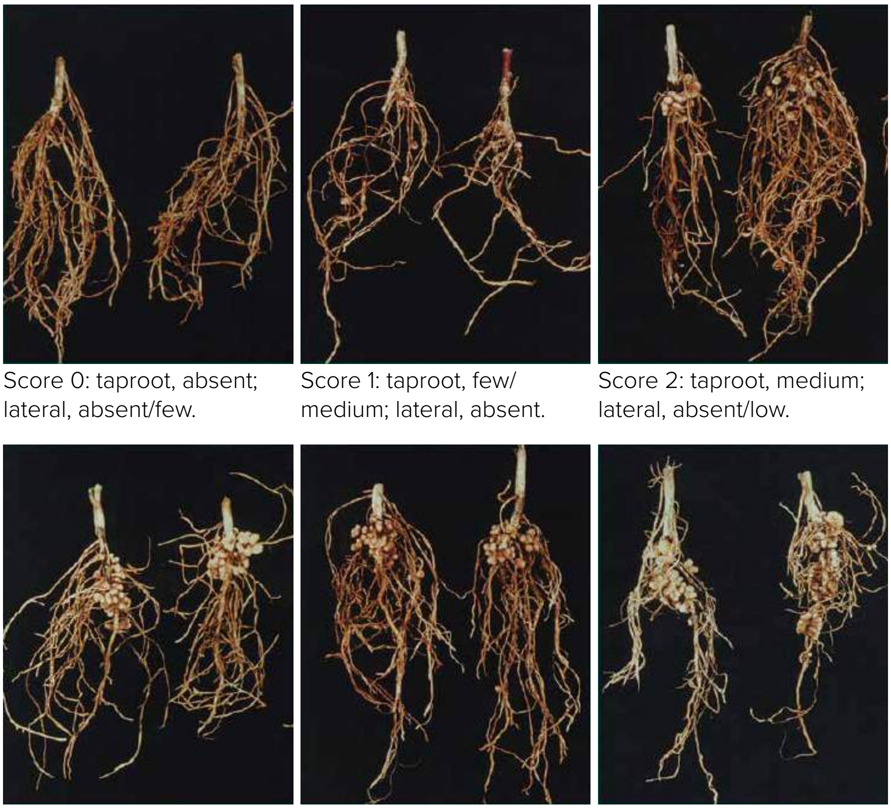
The best approach is to:

- Collect three samples of about 10 plants from three different spots within a paddock (suggested to be 20 m, 60 m and 100 m in from the edge), putting each sample of 10 plants in a separate bucket;
- Carefully wash off the soil in a bucket of water and rinse the roots to remove the remaining soil (soak for up to 30 minutes for heavy soil);
- Score each sample for the percentage of plants adequately nodulated and work out an average of scores for the three sampling locations.

Growers should look for:

18 Gan, Y. T., Warkentin, T. D., Bing, D. J., Stevenson, F. C., & McDonald, C. L. (2010). Chickpea Water Use Efficiency in relation to cropping system, cultivar, soil nitrogen and Rhizobial inoculation in semiarid environments. Agricultural water management, 97(9), 1375–1381.

- The number of nodules on a plant. The desirable number of nodules varies for different legumes (Figure 11). For example, 50 per plant is adequate for field pea, vetch and faba bean. The number of nodules also varies between soil types (lower numbers per plant are found on lighter soils);
- The location of nodules on the plant. Where growers have inoculated seed, expect to see more nodules around the crown of the plant (where root meets shoot). These will boost the early growth of seedlings. Non-inoculated legumes will have nodules spread over the root system on crown, taproots and laterals, if rhizobia are already present in the soil;
- The colour inside the nodules. A red/pink colour means the nodules are effective and are fixing N (Figure 12). White or green nodules mean they are ineffective.



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.

Figure 11: *Assessment of nodulation.*

Photos A. Gibson. Source: GRDC

Figure 12: *A strong pink colour inside the nodules indicates that the rhizobia are actively fixing nitrogen.*

Photo: J Howieson. Source: Pulse Australia

If poor nodulation is apparent, growers should check their inoculation strategy to ensure best management practices are being 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, not to mention the lower potential N benefits to following crops. While a visual assessment will not indicate the actual level of N being fixed, which requires sophisticated scientific methods, looking at the roots to determine if there has been a nodulation failure or delay is worthwhile.

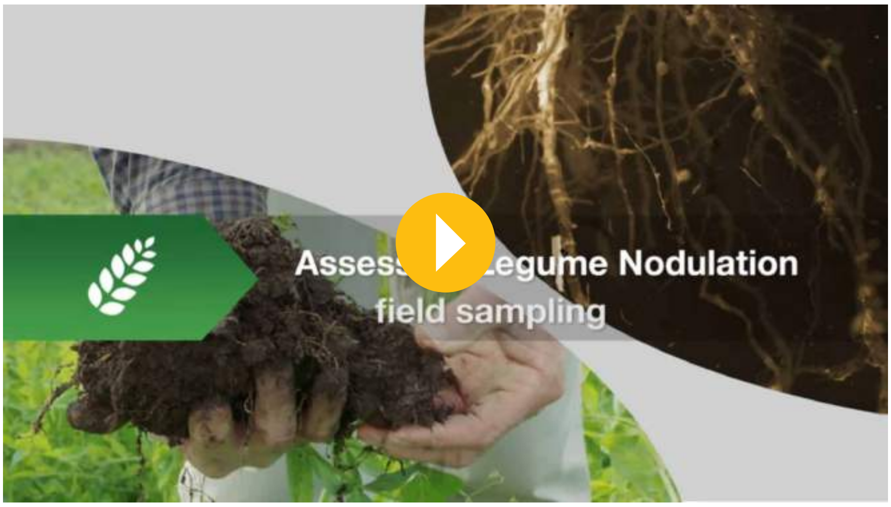
When looking at plants in the field, it is likely growers will find nodules on lateral roots as well as the main tap root. Look at all nodules when comparing the total nodule numbers in order to work out good or poor nodulation. Pulse crops that are poorly nodulated will be using more soil N than adequately nodulated crops, and fixing less N from the air.

Nodulation assessment will indicate whether this year's inoculation has been successful or whether troubleshooting is necessary. It will also tell a grower if non-inoculated legume should be inoculated next time it is grown in that paddock.

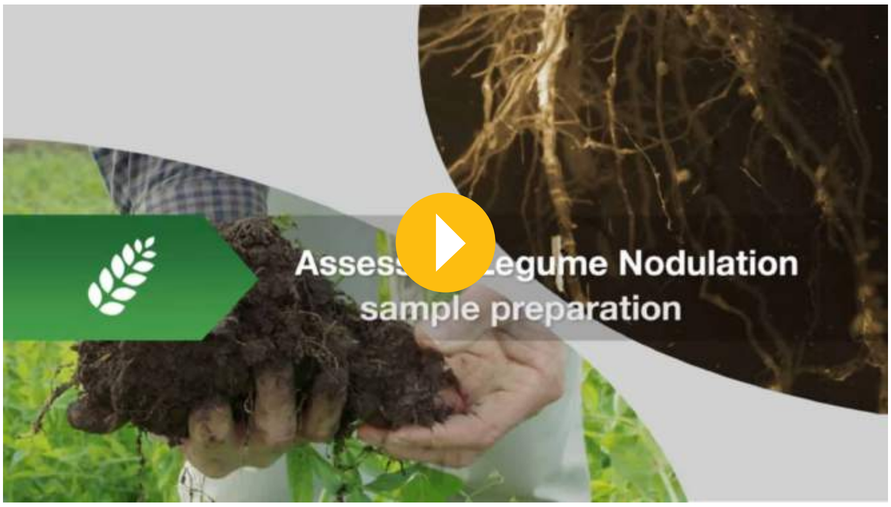
Poor nodulation can be caused by: no inoculation where low rhizobia numbers are present in soil; incorrect inoculant group or inoculant not being stored in cool conditions before use; inoculant effectiveness that has been reduced after mixing with certain types of seed dressings or liquid in-furrow treatments (trace elements, pesticides, fertilisers or organic amendments); inoculated seed left for more than one day before sowing; and crop stress, such as nutrition, waterlogging, diseases or herbicides causing root damage. [19]

19 GRDC. 17/08/16 Media Releases. Growers get the nod to check legumes for nitrogen fixation. www.grdc.com.au/media-news

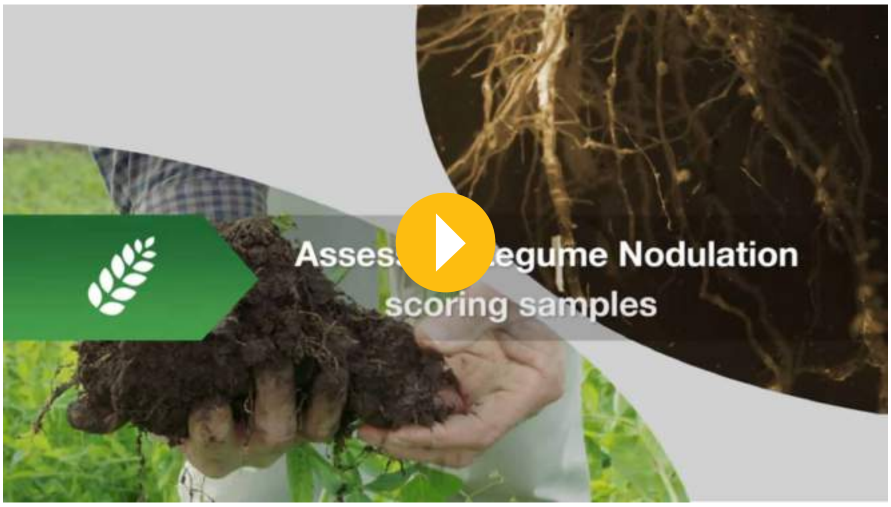
WATCH: GCTV17: Legume nodulation – field sampling.



WATCH: GCTV17: Legume nodulation – sample preparation.



WATCH: GCTV17: Legume nodulation – sample scoring.



3.1.14 Use of nitrogen in inoculation

There has been some research into the effects of adding N to inoculated chickpea. One study applied inorganic N fertiliser at four levels (0, 50, 75 and 100 kg ha–1 (applied in urea form)) and two levels of inoculation with rhizobium bacteria (with and without inoculation) as sub plots. Application of N and rhizobium inoculation continued to have positive effect on growth indices and yield components of chickpea. Lower levels of N application and non-inoculated plants showed less growth indices including total dry matter (TDM), leaf area index (LAI), crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) while the highest values of these indices were observed at the high levels of N application and inoculated plants. The highest plant height, number of primary and secondary branches, number of pods per plant and number of grains per plant were obtained from the highest level of N fertiliser (100 kg urea ha–1) and rhizobium inoculation. Application of 75 and 100 kg urea ha–1 showed no significant difference in these traits. Moreover, the highest grain yield was recorded in the inoculated plants that were treated with 75 kg urea ha–1. The results indicated that the application of suitable amounts of N fertiliser (i.e. between 50 and 75 kg urea ha–1) as a starter can be beneficial in improving growth, development and total yield of inoculated chickpea. [20]

3.2 Seed treatments

It is recommended that whenever possible seed should be obtained from a source where the crop was free from ascochyta blight and botrytis grey mould.

All seed, regardless of source, should be treated with a registered thiram-based fungicide seed dressing before sowing (Table 5).

These seed treatments will help minimise the levels of seed-borne ascochyta and botrytis grey mould. Research has shown that thiram plus thiabendazole products (e.g. P-Pickle-T®) and thiram-only products (e.g. Thiraflo®) are equally effective against ascochyta and botrytis.

A fungicidal seed dressing to suppress early development of ascochyta blight is also essential. Use thiram or thiabendazole and thiram combined, which is also effective against botrytis grey mould. There are no known fungicide seed dressings or treatments to control sclerotinia, although grading may assist by physically reducing the number of small sclerotes (fungal fruiting bodies) in the seed sample.

Kabuli chickpeas may show a response to the application of fungicide seed dressings even in the absence of known fungal diseases. This is because kabulis have a thinner seed coat than desi types and a lower content of phenolic compounds, which help protect the seed against fungal attack. [21]

Table 5: *Seed dressings registered for the control of seed borne ascochyta blight and botrytis grey mould.*

Active ingredient	Example of trade name	Rate (per 100 kg seed)
thiram (600 g/L)	Thiraflo	200 mL
thiram (800 g/kg)	Thiragranz	150 g
thiram + thiabendazole (360 + 200 g/L)	P-Pickel T	200 mL

Refer to the current product label for complete 'Direction for use' prior to application.

20 Namvar, A., Sharif, R. S., & Khandan, T. (2011). Growth analysis and yield of chickpea (Cicer arietinum L.) in relation to organic and inorganic nitrogen fertilisation. Ekologija, 57(3).

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

All chickpea seed should be inoculated with Group N inoculant. Fungicide seed dressings can reduce the longevity of this nitrogen fixing bacteria. But if contact is kept to a minimum duration, satisfactory nodulation will be obtained in most cases.

Fungicide seed dressings can be applied at any convenient time leading up to sowing. However, inoculation of seed needs to occur as close as possible to the time of sowing.

All inoculated seed should be sown into moist soil within 12 hours of treatment (or as per the inoculant's label directions), and the sooner the better. If inoculated seed is not sown within 12 hours, re-inoculate before sowing. [22]

MORE INFORMATION

Inoculating pulses

Seed treatment is very effective against seed rot, permitting early seeding of kabuli types to help offset the later maturity of currently available kabuli chickpea varieties. Because the large-seeded kabuli varieties mature later than the desi varieties, they may need to be sown earlier than desi in some districts.

If the seed is treated, it should be planted immediately after inoculation, as seed treatments can be toxic to the inoculant. The longer the inoculant is in contact with the seed treatment, the less effective it will be. [23]

3.3 Time of sowing

Time of sowing has been identified as a major factor affecting chickpea yield and disease incidence. [24] The key to planting chickpeas is to be mindful that the crop is susceptible to stress during flowering. Selecting a planting date that will limit this stress is a practical way to give the crop the best chance of achieving its potential yield.

The later a crop is planted the shorter the potential season for growth and development, especially if the season has a hot dry spring. When this occurs, plants have less time to develop canopies and roots, resulting in only partial use of soil water and a yield that is below potential. Reducing the row spacing of late-planted crops and ensuring an adequate plant density is one method to help late-planted crops access all available soil water. [25]

Chickpea shows a marked response to time of sowing. Crops sown 'on time' have an excellent chance of producing very high yields. However, crops sown earlier or later than recommended often suffer reduced yields. Spring sowing is a preferred option in high rainfall areas (greater than 550 mm). [26]

The chickpea sowing window for low rainfall is April 20–May 25, and in medium rainfall from May 15–June 15.

Yield increases exhibited by winter sown chickpea have been ascribed to the longer vegetative growth periods leading to a larger vegetative structure. This larger vegetative structure intercepts photosynthetically active radiation (PAR) more effectively in spring and supports a proportionally larger reproductive sink with adequate partitioning of dry matter. [27]

One study found that chickpea yield per unit area increases with both earlier sowing and increased supplemental irrigation. However, WUE under supplemental irrigation decreases with earlier sowing, due to the relatively large increase that occurs in the

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

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

24 Knights EJ, Siddique KHM (2002) Chickpea status and production constraints in Australia. In: Integrated management of botrytis grey mould of chickpea in Bangladesh and Australia. Summary Proceedings of a Project Inception Workshop, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur, Bangladesh. (Eds MA Bakr, KHM Siddique, C Johansen). June 2002, pp 33–41.

25 J Whish, B Cocks (2011) Sowing date and other factors that impact on pod-set and yield in chickpea. GRDC Update Papers 20 April 2011, http://elibrary.grdc.com.au/ark!!33517/vhnf54 t/tj680np

26 W Hawthorne, W Bedggood. (2007) Chickpeas in South Australia and Victoria. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpeas-SA-Vic.pdf

27 Croser, J. S., Clarke, H. J., Siddique, K. H. M., & Khan, T. N. (2003). Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

amount of evapotranspiration at early sowing dates. [28] WUE is commonly in the range of 8–12 kg grain/ha/mm for sowings made during the preferred sowing window. This drops away to 4–6 kg/ha/mm for very late or very early sowings.

Sowing before the recommended sowing window tends to result in greater vegetation and crops suffer from:

- poor early pod set because of low temperatures (<15°C) at flowering commencement
- higher risk of botrytis grey mould at flowering–podding (Figure 18)
- greater pre-disposition to lodging
- increased frost risk at early podding
- high water use prior to effective flowering and the earlier onset of moisture stress during podding
- increased risk of ascochyta blight

Late-planted crops are more likely to suffer from:

- high temperatures and moisture stress during podding
- greater native budworm pressure
- shorter plants, which are more difficult to harvest

To achieve maximum yields, critical management factors such as weed control and seedbed preparation must be planned to allow crops to be sown as close as possible to the 'ideal sowing dates'.

Ideal sowing dates should ensure that all chickpea crops:

- finish flowering before they are subjected to periods of heat stress, generally when maximum day temperatures over a week average 30°C or more; and
- flower over an extended period to encourage a better pod set and produce sufficient growth to set and fill an adequate number of pods.

Sowing must not be too early, otherwise:

- flowering may occur during a frost period;
- growth may be excessive, resulting in the crop lodging while dramatically increasing the likelihood of fungal disease problems in the medium–high rainfall districts; and
- conditions at seeding time may not be suitable for controlling broadleaved weeds with recommended herbicides, resulting in weedy crops.

This means that there can be a significant difference between the optimum sowing time for maximum potential yields and the ideal sowing time for reducing yield loss factors. The ideal seeding time for pulses depends largely on where the crops are being grown. Key factors include rainfall and the date of risk periods such as frost and critical heat stress. Soil type and fertility can also influence crop growth. With all pulses, it is essential to have adequate soil moisture at seeding time.

In some areas, the ideal sowing date will be a compromise. Optimum yields achieved by early sowing may have to be sacrificed, with sowing being delayed until risk factors have been reduced to an acceptable level (Figure 13). [29]

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28 Oweis, T., Hachum, A., & Pala, M. (2004). Water Use Efficiency of winter-sown chickpea under supplemental irrigation in a Mediterranean environment. Agricultural water management, 66(2), 163–179.

29 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

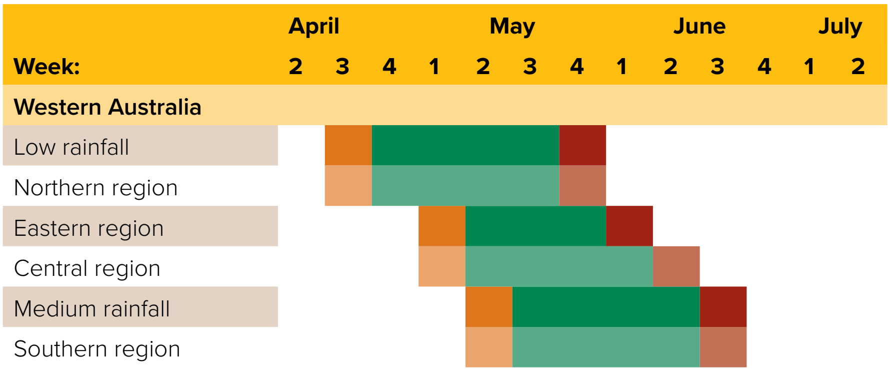

Figure 13: *Preferred chickpea planting times for districts with in the Western growing region.*

Source: Pulse Australia

WATCH: Early Seeding, WA.

IN FOCUS

When to sow chickpea in south-western Australia.

The optimum time of sowing of several desi chickpea varieties varying in phenology over a range of dryland Mediterranean-type environments in south-western Australia has been examined. Chickpea showed good adaptation, particularly in the northern grain belt where growing conditions are warmer than southern areas. Seed yields were not clearly increased by altering sowing time to match the phenology of the current varieties to the growing season rainfall and temperatures, except at the early sowing times (April and early May). Generally, the greatest seed yields were produced by sowing between mid to late June at southern sites, and early May at central and northern sites.

In chickpea grown in the Mediterranean regions of Australia, early phenology is associated with higher seed yield because it facilitates escape from terminal drought. However, flowering too early exposes chickpea to temperatures that are too low to support podset. Unlike cereal crops, chickpea has an indeterminate growth habit and is able to continue flowering and podding if environmental conditions are favourable, hence varietal responses to time of sowing may differ. This study examined the optimum time of sowing for several desi chickpea varieties varying in phenology over a range of dryland Mediterranean-type environments in south-western Australia.

Several desi chickpea varieties were sown at three or four times between early-April and mid-July at 19 sites between 1994 and 1998, corresponding to southern, central and northern production zones in south-western Australia. Entire plots (34- 36 m^2) were machine harvested to determine seed yield. Seed yields were analysed across sites and seasons using a linear mixed model to determine interactions between variety, time of sowing and region. For this analysis, regions were specified as north, central or south and sowing time was grouped into early, mid or late periods of each month.

Conclusions

Chickpea showed good adaptation to the dryland environments of south-western Australia, particularly in the northern and central agricultural regions where growing conditions are warmer than southern areas. This may be a consequence of the lack of chilling tolerance in chickpea. The optimal time of sowing for chickpea was from mid to late June at southern sites, and early May at central and northern sites. Seed yield of chickpea was not clearly increased by matching sowing time of current varieties with varied phenology in this study. [30]

3.3.1 Frost damage

Chickpea seedlings are tolerant of frost. Desi chickpea seed can germinate in soil as cold as 5°C, but seedling vigour is greater if soil temperatures are at least 7°C. Kabuli chickpea seed is more sensitive to cold soils and should not be seeded into excessively wet soil or into soil with temperatures below 12°C at the placement depth.

Damage to vegetative growth:

Damage is more likely to occur where the crop has grown rapidly during a period of warm weather, and is then subjected to freezing temperatures. The visible effect may occur as patches in the field, or on individual plants or branches of plants. Damage is usually more severe where stubble has been retained. Regrowth will generally occur provided soil moisture levels are adequate.

Damage to flowers and pods:

Freezing temperatures destroy flowers and young developing seed (Figure 14). Pods at later stage of development are generally more resistant and only suffer from a mottling and/or darkening of the seed coat. Varieties with an extended podding period can compensate for damage better than varieties that tend to pod up over a shorter period provided soil moisture levels are adequate.

Frost is most damaging to yield:

- when it occurs during later flowering–early pod fill
- under dry conditions where moisture limits the plant's ability to re-flower and compensate for frost damage.

30 Regan, K., & Siddique, K. H. (2006, September). When to sow chickpea in south-western Australia. In Proceedings of the 13th Australian Agronomy Conference (pp. 10–14).

Figure 14: *Frosted chickpea at flowering.*

For more information on frost damage and management in chickpeas, see Section 14: Environmental issues.

3.4 Seed rate

Sowing rate affects plant establishment and is an important crop management decision. While yields are relatively stable within the range of 35–50 plants/m^2, higher seeding rates (50 plants/m^2) produce the highest yields in western and southern areas (Table 6). High populations planted on wide rows often result in thin main stems and a higher risk of lodging.

Higher populations are justified for late sowings, while lower populations of around 20 plants/m^2 are often recommended for crops grown on wide row spacing (e.g. 100 cm). High populations sown on wide rows often result in thin main stems and a higher risk of lodging. [31]

Table 6: *Seeding rate (kg/ha) required for targeted plants/m^2 for a range of chickpea varieties at 95% germination and 80% establishment.*

Example variety type		Seed weight (g/100)	Seeding rate (kg/ha):		
			20 plants/m^2	25 plants/m^2	30 plants/m^2
Almaz(b	Large Kabuli	42	111	138	166
Genesis™079	Small Kabuli	26	68	86	103
Genesis™090	Small Kabuli	30	79	99	118
Genesis™114	Large Kabuli	44	116	145	174
Genesis™425	Small Kabuli	29	76	95	114
Genesis™Kalkee	Larger Kabuli	46	121	151	182
Flipper(b	Medium Desi	18	47	59	71
Genesis™509	Small Desi	16	42	53	63
Genesis™510	Small Desi	16	42	53	63
Genesis™836	Medium Desi	18	47	59	71
Kyabra(b	Large Desi	25	66	82	99
PBA Boundary(b	Medium Desi	20	53	66	79
PBA HatTrick(b	Medium Desi	21	55	69	83
PBA Slasher(b	Medium Desi	20	53	66	79
Yorker(b	Medium Desi	21	55	69	83

Source: Pulse Australia

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

IN FOCUS

Optimum plant density of desi chickpea (Cicer arietinum L.) increases with increasing yield potential in south-western Australia

The response of chickpea (cv. Tyson) seed yield to sowing rate (30ñ180 kg/ha) was examined in 18 field experiments across three years in south-western Australia. The economic optimum plant density was estimated at each site and the point where the cost of extra seed equalled the return from additional seed yield was calculated, allowing a 10% opportunity cost for the extra investment. When averaged across all sites and seasons, plant densities varied from 14 plants/m^2 when sown at 30 kg/ha, to 84 plants/m^2 when sown at 180 kg/ha. Therefore, only about 54% of seeds sown established into viable plants, even though the germination test of the seed was about 80%. The poor establishment rate is thought to be mainly due to physical damage to the seed during transport and sowing, as well as unfavourable seedbed moisture and temperature conditions. At most experimental sites the seed yield of desi chickpea responded positively to an increase in sowing rate up to about 120 kg/ha. Increased yields at high sowing rate can be directly attributed to large plant populations. Although in many cases the number of pods per plant, seed size, and harvest index were reduced at high plant populations, increased plant density compensated for these effects and seed yield tended to increase. There was a good relationship between economic optimum plant density and yield potential derived in this study and this improves the ability of desi chickpea producers to select the most profitable sowing rate, depending upon their yield potential. These results suggest that the optimum plant density is 50 plants/m^2 for most chickpea crops in south-western Australia yielding about 1.0 t/ha, whereas in high-yielding situations (>1.5 t/ha), plant densities >70 plants/m^2 produce the most profit. Although not observed in these experiments, high plant densities can exacerbate fungal diseases, and hence, reduced plant densities are desirable in disease-prone situations. Differences in sowing rate responses may be expected between Tyson and new large-seeded cultivars such as Heera and Sona, which have longer branches and more open canopy, or kabuli types, and this deserves further investigation. [32]

3.4.1 Calculating seed requirements/sowing rate

Seeding rate for the target plant density can be calculated using germination percentage, 100 seed weight and establishment percentage (Figure 15).

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

32 Jettner, R. J., Loss, S. P., Siddique, K. H. M., & French, R. J. (1999). Optimum plant density of desi chickpea (Cicer arietinum L.) increases with increasing yield potential in south-western Australia. Crop and Pasture Science, 50(6), 1017–1026.

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

Example

100 seed weight = 21 grams

Target plant density = 25 plants/m² (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 15: *Seeding rate calculation – desi chickpea example.*

Source: Pulse Australia

3.5 Targeted plant population and row spacing

As part of an overall farming system, there is a move towards using row spacing configurations with chickpeas wider than the standard 15–25 cm [33] (Table 7).

Sowing at 30–50 cm spacing is becoming common. There was a need to look at the effect of row spacing under situations of high yield potential, with current varieties and newer agronomic practices.

The research shows that new varieties have a lower rate of yield decline at wider row spacing than older varieties. Researchers recommend the following rules of thumb when sowing within the optimum window of mid-May–mid-June under conditions of high yield potential:

- For yield potential ≥2.0 t/ha, sow on narrow rows (≤40 cm).
- For yield potential ≤2.0 t/ha, row spacing has less of an impact on yield.
- When sowing very late, sow on narrow rows at adequate plant density.
- When sowing very early, sow on wider rows to reduce early soil water extraction. [34]

Some innovators are sowing in 50–100 cm row spacing and using inter-row spraying for weed control. Wider rows require adequate stubble presence to minimise soil evaporative losses and viruses. Weed control must be considered too. Standing stubble and wider rows improve chickpea harvestability and may have advantages in:

- low yielding or lower rainfall situations, or
- when dense canopies would otherwise reduce pod set and potentially lead to Botrytis grey mould.

Fitting the farming system is the important issue. Disadvantages are normally more than offset by the advantages offered by machinery access and zero or minimum tillage systems with stubble retention. [35] The advantage of row-cropping chickpea outweigh any potential yield reductions as no-till weed control methods can be applied and may be the difference between farmers electing to no-till or continue to cultivate their fallow. [36]

33 Felton, W. L., Marcellos, H., & Murison, R. D. (1996, January). The effect of row spacing and seeding rate on chickpea yield in northern New South Wales. In Proceedings of the 8th Australian Agronomy Conference. Queensland, Australia: The Australian Society of Agronomy (pp. 250–253).

34 A Verrell (2013) Row placement strategies in a break crop wheat sequence. GRDC Update Papers 26 Feb 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Row-placement-strategies-in-a-break-crop-wheat-sequence

35 Pulse Australia. Southern Pulse Bulletin PA 2010 #05—Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

36 Felton, W. L., Marcellos, H., & Murison, R. D. (1996, January). The effect of row spacing and seeding rate on chickpea yield in northern New South Wales. In Proceedings of the 8th Australian Agronomy Conference. Queensland, Australia: The Australian Society of Agronomy (pp. 250–253).

Table 7: *The effects of row spacing on grain yield in various chickpea trials.*

Crop	Row spacing (cm)	Grain yield (kg/ha)	Source
Chickpea	18	2480	Beech and Leach 1988
	36	2620	
	53	2520	
	71	2490	
	18	690	
	36	890	
	53	850	
	71	740	
Kabuli chickpea	18	933	Kleeman and Gill 2010
	36	900	
	54	883	
Desi chickpea	18	1601	
	36	1383	
	54	1117	
Kabuli chickpea	22.5 (stubble removed)	1300	Hart Trial Cropping Results 2009
	45 (stubble removed)	1270	
	22.5 (standing stubble)	1350	
	45 (standing stubble)	1270	

Source: GRDC

Chickpeas are successfully grown using a wide range of planting equipment and row spacings ranging from 18 cm to 1 metre. Stubble retention, preferably standing stubble, is essential with wide rows.

The recent trend is toward an increasingly higher proportion of crops (in the northern region) being grown in either:

- wide rows of 0.5–1.0 metres.
- controlled traffic layouts with a modified 'broadacre' configuration.

3.5.1 Wide rows (50–100 cm) offer:

- Greater ability to plant into heavy stubble cover. Zero tillage systems have shown a consistent 10–15% yield advantage over cultivated systems.
- Precision planters often provide more accurate seed placement, resulting in better establishment and more even plant stands. This often results in more even crop maturity.
- Improved harvestability due to plants being more erect, with a higher pod set as a result of 'within row' plant competition (Figure 16). This is particularly important in low yielding situations.
- In low yield situations, crops planted on wide rows often 'feed in' better over the knife section of the header due to the concentration of growth within the row.
- Reduced input costs through band-spraying of insecticides and defoliants.
- Relatively cheaper weed control using glyphosate through shielded spraying equipment.

- Easier access and 'marking' for ground spraying pesticides and desiccants in permanent controlled traffic (CT) lanes.
- Better yields under severe moisture stress conditions attributed to the combination of wide-rows and heavy stubble cover than narrow rows configurations (Figure 17).
- Easier access to the crop when checking for pests such as *Helicoverpa*.
- Improved air circulation in the crop, which lowers humidity levels and can reduce the severity of foliar fungal diseases.
- Allows interow cultivation and 'directed' herbicide sprays e.g. Broadstrike®.

Figure 16: *Wide row pulses held erect on standing stubble for harvest.*

Source: Pulse Australia

Figure 17: *Chickpeas planted 1 June on a full moisture profile at 65 kg/ha on 800 mm row spacing and showing good growth despite cold conditions.*

Source: Farmnet

3.5.2 Narrow rows (15–40 cm) offer:

- Potential yield advantage at yields levels above 1.5 t/ha. Any yield advantage is often negated however, by the inability to maintain a zero-till system when planting on narrow row spacings.

MORE INFORMATION

Wide rows and stubble retention

- Relatively fewer lodging problems in high yield situations.
- Suits conventional wheat planting equipment. [37]

IN FOCUS

Yield response of kabuli and desi chickpea (Cicer arietinum L.) genotypes to row spacing in southern Australia

A field experiment was undertaken to investigate the response of kabuli (three varieties) and desi (three varieties) chickpea genotypes to row spacing (RS) (18, 36 and 54 cm). The response of chickpeas to RS was related to the branching habit of the genotype. Among kabuli genotypes Almaz⒟, which had a lower branch number per plant, showed greater yield loss at the wider row spacing than Genesis 079 and Genesis 090, which had greater branch number. All three desi genotypes showed similar sensitivity to widening row spacing. In the three desi cultivars, grain yield decreased by 4–21% as RS increased from 18–36 cm and by 17–36% at 54 cm RS. Grain yield of desi genotypes was correlated to podding (r2=0.60–0.69) and branch number (r2=0.62–0.75). Of the kabuli types, there was a strong correlation between pod number and grain yield for Almaz⒟ (r2=0.70) with seed number per pod and seed size stable across all genotypes. Although Genesis kabuli genotypes showed lower yield potential (694–1158 kg ha^{-1}) than desi genotypes (1036–1636 kg ha^{-1}), they were less sensitive to widening row spacing which could be related to their greater branching capacity and appear better suited to wide row cropping systems in southern Australia. [38]

3.6 Row placement

A break crop (pulse or oilseed) following a wheat crop should be sown between the standing stubble rows. In the next year, the wheat crop should be sown directly over the previous season's break crop row. Then in the next year of the rotation, the break crop should be shifted back and be sown between the standing wheat rows. Finally, in the fifth year, the wheat crop again should be sown directly over the previous year's break crop row.

There are two simple rules that need to be followed:

1. Sow break crops between standing wheat rows, which need to be kept intact.
2. Sow the following wheat crop directly over the row of the previous year's break crop.

Following these two rules will ensure the following:

- that four years elapse between wheat crops being sown in the same row space
- substantial reduction in the incidence of crown rot in wheat crops
- improved germination of break crops, especially canola, not hindered by stubble
- benefit to chickpeas from standing stubble, reducing the impact of virus infections
- better protection to break-crop seedlings from standing wheat stubble. [39]

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

38 Kleemann, S., & Gill, G. Yield response of kabuli and desi chickpea (Cicer arietinum L.) genotypes to row spacing in southern Australia. Genesis, 79, 0–10.

39 A Verrell (2013) Row placement strategies in a break crop wheat sequence. GRDC Update Papers 26 Feb 2013, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Row-placement-strategies-in-a-break-crop-wheat-sequence

3.6.1 Row orientation

Every grain grower has seen how well weeds grow when they have a blocked seeding tube creating extra-wide row spacing. Instinctively, we all know how important crop competition is for good weed management. The competitive ability of cereal crops can be increased by orientating crop rows at a right angle to the sun light direction; i.e. sow crops in an east-west direction. East-west crops more effectively shade weeds in the inter-row space than north-south crops. The shaded weeds have reduced biomass and seed set. The advantage of this technique is that it's free!

East-west crop orientation

The competitive ability of cereal crops can be increased by orientating crop rows at a right angle to the sun light direction; i.e. sow crops in an east-west direction. East-west crops more effectively shade weeds in the inter-row space than north-south crops. The shaded weeds have reduced biomass production and reduced seed set. In particularly weedy fields, the reduced weed growth leads to increased crop yield.

Altering the orientation of a broadleaf crop has less impact on weed growth. This is because broadleaf plants will alter the angle of their leaves over the course of the day to 'track' the sun as it moves across the sky. Therefore, as the leaves of the broadleaf crop move to catch the most sunlight, they cast less shade over the inter-row space.

In paddocks with a high weed burden, crop orientation has a significant impact of crop and weed growth. Trials at Merredin and Beverley Western Australia (WA) (2002-2005) indicated that weed biomass was reduced by 51% in wheat crops and 37% in barley crops, when crops were sown in an east-west rather than north-south orientation. Grain yield increased by 25% in wheat and 17% in barley crops. When the weed burden is low (due to herbicides use) the impact of crop orientation on grain yield and weed biomass may not be apparent. However, there is still a significant reduction in weed seed production. Trials at Merredin, Katanning and Wongan Hills WA (2010-2011) indicated that annual ryegrass seed production in east-west wheat and barley crops was halved (Table 8). Annual ryegrass in east-west crops produced an average of 2977 seeds per square metre (seeds/m^2), compared to the 5691 seeds/m^2 in north-south crops. The only exception was Katanning 2010 where annual ryegrass emerged two weeks after the crop, ensuring that the crop was highly competitive regardless of crop orientation.

Table 8: *Annual ryegrass seed production/m^2 in east-west and north-south orientated crops, at six trials in WA. Seed production was reduced in east-west crops in five out of six trial sites.*

Year	Location	Annual ryegrass seeds/m^2 in east-west crops	Annual ryegrass seeds/m^2 in north-south crops
2010	Merredin	503	911
	Wongan Hills	24	300
	Katanning	529	465
2011	Merredin	27	125
	Wongan Hills	2610	6155
	Katanning	14113	26276

Consider the weed species in the field. Broadleaf weeds can alter the angle of their leaves to 'track' the sun throughout the day. So while a crop can shade broadleaf weeds, the weeds will still be able to get maximum benefit from any sunlight that reaches them through the crop canopy. Further, any weeds that grow taller than the crop will not be effectively shaded by the crop canopy.

Consider the layout of the paddock. It may not be possible to sow a paddock in an east-west direction, depending of the shape of individual fields.

Consider the location of the paddock. The sun angle in winter is highest at the equator (where the sun is close to being directly overhead at midday). Sun angle becomes lower south of the equator. A low sun angle in winter will cause an east-west crop to cast shade on the inter-row space for a great proportion of the day. Therefore, a crop orientation will have a greater impact in southern Australia, compared to northern Australia.

Using an east-west orientation may be more practical with auto-steer. Without auto-steer, driving directly into the sunrise/sunset for seeding/spraying/harvest of an east-west crop will be unpleasant and potentially dangerous.

Increased shading by an east-west crop reduces the soil surface temperature in the inter-row space and reduces evaporation, leading to increased soil moisture. This increased moisture occasionally increases crop yield where moisture is limited. However, the cool, moist environment of the inter-row space may influence the development of crop disease in some locations (although altered levels of disease were not noted in previous trials). [40]

3.7 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. Chickpeas have hypogeal emergence where their cotyledons remain where the seed is sown while only the shoot emerges from the soil surface.

Chickpea seed is best sown into friable soil, with direct drilling often possible following a cereal crop. Good depth and adequate seed-to-soil contact is required and the large seed size of chickpeas assists in this regard.

Deeper sowing depths are used when the top soil layer is dry or where greater ‘depth’ protection is needed from residual herbicides used on the soil surface. However, deeper sowing can result in greater soil disturbance and delayed crop emergence although it helps to reduce lodging of the crop. [41]

Sow chickpeas 5–7 cm deep into good moisture. The seedlings are robust, provided high quality seed is used. The agronomic advantages of sowing at 5–7 cm include:

- reduced risk of damage from pre-emergent residual herbicides such as simazine, Balance® etc.
- improved early formation of lateral roots in the top soil
- enhanced inoculum survival in moist soil
- a significant proportion of ascochyta-infected seed is eliminated due to high mortality of diseased seed

Avoid sowing deeper than 5 cm on soils prone to surface sealing and crusting.

Press-wheels can improve establishment, although heavy pressures should be avoided. V shaped press-wheels will leave a furrow down the planting line that can lead to a concentration of residual herbicides in the furrow after rainfall and subsequent crop damage. [42]

It is generally recommended that chickpea seed should be sown 5–7 cm deep into moist soil. The preferred depth when using Balance® or simazine herbicides is 7 cm.

Sowing poor quality seed too deeply, into cold and/or wet soils, hard setting (crusting) soils and with some PSPE herbicides can reduce the ability of the germinating seedling to quickly reach the soil surface, which increases the seedling’s susceptibility to both soil and seed-borne pathogens, and soil-borne insect pests.

40 C Borger. (2016). East-west orientation for improved crop competition. DAFWA. https://www.agric.wa.gov.au/grains-research-development/east-west-orientation-improved-crop-competition

41 http://www.regional.org.au/au/asa/2012/crop-production/8197_haighb.htm

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

Moisture seeking strategies (i.e. planting at a depth of 10–15 cm below the soil surface) should be avoided for all weather damaged or low vigour seed. [43]

One study showed that lodging increased with shallower (5 cm vs. 10 cm) sowing depth on grey clay soil. [44]

IN FOCUS

Sowing Depth for Chickpea, Faba Bean and Lentil in a Mediterranean-type Environment of South-western Australia

Pulses such as chickpea, faba bean and lentil have hypogeal emergence and their cotyledons remain where the seed is sown, while only the shoot emerges from the soil surface. The effect of three sowing depths (2.5, 5 and 10 cm) on the growth and yield of these pulses was studied at three locations across three seasons in the cropping regions of south-western Australia, with a Mediterranean-type environment. There was no effect of sowing depth on crop phenology, nodulation or dry matter production for any species (Table 9). Mean seed yields across sites ranged from 810 to 2073 kg ha−1 for chickpea, 817–3381 kg ha−1 for faba bean, and 1173–2024 kg ha−1 for lentil. In general, deep sowing did not reduce seed yields, and in some instances, seed yield was greater at the deeper sowings for chickpea and faba bean (Figure 18). We conclude that the optimum sowing depth for chickpea and faba bean is 5–8 cm, and for lentil 4–6 cm. Sowing at depth may also improve crop establishment where moisture from summer and autumn rainfall is stored in the subsoil below 5 cm, by reducing damage from herbicides applied immediately before or after sowing, and by improving the survival of rhizobium inoculated on the seed due to more favourable soil conditions at depth. [45]

Table 9: *Time from sowing to emergence in days after sowing, nodulation score (0=none, 5=crown nodulation) and dry matter production at approximately flowering (g m^{-2}) of chickpea at Merredin and Northam in 1995.* [46]

Seeding depth (cm)	Days to emergence		Nodulation score		Dry matter production	
	Merredin	Northam	Merredin	Northam	Merredin	Northam
2.5	19	25	2.6	2.4	182	-
5	19	25	2.5	2.0	183	-
10	19	25	2.4	2.2	180	-
l.s.d. (P<0.05)	-	-	0.6	0.66	82.2	-

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

44 B Haigh, G McMullen. (2012). The Influence of planting date, sowing depth and soil type on chickpea production with no-tillage in northern New South Wales. http://www.regional.org.au/au/asa/2012/crop-production/8197_haighb.htm

45 Siddique, K. H. M., & Loss, S. P. (1999). Studies on sowing depth for chickpea (Cicer arietinum L.), faba bean (Vicia faba L.) and lentil (Lens culinaris Medik) in a Mediterranean-type environment of South-western Australia. Journal of Agronomy and Crop Science, 182(2), 105-112.

46 Siddique, K. H. M., & Loss, S. P. (1999). Studies on sowing depth for chickpea (Cicer arietinum L.), faba bean (Vicia faba L.) and lentil (Lens culinaris Medik) in a Mediterranean-type environment of South-western Australia. Journal of Agronomy and Crop Science, 182(2), 105-112.

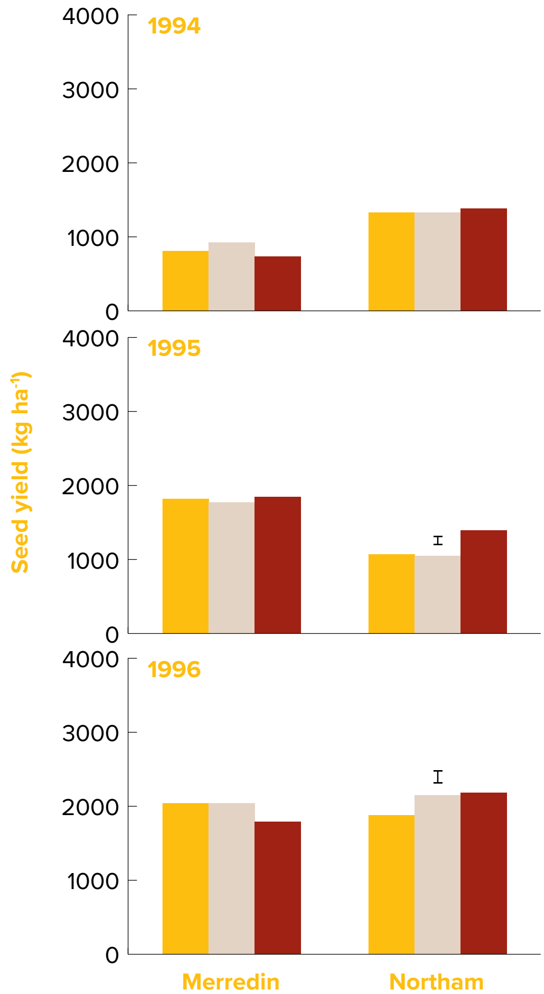

Figure 18: *Seed yield of chickpea sown at 2.5 cm (yellow), 5.0 cm (grey) and 10.0 cm (red) at Merredin and Northam in 1994, 1995, and 1996. Vertical bars denote l.s.d. (P= 0.05) where differences are significant.*

3.7.1 Deep seeding strategies

Deep planting has proven to be an extremely valuable risk management tool in many seasons. It has allowed chickpea to be planted in situations where winter crop planting rains have either been very late or have failed to eventuate altogether. In these conditions, a large proportion of the Australian chickpea crop is planted using deep-planting techniques. Crops are commonly planted at depths of 10–20 cm and this has often been the difference between achieving a reasonably profitable crop or no crop at all. Note that when deep planting, growers should use seed that show good vigour in seed testing.

Deep-planting is not only an extremely valuable tool under drought conditions, but can also offer major advantages in most years. It allows growers to plant chickpea at the optimum time for their district regardless of highly variable rainfall events. This maximises crop Water Use Efficiency, grain yield, crop height and profitability.

Critical issues that need to be addressed include:

- seed quality and vigour
- planter configuration and operation
- filling in the seed trench (furrow)
- harvestability of the crop

Chickpea seedling features

Field research and commercial experience have shown that chickpea has the ability to emerge through over 15 cm of soil cover.

The chickpea seedling has clearly shown that it has a superior ability to emerge from depth than most other grain crops. Research on alluvial clay soils demonstrated that chickpea was much better suited to deep-planting situations than wheat (cv Hartog).

Chickpea are different to most other pulses in that their cotyledons (seed storage organs) remain underground, with the seed sending up a narrow shoot to emerge through the soil. This hypogeal emergence allows chickpea to emerge from depths of over 15 cm with little or no reduction in emergence and seed yield. Research in WA and overseas has shown that deeper plantings can actually increase yields through:

- avoidance of residual herbicide damage
- improved nodulation
- better development of lateral roots near the soil surface.

The plant's capacity to emerge from depth clearly provides an opportunity for growers to use deep-planting methods to establish crops during the optimum sowing window. This can readily be achieved by varying planting depth from 5–20 cm according to seasonal conditions at the time.

Deep planting checklist

- **Plan ahead if you are considering deep-planting of chickpea.** Growers can use this technique in most years to ensure that they plant at the optimum time for chickpea in their district rather than relying on highly variable rainfall events. This is preferable to using deep planting as a last resort after planting rains fail to eventuate and the optimum planting window has already passed. **The key to deep planting is to make the decision early and sow on time.**
- **Exercise caution** when deep planting on hard setting or crust-prone soils.
- **Decide on the best combination of sowing point, press-wheel, and operational speed for your planter and soil type.** Be prepared to alter this combination depending on soil conditions at the time of planting. Speed is critical as it can have a major impact on depth control, as well as the amount of soil coverage over the seed.
- **Ensure you have high quality planting seed.** The deeper you plant, the greater the importance of using high quality planting seed. Check your germination percentage and seed counts (seeds/kg) and adjust seeding rates accordingly. Only use the highest quality seed when attempting deep planting. There are two additional seed tests that can be used to better determine seed quality.
- **The Accelerated Ageing (AA) Test.** This test is normally undertaken after harvest or well before planting and gives an indication of the seed vigour at planting time providing storage conditions are good. The value of this test is that seed showing poor vigour can be identified early and alternative actions can be taken. This test is highly recommended for seed that is likely to be deep sown. A germination test should also be done at the same time. If the results from the AA test are similar to the germination test then the seed has good vigour. If there is a significant difference between the two tests then advice on the interpretation of the test should be sought.
- **The Vigour or Soil Germination Test.** This test is recommended before planting and gives a guide to seed vigour in soil conditions at that time. The guidelines for interpreting the results of this test are the same as for the AA test above.

- **Increased weed pressure.** When deep planting under dry conditions, the first general winter rain will now fall in-crop and winter weeds will germinate on this in-crop rainfall.
  This places a lot more pressure on broadleaf and grass weed control as growers can no longer rely on a glyphosate spray at planting to tidy up winter weeds. Growers need to ensure that they have an appropriate weed strategy mapped out before planting.
- **Use fungicide treated seed.** As a precaution against the seed transmission of ascochyta blight.
- **Spray out fallow weeds prior to planting.** These can be difficult to control if moisture stressed and covered in dust (because of the dry conditions). Adjust herbicide rates and water volumes accordingly.
- **If you are using residual herbicides such as Balance® or simazine you will need to fill in the furrow (seed trench) prior to applying the herbicide.** If you cannot fill in the trench completely, then you should at least ensure you have 8–10 cm of soil coverage above the seed. Both these measures will ensure that the risk of herbicide damage after rain is minimised.
- **Avoid deep-planting into compacted wheel-tracks** as it usually results in variable depth control and poor seed coverage. Both are major contributors to patchy, uneven plant stands. Adopt the use of controlled-traffic systems wherever possible.
- **Decide on a planting depth that will ensure that all seeds are planted into moisture.** Thoroughly inspect seedbed moisture levels across paddocks and different soil types and ensure you plant into moisture. Experience indicates that you are better to err on the 'deeper side' rather than plant 'too shallow' into marginal moisture.
- **Ensure that the planter can maintain uniform depth control across the full width of the machine under normal operational speeds.** Poor or variable depth control will result in gappy, uneven plant stands.
- **Harvestability is a major issue.** Deep-planted crops can experience adverse, dry conditions where crop height and harvestability are significant problems.

The following management decisions can have a significant impact on harvestability of the crop:

- **Levelling of the soil surface at planting** Harvest losses of up to 50% have been reported in paddocks that were left unlevelled at planting, with mounds of dirt and stubble left either side of the furrow.
- **Choice of variety.** If harvestability is a major concern then consider planting a tall, upright variety that sets its pods higher up in the bush.
- **Planting time.** Planting during the recommended sowing window for your district will maximise plant height and harvestability.
- **Maintain plant populations of 20–25 established plants/square metre.** This will encourage a more upright growth habit and more even maturity.
- **Use wide-row spacings of 50–100 cm to encourage a taller, more erect plant.**

Deep planting method

The technique referred to as 'moisture seeking' has been used for over 20 years to plant cereals into stored fallow moisture without a planting rain. The practice usually requires the deliberate formation of a furrow or trench above the seed row because wheat and barley have relatively short coleoptiles, which limit the depth of soil they can successfully emerge through to approximately 8 cm.

This practice is referred to as 'deep-furrow planting' because the furrows are deliberately left intact at the completion of the planting operation.

Sweeps or 'shovels' may need to be mounted on the sowing tyne assemblies to help shift dry soil out of the furrow.

MORE INFORMATION

Chickpea: Deep Seeding strategies.

This technique of 'deep-furrow planting' is not suited to crops such as chickpea for two very good reasons:

- The short stature of the chickpea crop and the need to set the header front as close to the ground as possible
- The reliance on using pre-emergent, residual herbicides for broadleaf weed control. These herbicides can concentrate in the furrow after rain and cause considerable crop damage.

The more appropriate technique for chickpea is 'deep-planting' where growers fill in the furrow and level the soil surface after planting and rely on the chickpea plants' ability to emerge from depth to achieve crop establishment.

Levelling the soil surface considerably reduces the risk of herbicide residue damage and minimises harvest difficulties. [47]

3.8 Sowing equipment

There are few problems when sowing desi and most kabuli chickpeas with conventional seeding equipment, but occasionally cracking of seed may occur with the larger seeded kabuli types. [48]

Ensure that the seed handling equipment and seeder is not too aggressive on the seed (e.g. use shifters instead of augers and avoid high blower speeds in air seeders). [49]

Success with pulses may depend on the type of sowing equipment used. 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.

Kabuli chickpeas can be sown with a standard airseeder or conventional harvester but care should be taken, as seeds tend to bridge over the outlets, causing very uneven sowing. This difficulty can be eliminated by filling the box to only a third or a half capacity or by fitting an agitator.

3.8.1 Seeders

Harvesters with fluted roller feeds have few problems feeding seed of <15 mm down to the metering chamber. Harvesters with peg roller and seed wheel feeds will seed grains up to the size of kabuli chickpeas without problems, provided adequate clearances are used around the rollers. Harvesters with internal force-feed seed meters perform well on small seeds but cannot sow seed >9 mm because of bridging at the throat leading to the seed meter. The restricted internal clearance in this type of design can damage larger seeds.

47 Pulse Australia. Chickpea: Deep seeding strategies. Australian Pulse bulletin.

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

49 Pulse Australia. Southern Pulse Bulletin PA 2010 #05 – Chickpea checklist for southern growers. http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Chickpea-checklist-south.pdf

3.8.2 Airseeders

Airseeders that use peg-roller metering systems will handle grain up to the size of smaller faba beans without problems because of the banked metering arrangement. The optional rubber star roller will be necessary for larger seeds. Airseeders using metering belt systems can meter large seed at high rates with few problems. 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. Figure 19 shows a standard secondary distributor head (on the left) and a conversion to suit Connor Shea airseeders. The conversion head increased the bore from 23–41 mm. Four larger hoses replace the original eight, and row spacings are increased from 150–300 mm. This conversion allows large seeds such as kabuli chickpea or beans to be sown easily. Consult the dealer about possible modifications. Significant levels of seed damage can be caused in airseeders by excessive air pressure, so be careful to use only enough air to ensure reliable operation.

Figure 19: *Conversion heads, such as this one for a Connor-Shea airseeder, allow large seeds such as broad beans, faba beans and kabuli chickpeas to be sown with ease.*

Source: Grain Legume Handbook, 2008

3.8.3 Seeder and tyne comparisons

In the establishment of all crops, especially pulses, there are several key functional or mechanical issues with respect to seeding equipment, which should:

- Have an adequate seeding mechanism to handle the pulse seed without damaging it, especially when larger seeded types are being sown.
- Have adequate sizes of seed and fertiliser tubes and boots to prevent seed blockages and bridging during sowing.
- Sow into stubbles and residues, without blockages.
- Have sufficient down-pressure to penetrate the soil, sow at the desirable depth and place all seeds at a uniform depth.
- Cover the seeds to ensure good seed-to-soil contact and high moisture vapour, which will promote rapid germination.

- Compact the soil as required, by press-wheels or closers (Figure 20) (otherwise, a prickle chain or roller is required afterwards for many pulses).
- Disturb the soil to the extent required, which means none in no-till with disc sowing. It may also mean having sufficient soil throw to incorporate herbicides like trifluralin. This can be achieved by using either aggressive discs or narrow point set-ups in no-till, or full disturbance in more conventional or direct-drill systems.

Inability to get adequate plant establishment is one of the bigger problems faced by pulse growers. This can lead to a multitude of problems later. Many different seeding mechanisms or openers are now available to pulse growers. Narrow points are widely used in minimum-till or no-till systems, but many different points can be used. Likewise, with disc seeders, many different types are now available, and they differ greatly in their soil disturbance and soil throw, as well as their ability to handle trash and sticky conditions.

Figure 20: *One of several seeding mechanisms for uniform sowing depth using the press wheel for depth control.*

A comparison of the key functions that are critical for seed drills and no-till is shown in Table 10.

In interpreting the functions listed in Table 10 it should be noted that:

- With tynes, the slot created is different depending on the type of tyne used. Some create a vertical slot, others a 'V, while the inverted 'T' (or 'baker boot') leaves a slot with a narrow entrance and wider trench underneath (Figure 21). These tynes do perform differently in some functions in Table 10.
- Residues need to be handled in all conditions, not just when dry.
- Hairpins' (stubble is pressed into the slot) needs to be avoided by not creating them or by placing seeds away from them. Note that tynes rarely make hairpins.
- Vertical slots are hard to self-close.
- Ability for openers to follow ground-surface variation is critical for uniform depth of sowing (Figure 22).
- Springs cannot apply consistent down force on openers throughout a range of soil conditions.

- Banding of fertiliser away from the seed is important for crop establishment, particularly when high rates or high-analysis products are applied and the seed is in a narrow opening slot.
- Tynes handle stones, but bring them up, hence requiring rolling to press them back again.

Table 10: *Comparison scores (rating basis: 1, poor; 5 excellent) of no-till openers by function (after Baker 2010) Note that this table is a broad guide only. Scores given in this table are subjective and may vary with individual openers, etc. You may wish to use your own scores for each function and not count those not relevant to your situation.*

	Narrow point	Wide point	Sweep	Double disc	Single disc	Slanted disc	Combined winged tine & disc[B]
Ability to mechanically handle heavy residues without blockage	2	1	1	4	4	4	5
Leave 70%+ of original residue in place after drill has passed	3	2	2	5	4	4	5
Trap moisture vapour in the seeding slot in dry soils using residues as slot cover	3	2	3	1	2	4	5
Avoid placing seeds in 'hairpins'	5	5	5	1	2	2	5
Maximise in-slot aeration in wet soils[A]	3	4	3	1	3	3	5
Avoid in-slot soil compaction or smearing in wet soils[A]	1	1	3	1	5	5	5
Maximise soil-seed contact, even in greasy or 'plastic' conditions	4	3	4	3	3	4	5
Self-close the seeding slots	2	1	3	2	3	4	5
Mitigate slot shrinkage when soils dry out after sowing[A]	3	5	5	1	2	4	5
Individual openers faithfully follow ground surface variations	2	1	2	2	4	2	5
Individual openers have a larger than normal range of vertical travel	2	1	1	2	2	1	5
Maintain consistent down force on individual openers	3	1	1	2	3	3	5
Openers seed accurately at shallow depths[A]	2	1	1	2	2	1	5
Opener down force auto-adjusts to changing soil hardness	1	1	1	1	1	1	5
Simultaneously band fertiliser with, but separate from, the seed	5	5	5	1	2	3	5
Ensure that fertiliser banding is effective with high analysis fertilisers	5	5	51	1	1	2	5
Be able to handle sticky soils[A]	5	5	4	1	3	3	2
Be able to handle stony soils[A]	4	3	1	4	4	2	4
Avoid bringing stones to the surface[A]	1	1	1	5	5	3	5
Functionality unaffected by hillsides[A]	5	5	4	5	2	1	5
Minimal adjustments required when moving between soil conditions	3	3	3	4	1	1	5
Ability to maintain most critical functions at higher speeds of sowing	3	1	1	4	3	3	5
Wear components are self-adjusting	5	5	5	3	2	2	5
Design life of machine matches that of the tractors that pull it	4	4	4	2	2	2	5
Low wear rate of soil-engaging components	5	4	4	2	3	3	3

	Narrow point	Wide point	Sweep	Double disc	Single disc	Slanted disc	Combined winged tine & disc[B]
Wear components, including bearings, are cheap and easily replaced	5	5	4	2	2	2	4
Requires minimal draft from tractor	4	3	2	5	4	3	3
Proven, positive impact on crop yield	3	2	2	1	3	4	5
Total score (maximum = 140)	**93**	**80**	**80**	**68**	**77**	**76**	**131**
Rating score as % of maximum possible	**66**	**57**	**57**	**49**	**55**	**54**	**94**

In Table 10, neither pure-disc nor pure-tyne openers rate highly over all functions using this scoring. Disc openers rated lowest (49–55%), and of the tynes (57–66%), narrow points were the best (66%). The combination of winged tyne and disc, known as the Bio Blade or Cross SlotTM, had the highest score (94%). It allegedly combines the best attributes of pure disc openers with the best attributes of pure tyne openers, and adds some unique features of its own. Its weaknesses were its lesser ability to handle 'sticky' soils, its horsepower requirement and its wear rate of soil-engaging components.

Use Table 10 as a guide only to help select your own openers to suit your conditions and circumstances.

Figure 21: *A Primary Precision Seeder fitted with hydraulic breakout for consistent penetration. It is also fitted with narrow points that form an 'inverted T' slot and is capable of deep or side placement of fertiliser.*

Figure 22: *The DBS system parallelogram for uniform seeding depth and deep placement of seed or fertiliser.*

The seeding mechanism of the seeder must be able to handle pulses, which are larger seeded than cereals and oilseeds. Hoses, distributor heads and boots must also be able to handle pulses without blockages or bridging. This is especially true for larger seeded types such as kabuli chickpeas or faba and broad beans (Figure 23).

Figure 23: *Bio Blade or Cross slotTM disc opener with opening disc and seeding tine, followed by paired press wheels. Note that the seed and fertiliser tube has sharp bends and may not be wide enough to avoid blockages when larger seeded pulses like faba or broad beans are being sown.*

Table 10 does not list as a function deep working to assist in rhizoctonia control. This was a weakness of early disc drills compared with narrow points with deep openers. Many newer discs are addressing this issue, including using opening coulters and rippled discs (Figure 24).

Figure 24: *A Case IH SDX-40 single-disc drill.*

Plant growth and physiology

Key messages

- Under optimum moisture and temperature conditions, chickpea seeds imbibe water quickly and germinate within a few days, providing temperatures are >0°C.
- Emergence occurs 7–30 days after sowing, depending on soil moisture and temperature conditions and depth of sowing.
- Flowering is invariably delayed under low temperatures but more branching occurs.
- Chickpea in its reproductive stage is sensitive to heat stress (20°C or higher as day/night temperatures) with consequent substantial loss of potential yields at high temperatures. In Australia, drought stress often accompanies high temperatures in spring, causing the abortion of flowers, immature pods and developing seeds.
- Chickpea is a photoperiod sensitive, long-day plant, where flowering is delayed as day length becomes shorter than a base photoperiod (17 h).
- Starting soil water can have a strong influence on the yield expectation of chickpea as well as the riskiness of production.

Chickpea, being a legume, belongs to the botanical family of *Fabaceae*, subfamily *Faboideae*. It is a semi-erect annual with a deep taproot. Worldwide, two main types of chickpea, Desi and Kabuli are cultivated. Kabuli types, grown in temperate regions, are large-seeded and mainly consumed as a whole seed, whereas Desi types, grown in semiarid tropical and subtropical regions, are mainly consumed as split dhal or turned into flour. Chickpea seed contains about 20% protein, 5% fat and 55% carbohydrates.

The phenology of most crops can be described using nine phases:

1. Sowing to germination
2. Germination to emergence
3. A period of vegetative growth after emergence, called the basic vegetative phase (BVP), during which the plant is unresponsive to photoperiod
4. A photoperiod-induced phase (PIP), which ends at floral initiation
5. A flower development phase (FDP), which ends at 50% flowering
6. A lag phase prior to commencement of grainfilling (in chickpea this period can be very long, up to two months in some cases, under cool temperature conditions (<15°C), which inhibit pod set and pod growth)
7. A linear phase of grainfilling
8. A period between the end of grainfilling and physiological maturity
9. A harvest-ripe period prior to grain harvest.

These stages of development are generally modelled as functions of temperature (phases 1–8) and photoperiod (phase 4).

Chickpea is a medium-duration crop, usually beginning flowering within 90–110 days of planting, depending on photoperiod and temperature (Figure 1). Chickpea is a photoperiod sensitive, long-day plant, where flowering is delayed as day length becomes shorter than a base photoperiod (17 h). [1]

1 W Parker. DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

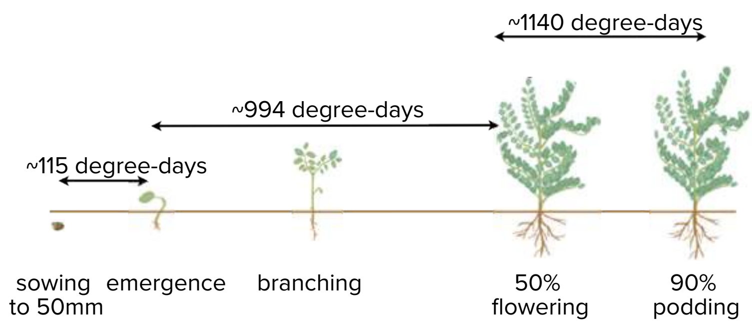

Figure 1: *Key developmental stages of chickpea and their thermal time targets.*

Source: J. Whish, CSIRO

4.1 Germination and emergence issues

4.1.1 Germination

Good germination and seedling emergence are important prerequisites for a successful crop, and soil and air temperature is one of the key factors affecting seed germination. Under optimum moisture and temperature conditions, chickpea seeds imbibe water quickly and germinate within a few days, providing temperatures are >0°C. Chickpeas will not germinate in soils with temperatures below 0°C.

Generally, the longer a germinating seed of a sensitive species is exposed to a chilling temperature, the greater the injury it will sustain. Desi types generally suffer less damage from low temperatures at germination than kabuli types. Visual symptoms of chilling injury at the seedling stage can include the inhibition of seedling growth, accumulation of anthocyanin pigments, waterlogged appearance with browning of mesocotyls, and the browning and desiccation of coleoptiles and undeveloped leaves. The main effects of chilling range temperatures on the developing seedling are related to membrane injury and include reduced respiration and photosynthesis and loss of turgor, resulting in wilting and cold-induced water stress. Exposure to chilling range temperatures during early growth of established seedlings can exert macroscopic formative effects on leaf shape and size, plant height, root development, and floral initiation. [2]

Chickpea germination is hypogeal, with the cotyledons remaining below the soil surface (Figure 2). This enables it to emerge from sowing as deep as 15 cm. In arid regions, chickpea is sown deep as surface moisture is often inadequate to allow sufficient crop establishment. [3]

2 JS Croser,,HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

3 Pulse Australia. Chickpea Production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

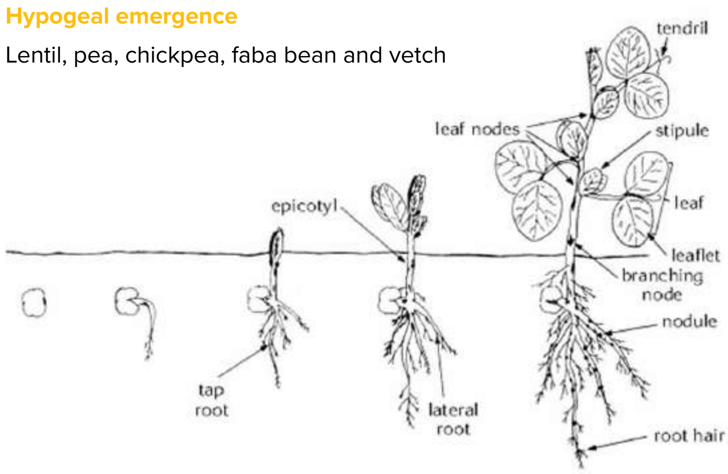

Figure 2: *Hypogeal emergence of chickpea seedlings makes the plant less prone to environmental stress and damage in the early growth stages.*

Source: Pulse Australia

One of the environmental constraints for the germination is the temperature, that can negatively affect the seed germination. The optimum temperature for maximum final germination is between 10 and 15°C. Low temperatures are a major constraint for improving the yield of chickpea in numerous regions of the world.

In one study, all chickpea seeds were able to germinate on a wide thermal range (15–35°C). However, the thermal optimum was approximately 20–25°C with 80 to 100% of seeds germinated within 7 days between 10 and 30°C. [4]

Salinity is one of the major stresses, especially in arid and semiarid regions, which severely limit crop production. Salinity impairs seed germination, reduces nodule formation, retards plant development and reduces crop yield. Salinity affects germination and physiology of crops due to; the toxic effect of ions on the viability of embryos, and by altering osmotic potential, preventing water uptake. [5]

One study found that small seeds germinated and grew more rapidly compared to medium and large seeds under salt stress. The study also found that although there was no effect of NaCl treatments on frequency of germination, there was a drastic decrease in early seedling growth under increased NaCl concentrations (12.7 and 16.3 dS/m). [6]

4.1.2 Emergence

Emergence occurs 7–30 days after sowing, depending on soil moisture and temperature conditions and depth of sowing. Growth of the shoot produces an erect shoot and the first leaves are scales. The first true leaf has two or three pairs of leaflets plus a terminal one. Fully formed leaves with 5–8 pairs of leaflets usually develop after the sixth node.

The node from which the first branch arises on the main stem above the soil is counted as node one. In chickpeas, alternate primary branches usually originate from nodes just above ground level (usually one to eight primary branches on the main

4 N Sleimi, I Bankaji, H Touchan, F Corbineau (2013) Effects of temperature and water stresses on germination of some varieties of chickpea (Cicer arietinum). African Journal of Biotechnology, 12(17).

5 TH Haileselasie, G Teferii (2012) The effect of salinity stress on germination of chickpea (Cicer arietinum L.) land race of Tigray. Current Research Journal of Biological Sciences, 4(5), 578–583.

6 M Kaya, G Kaya, MD Kaya, M Atak, S Saglam, KM Khawar, CY Ciftci (2008) Interaction between seed size and NaCl on germination and early seedling growth of some Turkish cultivars of chickpea (Cicer arietinum L.). Journal of Zhejiang University SCIENCE B, 9(5), 371–377.

stem, depending on growing conditions). A node is counted as developed when 6–15 leaflets have unfolded and flattened out (Figure 3). [7]

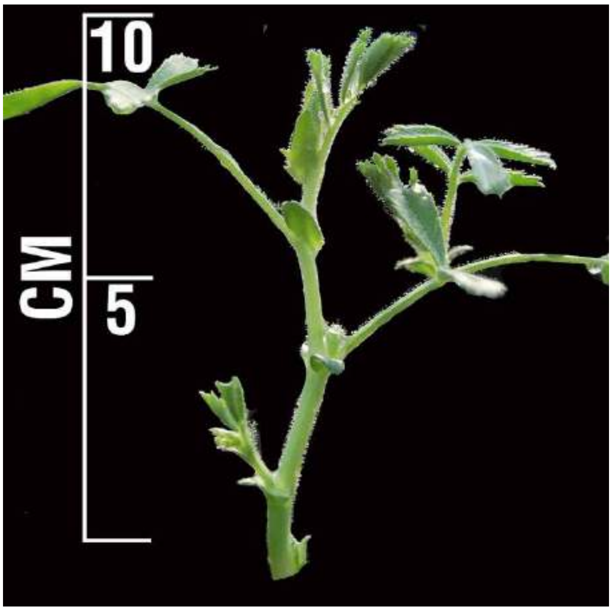

Figure 3: *Chickpea plant with four branches at 8 cm tall.*

IN FOCUS

Effect of Soil Moisture Content on Seedling Emergence and Early Growth of Some Chickpea Genotypes in WA.

Soil water content at sowing is an important determinant of chickpea seed emergence and early growth.

A controlled glasshouse investigation at day/night temperatures of 22/15°C based at Perth City, Western Australia was performed in 2006 to assess the influence of different soil moisture contents (field capacity percentage basis) on emergence, as well as early plant growth in 20 chickpea genotypes. The experiment was laid out in split plot design with soil moisture content as the main treatment and genotype as sub-treatment. Significant differences ($P < 0.001$) regarding plant emergence and early growth were observed among different soil moisture contents (100, 75, 50 and 25% field capacity) (Figure 4 and Table 1). This brought about a reduction in average emergence percentage (86.4% in 75% moisture treatment and 56.5% in 25% moisture treatment), delayed the first day to emergence and suppressed the early growth in all the chickpea genotypes.

Highly significant differences were also noticed among the genotypes for mean emergence percentage, first day to emergence, plant height, leaf area, total aboveground biomass (plant size) as well as specific leaf area. An inverse relationship between first day to emergence with plant height and aboveground biomass was observed; indicating that the chickpea genotypes that emerged sooner produced greater plant size. Seed size and density were found to have no relationship with plant size. Kabuli types on average germinated faster and produced larger plants than the Desi types under limited soil moisture content conditions. Susceptibility of the genotypes to limited soil moisture condition was shown through relatively

7 Pulse Australia. Chickpea Production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

longer delays in time to emergence (lower germination rate) and reduction in seedling parameters as compared to the resistant genotypes. Final average aboveground biomass (plant size) and plant height under limited soil moisture content condition, as opposed to adequate moisture level (25% vs. 100%), were reduced 79–85% in kabuli and 77–79% in desi types, respectively. [8]

Figure 4: *Effect of soil moisture content (% field capacity basis) on germination rate (averaged over replications and genotypes).* [9]

Table 1: *Mean soil moisture effects on chickpea genotypes characteristics (averaged over genotypes and replications).* [10]

Soil moisture (%)	Emer-gence (%)	Time to emer-gence	Plant height (cm)	Branch no. per plant	Leaf area cm^2	Above-ground biomass (g $plant^{-1}$)	Specific leaf areas (cm^2 g^{-1})
100	78.4	3.8	20.2	4.5	102.6	0.98	178
75	86.4	6.2	19	4.4	81.8	0.83	164.8
50	83.7	7.9	14.4	3.5	41.6	0.54	131.3
25	56.5	13.9	3.7	1	2.5	0.21	37.3
l.s.d. (P = 0.05)	10.8	1.06	2.3	0.4	23.3	0.2	11.4

For more information on the effects of drought stress, see Section 14: Environmental issues.

8 N Majnoun Hosseini, KHM Siddique, JA Palta, J Berger (2009) Effect of soil moisture content on seedling emergence and early growth of some chickpea (Cicer arietinum L.) genotypes. Journal of Agricultural Science and Technology, 11, 401–411.

9 N Majnoun Hosseini, KHM Siddique, JA Palta, J Berger (2009) Effect of soil moisture content on seedling emergence and early growth of some chickpea (Cicer arietinum L.) genotypes. Journal of Agricultural Science and Technology, 11, 401–411.

10 N Majnoun Hosseini, KHM Siddique, JA Palta, J Berger (2009) Effect of soil moisture content on seedling emergence and early growth of some chickpea (Cicer arietinum L.) genotypes. Journal of Agricultural Science and Technology, 11, 401–411.

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

During their growth, crop plants are usually exposed to different environmental stresses that limit their growth and productivity.

Figure 5 shows crop biomass is driven by:

- The capacity of roots to capture water and nutrients, chiefly nitrogen and phosphorus (black arrow in Figure 5);
- the capacity of canopies to capture radiation and carbon dioxide used in photosynthesis (green arrow in Figure 5);
- the efficiency of the crop to transform resources (water, nutrients, radiation, carbon dioxide) into dry matter (red arrow in Figure 5).

Crop growth and yield depends on the ability of crops to capture above ground and soil resources, and on the capacity of crops to transform these resources into biomass. Environmental factors, such as ambient temperature or soil salinity, modulate the rate of capture of resources and the efficiency of the transformation of resources into plant biomass. The dashed lines in Figure 5 illustrate these. [11]

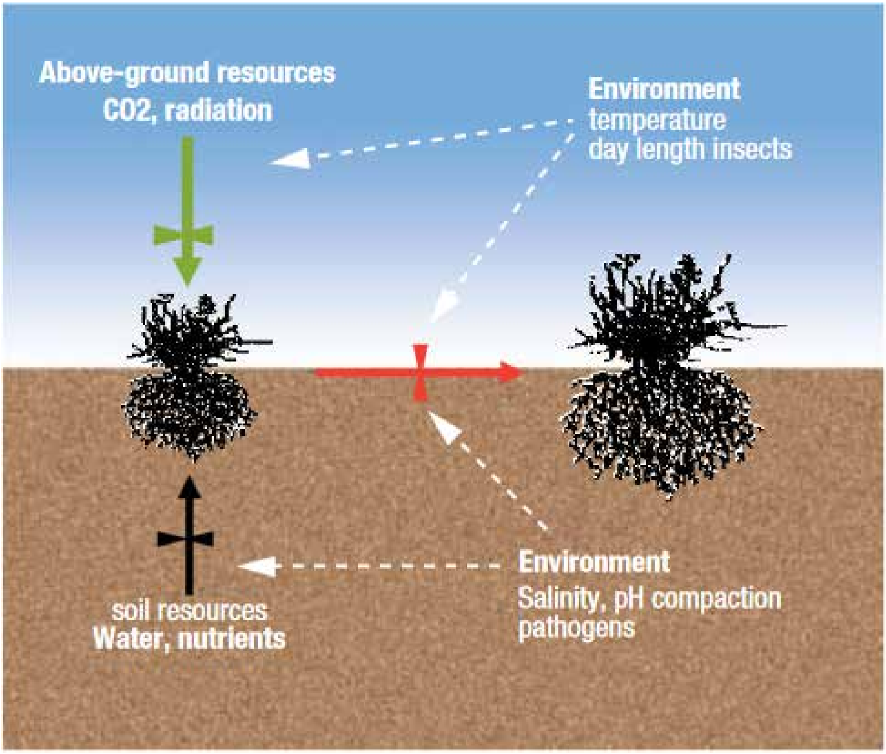

Figure 5: *Factors that drive crop biomass.*

Source: GRDC

Temperature, day length and drought are the three major factors affecting flowering in chickpea. Temperature is generally more important than day length.

4.2.1 Temperature

The timing of flowering is an important trait affecting the adaptation of crops to low rainfall, Mediterranean-type environments (such as the south-west of Western Australia). Seed yields of many crops in these areas have been increased by early sowing and the development of early flowering varieties.

11 V Sandras, G McDonald (2012) Water Use Efficiency of grain crops in Australia: principles, benchmarks and management. GRDC.

Cold temperatures

Air temperature and photoperiod have a major influence on the timing of reproductive events in chickpea, with the rate of progress to flowering being a linear function of mean temperature. Flowering is invariably delayed under low temperatures, but more branching occurs. [12]

Crop duration is highly correlated with temperature, such that crops will take different times from sowing to maturity under different temperature regimes. Unlike other cool season legumes, Chickpea is very susceptible to cold conditions, especially at flowering. Any advantage derived from early flowering is often negated by increased flower and pod abortion. Experiments have shown that the average day/night temperature is critical for flowering and pod set, rather than any specific effects of maximum or minimum temperatures. Pods at a later stage of development are generally more resistant to frost than flowers and small pods, but may suffer some mottled darkening of the seed coat. The critical mean or average daily temperature for abortion of flowers in most current varieties is <15°C. Abortion occurs below this temperature because the pollen becomes sterile and reproductive structures do not develop. Flowers may develop below this temperature but they contain infertile pollen. [13]

In many chickpea crops, it is not until temperatures rise in late August and September that pod set and seed filling commence. When temperatures rise, true flowers develop within 3–4 days. Even after the production of true flowers, periods of low temperature may result in further flower and pod abortion at intermittent nodes on the stems.

Pollen germination and vigour is also affected by chilling range temperatures. [14] Sub-zero temperatures in winter and spring can damage leaves and stems of the plant. Frosts can cause bleaching of leaves, especially on the margins, and a characteristic 'hockey stick' bend in the stem (Figure 6). However, chickpea has an excellent ability to recover from this superficial damage and is able to regenerate new branches in severe cases.

Figure 6: *Frost can cause bends like a hockey stick in chickpea stems.*

Photo: S. Loss, DAFWA

12 Pulse Australia. Chickpea Production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

13 Pulse Australia. Chickpea Production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

14 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

Late frosts also cause flower, pod and seed abortion (Figure 7). Pods at a later stage of development are generally more resistant to frost than flowers and small pods, but may suffer some mottled darkening of the seed coat.

Figure 7: *Frost can cause pod abortion (usually low on the stem) but the plant may set many pods late in the season if conditions are favourable.*

Photo: T. Knights, NSW DPI

NOTE: The impacts of low air temperatures will be moderated by topography and altitude; i.e. there will be warmer and cooler areas in undulating country.

For more information, see Section 14: Environmental issues.

Heat stress

Chickpea in its reproductive stage is sensitive to heat stress (32/20°C or higher as day/night temperatures) with potentially major yield loss under high temperatures. Temperatures over 35°C in spring may also reduce yield in chickpea, causing flower abortion and a reduction in the time available for seed filling. Chickpea, however, is considered more heat tolerant than many other cool season grain legumes. The anthers of heat sensitive genotypes have been found to reduce synthesis of sugars due to inhibition of the appropriate enzymes. Consequently, effected plant pollen can have considerably lower sucrose levels resulting in reduced pollen function, impaired fertilisation and poor pod set in the heat sensitive genotypes. [15]

In Australia, drought stress often accompanies high temperatures in spring, causing the abortion of flowers, immature pods and developing seeds. On the other hand, high levels of humidity and low light also prevent pod set.

Chickpea pollen grains are more sensitive to heat stress than the stigma. High temperatures have been found to reduce pollen production per flower, amount of pollen germination, pod set and seed number. [16]

High air temperatures during the period from flowering to maturity have also been found to reduce the time to maturity of late-sown chickpea and lead to reduced seed size and lower yields. [17]

15 N Kaushal, R Awasthi, K Gupta, P Gaur, KH Siddique, H Nayyar (2013) Heat-stress-induced reproductive failures in chickpea (Cicer arietinum) are associated with impaired sucrose metabolism in leaves and anthers. Functional Plant Biology, 40(12), 1,334–1,349.

16 V Devasirvatham, PM Gaur, N Mallikarjuna, RN Tokachichu, RM Trethowan, DK Tan (2012) Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. Functional Plant Biology, 39(12), 1,009–1,018.

17 MVK Sivakumar, P Singh, P. (1987) Response of chickpea cultivars to water stress in a semi-arid environment. Experimental agriculture, 23(01), 53–61.

Chickpea can tolerate high temperatures if there is adequate soil moisture, and it is usually one of the last grain legume crops to mature in Mediterranean-type environments.

For more information, see Section 14: Environmental issues.

4.2.2 Photoperiod

Photoperiod is one of the major environmental factors determining time to flower initiation and first flower appearance in plants. In chickpea, photoperiod sensitivity (expressed as delayed to flower under short days (SD) as compared to long days (LD)) may change with the growth stage of the crop. Chickpea is a photoperiod sensitive, long-day plant, where flowering is delayed as day length becomes shorter than a base photoperiod (17 hours). Progress towards flowering is rapid during long days (17+ hours) and flowering is delayed but never prevented under short-day (<17 hours) conditions. [18]

IN FOCUS

Determination of Photoperiod-Sensitive Phase in Chickpea (Cicer arietinum L.).

Eight chickpea cultivars with differing degrees of photoperiod sensitivity were grown in two separate chambers, one of which was adjusted to long-day (LD, 16 h light/8 h dark) and the other adjusted to short-day (SD, 10 h light/14 h dark) with temperatures of 22/16°C (12 h light/12 h dark) in both chambers. The cultivars included were day-neutral, intermediate, and photoperiod-sensitive. Control plants were grown continuously under the respective photoperiods. Reciprocal transfers of plants between the SD and LD photoperiod treatments were made at seven time points after sowing, customised for each accession based on previous data. Photoperiod sensitivity was detected in intermediate and photoperiod-sensitive cultivars. For one day-neutral cultivar, there was no significant difference in the number of days to flowering of the plants grown under SD and LD as well as subsequent transfers. In photoperiod-sensitive cultivars, three different phenological phases were identified: a photoperiod-insensitive pre-inductive phase, a photoperiod-sensitive inductive phase, and a photoperiod-insensitive post-inductive phase. The photoperiod-sensitive phase extends from after flower initiation to full flower development. Results from this research will help to develop cultivars with shorter pre-inductive photoperiod-insensitive and photoperiod-sensitive phases to fit to regions with short growing seasons. [19]

4.2.3 Water and moisture

About 90% of chickpea in the world is grown under rainfed conditions where drought is one of the major constraints, limiting its production. Drought affects various morphological and physiological processes, resulting in reduced growth, development and economic yield of crop. Water stress has prominent effect on leaf number, total leaf area and secondary branches causing invariable reduction under rainfed conditions. Several studies have shown that optimum yield can be obtained by irrigation at branching, flowering and pod formation stages.

18 Pulse Australia. Chickpea Production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

19 K Daba, TD Warkentin, R Bueckert, CD Todd, B Tar'an (2016) Determination of Photoperiod-Sensitive Phase in Chickpea (Cicer arietinum L.). Frontiers in plant science, 7.

Reactions of plants to water stress vary depending upon intensity and duration of stress as well as plant species and stage of growth. Stress during vegetative phase reduces grain yield through reducing plant size, restricting leaf area, dry matter accumulation and limiting the number of pods. However, water deficits at the flowering and the post-flowering stages have been found to have greater adverse impact than at the vegetative stage. [20]

Starting soil water can have a strong influence on the yield expectation of chickpea as well as the riskiness of production.

Yields are best in areas with reliable winter rainfall for crop growth and mild spring conditions during seed filling. Chickpea is well suited to well-drained, non-acidic soils with medium to heavy clay texture. [21]

Soon after the development of pods and seed filling, senescence of subtending leaves begins. If there is plenty of soil moisture and maximum temperatures are favourable for chickpea growth, flowering and podding will continue on the upper nodes. However, as soil moisture is depleted, flowering ceases and eventually the whole plant matures. This is typical of grain legumes and annual plants in general.

Research has indicated that unlike other winter pulses under mild moisture stress, Chickpea is capable of accumulating solutes (sugar, proteins and other compounds) in their cells, thereby maintaining stomatal conductance and low levels of photosynthesis. This process is known as osmoregulation.

Chickpeas can access moisture to 90 cm depth provided there is no compaction or saline or sodic layers in the soil profile.

IN FOCUS

Growth and yield in chickpea genotypes in response to water stress.

Twenty chickpea genotypes were grown under rainout shelter to investigate the influence of water stress treatments imposed at varied growth stages: T1, Control; T2, one pre-sowing irrigation; T3, withholding irrigation at flower-initiation; T4, withholding irrigation at pod-initiation stage. The plant height, branches, dry weight of stem, leaves and root plant, leaf area, leaf area index were recorded at 120 days after sowing (DAS). The results showed significant variation with water stress at varied growth stages. The maximum reduction in height and branches was observed when irrigation was restricted at T2 stage. Restricted irrigation decreased the biomass of stem, leaves and roots leading to reduced leaf area and leaf area index as well. The yield traits 100 seed weight, total number of pods, percentage filled pods were reduced significantly under stress. The grain yield under restricted conditions was reduced by 40.50% to 55.91% over irrigated control in T4 to T2, respectively. [22]

For more information, see Section 14: Environmental Issues.

20 N Randhawa, J Kaur, S Singh, I Singh (2014) Growth and yield in chickpea (Cicer arietinum L.) genotypes in response to water stress. African Journal of Agricultural Research, 9(11), 982–992.

21 Pulse Australia. Chickpea Production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

22 N Randhawa, J Kaur, S Singh, I Singh (2014) Growth and yield in chickpea (Cicer arietinum L.) genotypes in response to water stress. African Journal of Agricultural Research, 9(11), 982–992.

4.3 Plant growth stages

The chickpea crop germinates, matures, senesces, and dies within 100 to 225 days from sowing, depending on environmental conditions before and after flowering, the magnitude of seed yield, and the rate and synchrony of seed filling (Figure 8). [23]

Figure 8: *Chickpea growth and development from germination to two months. Plants may vary according to variety and environment.*

Photo: H. Clarke, UWA

The chickpea plant is erect and freestanding, usually 15–60 cm in height, although well-grown plants may grow to 80 cm. The plants have a fibrous taproot system, a number of woody stems forming from the base, upper secondary branches and fine, frond-like leaves. Chickpea is considered very indeterminate in their growth habit, i.e. their terminal bud is always vegetative and keeps growing, even after the plant switches to reproductive mode and flowering begins. [24]

The chickpea growth stages key is based on counting the number of nodes on the main stem (Table 2). Uniform growth stage descriptions were developed for the chickpea plant based on visually observable vegetative (V) and reproductive (R) events. The V stage was determined by counting the number of developed nodes on the main stem, above ground level. The last (uppermost) node counted must have its leaves unfolded. The R stages begin when the plant begins to flower at any node.

Table 2: *Growth stages of a chickpea plant (Nolan 2001).*

Designation	Growth stage	Description
Vegetative growth stage (V-stage) in chickpeas		
VG	Germination	Cotyledons remain underground inside the seed coat and provide energy for rapidly growing primary roots (radicle) and shoots
VE	Emergence	The plumule emerges and the first two leaves are scales. The first true leaf has two or three pairs of leaflets plus a terminal leaflet

23 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

24 Pulse Australia. Chickpea Production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

Designation	Growth stage	Description
V1	First node	Imparipinnate (terminal unpaired) leaves attached to the first node are fully expanded and flat while the 1st imparipinnate leaf attached to the upper node starts to unroll
V2	Second node	1st imparipinnate leaf attached to the second node is fully expanded and flat while the 2nd imparipinnate leaf on the upper node starts to unroll
V3	Third node	2nd imparipinnate leaf attached to the third node is fully expanded and flat while the 3rd imparipinnate leaf on the upper node starts to unroll. The bulk of the yield is found on the branches stemming from the first three nodes
V(n)	N-node	A node is counted when its imparipinnate leaf is unfolded and its leaflets are flat
Reproductive growth stage (R-stage) in chickpea		
R0	False flowering	In the transition from vegetative to include reproductive growth, a number of false flowers (called pseudo flowers) may develop from the axillary buds. These flower buds lack fully developed petals and typically appear if flowering is triggered before mean temperatures are high enough for true flowers to develop, especially if soil has high moisture content coinciding with flowering, which enables it develop a bigger canopy
R1	Start flowering	One flower bud at any node on the main stem (see p. 5 in 'The chickpea book', Loss et al. 1988)
R2	Calyx opening	Bud grows but is still sterile, sepals begin to form
R3	Anthesis	Pollination occurs before the bud opens
R4	Wings extend	Flower petals extend to form a flower
R5	Corolla collapses	Flower collapses and petals senesce and peduncle reflexes so that the developing pod usually hangs below its subtending leaf
R6	Pod initiation	One pod is found on any node on the main stem
R7	Full pod	One fully expanded pod is present that satisfies the dimensions characteristic of the cultivar
R8	Beginning seed	One fully expanded pod is present in which seed cotyledon growth is visible when the fruit is cut in cross-section with a razor blade. (Following the liquid endosperm stage)
R9	Full seed	One pod with cavity apparently filled by the seeds when fresh
R10	Beginning maturity	One pod on the main stem turns to a light golden-yellow in colour
R11	50% golden pod	50% of pods on the plant mature
R12	90% golden pod	90% of pods physiologically mature (golden yellow), usually about 140–200 days after planting depending on season and cultivar

For populations, vegetative stages can be averaged if desired. Reproductive stages should not be averaged.

A reproductive stage should remain unchanged until 50% of the plants in the sample demonstrate the desired trait of the next reproductive (R) stage. The timing of a reproductive stage for a given plant is set by the first occurrence of the specific trait on the plant, without regard to position on the plant (Figure 9). [25]

Figure 9: *Growth habit of a chickpea plant.*

4.3.1 Leaves

Leaves in chickpea are alternate along the branch (Figure 10). The first true leaf has two or three pairs of leaflets plus a terminal one. Fully formed leaves, with 5–8 pairs of serrated leaflets (10–16 leaflets), usually develop after the sixth branch (node) stage. Leaflets can fold slightly in dry conditions to minimise transpiration. Despite having more leaves and branches than other legume crops such as faba bean, canopy development in chickpea is slow, especially during the cool winter months.

25 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

Figure 10: *Alternate leaves along the branch, with multiple leaflets on each leaf.*

Photo: G. Cumming, Pulse Australia

The entire surface of the plant shoot, except the flower, has a thick covering of glandular hairs (trichomes) that secrete a strong acid (mostly malic acid), particularly during pod set (Figure 11). The malic secretions from all vegetative surfaces of the plant seem to play a role in protecting the plant against pests such as red-legged earth mite, lucerne flea, aphids and pod borers. Similar substances are also secreted from the root system and can solubilise soil-bound phosphate and other nutrients. The acid also corrodes leather boots.

Figure 11: *A green pod covered in glandular hairs excreting acid.*

Photo: H. Clarke, UWA

4.3.2 Roots

Chickpea root systems are usually deep and strong, and contribute to the plant's ability to withstand dry conditions. The plant has a taproot with few lateral roots. Root growth is most rapid before flowering but will continue until maturity under favourable conditions. Although rare, in deep well-structured soils, roots can penetrate more than 1 m deep (Figure 12); however subsoil constraints such as soil chloride >800 mg/kg soil in the top 60 cm will restrict root growth and water availability.

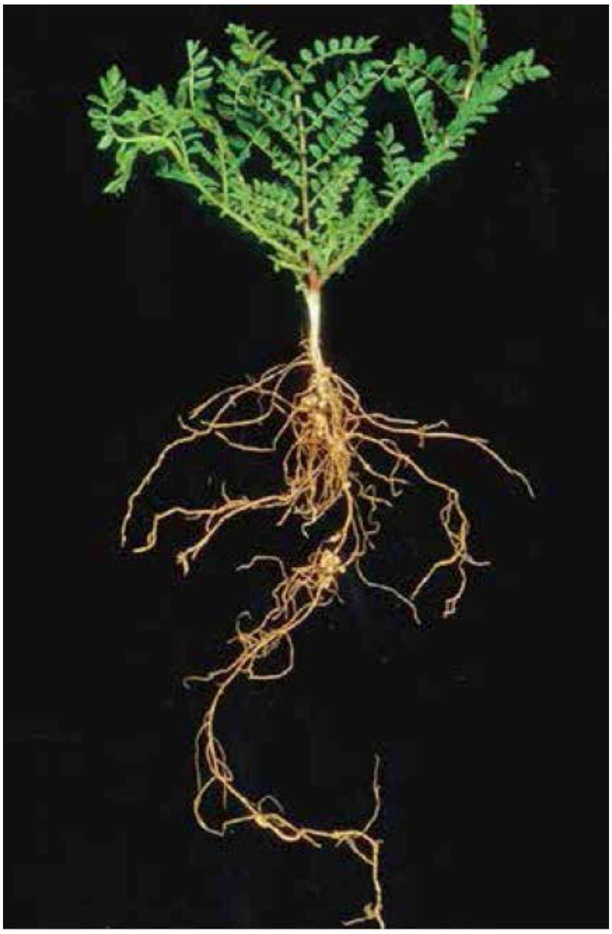

Figure 12: *Chickpea usually has a deep tap root system.*

Photo: P. Maloney, DAFWA

As well as their role in water and nutrient uptake, chickpea roots develop symbiotic nodules with the *Rhizobium* bacteria, capable of fixing atmospheric nitrogen. The plant provides carbohydrates for the bacteria in return for nitrogen fixed inside the nodules. Chickpea plants can derive more than 70% of their nitrogen requirement from symbiotic nitrogen fixation.

These nodules become visible within about a month of plant emergence, and eventually form slightly flattened, fan-like lobes (Figure 13). Practically all nodules are confined to the top 30 cm of soil and 90% are within the top 15 cm of the profile. When cut open, nodules actively fixing nitrogen have a pink centre. Nitrogen fixation is highly sensitive to waterlogging so it is essential that chickpea crops are grown on well-aerated and drained soils. [26]

26 Pulse Australia. Chickpea Production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

Figure 13: *Well-nodulated chickpea plants.*

Photo: G. Cumming, Pulse Australia

4.3.3 Branches

Primary branches, starting from ground level, grow from buds at the lowest nodes of the plumular shoot as well as the lateral branches of the seedling. These branches are thick, strong and woody, and they determine the general appearance of the plant (Figure 14). The main stem and branches can attain a height of about 40–100 cm. Kabuli varieties are generally taller than Desi varieties.

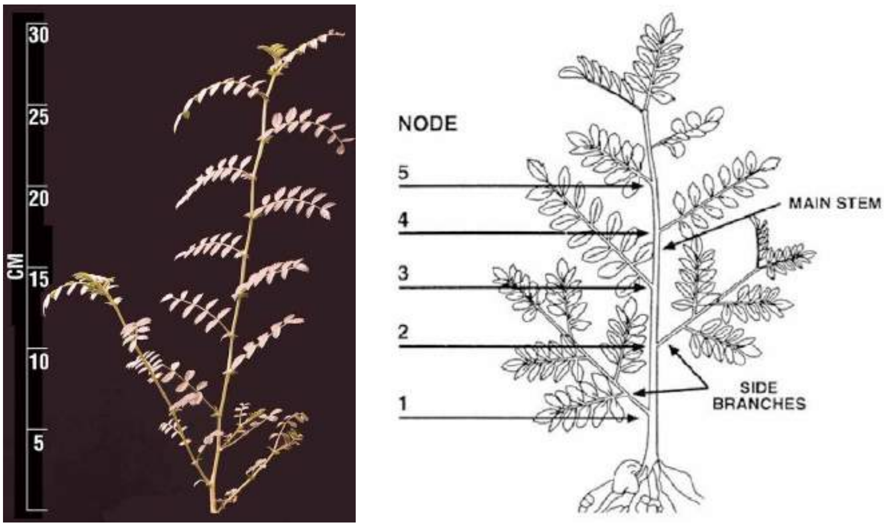

Figure 14: *Chickpea at the 5–7-node stage of development, prior to flowering.*

Secondary branches are produced by buds on the primary branches. They are less vigorous but contribute to a major proportion of the plant yield. Tertiary branches growing from buds on secondary branches are more leafy and carry fewer pods. The number of primary branches can vary from one to eight depending upon the variety and growing conditions. In chickpea, five branching habits based on angle of branches from the vertical are classified: erect, semi-erect, semi-spreading, spreading and prostate. Most modern varieties are erect or semi-erect, to enable mechanical harvesting. The final height of the plant is highly dependent on environmental conditions and the variety being grown, but in general range from 50 to 100 cm. [27]

4.3.4 Flowering

Growth in chickpea is often described as 'indeterminate'. This means that branch and leaf (or vegetative) growth continues as the plant switches to a reproductive mode and initiates flowering. Hence, there is often a sequence of leaf, flower bud, flower and pod development along each branch (Figure 15).

The onset and duration of flowering in chickpea are functions of genotype, photoperiod, and temperature. Flowering is indeterminate and can extend for up to 60 days with leaf initiation and stem elongation continuing into the reproductive period. [28]

Figure 15: *Different stages of flower development on the same chickpea branch.*

Photo: K. Siddique, DAFWA

Chickpea is peculiar among pulses in that a number of pseudo-flowers or false flower buds develop during the changeover from leaf buds to flower buds on the stem. Therefore, there could be a period of ineffective flowering when pod set does not occur.

In warmer tropical and subtropical environments this period is minimal, but in cooler temperate–subtropical environments, it can be as long as 50 days. Flowering commences on the main stem and lower branches and proceeds acropetally at intervals averaging 1.5–2 days between successive nodes along each branch. The bulk of the yield is found on the branches stemming from the first three nodes.

The fruit develops in an inflated pod containing 2–4 ovules, of which one or two usually develop into seeds. At any location, seasonal variations in temperature can

27 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

28 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

bring about a significant shift in flowering times (i.e. ±10 days from the figures quoted below). In general, warmer temperatures hasten development.

Petals are generally purple in the Desi type and white to cream in the Kabuli type (Figure 16). Purple-flowered Desi types generally contain high amounts of the red pigment anthocyanin, and their leaves, stems and seed coats are generally dark. By contrast, the white-flowered Kabuli types lack anthocyanin, have light green leaves and stems, and pale seeds. Increased pigmentation is evident following environmental stresses such as low temperature, salinity, waterlogging, drought, and virus infection, especially in Desi types.

Figure 16: *Desi chickpea purple flower (left) and kabuli chickpea flower (right). Kabuli chickpea lack anthocyanin, hence their white flowers.*

Photos: G. Cumming, Pulse Australia

Pollination in chickpea takes place before the flower bud opens, when the pollen and the receptive female organ are still enclosed within a fused petal, called the keel. Natural cross-pollination has been reported, however most studies indicate 100% self-pollination.

Flower terminals normally develop from the axillary bud at the base of each node. Flowers are borne on a jointed peduncle that arises from nodes. Flowers are primarily self-pollinated.

Chickpea plants generally produce many flowers. However, around 30% do not develop into pods, depending upon the variety, sowing date and other environmental conditions.

4.3.5 Podding

Under favourable temperature and soil moisture conditions, the time taken from fertilisation of the ovule (egg) to the first appearance of a pod (pod set) is about six days (Figure 17). The seed then fills over the next 3–4 weeks (Figure 18). Once a pod has set, the jointed peduncle of the senescing petals reflexes, so that the developing pod hangs beneath its subtending leaf. After pod set, the pod wall grows rapidly for the first 10–15 days, with seed growth occurring later.

Figure 17: *Chickpea podding (left) and chickpea plant seven weeks before harvest (right).*

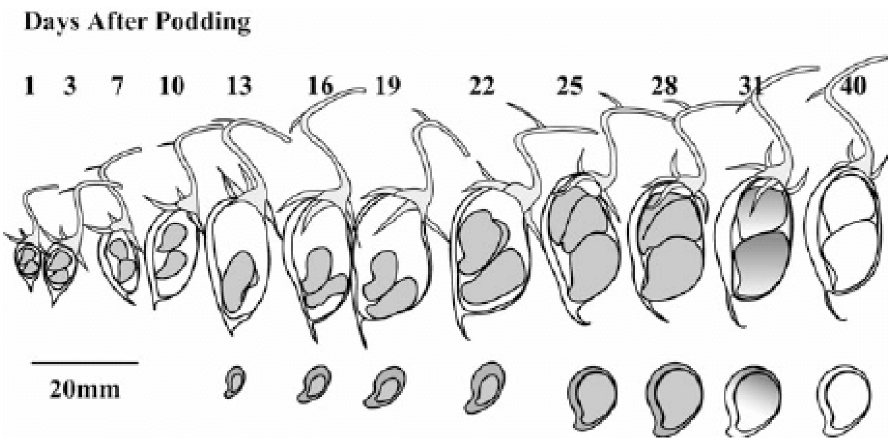

Figure 18: *Seed and pod development in chickpea showing the relative sizes of the pod, seed coat, embryo, and the internal pod gas volume.* [29]

Chickpea pods vary greatly in size between varieties. Pod size is largely unaffected by the environment. By contrast, seed filling and subsequent seed size are highly dependent on variety and weather conditions.

Seeds are characteristically 'beaked', sometimes angular, and with a ridged or smooth seed coat. Seed colour varies between varieties from chalky white to burgundy and brown, to black, and is determined by the colour and thickness of the seed coat and the colour of the cotyledons inside. Seeds vary from one to three per pod.

In southern Australia, chickpea crops can reach maturity 140–200 days after sowing, depending on the sowing date, variety, and a range of environmental factors including temperature. Chickpeas become ready to harvest when 90% of the stems and pods lose their green colour and become light golden yellow. At this point, the seeds are usually hard and rattle when the plant is shaken (Figure 19). [30]

29 RT Furbank, R White, JA Palta, NC Turner (2004) Internal recycling of respiratory CO_2 in pods of chickpea (Cicer arietinum L.): the role of pod wall, seed coat, and embryo. Journal of Experimental Botany, 55(403), 1,687–1,696.

30 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

Figure 19: *Physiologically mature grains 'rattle pod'.*

Photo: G. Cumming, Pulse Australia

Nutrition and fertiliser

Key messages

- Incorrect levels of nutrients (too little, too much or the wrong proportion) can cause plant growth problems.
- The main method to maintain or restore soil nutrients and help increase crop yields is applying mineral fertilisers such as nitrogen (N).
- A soil or plant tissue test will help to identify what nutrients are missing or in excess.
- Become familiar with plant and paddock symptoms of various nutritional deficiencies.
- If chickpea plants have effectively nodulated, they should not normally need N fertiliser.
- Molybdenum (Mo) and cobalt (Co) are required for effective nodulation and should be applied as needed. Foliar sprays of zinc and manganese may be needed where deficiencies of these micronutrients are a known problem, in particular in high-pH soil types.

Incorrect levels of nutrients (too little, too much or the wrong proportion) can cause plant growth problems. If the condition is extreme, plants will show visible symptoms that can sometimes be identified. Visual diagnostic symptoms are readily obtained, and provide an immediate evaluation of nutrient status. Visual symptoms do not develop until a major effect on yield, growth or development has occurred; therefore, damage can be done before there is visual evidence of it.

Healthy plants are more able to ward off disease, pests and environmental stresses and so achieve higher yield and better grain quality. [1] Ensuring adequate nutrition will assist the chickpea crop to generate dense uniform canopies, which deter aphids. [2]

The main method to maintain or restore soil nutrients and help increase crop yields is applying mineral fertilisers such as nitrogen (N) and phosphorus (P). [3]

The more attention we pay to all of the activities that contribute to nutrient management (Figure 1), the better the outcome we will get from soil and plant testing. Testing may not provide a useful contribution if one or more of these steps is not done well.

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

2 A Verrell (2103) Wirus in chickpea in northern NSW 2012. GRDC Update Papers 26 March 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Virus-in-chickpea-in-northern-NSW-2012

3 B Hirel, T Tétu, PJ Lea, F Dubois (2011) Improving nitrogen use efficiency in crops for sustainable agriculture. Sustainability, 3(9), 1,452–1,485.

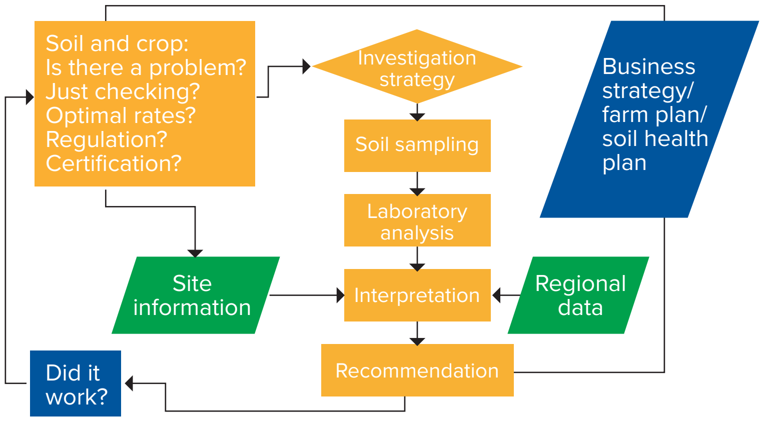

Figure 1: *Nutrient management flow chart.* [4]

5.1 Nutrient types

Plant nutrients are categorised as either macronutrients or micronutrients (also called trace elements). Macronutrients are those elements that are needed in relatively large amounts. They include nitrogen (N), phosphorus (P) and potassium (K), which are the primary macronutrients, with calcium (Ca), magnesium (Mg) and sulfur (S) considered as secondary. Higher expected yields of crops for grain or forage will place greater demand on the availability of major nutrients such as P, K and S. Nitrogen, P and at times S are the main nutrients commonly lacking in Australian soils. Others can be lacking under certain conditions. It should be noted that each pulse type is different, with different requirements for nutrients, and may display different symptoms of deficiency. A balance sheet approach to fertiliser inputs is often a good starting point when determining the amount and type (analysis) of fertiliser to apply. Other factors such as a soil test, paddock history, soil type and personal experience are useful. Tissue analysis can be helpful in identifying deficiencies once the crop is growing, and can assist in fine-tuning nutrient requirement even when deficiency symptoms are not visible. Micronutrients are those elements that plants need in small amounts, for example iron (Fe), boron (B), manganese (Mn), zinc (Zn), copper (Cu), chlorine (Cl) and molybdenum (Mo).

Both macro and micronutrients are taken up by roots, and certain soil conditions are required for that to occur. Soil must be sufficiently moist to allow roots to take up and transport the nutrients. Plants that are moisture stressed from either too little or too much moisture (waterlogging) can often exhibit deficiencies even though a soil test may show these nutrients to be adequate. Soil pH has an effect on the availability of most nutrients and must be within a particular range for nutrients to be released from soil particles. On acid soils, aluminium (Al) and Mn levels can increase and may restrict plant growth, usually by restricting the rhizobia and consequently the plant's ability to nodulate. Soil temperature must lie within a certain range for nutrient uptake to occur. Cold conditions can induce deficiencies of nutrients such as Zn or P. The optimum range of temperature, pH and moisture can vary for different pulse species. Thus, nutrients may be physically present in the soil, but not available to those particular plants. Knowledge of a soil's nutrient status (soil test) pH, texture, history and moisture status can be very useful for predicting which nutrients may become deficient. Tissue tests can help to confirm the plant nutrient status. [5]

4 GRDC (2013) Better fertiliser decisions for crop nutrition. GRDC Crop Nutrition Fact Sheet November 2013, http://grdc.com.au/Resources/Factsheets/2013/11/Better-fertiliser-decisions-for-crop-nutrition

5 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Effect of macro and micronutrients on grain yield in chickpea crops

Key findings:

- If any single nutrient is lacking or not adequately balanced with other nutrients, crop growth may be suppressed or inhibited.
- The application of macro and micronutrients to a crop that was both moisture and temperature stressed led to a reduction in yield. [6]

5.2 Crop removal rates

If the nutrients (P, N, Zn, etc.) removed as grain from the paddock are not replaced, crop yields and soil fertility may fall. This means that fertiliser inputs must be matched to expected yields and soil type. Often, the higher the expected yield, the higher the fertiliser input, particularly for the major nutrients P, K and S. The nutrient removal per tonne (t) of grain of the various pulses is shown in Table 1. Actual values may vary by 30%, or sometimes more, because of differences in soil fertility, varieties and seasons. From the table, a 2 t/ha crop of chickpeas will on average remove ~ 6.5 kg/ha of P. This amount of P will need to be replaced, unless soils are already high in P. Higher quantities may be needed to build up soil fertility or overcome soil fixation of P.

Table 1: *Nutrients removed by one tonne of chickpea grain.*

Chickpea	Kilograms (kg)					Grams (g)			
	N	P	K	S	Ca	Mg	Cu	Zn	Mn
Desi	33	3.2	9	2.0	1.6	1.4	7	34	34
Kabuli	36	3.4	9	2.0	1.0	1.2	8	33	22

Source: Pulse Australia

Soil types do vary in their nutrient reserves. For example, most black and red soils have sufficient reserves of K to grow many crops. However, the light, white sandy soils that, on soil tests have <50 µ g/g (ppm) (bicarbonate test) of K, may respond to applications of K fertiliser. Other soils may have substantial nutrient reserves that vary in availability during the growing season or are unavailable due to the soil pH. This can often be the case with micronutrients. Foliar sprays can be used in these cases to correct any micronutrient deficiencies. [7]

5.2.1 Nutrient budgeting

When grain is harvested from the paddock, nutrients 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. Nutrient budgeting is a simple way to calculate the balance between nutrient removal (via grain) and nutrient input (via fertiliser).

Table 2 uses standard grain nutrient analyses from Table 1. For a more accurate guide to nutrient removal, use analysis of grain grown on your farm. A more complete picture emerges when several years of a rotation are budgeted.

6 A Verrell & L Jenkins, GRDC (2015) Effect of macro and micro nutrients on grain yield in chickpea crops https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Effect-of-macro-and-micro-nutrients-on-grain-yield-in-chickpea-crops-at-Trangie-and-Coonamble

7 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Table 2: *An example of nutrient budgeting.* [8]

Year	Crop	Yield (t/ha)	Nutrients removed (kg/ha)			
			N	P	K	S
2006	Faba bean	2.2	90	8.8	22	3.3
2007	Wheat	3.8	87	11.4	15	5.7
2008	Barley	4.2	84	11.3	21	6.3
2009	Chickpea	1.8	59	5.8	16	3.6
		Total	320	37.3	74	18.9
Year	**Fertiliser**	**Rate (t/ha)**	**Nutrients applied (kg/ha)**			
			N	**P**	**K**	**S**
2006	0 : 20 :0 (NPK)	50	0	10	0	1
2007	18 : 20 :0 (NPK)	70	12.6	14	0	1
2008	18 : 20 :0 (NPK)	70	12.6	14	0	1
	Urea	60	27.6	0	0	0
2009	0 : 16 :0 :20 (NPK)	80	0	12.8	0	16
		Total	52.8	50.8	0	19
Balance			-267.2	+13.5	-74	0

As can be seen from the simple nutrient budget in Table 2, some interpretation is needed:

- Nitrogen: The deficit of 267 kg needs to be countered by any N fixation that occurred. This may have been 50 kg/ha per legume crop. It still shows that the N status of the soil is falling and that it should be increased by using more N in the cereal phase. Estimating N fixation is not easy. One rule to use is that 20 kg of N is fixed per tonne of plant dry matter at flowering.
- Phosphorus: The credit of 13 kg will be used by the soil in building P levels, hence increasing soil fertility. No account was made for soil fixation of P.
- Potassium: Some Australian cropping soils (usually white sandy soils) are showing responses to K, and applications should be considered to at least replace the K used by the crop. However, soils high in K may not need replacement in the short term.
- Sulfur: Crop removal of S may exceed inputs.

Other nutrients such as Zn and Cu can also be included in a nutrient-balancing exercise. This is a useful tool for assessing the nutrient balance of a cropping rotation; however, it needs to be considered in conjunction with other nutrient-management tools such as soil and tissue testing, soil type, soil fixation and potential yields. Because P is the basis of soil fertility and hence crop yields, all fertiliser programs are built on the amount of P needed. Table 3 shows the required P rates and the rates of various fertilisers needed to achieve this. Many fertilisers are available to use on pulses; for the best advice check with your local fertiliser reseller or agronomist.

8 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Table 3: *Fertiliser application rate ready-reckoner (all rates are kg/ha) for some of the fertilisers used on pulses.*

P	Single 8.6% P		Superphosphate Gold Phos 10 18% P		Triple 20% P		6:16:0:10 Legume Special			10:22:0 MAP		18:20:0 DAP		0:15:0:7 Grain Legume Super	
	Fert.	S	Fert.	S	Fert.	S	Fert.	N	S	Fert.	N	Fert.	N	Fert.	S
10	116	13	50	5	45	0.7	62	4	6	46	5	50	9	69	5
12	140	15	67	7	60	0.9	75	4	8	55	6	60	11	83	6
14	163	18	78	8	70	1.1	87	5	9	64	6	70	13	97	7
16	186	20	89	9	80	1.2	99	6	10	73	7	80	14	110	8
18	209	23	100	10	90	1.4	112	6	11	82	8	90	16	124	9
20	223	25	111	11	100	1.5	124	7	12	91	9	100	18	138	10
22	256	28	122	12	110	1.7	137	8	14	100	10	110	20	152	11
24	279	31	133	13	120	1.8	149	8	15	110	11	120	22	166	12

There is a trend towards using ‘starter’ fertilisers such as mono- and di-ammonium phosphate (MAP and DAP) on pulses. Some growers are concerned that using N on their pulse crop will affect nodulation. This is not the case with the low rates of N supplied by MAP or DAP. A benefit of using the starter N is that early plant vigour is often enhanced, and on low fertility soils, yield increases have been gained. [9]

5.3 Identifying nutrient deficiencies

Many nutrient deficiencies may look similar. To identify deficiencies:

- Know what a healthy plant looks like in order to recognise symptoms of distress.
- Determine what the affected areas of the crop look like. For example, are they discoloured (yellow, red, brown), dead (necrotic), wilted or stunted?
- Identify the pattern of symptoms in the field (patches, scattered plants, crop perimeters).
- Assess affected areas in relation to soil type (pH, colour, texture) or elevation.
- Look at individual plants for more detailed symptoms such as stunting, wilting and where the symptoms are appearing (whole plant, new leaves, old leaves, edge of leaf, veins etc.).

If more than one problem is present, typical visual symptoms may not occur. For example, water stress, disease or insect damage can mask a nutrient deficiency. If two nutrients are simultaneously deficient, symptoms may differ from the deficiency symptoms of the individual nutrients. Micronutrients are often used by plants to process other nutrients or work together with other nutrients, so a deficiency of one may look like deficiency of another. For instance, Mo is required by pulses to complete the process of N fixation. [10]

See sections below for specific symptoms of each nutrient deficiency.

5.3.1 Tests for nutrient deficiency

It is commonly believed that a soil or plant tissue test will show how much nutrient the plant requires. This is not so. A soil or plant tissue test will only help to identify what is missing or in excess. A soil test will only show whether at a certain soil concentration the plant is likely or unlikely to respond to that nutrient. These tests are specific for both soil type and plant being grown (Table 4).

9 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

10 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Experience suggests that the only worthwhile soil tests will be for P, K, organic matter, soil pH and soil salt levels. An S test has now been developed. Pulse crops can have different requirements for K, hence different soil test K critical levels.

Table 4: *Adequate levels for various soil test results.*

Nutrient	Test Used		
Phosphorus			
	Colwell	**Olsen**	
Sand	20-30	10-15	
Loam	25-35	12-17	
Clay	35-45	17-23	
Potassium			
	Bicarb.	**Skene**	**Exchangeable K**
Sand	50	50-100	Not applicable
Other soils	100	-	0.25 m.e/100 g
Sandy loam	-	-	-
Faba bean	100-120	-	-
Field pea	70-80	-	-
Lupin	30-40	-	-
Canola	40	-	-
Cereals	30	-	-
Sulfur			
	KCl		
Low	5µg/g (ppm)		
Adequate	8µg/g		

Source: Grain Legume Handbook 2008

5.4 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.
- Revised critical soil test values and ranges have been established for combinations of nutrients, crops and soil.
- A single database collated more than 1,892 trials from Western Australia for different crops.
- Nutrient sufficiency is indicated if the test value is above the critical range.
- Where the soil test falls below the critical range there is likely to be a crop yield response from added nutrients.
- Critical soil test ranges have been established for 0–10 cm and 0–30 cm of soil.
- Soil sampling to greater depth is considered important for more mobile nutrients (N, K and S) as well as for pH and salinity.
- Use local data and support services to help integrate critical soil test data into profitable fertiliser decisions.

Accurate soil tests allow small landholders to maximise the health of their soils and make sound decisions about fertiliser management to ensure crops and pastures are as productive as possible. Up-to-date critical soil test values will help improve test interpretation to inform better fertiliser decisions. Identifying potential soil limitations enables landholders to develop an action plan (such as an appropriate fertiliser program) to reduce the potential of 'problem' paddocks. [11]

In Western Australia, profitable grain production depends on applied fertiliser, particularly N, P, K S. Fertiliser is a major variable cost for grain growers. Crop nutrition is also a major determinant of profit. Both under and over fertilisation can lead to economic losses due to unrealised potential or wasted inputs.

Before deciding how much fertiliser to apply, it is important to understand the quantities of available nutrients in the soil and where they are located in the soil profile. It is also important to consider whether the fertiliser strategy aims to build, maintain or mine the soil reserves of a particular nutrient. Soil test critical values indicate if the crop is likely to respond to added fertiliser, but these figures do not predict optimum fertiliser rates. Soil test results can be compared against critical nutrient values and ranges, which indicate nutrients that are limiting or adequate. When considered in combination with information about potential yield, the previous year's nutrient removal and soil type, soil tests can help in making fertiliser decisions.

Principal reasons for soil testing for nutrition include:

- monitoring soil fertility levels;
- estimating which nutrients are likely to limit yield;
- measuring properties such as pH, sodium (sodicity) and salinity, which affect the availability of nutrients to crops;
- zoning paddocks for variable application rates;
- comparing areas of varying production; and
- as a diagnostic tool, to identify reasons for poor plant performance.

Soil acidity or alkalinity can influence the amount of nutrients available to plants. Table 5 demonstrates nutrient constraints based on soil pH.

Table 5: *Soil classifications for pH (1:5 soil:water).*

Increasing acidity							**Increasing alkalinity**
Acidic				Neutral	Alkaline		
3	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Toxicity of : Aluminium (Al) Manganese (Mn) Iron (Fe)			**Ideal pH Range** for plant growth			Toxicity of : Sodium (Na) Boron (Bo) Bicarbonate (HCO3)	
Deficiency of: Magnesium (Mg) Calcium (Ca) Potassium (K) Phosphorus (P) Molybdenum (Mo)						Deficiency of: Fe Zinc (Zn) Mn Copper (Cu) P	

11 DAFWA (2016) Soil sampling and testing on a small property. https://www.agric.wa.gov.au/soil-productivity/soil-sampling-and-testing-small-property

5.4.1 Types of test

Appropriate soil tests for measuring soil extractable or plant available nutrients in WA are:

- bicarbonate extractable P (Colwell-P);
- bicarbonate extractable K (Colwell-K);
- KCl-40 extractable S; and
- 2M KCl extractable inorganic N, which provides measurement of nitrate-N and ammonium-N.

For determining crop N requirement, soil testing is unreliable. This is because soil nitrogen availability and crop demand for nitrogen are both highly influenced by seasonal conditions.

Other measurements that aid the interpretation of soil nutrient tests include soil pH, percentage of gravel in the soil, soil carbon/organic matter content, P sorption capacity (currently measured as Phosphorus Buffering Index (PBI)), electrical conductivity, chloride and exchangeable cations (CEC) including aluminium.

Collecting soil samples for nutrient testing

The greatest source of error in any soil test comes from the soil sample. Detailed sampling instructions are usually provided in soil test kits. The following information is provided as a reference only.

When sampling the 0–10 cm soil layer, 20–30 cores per site are required, while for the 10–30 cm soil layer, 8–10 cores per site are required. Cores per sample from a uniform zone should be bulked, mixed and sub-sampled for testing. Because it is often more useful to see how pH figures vary within the paddock or across soil types, sampling for pH will always be less than ideal. For pH, 8–10 cores bulked from six locations in a paddock is usually adequate.

To ensure that a sample is representative:

- check that the soil type and plant growth where the sample is collected are typical of the whole area;
- avoid areas such as stock camps, old fence lines and headlands;
- 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, a handful or a spadeful of soil; and
- avoid contaminating the sample, the sampling equipment and the sample storage bag with fertilisers or other sources of nutrients such as sunscreen, containing zinc.

Depth for nutrient sampling

The Better Fertiliser Decisions for Cropping (BFDC) project has highlighted that deeper soil sampling provides more appropriate critical soil values and ranges for many soil types in WA (see Tables 3 and 4). Soil sampling depth for nutrient analysis is currently 0–10 centimetres. The 0–10 cm soil layer was originally chosen because nutrients, especially P, and plants roots are concentrated within this layer. Increasingly, there is evidence of the need to assess production constraints, including acidity, in both the surface soil and subsoil layers.

The importance of subsoil K and S contributions to plant nutrient uptake has been long understood. To obtain more comprehensive soil data, including nutrient data, sampling to 30 cm should be considered, providing there are no subsoil constraints (Figure 2). Collecting deeper soil samples does raise issues of logistics and cost, which should be discussed with soil test providers. One suggested approach is to run a comprehensive suite of soil tests on all 0–10 cm samples and only test for N, K, S and salinity in 10–30 cm samples.

Note that pH samples need to be taken at 10 cm increments to depth. If sampling to 30 cm, the 0–10 cm, 10–20 cm and 20–30 cm soil layer samples should be tested for pH so that soil acidity can be better understood.

Figure 2: *Nutrients, even relatively immobile ones such as phosphorus (P), can move down the profile in sandy soil, so testing nutrient reserves to depth can be useful.*

Source: GRDC. Photo: Gavin Sarre

Critical values and ranges

A soil test critical value is the soil test value required to achieve 90% of crop yield potential. The critical range around the critical value indicates the reliability of the test. The narrower the range the more reliable the data (Table 6).

Table 6: *Summary table of critical values (mg/kg) and critical ranges for the 0–10 cm sampling layer.*

Nutrient	Crop	Soil types	Critical values (mg/kg)	Critical range (mg/kg)
P	Wheat	Grey sands	14	13–16
		Other soils	23	22–24
	Lupins	Grey sands in Northern Region	9	6–12
		Yellow sands in Northern Region	22	21–23
		Grey sands in Southern Region	12	10–15
		Yellow sands in Southern Region	30	25–37
	Canola	All	19	17–25
K	Wheat	All	41	39–45
		Yellow sands	44	34–57
		Loams	49	45–52
		Duplexes	41	37–44
	Lupins	Grey sands	25	22–28
	Canola	All	44	42–45
S	Wheat	All	4.5	3.5–5.9
	Lupins	All	n/a	N/A
	Canola	All	6.8	6.0–7.7

Source: DAFWA and Murdoch University in GRDC

The critical value indicates if a nutrient is likely to limit crop yield based on whether the value is greater than or less than the upper or lower critical range value (see Figure 3). If the soil test value is less than the lower limit, the site is likely to respond to an application of the nutrient. For values within the range there is less certainty about whether a response will occur. In this case, growers have to exercise judgement about the costs and benefits of adding fertiliser in the forthcoming season, versus those associated with not applying. If the soil test is above the critical range, fertiliser is applied only to maintain soil levels or to lower the risk of encountering deficiency. The larger the range around the critical value, the lower the accuracy of the critical value. [12]

12 GRDC (2014) Crop Nutrition Fact Sheet–Western Region. Soil Testing for crop nutrition. http://www.grdc.com.au/GRDC-FS-SoilTestingW

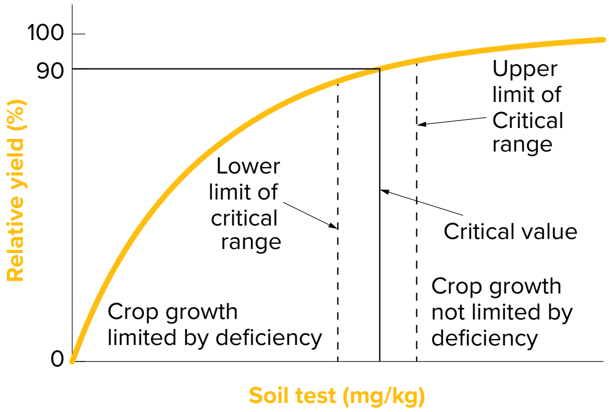

Figure 3: *Generalised soil test response calculation curve. A generalised soil test/crop response relationship defining the relationship between soil test value and percent grain yield expected. A critical value and critical range are defined from this relationship. The relative yield is the unfertilised yield divided by maximum yield, expressed as a percentage. The BFDC Interrogator fits these curves and estimates critical value and critical range. Normally 90% of maximum yield is used to define the critical value, but critical values and ranges at 80% and 95% of maximum yield can also be produced.*

Source: DAFWA, Murdoch University in GRDC

MORE INFORMATION

GRDC Soil testing for crop nutrition – Western Region Fact sheet.

5.4.2 West Australian Soil Quality Monitoring Program

Key Points

- Soil quality is currently being measured in grain producing areas across Australia.
- The Soil Quality Monitoring Program and associated website (www.soilquality.org.au) provides the Australian grains industry with a unique resource on soil quality including soil biology, chemistry and physics.
- Each grower's soil quality information is housed on the Soil Quality website and workshops provide growers with training to access and interpret this information to support improved soil management.

The Soil Quality website provides an, interactive resource to the Australian grains industry on soil quality, including soil biology, soil chemistry and physics. The website allows growers to benchmark their paddocks against values for their local catchment and region, as well as against expert opinion. This information aids growers in determining if they are heading in the right direction with their systems and practices, and supports growers to improve soil management practices. The Soil Quality Monitoring Program and website are expanding to include grain producing areas across Australia. This will give growers access to regionally specific data on soil biological, chemical and physical constraints to production. This will in turn aid the Australian grains industry in making better management decisions. [13]

5.5 Plant and/or tissue testing for nutrition levels

Plant tissue testing can also be used to diagnose a deficiency or monitor the general health of the pulse crop. 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.

13 The National Soil Quality Monitoring Program. http://www.soilquality.org.au/factsheets/w-a-soil-quality-program

Several companies perform plant tissue analysis and derive accurate analytical concentrations. However, it can be difficult 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 differ in their critical concentrations.

Table 87 lists the plant analysis criteria for chickpea. These should be used as a guide only. Care should be taken to use plant tissue tests for the intended purpose.

Table 7: *Critical nutrient levels for chickpea at flowering.*

Nutrient	Plant Part	Critical Range
Nitrogen (%)	Whole shoot	2.3
Phosphorus (%)	Whole shoot	0.24
Potassium (%)	Whole shoot	2.1
Potassium (%)	Youngest mature leaf	1.5
Sulfur (%)	Whole shoot	0.15-0.20
Boron (mg/kg)	Whole shoot	40
Copper (mg/kg)	Whole shoot	3
Zinc (mg/kg)	Whole shoot	12

Most tests diagnose the nutrient status of the plants only at the time they are sampled; they cannot reliably indicate the effect of a particular deficiency on grain yield. Another strategy is to tissue test a number of paddocks and farms. If there is concern over poor-performing areas, the tissue test can be used to diagnose the potential nutrient deficiency. The critical range (see Table 8, above) can be difficult to use. Wide variations in tissue test results can be due to stress such as frost or waterlogging, or even more subtle factors such as solar radiation or time of day of sampling. Although a valuable tool, tissue testing must be used as only one part of an integrated nutrition program. [14]

5.6 Fertiliser

Fertiliser recommendations for chickpeas—as with most pulses—tend to be generic, with an overreliance on the recommendation of MAP-based starter fertilisers across nearly all situations. This is often driven by convenience and availability rather than to meet the specific nutrient requirements of the crop.

Fertiliser recommendations need to be more prescriptive, and should take into account:

- soil type;
- rotation (fallow length and impact arbuscular mycorrhizal fungi (AMF) levels);
- yield potential of the crop;
- plant configuration (row spacing, type of opener and risk of 'seed burn');
- soil analysis; and
- effectiveness of inoculation techniques.

Molybdenum (Mo) and Cobalt (Co) are required for effective nodulation and should be applied as needed. Soil P levels influence the rate of nodule growth. The higher the P level, the greater the nodule growth.

Nitrogen (N) fertilisers in small amounts (5–15 kg N/ha) are not harmful to nodulation and can be beneficial by extending the early root growth to establish a stronger plant. MAP or DAP fertilisers can be used. However, excessive amounts of N will restrict nodulation and reduce N fixation. Inoculated seed and acidic fertilisers should not be

14 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

sown down the same tube. The acidity of some fertilisers will kill large numbers or rhizobia. Neutralized and alkaline fertilisers can be used.

Acid fertilisers include:

- superphosphates (single, double, triple)
- fertilisers with Cu and/or Zn
- MAP, also known as 11:23:0 and Starter 12

Neutral fertilisers include:

- 'Super lime'

Alkaline fertilisers include:

- DAP, also known as 18:20:0
- starter NP [15]

WATCH: Western communicator video: Gray Robertson.

5.6.1 Fertiliser toxicity

All pulses can be affected by fertiliser toxicity. Drilling 10 kg/ha of P with the seed in 18 cm row spacing through 10 cm points rarely causes problems. However, with the changes in sowing techniques to narrow sowing points, minimal soil disturbance, wider row spacing and increased rates of fertiliser (all of which concentrate the fertiliser near the seed in the seeding furrow), the risk of toxicity can be high.

The effects of toxicity are also increased in highly acidic soils, in sandy soils, and where moisture conditions at sowing are marginal. Drilling concentrated fertilisers to reduce the product rate per hectare does not reduce the risk.

The use of starter N (e.g. DAP) banded with the seed when sowing pulse crops has the potential to reduce establishment and nodulation if higher rates are used. On sands, up to 10 kg/ha of N at 18 cm row spacing can be safely used. On clay soils, do not exceed 20 kg/ha of N at 18 cm row spacing.

Deep banding of fertiliser is often preferred for chickpeas, otherwise broadcasting and incorporating, drilling pre-seeding or splitting fertiliser applications so that a lower P rate or no P is in contact with the seed. [16]

15 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

16 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Topdressing P on heavy soils can be relatively ineffective.

Agronomist's view

5.7 Nitrogen

Key points:

- Nitrogen (N) is needed for crop growth in larger quantities than any other nutrient.
- Nitrate (NO3-) is the highly mobile form of inorganic nitrogen in both the soil and the plant.
- Sandy soils in high rainfall areas are most susceptible to nitrate loss through leaching.
- Soil testing will help determine seasonal nutrient requirements. [17]

Plants require more nitrogen (N) than any other nutrient, but only a small portion of the N in soil is available to plants—98% of the N in soil is in organic forms. Most forms of organic nitrogen cannot be taken up by plants, with the exception of some small organic molecules. In contrast, plants can readily take up mineral forms of N, including nitrate and ammonia. However, mineral nitrogen in soil accounts for only 2% of the N in soil. Soil microorganisms convert organic forms of nitrogen to mineral forms when they decompose organic matter and fresh plant residues. This process is called mineralisation.

Crop nitrogen demand is related to actual yield, which is determined by seasonal conditions including the amount and timing of growing season rainfall. As the water-holding capacity of WA soils fluctuates, N crop use efficiency is highly variable also. There has generally been a poor relationship between pre-sowing soil test N and wheat and canola yield response. The pattern of crop demand for N during the growing season also has to be considered. The highest demand is when the crop is growing most rapidly.

In-crop soil sampling can help identify how much nitrogen is being mineralised, but this is generally not practical. Surrogate measurements of crop nitrogen using crop sensors are a more practical alternative. Consequently, predicting N supply to crops is complex.

In WA, nitrogen fertiliser recommendations are based around a budgeting approach using a series of relatively simple, well developed equations. These equations attempt to predict the soil processes of mineralisation, immobilisation, leaching, volatilisation, denitrification and plant uptake. They are built into models such as Yield Prophet and Select Your Nitrogen (SYN). [18]

17 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program. Nitrogen–Western Australia. http://www.soilquality.org.au/factsheets/mineral-nitrogen

18 GRDC (2014) Crop Nutrition Fact Sheet–Western Region. Soil Testing for crop nutrition. http://www.grdc.com.au/GRDC-FS-SoilTestingW

WATCH: Over the Fence West: Yield Prophet delivers fertiliser cost savings.

The N used in commercial fertilisers is particularly soluble for easy uptake and assimilation by plants. Because of the simplicity of its storage and handling, N can easily be applied when plants need it most (Figure 4).

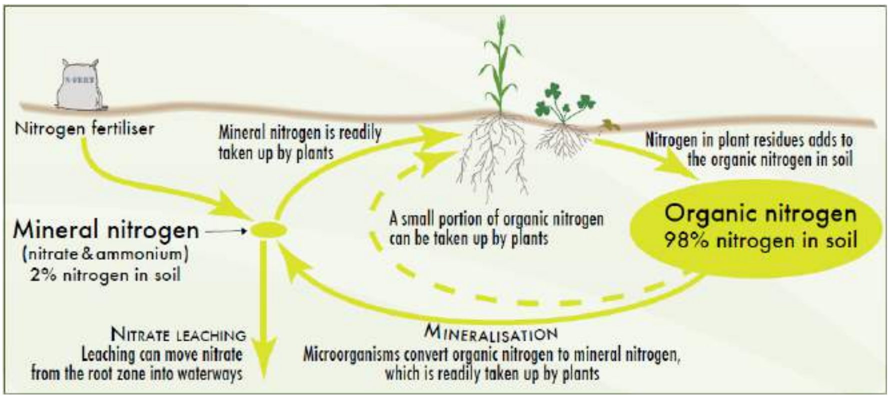

Figure 4: *The soil nitrogen cycle showing the role of mineralisation in making organic nitrogen in soil available for plants to take up.*

Source: Soilquality.org

WATCH: GCTV14: Nitrogen deficiency.

5.7.1 Chickpeas and nitrogen

If chickpea plants have effectively nodulated, they should not normally need N fertiliser (Table 8). Some situations where N fertiliser may warrant consideration include:

- where the grower is unwilling to adopt recommended inoculation procedures;
- late or low fertility planting situations where rapid early growth is critical in achieving adequate height and sufficient biomass to support a reasonable grain yield.

If available soil N is low or sowing is late then "starter" N rates of 5-10 kg/ha may be beneficial. [19]

Table 8: *Nitrogen balance for chickpeas. Grain harvest index (HI) is the grain yield as a percentage of total shoot dry matter production (average ~40%). Chickpea grain contains 3,234 kg N/t.* [20]

Total plant dry matter (t/ha)	Total shoot dry matter yield (t/ha)	Grain yield (t/ha) 40% HI	Total crop N requirement (2.3% N) (kg/ha)	N removal in grain (kg/ha)
1.75	1.25	0.5	40	17
3.50	2.50	1.0	80	33
5.25	3.75	1.5	120	0
7.00	5.00	2.0	160	66
8.75	6.25	2.5	200	83
10.50	7.50	3.0	240	100

5.7.2 Deficiency symptoms

As proteins make up much of the content of cells, nitrogen is needed in greater quantity that any other mineral nutrient. Nitrogen plays an essential role in the production of chlorophyll. Any deficiency is displayed as yellowing leaves and reduced tillering in cereal crops. This ultimately leads to reduced yields.

Nitrogen is highly mobile within the growing plant allowing it to remobilise and move to tissues that can use it more effectively. As a result, older leaves tend to exhibit nitrogen deficiency symptoms first.

Nitrogen fixation reaches the maximum level at flowering stage and then declines sharply during pod filling. Nitrogen deficiency restricts plant growth and reduces branching. Plants have fewer flowers. Fewer pods are formed resulting in poor yields.

What to look for

1. When nitrogen supplies become restricted the older leaves display deficiency symptoms first.
2. The entire plant appears chlorotic, while older leaves turn more yellow than upper leaves (Figure 5).
3. Pink pigmentation develops on the lower part of the stem (Figure 6 left).
4. In prolonged deficiency conditions, the lower leaves turn yellow with reddish pink margins and a pink colouration develops on the lower stem (Figure 7).
5. In the later stage, the yellow older leaves turn white and drop prematurely (Figure 6 right). [21]

19 W Hawthorne, W Bedggood. (2007). Chickpeas in South Australia and Victoria. Pulse Australia. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpeas-SA-Vic.pdf

20 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

21 P Kumar, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

Figure 5: *Nitrogen-deficient crop in foreground compared with nitrogen-fertilised crop behind.*

Source: CABI. Photo: Dr P Kumar

Figure 6: *Pink pigmentation on lower stem and pale yellow to white chlorotic older leaves (left). Severely deficient whiting yellow leaflets with reddish pink colouration on the edges (right).*

Source: CABI. Photo: Dr P Kumar

Figure 7: *Plant showing bottom leaves white, middle leaves yellow and top leaves green.*

Source: CABI. Photo: Dr P Kumar

5.7.3 Yield potential and nitrogen requirement

Nitrogen requirement of cereal crops is driven by yield potential, where every tonne of grain produced requires 40–50 kg/ha of N.

- Cereal crops access nitrogen from three major pools:
- **Stable Organic Nitrogen** (SON) is released slowly throughout the season, and is by far the largest nitrogen source in the soil. Approximately 2% of SON becomes available to crops during the season.
- **Residue Organic Nitrogen** (RON) is mineralised rapidly into NH4+ and NO3-, and is highest following legume crops.
- **Fertiliser Nitrogen** is applied to a crop by growers where the above sources cannot meet the needs of the crop.

Due to the number of different nitrogen sources accessible to the crop, it is best to use models to gauge nitrogen status in the soil. Most current models measure the following soil and crop attributes to determine soil nitrogen status/requirement:

- Yield potential — determines nitrogen demand of the crop.
- Total organic carbon (%) — gives indication of potential SON contribution.
- Rotation — characteristic of the last legume crop (RON).
- Soil type — gives indication of the potential for leaching.
- Rainfall — determines RON breakdown and contribution to leaching.

MORE INFORMATION

Soil Nitrogen supply factsheet.

Models that use this information are SYN (Select Your Nitrogen) from the Department of Agriculture and Food, Western Australia, and NuLogic from the commercial fertiliser company CSBP. [22]

Nitrogen application to chickpeas is often not worth the cost

The application of nitrogen to chickpea crops is not recommended, as yield benefits are unlikely to outweigh the cost of N application. Trials in eastern Australia, funded by the Grains Research and Development Corporation found that adding N to crops did not have any impact on yield, making the additional cost and potential loss in nitrogen fixing ability a double hit. The research looked at the impact of various nitrogen application rates: 0 kg/ha, 23 kg/ha and 46 kg/ha in the first year and 10 kg/ha and 50 kg/ha in the second year. Two application timings: at planting and in crop, and with or without Rhizobia inoculation, were also tested. None of the research sites showed any significant increase in yield from the application of N. In relatively low-yielding seasons there was no consistent impact on yield from the addition of nitrogen alone in chickpeas, across a wide range of starting soil nitrate levels. However, both 2012 and 2013 were low rainfall, poor yielding years and the project was initiated following observations during the wet, high yielding season of 2011 that paddocks with high N levels were yielding best. Significant yield increases would need to be seen to offset the cost of the fertiliser and the lost N fixation, with on average about 100-160 kg/ha of additional grain needed to offset nitrogen fertiliser cost and lost nitrogen fixation. [23]

5.8 Phosphorus

Key points:

- Phosphorus (P) is one of the most critical and limiting nutrients in agriculture in Western Australia. However, due to phosphorus management, most soils across the WA wheatbelt now exceed critical levels for soil P. [24]
- Phosphorus cycling in soils is particularly complex, and agronomic advice is recommended when interpreting soil test results.
- Only 5–30% of phosphorus applied as fertiliser is taken up by the plant in the year of application.
- Phosphorus does not move readily in soils except in very light sandy soils in high rainfall areas.

Ancient and highly weathered soils with very low levels of natural phosphorus (P) dominate much of Australia, particularly Western Australia. Many of our agricultural soils are among the most acutely phosphorus deficient in the world, and profitable crop production has only been possible through significant applications of P fertilisers.

Phosphorus is an essential element for plant and animal growth, and important during cell division and development. Complex soil processes influence the availability of phosphorus applied to the soil, with many soils able to 'tie up' phosphorus, making it unavailable to plants. The soil's ability to do this must be measured when determining requirements for crops and pastures. [25]

Soil phosphorus levels influence the rate of nodule growth. The higher the phosphorus level, the greater the nodule growth. A 2 t/ha chickpea crop will on average remove approximately 6.5 kg/ha of phosphorus. This amount of P will need to be replaced, unless soils are already high in P. Higher quantities may be needed to build up soil fertility or overcome soil fixation of phosphorus.

22 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program..Nitrogen–Western Australia. http://www.soilquality.org.au/factsheets/mineral-nitrogen

23 M Thomson. (2014). Adding Nitrogen to chickpeas is a double hit. GRDC. https://grdc.com.au/Media-Centre/Media-News/North/2014/02/Adding-nitrogen-to-chickpeas-is-a-double-hit

24 J Paterson. (2014). Ground Cover Supplement: Crop nutrition: region by region. GRDC.

25 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program. Phosphorus – Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

Chickpea is not as responsive to phosphorus fertiliser as some of the other pulses. In order to match the nutrient requirement of a crop yielding 1.5–3.5 t/ha, a guide for alkaline soils with a good fertiliser history is 7–16 kg/ha of P. This is equivalent to 80–186 kg/ha of single super or 40–95 kg/ha of double super. [26]

Chickpea is adapted to alkaline soils with high levels of unavailable P, and has evolved methods of extracting P from the soil (along with some other nutrients) that would be inaccessible to many other pulse and cereal crops. This ability is largely due to a combination of two factors: organic acids secreted from the root system and arbuscular mycorrhizalfungi (AMF) colonising the chickpea root system, increasing uptake of P and Zn. More P may be required in low AMF situations (e.g. after a long fallow). High rates of P and Zn will be required in most long-fallow situations (fallows longer than 10 months) where soil VAM levels may be low. [27]

Chickpea is considered highly dependent on AMF to reach yield potential, so yield reduction of 60–80% can occur in low AMF situations. [28]

High AMF situations

Where soil AMF levels are moderate to high (double-crop situations or short, six month fallows from wheat), consistent responses to applied phosphate fertiliser are only likely where soil bicarbonate-P levels fall <6 mg/kg and are critically low.

Low AMF situations

Levels of AMF become depleted as fallow length is increased (Table 9), or after crops such as canola that do not host AMF growth. In these conditions of low AMF (long fallows of over 8–12 months), chickpea is very responsive to applied P and Zn. Although chickpea in this situation will usually show a marked growth response to starter fertilisers (Table 11), this may not always translate into a positive yield response.

The most cost-effective strategy in a long fallow situation (low AMF) may be to ensure that the paddock is sown relatively early in the recommended sowing window, so that sufficient time is allowed for the crop to recover from the delay in early growth. These recommendations are based on soil samples taken to a depth of 0–10 cm.

Table 9: *An example of effect of fallow length on arbuscular mycorrhizae (AM) spore survival, and crop yield response to fertilisation after the fallow.*

Fallow duration (months)	AM Spores (no./g soil)	Crop yield (kg/ha)	
		Nil (P & Zn)	+ (P & Zn)
21	14	2865	4937
11	26	3625	3632
6	44	5162	4704

Source: J Thompson (1984)

Results in Table 10 show that chickpea growth on short-fallow land (six months after wheat) was much better than growth after long fallow on the same property. The addition of P and Zn fertilisers could not entirely compensate for the lack of AMF in chickpea on the long fallow.

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

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

28 Pulse Australia. Chickpea Production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

MORE INFORMATION

VAM and long fallow disorder.

Table 10: *Effect of fallow length and fertiliser on chickpea growth.* [29]

Fallow duration (months)	Dry weight (g/plant) of chickpea at 12 weeks			
	Nil fertiliser	P (50 kg/ha)	Zn (10 kg/ha)	P & Zn
Long (14 months)	1	1.2	0.4	1.9
Short (6 months after wheat)	3.1	2.8	2.7	3.3

One study found that there is a poor relationship between the commonly used indicator (Colwell P 0–10 cm) and the response to added P to chickpea. It has been suggested that a more reliable test than the Colwell P determination is warranted to get more efficient use out of applied P to inherently low P soils. [30]

WATCH: GCTV13: Phosphorus deficiency.

5.8.1 Deficiency symptoms

Phosphorus deficiency is difficult to detect visually in many field crops, as the whole plant tends to be affected. Stunted growth, leaf distortion, chlorotic areas and delayed maturity are all indicators of phosphorus deficiency. Phosphorus is concentrated at the growth tip, resulting in deficient areas visible first on lower parts of the plant.

A purple or reddish colour associated with accumulation of sugars is often seen in deficient plants, especially when temperatures are low. Visual symptoms, other than stunted growth and reduced yield, are not as clear as are those for nitrogen and potassium. At some growth stages, phosphorus deficiency may cause the crop to look darker green.

The role of phosphorus in cell division and expansion means crop establishment and early growth is highly dependent on sufficient sources of the nutrient. Trials have shown significant agronomic penalties from applying phosphorus more than 10 days after germination. Most of these phosphorus timing trials indicate that the optimum time for P fertiliser application is before or during seeding. [31]

What to look for

1. Affected stems develop a reddish purple pigmentation that intensifies and becomes darker in prolonged deficiency conditions (Figure 8).

29 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

30 R Routley, G Spackman, M Conway (2008) Variable response to phosphorous fertilisers in wheat and chickpea crops in central Queensland.

31 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program..Phosphorus–Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

2. In phosphorus deficient plants the top edges and upper surface of the leaflets exhibit reddish purple discolouration (Figure 9). [32]

Figure 8: *Plant showing dark green leaves with reddish purple disclouration in older leaves.*

Source: CABI. Photo: Dr P Kumar

Figure 9: *Purpling appearing on edges of leaflets (left) through to purple pigmentation spreading inwards to cover upper surface of leaflets (right).*

Source: CABI. Photo: Dr P Kumar

5.8.2 Fate of applied fertiliser

Phosphorus fertiliser is mostly applied in a water soluble form which can be taken up by plants, retained by soil and lost through erosion and leaching (Figure 10). In the water soluble form phosphorus is not stable, and rapidly reacts in the soil (principally

32 P Kumar, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

with iron, aluminium and calcium) to form insoluble, more stable compounds. Therefore, competition between the soil and plant roots for water soluble phosphorus arises, with only 5% to 30% of the phosphorus applied taken up by the crop in the year following application. Furthermore, at low pH (< 5.0) the soil's ability to fix phosphorus rises dramatically, thereby decreasing plant availability. [33]

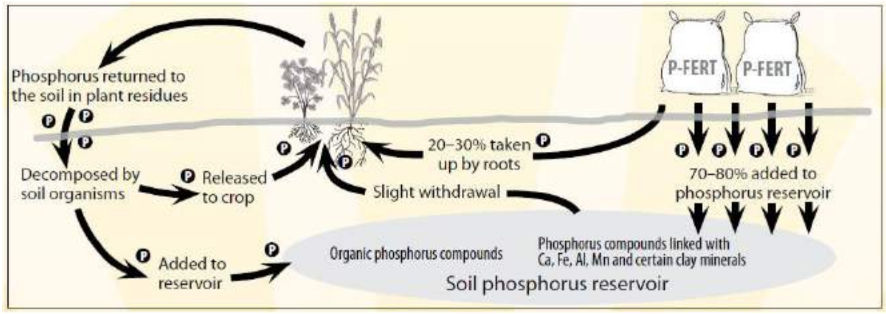

Figure 10: *The phosphorus cycle in a typical cropping system is particularly complex, where movement through the soil is minimal and availability to crops is severely limited*

Glendinning, 2000. Source: The National Soil Quality Monitoring Program

5.8.3 Measuring a soil's ability to fix phosphorus

Knowing the soil's ability to fix phosphorus is vital in determining the rates of fertiliser application. A high fixing soil will require significantly more P fertiliser, and commercial tests have been developed to determine this. These are used in conjunction with other soil and crop traits to optimise fertiliser P requirements:

1. **Reactive Iron Test** measures the amount of iron extracted from soil by ammonium oxalate. This indirect measure of a soil's ability to fix P is only accurate when soil is adjusted for pH.
2. **Phosphorus Retention Index** (PRI) is a direct measure of P-sorption and involves mixing a quantity of soil in solution with a single amount of P for a set period of time. The amount of P remaining in solution measures the soil's ability to fix phosphorus.
3. **Phosphorus Buffering Index** (PBI) is similar to PRI except that a range of P rates are mixed with the soil, and the index is adjusted for pH. This is becoming the Australian standard for measuring soil P-sorption.
4. **Diffuse Gradient Technology Phosphorus** (DGT-P) is a relatively new method currently being tested for use with Australian soils, and mimics the action of the plant roots in accessing available phosphorus (see DGT-P factsheet). [34]

5.8.4 Phosphorus retention and removal

Phosphorus that is not removed from the soil system remains as:

1. undissolved in fertiliser granules;
2. adsorbed by the soil; or
3. present in organic matter.

These sources all supply some P for plant uptake and thus maintain a residual fertiliser value. A long term regime of applying P fertiliser decreases the capacity of the soil to adsorb phosphorus, giving increased effectiveness of subsequent applications.

Each crop species will remove different amounts of phosphorus from soil following harvest (see Table 1), which must be accounted for during nutrient budgeting.

33 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program. Phosphorus—Western Australia. http://www.soilquality.org.au/factsheets/phosphorus

34 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program. Phosphorus—Western Australia. http://www.soilquality.org.au/factsheets/phosphorus.

5.8.5 Leaching and placement of phosphorus

Phosphorus movement in soil varies depending on soil type, although it generally stays very close to where it is placed. With the exception of deep sandy soils, very little phosphorus is lost to leaching. Tests on loamy and clay soils with a history of P-fertiliser application show a rapid reduction in phosphorus with depth.

Agronomic benefits of banding P-fertiliser on high fixing soils have only been evident in trials with lupins, with this attributed to less soil coming in contact with the concentrated phosphorus layer. Wheat and canola have not responded to banded phosphorus on high fixing soils.

Placing high rates of phosphorus close to germinating seedlings can reduce germination and establishment, and should be placed at least 2 cm below the seed. Some considerations when banding phosphorus are:

- Drying conditions in the furrow following seeding, where a 'salting' effect draws moisture from around the seed.
- Canola and lupins are more sensitive to higher phosphorus concentrations.
- Higher concentration of fertiliser in furrow when seeding at higher row spacing.
- Nitrogen containing fertilisers (e.g. DAP) are more damaging than superphosphate fertilisers. [35]

5.8.6 Soil P testing

The Soil P test needs to be interpreted in association with the soil's P sorption capacity, which is estimated by the PBI. The higher the PBI value, the more difficult it is for a plant to access P. Phosphorus is relatively immobile in soils and P applied to the 0 to 10 cm layer tends to remain in that layer, especially in no-till systems. This is the case for loams, duplexes and red and yellow sands. However, grey sands have low P sorption capacity and P can leach from the 0–10 cm soil layer and accumulate in the layers below 10 cm.

For lupins (pulse variety) grown in the northern agricultural region of WA, critical values are 8 mg P/kg for grey sands and 22 mg P/kg for yellow sands (both 0–10 cm). For lupins grown in the central and southern agricultural regions, critical values are 9 mg P/kg for grey sands and 30 mg P/kg for yellow sands (0 to 10 cm). However, a single critical value of 9mg P/kg is suitable for all soil types and regions when a sampling layer of 0–30 cm is used. [36]

5.9 Sulfur

Sulfur (S) is needed at higher rates for chickpea than some other crops. Use 'grain legume' fertilisers. If the paddock has a history of single super then S may be adequate, particularly on clay soils. Prolonged use of double or triple super could lead to an S deficiency, especially on lighter soils.

Historically, S has been adequate for crop growth because S was supplied in superphosphate. Sulfur deficiency occurs when growers use high analysis N and P fertilisers that are low in S and in wet growing seasons due to leaching of S. Occurrence of S deficiency appears to be a complex interaction between the seasonal conditions, crop species and plant availability of subsoil S. As with N, these factors impact on the ability of the soil S test to predict plant available S. [37]

Certain soil types are prone to S deficiency, for example some basaltic, black earths. On these soils with marginal S levels, deficiency is most likely to occur with double-cropping where levels of available S have become depleted, for example when double-cropping chickpeas after high-yielding crops.

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35 R Quinlan, A Wherrett. The National Soil Quality Monitoring Program. Phosphorus—Western Australia. http://www.soilquality.org.au/factsheets/phosphorus.

36 GRDC (2014) Crop Nutrition Fact Sheet–Western Region. Soil Testing for crop nutrition. http://www.grdc.com.au/GRDC-FS-SoilTestingW

37 GRDC (2014) Crop Nutrition Fact Sheet–Western Region. Soil Testing for crop nutrition. http://www.grdc.com.au/GRDC-FS-SoilTestingW

5.9.1 Symptoms

- Sulfur deficiency symptoms are often seen in the early growth stage of the crop.
- Sulfur deficient plants become smaller and slender.
- The yield is severely reduced as the deficient plants produce fewer pods and smaller seeds.
- Deficiency symptoms of Sulfur first appear and become more severe in younger leaves (Figure 11, left).
- Younger leaves turn pale green to pale yellow while the lower leaves remain dark green.
- In severe deficiency conditions, the youngest leaflets turn completely yellow (Figure 11, right) and the entire plant can turn chlorotic. [38]

Figure 11: *Yellowing intensified on younger leaflets (left). Leaflets showing uniform yellowing (right).*

Source: CABI. Photo: Dr P Kumar

5.9.2 Applying Sulfur

Application of 5–10 kg S/ha will normally correct S deficiency. Where soil phosphate levels are adequate, low rates of gypsum are the most cost-effective, long-term method of correcting S deficiency.

Granulated sulfate of ammonia is another effective option where low rates of N are also required.

Marked responses to 25 kg/ha of sulfate of ammonia have been observed when sowing chickpeas in double-crop situations due to sulfur removal rates. [39]

IN FOCUS

Growth, nitrogen fixation and nutrient uptake by chickpea in response to phosphorus and sulfur application under rainfed conditions in Pakistan.

A field experiment was conducted to assess the seed yield, nitrogen fixation and nutrient uptake by chickpea in response to application of different levels of phosphorus (P) and sulfur (S). The treatments comprised three levels (0, 40 and 80 kg P 2O 5 ha -1) of P and three levels (0, 15 & 30 kg S ha -1) of S from two sulfur S sources (gypsum and ammonium sulfate) in different combinations. In a soil with 3 ppm of Phosphorus and 6 ppm of Sulfur, application of P and S resulted in significant yield increases under rainfed conditions. The addition of Sulfur had a direct effect on N fixation and also resulted in the improvement of protein content. Application of

38 P Kumar, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

39 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

P and S resulted in significant increase in seed yield by 21% and 12% more than control, respectively. Sulfur application had significant effect on percent nitrogen derived from atmosphere (% N dfa), while effect of P was non-significant. There was significant increase in protein content of chickpea seed due to application of S. Application of both P and S resulted in increase in N fixation by 16%. An economic analysis indicated that the most profitable application of P and S on this soil was 40 kg/ha P and 30 kg/ha S. [40]

5.10 Potassium

Diagnosis of potassium (K) deficiency before visual symptoms occur is important in order to avoid large yield losses. K is mobile and readily transferred from old to young leaves when a deficiency occurs.

Factors such as soil acidity, soil compaction and waterlogging will modify root growth and the ability of crops to extract subsoil K. Consequently, interrogation of results across all soil types has identified a poor relationship between the soil test for K and crop yield response.

However, the critical value (0–10 cm) for K is defined across all soil types as 41 mg K/kg to achieve a relative yield of 90% (for wheat).

When interrogating by soil type, loams have a higher critical value of 49 mg K/kg. The critical soil K test value for lupins grown on grey sands is 25 mg K/kg (0–10 cm) to achieve 90% of maximum yield. [41]

IN FOCUS

Diagnosis of potassium deficiency in faba bean and chickpea by plant analysis

Critical potassium (K) concentrations for the diagnosis of K deficiency were determined in various shoot parts of faba bean and chickpea plants grown at K rates of 0–240 mg K/kg in a K-deficient soil in the glasshouse. It is recommended that the critical values for the diagnosis of K deficiency at 7–8 leaf stages are 1.3–1.5% in the youngest fully extended leaf (YFEL), 1.1–1.2% in the first plus second leaf blades below the YFEL and 1.8–2.0% in whole shoot of faba bean, and 1.4–1.5% in YFEL, 2.7–2.8% in the first plus second leaf petioles and 2.1–2.2% in whole shoot of chickpea. [42]

40 M Islam, S Mohsan, S Ali, R Khalid, F Ul-Hassan, A Mahmood, A Subhani, A (2011) Growth, Nitrogen Fixation and Nutrient Uptake by Chickpea (Cicer arietinum) in Response to Phosphorus and Sulfur Application under Rainfed Conditions in Pakistan. International Journal of Agriculture & Biology, 13(5).

41 GRDC (2014) Crop Nutrition Fact Sheet–Western Region. Soil Testing for crop nutrition. http://www.grdc.com.au/GRDC-FS-SoilTestingW

42 N Aini, C Tang (1998) Diagnosis of potassium deficiency in faba bean and chickpea by plant analysis. Animal Production Science, 38(5), 503–509.

5.10.1 Symptoms

Figure 12: *Tips of leaflets show brown necrotic patches and eventually die.*

Photo: Michael Bell, QAAFI

Figure 13: *Margins and tips of lower leaves show chlorosis.*

Photo: Michael Bell, QAAFI

5.10.2 Applying potassium

Responses to K are unlikely on most black earths and grey clays. Potassium fertilisers may be warranted on red earths (kraznozems) but this should be based on soil analysis. Fertiliser responses are likely where soil test levels using the ammonium acetate test fall below:

- exchangeable K of 0.25 meq/100 g (or cmol/kg) on black earths and grey clays;
- exchangeable K of 0.40 meq/100 g K on red earths and sandy soils.

Application of 20–40 kg K/ha banded 5 cm to the side of, and below, the seed line is recommended in situations where soil test levels are critically low. [43]

5.11 Micronutrients

Molybdenum and cobalt are required for effective nodulation and should be applied as needed. Foliar sprays of zinc and manganese may be needed where deficiencies of these micronutrients are a known problem, in particular on high-pH soil types.

5.11.1 Zinc

Chickpea is considered to have a relatively high demand for Zinc (Zn), but also possess highly efficient mechanisms for extracting Zn from the soil. Zinc seed treatments may be a cost-effective option in situations where soil P levels are adequate but Zn levels are likely to be deficient.

Chickpea is prone to Zn deficiency. Low or marginal Zn levels are widespread in many cropping districts. Zinc, and to a lesser extent iron, deficiency is prevalent on calcareous soils, particularly dark brown clay soils with high pH.

Zinc applications last about two years on calcareous clays and 6–7 years on loamy soils. Zinc is not mobile in the soil and an even distribution is important. Zinc can be applied by spray to the soil, in furrow, coated on granular fertiliser or as a foliar spray. [44]

Zinc deficiency affects plant-water relationships, induces stomatal closure and decreases transpiration in plants.

Symptoms

- Zinc deficient plants appear stunted and have fewer branches. The size of leaflets is reduced. Crop maturity gets delayed.
- The younger leaves become pale green first, then a reddish brown discolouration appears on margins of leaflets and on the lower parts of the stem (Figure 14, left).
- In severe deficiency, bronzing and necrosis occurs on the leaflets (Figure 14, right). [45]

43 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

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

45 P Kumar, P, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

Figure 14: *Reddish brown pigmentation spreading on the entire upper surface of the leaflets (left). Deficient leaflets showing reddish pigmentation and necrosis on the margins (right).*

Source: CABI. Photo: Dr P Kumar

Applying Zinc

There is a lack of Australian and overseas research on Zn responses in chickpeas, and Zn fertiliser recommendations are being conservatively based on a general recommendation used for all crops. Based on DTPA analysis of soil samples at 0–10 cm, critical values of Zn are:

- below 0.8 mg/kg on alkaline soils;
- below 0.3 mg/kg on acid soils.

AMF are extremely important to Zn nutrition in chickpea, and large responses can be expected where AMF levels have become depleted due to long fallows (over 8–10 months).

Pre-plant treatments

Severe Zn deficiency can be corrected for a period of 5–8 years with a soil application of 15–20 kg/ha of zinc sulfate monohydrate, worked into the soil 3–4 months before sowing.

Zinc is not mobile in the soil and needs to be evenly distributed over the soil surface, and then thoroughly cultivated into the topsoil. In the first year after application, the soil-applied Zn may be not fully effective and a foliar Zn spray may be required.

Seed treatments

Zinc seed treatments may be a cost-effective option where soil P levels are adequate but Zn levels are likely to be deficient:

- Broadacre Zinc (Agrichem): contains 650 g/L of Zn and is applied as 4 L product/t seed. Pre-mix with 1 L water prior to application. To minimise damage to the rhizobia, the Broadacre Zinc treatment needs to be applied first and then allowed to dry before applying the inoculum. Broadacre Zinc is compatible with Thiraflo or P-Pickel T and can be mixed with either product to treat chickpea seed in the one operation.
- Teprosyn Zn (Phosyn): contains 600 g/L of Zn and is applied as 4 L product/t seed. Pre-mix with 2–3 L water to assist coverage.

Fertilisers applied at sowing

A range of phosphate-based fertilisers either contain, or can be blended with, a Zn additive.

Foliar zinc sprays

A foliar spray per ha of 1.0 kg zinc sulfate heptahydrate + 1.0 kg urea + 1200 mL of non-ionic wetter (1000 g/L) in at least 100 L of water will correct a mild deficiency. One or two sprays will need to be applied within 6–8 weeks of emergence.

Hard water (high in carbonate) will produce an insoluble sediment (zinc carbonate) when the zinc sulfate is dissolved, with the spray mix turning cloudy. Buffer back with L1-700 or Agri Buffa if only hard water is available; zinc oxide products are highly alkaline, with a pH of 9.5–10.5. [46]

5.11.2 Boron

Key points

- Boron is essential for plant growth, but only needed in very small amounts.
- Soils deficient in boron are often deep sands in high rainfall zones.
- Toxic levels of boron tend to be found in the heavier soils of the Mallee regions.
- Boron toxicity is best managed through the use of crops that exhibit tolerance to the nutrient.

Boron (B) is essential for crop growth and development but in very small quantities. While the precise role of boron in plants is not fully known, there is evidence to show that boron is important for cell division, the production of nucleic acids (DNA, RNA), the movement of sugars across membranes and the development of reproductive structures (i.e. pollen tubes, fruit, grain). [47]

For most crops, 1–4 mg-B/kg soil is sufficient to prevent nutrient deficiencies. Less than 0.5 mg-B/kg is rated as marginal to deficient. Boron is generally present in soils as B4O72-, H2BO3-, HBO32- and BO33-. Each of these ionic forms is readily leached under high rainfall conditions. Acid deep sands in higher rainfall regions (>600 mm) where there is little clay and organic matter within the root zone are at most risk of having low boron levels. Symptoms of boron deficiency vary between plants, ranging from hollow cavities in vegetable crops, distorted growing tips, discoloration and a 'corky' appearance in fruit and flower and pod abortion in canola. Symptoms are most noticeable in actively growing sites. A map of potentially boron deficient soils in Western Australia is given in Figure 15.

46 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited

47 D Hall. The National Soil Quality Monitoring Program. Boron–Western Australia. http://www.soilquality.org.au/factsheets/boron

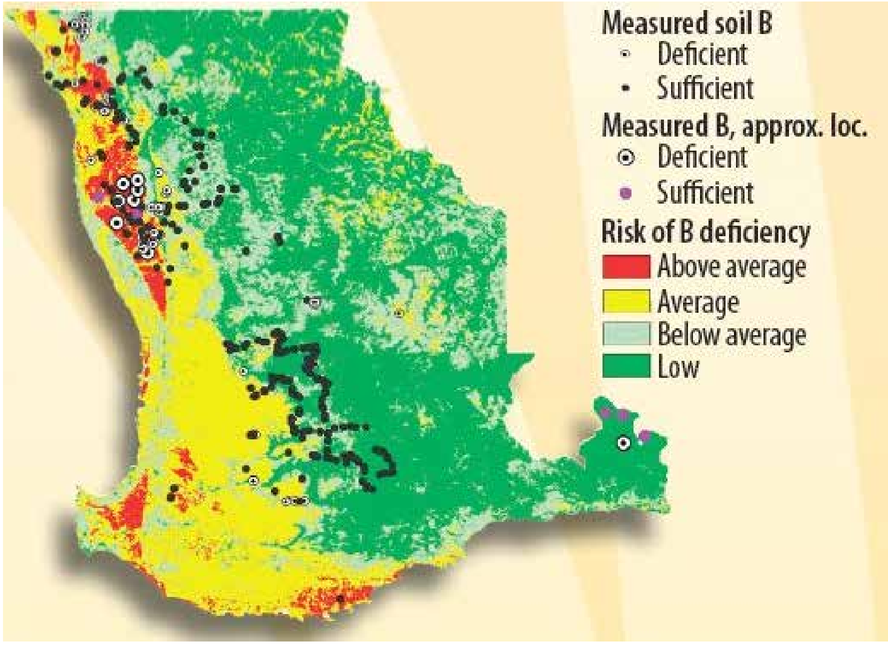


Figure 15: *Areas within south-western Australia cropping region believed to be at risk of boron deficiency based on surface geology, topsoil pH and clay content*

Adapted from Wong et al., 2005. Source: The National Soil Quality Monitoring Program

5.11.3 Boron toxicity

Soil pH affects the availability of most nutrients. Occasionally, some nutrients are made so available that they inhibit plant growth. For example, on some acid soils Al and Mn levels may restrict plant growth, usually by restricting the rhizobia and so the plant's ability to nodulate.

Boron toxicity in Australia is mainly confined to the low rainfall (less than 550 mm per year) Mallee vegetation communities of Western Australia, South Australia and Victoria. The soils typically contain highly alkaline (pH greater than 8) and sodic clay subsoils which are poorly leached and have boron concentrations greater than 12 mg-B/kg of soil. Often boron toxic soils have formed from marine sediments or boron rich minerals including tourmaline. Symptoms of boron toxicity in barley are chlorotic and necrotic lesions in older leaves, whereas in wheat there are few visual symptoms. Soils with potentially high levels of boron in WA are shown in Figure 16.

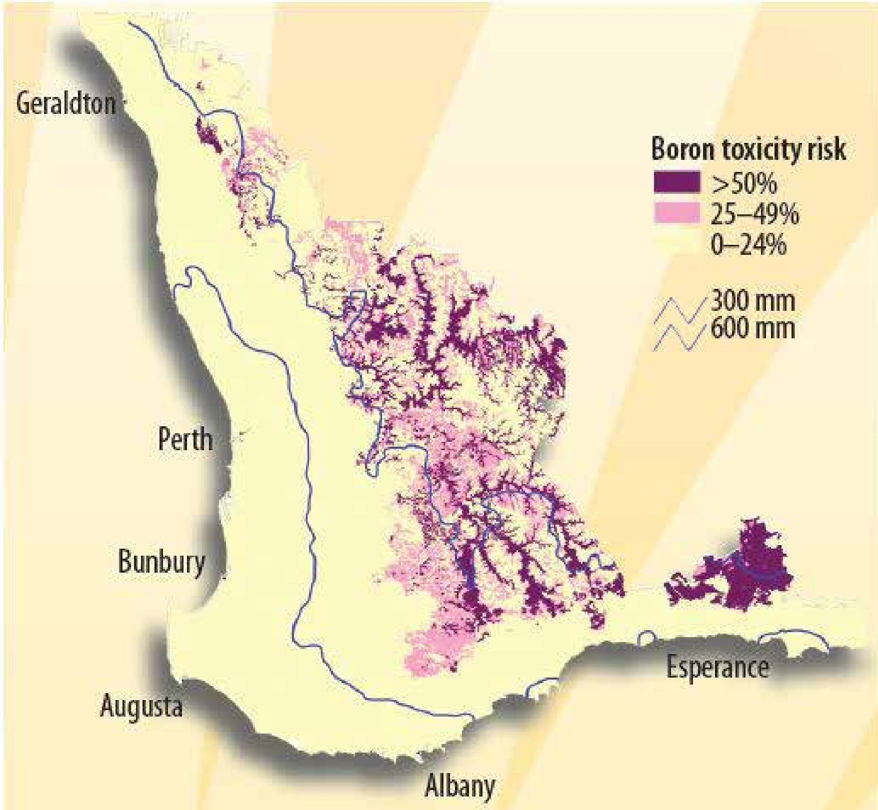


Figure 16: *Areas in Western Australian cropping region prone to boron toxicity.*

Source: The National Soil Quality Monitoring Program

Chickpea is considered sensitive to boron toxicity and occurs on many of the alkaline soils of the southern cropping areas. Symptoms show as a yellowing or dying of the tips and margins of the leaves, with the older leaves being more severely affected than younger leaves (Figure 17). There appears to be little difference in reaction between current varieties. [48]

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

Figure 17: *Symptoms of boron toxicity in chickpea leaves.*

Source: CSIRO

Managing boron toxicity can be achieved through leaching, the application of amendments and using tolerant varieties. Irrigating to encourage leaching is highly effective. In the absence of irrigation water, amending soils with gypsum can increase water infiltration in sodic clays and consequently leach boron deeper into the soil. Dryland trials near Esperance, WA, have shown high rates of gypsum over 20 years can leach boron approximately 10–20 cm. In some circumstances foliar sprays of zinc have been shown to alleviate boron toxicity, although the interaction between boron and zinc is poorly defined.

Boron testing

Soil testing is considered the best method for determining the presence of boron deficiency or toxicity. However due to the high spatial variability in soil boron, testing needs to be done strategically in areas of high and low plant production and throughout the root zone. Due to the mobile characteristics of boron in soil, the most accurate determination of boron status is to sample soil to depth. Hot water extraction in 0.01 M $CaCl_2$ solution is the recommended method for determining soil boron.

Plant tissue testing is less reliable as critical limits cannot be easily determined due to the uneven accumulation of boron in plant tissues, variation in boron uptake at different growth stages and the leaching of boron from plant tissue during rainfall. Seed testing is seen as a more reliable method for determining potential boron toxicity. Grain with more than 3 mg-B/kg is likely to have been grown in boron toxic soils. [49]

5.11.4 Iron

Chickpeas vary in their sensitivity to iron (Fe) deficiency. Considerable yield losses due to iron deficiency chlorosis may occur when susceptible varieties are grown in calcareous soils with high pH. Iron deficiency generally results in stunted growth, with deficient plants showing poor nodulation. [50]

49 D Hall. The National Soil Quality Monitoring Program. Boron–Western Australia. http://www.soilquality.org.au/factsheets/boron

50 P Kumar, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

Major problems with Fe deficiency have largely been overcome through plant breeding. Iron deficiency symptoms tend to be transient, with the crop making a rapid recovery once the soil begins to dry out.

Iron deficiency is observed occasionally in alkaline, high-pH soils. It is usually associated with a waterlogging event following irrigation or heavy rainfall, and is attributed to interference with Fe absorption and translocation to the foliage.

A mixture of 1 kg/ha of iron sulfate +2.5 kg/ha of crystalline sulfate of ammonia (not prilled) +200 mL of non-ionic wetter added to 100 L water has been successfully used to correct Fe deficiency.

The addition of sulfate of ammonia will improve absorption of Fe, with a significantly better overall response. [51]

Symptoms

- Plants display deficiency symptoms first on younger leaves which turn bright yellow then white, while older leaves remain dark green (Figure 18).
- As symptoms advance, white necrotic areas develop in the distal half of the leaflets in young leaves.
- In the later stage of deficiency, the white necrotic areas enlarge and the leaves wither, die and drop off. [52]

Figure 18: *Leaflets of younger leaves are uniformly bright yellow to white, while older leaves remain dark and healthy.*

Source: CABI. Photo: Dr P Kumar

MORE INFORMATION

Crop nutrition Factsheet

Detecting and managing trace element deficiencies in crops

5.12 Nutritional deficiencies

Many soils in the cropping zone of south-western Australia are deficient in macro and micronutrients in their native condition. Plants require a number of nutrients to successfully grow and produce a crop. Western Australia's weather conditions can result in poor soil fertility and limited water supply which restrict a plants ability to uptake and use nutrients. To help identify nutritional deficiencies, see the GRDC Winter Cereal Nutrition: the Ute Guide.

5.13 Green and Brown Manuring

Green manuring and brown manuring are practices where plant material is returned to the soil to improve soil fertility, conserve soil water, reduce weed and disease burdens, and increase soil organic matter. These practices can be included as part of carbon farming, given their potential to increase soil organic matter. Increased stored soil organic carbon (SOC) would help to offset greenhouse gas emissions, increase farm productivity and potentially create offsets under the Emissions Reduction Fund (ERF). Green manuring has a very long history of managing weeds and building soil

51 Pulse Australia (2013) Northern chickpea best management practices training course manual–2013. Pulse Australia Limited.

52 P Kumar, MK Sharma (Eds.) (2013) Nutrient Deficiencies of Field Crops: Guide to Diagnosis and Management. CABI.

fertility in systems where herbicides are not an option or not available, such as in organic farming systems.

The Department of Agriculture and Food, Western Australia (DAFWA) has published fact sheets on green and brown manuring, which show a number of benefits and practicalities of these farming approaches. More farmer experiences, research and field trial information are available on the Western Australian No-Tillage Farmers Association (WANTFA) website.

Practicalities to consider include:

- timing
- the crop species used to renovate the paddock
- the approach to maximising seed kill
- monitoring and managing regrowth
- economics
- the long-term benefits to be achieved.

Loss of income in the year that the practice is conducted must be considered, but this is likely to be offset by yield and quality benefits in the subsequent cropping year.

5.13.1 Outline of procedure

Green manuring incorporates green plant residue into the soil with a cultivation implement, commonly an offset disc plough. It aims to kill weeds and control seedset while building soil organic matter and nitrogen status. More than one tillage pass may be required for a successful kill, and cultivation may lead to losses of soil organic matter and cause soil structure damage.

Brown manuring is a 'no-till' version of green manuring, using a non-selective herbicide to desiccate the crop (and weeds) at flowering instead of using cultivation. A follow-up treatment may be required to control survivors. The plant residues are left standing, helping to retain surface cover and soil structure. Soil organic matter is increased.

A variation on brown manuring is mulching, where the crop or pasture is mowed, slashed or cut with a knife roller and the residue is left lying on the soil surface. This maximises soil surface cover to reduce wind erosion and helps to reduce soil moisture loss through evaporation. However, residues may break down more rapidly than during brown manuring because of the increased contact with soil and smaller pieces.

In Western Australia, pulses are generally the preferred crop to grow for green manuring practices as they improve the nitrogen status of the soil, and the potential foregone profit is lower relative to cereals and canola. Green manuring pulse crops, however, carries the risk of increased nitrous oxide (N_20) emissions, discounting increases in soil carbon sequestration. In some locations, it may be possible to grow a summer crop—for example, broad-leafed plants such as sunflower and safflower or grasses such as sorghum and millet—for green manuring purposes, especially on sandplain soils and in higher rainfall areas. However, high carbon to nitrogen (C:N) ratios may tie up nitrogen and depress subsequent yields.

5.13.2 Benefits

- The SOC content of soils in Western Australian cropping land is low—between about 1% and 4% with a mean of about 2% . [53] Manuring can help increase SOC.
- Improved soil fertility (largely observed in leguminous green manures) achieved by building soil organic matter and nutrient status, and increasing buffering capacity to moderate changes in pH.
- Reduced weed burdens, particularly when herbicides are not an option or effective, or a break is required.

53 Australian Soil Resource Information System (ASRIS), http://www.asris.csiro.au/methods.html

- Increasing soil organic matter to improve soil structure and provide a protective cover for the soil surface: this increases water infiltration and retention, reduces wind and water erosion, and reduces the impact of extreme temperatures. Conserving soil water and disease control in high rainfall environments are also major benefits.

5.13.3 Risks

- There is limited data clearly quantifying the change in SOC linked solely to manuring practices that could be used to calculate a potential carbon sequestration value.
- While most farmers have the appropriate equipment and tools (for example, a tractor, sprayer and some offset disks) to undertake green or brown manuring, others will incur costs when purchasing more specialised machinery (for example, stubble rollers and mulchers).
- There will be a revenue loss from not cropping the paddock in the year of manuring, but this may be offset in future years if improved soil quality increases the performance of subsequent crops.
- These practices will likely be part of rotational cropping management for the paddock, making it difficult to isolate the component(s) of the farming system impacting on soil organic change.
- Green manuring (ploughing in) can result in increased methane production through anaerobic decay.

Western Australian trials (three sites) have shown soil organic content in the topsoil increasing from an average value of 1.41% to 1.81%, 2.19% and 2.11% after one, two and three years of green manuring respectively. [54] The decline in the third year was due to dry conditions, which reduced the amount of biomass returned to the soil via the third green manure crop. The Western Australian No-Tillage Farmers Association (WANTFA) is conducting ongoing field trials, such as investigating the impact of cover crops that are knife rolled, measuring changes over a six year period. [55]

5.13.4 Current level of adoption

There is no adoption for specifically sequestering carbon. The limited data on the current level of adoption of these farming practices suggests that it is more often opportunistic rather than being a routine part of the agricultural system, often associated with herbicide resistance problems, degraded paddocks or failed crops. There is increasing interest in these farming systems however, due to increasing awareness of the benefits to soil quality and ecosystem services. [56]

The practices may be more widely adopted as the goal of increasing SOC improves soil quality and brings economic benefits, without the need to sell carbon credits. Adoption solely for carbon credits is probably not viable, but green or brown manuring could be one component of the overall farming system. [57]

54 F Hoyle, L Schulz, (2003). Restoration of paddock productivity through renovation cropping, in *DAW 628 trial results*, appendix 3, GRDC final report DAW 628.

55 Western Australian No-Tillage Farmers Association (WANTFA), 'Long term no-till farming systems "improving the quality of no-till",' http://www.wantfa.com.au/index.php?option=com_content&view=article&id=77&Itemid=73

56 K Broos, J Baldock, (2008). Building soil carbon for productivity and implications for carbon accounting, in *2008 South Australian GRDC Grains Research Update*.

57 DAFWA (2015) Carbon farming in WA–Green and brown manuring as part of carbon farming. https://www.agric.wa.gov.au/sites/gateway/files/CFWANo%207web%202015.pdf

Weed control

Key messages

- Chickpeas are poor competitors with weeds because of slow germination and early growth.
- Weed control is essential if the chickpea crop is to make full use of in-crop rainfall and stored soil moisture and nutrients and to prevent weed seeds from contaminating the grain sample at harvest.
- Weed management should be planned well before planting, with chemical and non-chemical control options considered.
- There are limited options for pre-emergent and post-emergent weed control.
- Broadleaf weeds must be heavily targeted in the preceding crop and/or fallow. Always assess the broadleaf weed risk prior to planting.
- Chickpeas should always be planted into planned paddocks that have low weed populations.
- Chickpeas are late-maturing compared with other pulses; hence, crop-topping to prevent ryegrass and other weed seed-set is reduced.

Weeds are estimated to cost Australian agriculture A$2.5–4.5 billion per annum, with winter cropping systems alone bearing a $1.3 billion cost. In-crop weed competition causes losses costing around $1 billion per annum for Western Australia (Table 1). Consequently, any practice that can reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry.

MORE INFORMATION

GRDC Weed management hub

Impact of weeds on Australian grain production

Table 1: *Yield loss and revenue loss for residual weeds in all crops.*

Area	Residual weeds for all crops			
	Yield loss (t)	Revenue loss	Yield loss (t/ha)	Revenue loss (per hectare)
WA Central	222,486	$63.4m	0.05	$14.64
WA Eastern	33,244	$8.7m	0.03	$6.87
WA – Sandplain - Mallee	27,084	$8.9m	0.03	$9.34
WA Northern	57,208	$15.9m	0.04	$11.69

Source: GRDC.

Weed control is essential if the chickpea crop is to make full use of stored summer rainfall, to prevent weed seeds from contaminating the grain sample at harvest and to stop weed seed set for future years. Weed management should be planned well before planting, with chemical and non-chemical control options considered.

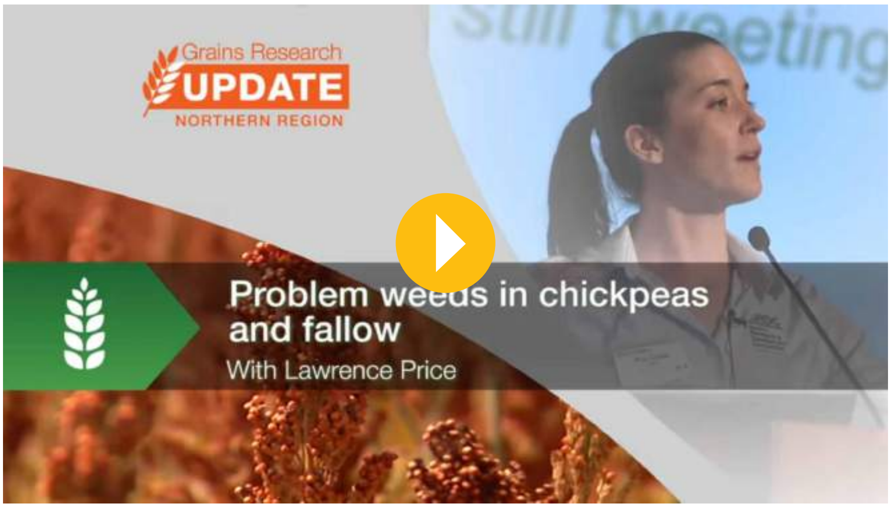
Chickpea crops are poor competitors with weeds because of their slow emergence and growth during winter. Kabuli chickpea competes poorly with weeds, particularly broad-leaved weeds such as radish, mustard, capeweed and doublegee. Effective weed control is essential to prevent yield loss and to avoid the build-up of troublesome weeds in the rotation. Because of the slow growth and open canopy in chickpeas, narrow or wide row spacing (30 *v.* 70 cm) makes little difference to the chickpea plant's ability to compete with weeds. The weed control strategy for growing a successful chickpea crop is based on substantially reducing the viable weed seedbank in the soil before the crop emerges, as post-emergence weed control options are limited. Broadleaf weed control options can be very limited in chickpeas, and this is a reason producers commonly give for not growing chickpeas.

The over-use of particular groups of herbicides through the rotation can lead to herbicide resistance, which has occurred in grass weeds and now some broadleaf weeds. To avoid resistance, weed management through the rotation should aim to minimise the need for herbicides, to avoid the overuse of any one group of herbicides and to use the least selective herbicide. Effective grass control in the chickpea crop has the benefit of reducing the need for selective grass herbicides in the following cereal year. [1]

Weed control is important, because weeds can:

- rob the soil of valuable stored moisture;
- rob the soil of nutrients;
- cause issues at sowing time, restricting access for planting rigs (especially vine-type weeds such as melons, tar vine or bindweed, which wrap around tines);
- cause problems at harvest;
- increase moisture levels of the grain sample (green weeds);
- contaminate the sample;
- prevent some crops being grown where in-crop herbicide options are limited, i.e. broadleaf crops;
- be toxic to stock;
- carry disease; and
- host insects.

WATCH: Grains research updates 2015: Problem weeds in Chickpea and Fallow.



6.1.1 Critical period for weed control

One study has found that chickpea must be kept weed free between the five leaf and full flowering stages (24–48 DAE), and from the four-leaf stage to beginning of flowering (17–49 DAE) in order to prevent >10% seed yield loss. The overall conclusion of this research was that chickpea should be weed free from 17–60 DAE, and that outside of this timeframe weeds are unlikely to significantly impact on yield. [2]

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

2 G Mohammadi, A Javanshir, FR Khooie, SA Mohammadi, S Zehtab Salmasi (2005) Critical period of weed interference in chickpea. Weed research, 45(1), 57–63.

6.2 Integrated weed management (IWM)

There are very effective strategic and tactical options available to manage weed competition that will increase crop yields and profitability. Weeds with herbicide resistance are an increasing problem in grain cropping enterprises. The industry and researchers advise that growers adopt integrated weed management (IWM) to reduce the damage caused by herbicide-resistant weeds.

The following five-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.

Integrated weed management (IWM) is a system for long-term weed management and is particularly useful for managing and minimising herbicide resistance.

The Grains Research and Development Corporation (GRDC) supports integrated weed management. Download the Integrated Weed Management Manual.

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. [3]

Because management of herbicide resistance is case specific, it is difficult to prescribe 'recipes' for how to manage a problem. Instead, you need to understand your situation and choose from a range of methods, such as those outlined below.

Choose a method from the IWM tool box. Consider how these might fit into your farming system and seek advice from your local agronomist. These methods allow you to keep weed populations under control and delay the onset of resistance.

Method 1. Autumn tickle: use light scarification to stimulate weed germination, then spray (paying attention to rotating your chemical groups) before sowing.

3 DAFWA. (2016). Crop weeds: Integrated Weed Management (IWM). https://www.agric.wa.gov.au/grains-research-development/crop-weeds-integrated-weed-management-iwm

Method 2. Barley for weed control: barley is competitive against weeds and use of pre-emergence herbicides is effective. Its shorter growing season also allows for pre-sowing weed control.

Method 3. Catching: use a bin attachment on your harvester to collect weed seed. Then burn the seed. Harvest weed seed management strategies are increasingly being implemented.

Method 4. Crop-topping: Use a non-selective herbicide (paraquat-based) to mature or near-mature crops to reduce weed seed set. However, crop-topping is difficult to implement in chickpeas and is not common practice. Crop-topping in pulse crops can be very effective—weed wiping weeds in lentil crops as a prelude to crop-topping is also effective.

Method 5. Cultivation: Use cultivation to kill germinated weeds.

Method 6. Delayed sowing: Delay sowing for two or more weeks so that additional weeds can be killed by non-selective herbicide. However, yield penalties need to be considered before altering sowing dates.

Method 7. Double-knock strategy: Use a glyphosate application followed by paraquat-based application to control weeds before sowing.

Method 8. Harvest low, no spread, burn: This method has three stages: harvest the crop lower than usual, put the residue (containing weeds) into narrow rows for burning (allows for hotter fire).

Method 9. Hay: Use crop for hay. Trials in southern Australia showed that hay making was most effective—reducing seeds per square metre. Hay cutting alone doesn't guarantee success; you also need to graze or spray-top after it re-shoots to prevent seed on regrowth, and take care when feeding hay out that ryegrass seeds aren't spread to other paddocks.

Method 10. Heavy grazing: Weed seed set is reduced by timely intense grazing of paddocks not sown to crop (and seedbank is reduced).

Method 11. High crop sowing rate: Used to produce a higher crop plant density to reduce yield loss due to weeds and to suppress weed seed production.

Method 12. Manuring: Use the crop for 'green manure' before it matures to prevent weed seed set and increase organic matter.

Method 13. Mechanical pasture top: Slash the pasture before weed maturity.

Method 14. Spray-topping: Use a low-rate of non-selective herbicide applied to pastures to reduce weed seed set.

Method 15. Careful consideration of rotations (pasture phase instead of continuous cropping). A two-year (or more) pasture phase treated to reduce weeds before it goes back into crop. A pasture phase longer than two years is very effective (one year is not enough to reduce seedbank). It should be noted that it is not the pasture phase itself that helps to manage weeds, but it is what the phase allows you to do in addition, e.g. grazing and pasture topping. Crop rotations need to be managed carefully. Continuous cropping requires strong planning and management practices.

Method 16. Stubble burning: Stubble is burned in autumn to reduce viable weed seeds (but reduces organic matter).

Method 17. Windrowing for weed control: cutting crop near to full maturity and leave to dry in rows to reduce seed shatter (usually done in canola). Can be done in other crops but earlier than usual and lower than normal. [4]

MORE INFORMATION

[Herbicide resistance and integrated weed management (iwm) in crops and pasture monitoring tools]

[GRDC IWM Hub].

4 Agriculture Victoria. HERBICIDE RESISTANCE AND INTEGRATED WEED MANAGEMENT (IWM) IN CROPS AND PASTURE MONITORING TOOLS. http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance

6.3 Planting control strategies

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. An effective kill of grassy weeds in the pulse crop will reduce root disease carry over and provide a 'break crop' benefit in the following cereal crop. Grass control herbicides are now available which will control most grassy weeds in pulses. Volunteer cereals can also be controlled with some of these herbicides. Simazine alone and in mixtures with trifluralin can be used to control some other grasses (such as silver grass) that are not readily controlled by the specific grass herbicides. [5]

Do not sow chickpea into a pasture paddock where broadleaf weed pressure will be high. Make the most of opportunities to reduce broadleaf weeds in the preceding crop when weed control is likely to be more effective, cheaper and cause less damage to that crop. Delaying chickpea sowing until after a germination of broadleaf weeds also assists in areas or seasons where this is possible. [6]

The use of rotations that include both broadleaf and cereal crops may allow an increased range of chemicals—three to five MOAs—or non-chemical tactics such as cultivation or grazing.

Where continuous summer cropping has led to development of Group M resistant annual ryegrass, a winter crop could be included in the rotation and a Group A, B, C, D, J or K herbicide used instead, along with crop competition and potential harvest-management tactics.

Strategic cultivation can provide control of herbicide-resistant weeds and those that continue to shed seed throughout the year. It can be used to target large, mature weeds in a fallow, for inter-row cultivation in a crop, or to manage isolated weed patches in a paddock. Take into consideration the size of the existing seedbank and the increased persistence of buried weed seed. [7]

It is important that broadleaf populations are considered when selecting a paddock for chickpea production. Broadleaf weeds should be heavily targeted in the preceding wheat or barley crop or fallow. Paddocks with severe broadleaf weed infestation should be avoided. [8] If broadleaf weeds that are not well controlled by registered broadleaf herbicides are present, then consider altering the cropping rotation until the weed species is controlled.

6.3.1 Managing wild oats in chickpeas

Chickpea rotations provide an opportunity to control wild oats, which is a costly weed in a wheat-based system if it shows levels of herbicide resistance. However, care should be taken to ensure that surviving weeds are identified and removed to reduce the chance of resistance developing. Herbicide-resistant wild oats are becoming a key threat to sustainable farming systems. Herbicide resistance in wild oats poses management problems in any crop where these herbicides have previously been relied upon, but the threat appears greater to chickpea production. Chickpea is most at risk because it is a poorly competitive crop and is often produced on wide rows. In addition, chickpea only has Group A herbicides available for post-emergent control. Effective use of crop rotation must be made to assist in management of wild oats. This will allow the use of the winter fallow and other effective herbicides (differing MOAs including knockdowns) as well as improved crop competition to reduce seed-set of wild oats. [9]

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5 GRDC Grain Legume Handbook – Weed control.

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

7 GRDC (2012) Herbicide resistance. Cropping with herbicide resistance. GRDC Hot Topics, http://www.grdc.com.au/Media-Centre/Hot-Topics/Herbicide-Resistance

8 DAFF (2012) Chickpea—weed management. Department of Agriculture, Fisheries and Forestry, Queensland, http://www.daff.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/weed-management

9 Storrie (2007) Managing wild oats in chickpeas—our practices must change. Northern Grower Alliance, http://www.nga.org.au/results-and-publications/download/45/australian-grain-articles/weeds-1/wild-oats-inchickpeas-tip-of-the-iceberg-september-2007.pdf

6.3.2 Row spacing

Why do narrow rows yield more?

- reduced weed competition
- early canopy closure
- increased light interception
- reduced evaporation
- reduced competition between crop plants within the row

The simple reason for reduced ryegrass seed set in narrow row spacing is light interception by the crop (Figure 1). In the 1990s, when no-till was being adopted, most growers had little choice but to adopt wide row spacing. Stubble retention and no-till go hand in hand, so burning for stubble handling became frowned upon for good reason. Harvester capacity was limited, so harvesting low was out of the question, and seeders struggled to handle stubble. Wide rows were the only option.

Figure 1: *Narrow v. wide row canola in 2009. No light reaching the ground in narrow row spacing plots. Ryegrass germinated about when this photo was taken and was not sprayed due to crop safety concerns. Very low ryegrass seed set in the 9 and 18 cm row spacing treatments (top) compared to 27 and 36 cm treatments (bottom).*

Source: UWA

In 2016 growers have harvesters that can harvest low (10–15 cm) and cut and spread the straw evenly. There are also seeders that can handle more stubble than their predecessors. Many growers in regions that regularly achieve wheat yields of 3 to 4 t/ha have successfully adopted 7” (19 cm) row spacing with both tine and disc machines. It is less convenient than wide rows and it costs more, but the benefits outweigh the negatives.

You don’t have to achieve 7” row spacing

Seven inch row spacing may well be achievable for some, but it may be difficult in very high rainfall areas where wheat yields are 5 t/ha or greater. Researchers have suggested that most growers can achieve narrower row spacing than they are currently using, and that they will benefit from doing so.

Crop competition with weeds will continue to become more and more important as herbicide resistance worsens. If narrow row spacing isn’t possible, growers may want to consider some of the other options to improve crop competition, such as East-West sowing, competitive cultivars and high seeding rates. East-West sowing is a good, free weed control tactic. But narrow row spacing is better than free; it makes more profit while improving weed control. Narrow row spacing is inconvenient, but the science is telling us that it is good for the crop and bad for the weeds. [10]

Trials have been conducted at the DAFWA research station at Merredin, 260 km east of Perth, Western Australia, exploring the effect of row spacing in weed control for a variety of crops. The trial began in 1987, but ryegrass measurement only commenced

10 University of WA (2016) Narrow row spacing—more crop, fewer weeds. http://ahri.uwa.edu.au/narrow-row-spacing/

in 2003. The site was on red loam salmon gum/gimlet soil. Average annual rainfall from 2003 to 2013 was 301 mm (range 168–400). Sown with a high box six rank combine that allows for a range of row spacing configurations with separate fertiliser tines deeper than the seed. Tynes were removed from the combine as row spacing widened. Narrow row spacing yielded more and had fewer ryegrass (Tables 2 and 3).

Table 2: *Crop yield (kg/ha).*

Year	Crop	Row Spacing			
		9 cm	18 cm	27 cm	36 cm
2003	Wheat	3210	3317	3099	3049
2004	Wheat	1823	1825	1760	1560
2005	Field pea	1995	2024	1761	1710
2006	Wheat	2585	2631	2358	2216
2007	Barley	366	385	394	441
2008	Chemical fallow	*	*	*	*
2009	Canola	929	887	832	766
2010	Wheat	1273	1077	988	1031
2011	Wheat	2140	2058	1969	1975
2012	Chickpea	176	148	119	141
2013	Wheat	2083	2021	2196	2035

Source: UWA

Table 3: *Annual ryegrass seed (per m^2) at harvest.*

Year	Crop	Row Spacing			
		9 cm	18 cm	27 cm	36 cm
2003	Wheat	324	296	702	382
2004	Wheat	318	312	757	1001
2005	Field pea	375	558	1930	1581
2006	Wheat	14	18	29	27
2007	Barley	25	54	424	789
2008	Chemical fallow	*	*	*	*
2009	Canola	140	319	3056	3468
2010	Wheat	17	24	36	173
2011	Wheat	159	162	334	552
2012	Chickpea	60	50	135	287
2013	Wheat	2	1	51	171

Source: UWA

WATCH: AHRI insight #70: Narrow row spacing, more crop, fewer weeds.

WATCH: Over the Fence West: Narrower rows result in more crops, fewer weeds in Mingenew.

MORE INFORMATION

UWA – Narrow Row spacing – more crop, fewer weeds.

IN FOCUS

Chemical and Non-chemical Weed Control in Wide Row Lupins and Chickpeas in Western Australia.

Wide row sowing systems (greater than 50 cm wide rows) are becoming more common in Western Australia, allowing growers to control inter-row weeds by inter-row cultivation for organic crops or by spraying non-selective herbicides using shielded sprayers. In one study, inter-row shielded spraying was found to be the most effective treatment for annual ryegrass control in the 66 cm wide rows, but future herbicide resistance will be a major limitation. With shielded spraying, some form of intra-row weed control will still be necessary to significantly reduce weed seed set. Automatic tractor steering control would also be essential for commercial growers to adopt shielded spraying. In 2006, inter-row cultivation reduced annual ryegrass biomass by 63% and the number of annual ryegrass heads by 43%, but this did not result in a significant increase in lupin yield. To be most effective, it is suggested that inter-row cultivation should be done relatively early while the weeds are small, and when the soil is relatively warm and dry with rain not predicted for a day or two. In 2006 and 2007, inter-row shielded spraying with glyphosate gave the best ryegrass control averaging 94%. Weed seed head trimming or cutting weeds above the crop prior to weed seed maturity may be a useful non-chemical method to reduce the number of weed seeds set if the weed seed is above the crop canopy and the cutting height is well controlled. Indian hedge mustard (*Sisymbrium orientale*) seed collected in the 2005 chickpea harvest samples was reduced by around 35% with all trimming treatments. In 2006, the late flower trimming reduced the seed number of wild oats and volunteer wheat in chickpeas. Lupin and chickpea grain yield was slightly reduced by trimming in 2005, but with improved height control did not reduce yields in 2006. Given the difficulties in controlling weeds by the growers due to widespread development of herbicide resistance in these weeds within the WA wheatbelt, this novel non-chemical way of weed control is a viable and promising option to reduce the soil weed seed bank. [11]

6.4 Herbicides explained

6.4.1 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 isoxaflutole, imazapyr, chlorsulfuron, atrazine and simazine.

The persistence of residual herbicides is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall and irrigation, temperature and the herbicide's characteristics. The persistence of herbicides will affect the enterprise's sequence (a rotation of crops, e.g. wheat–barley–chickpeas–canola–wheat).

Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and 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.

6.4.2 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, whereas pre-emergent refers to application of the herbicide to the soil before the weeds have emerged. [12]

6.5 Mode of Action (MOA)

Resistance has developed primarily because of the repeated and often uninterrupted use of herbicides with the same mode of action. Selection of resistant strains can occur in as little as 3–4 years if attention is not paid to resistance management. Remember that the resistance risk remains for products having the same MOA. If

11 GP Riethmuller, A Hashem, SM Pathan (2009) Chemical and non-chemical weed control in wide row lupins and chickpeas in Western Australia. Australian Journal of Multi-Disciplinary Engineering, 7(1), 15–26.

12 T McGillion, A Storrie (Eds.) (2006) Integrated weed management in Australian cropping systems—A training resource for farm advisors. Section 4: Tactics for managing weed populations. CRC for Australian Weed Management, Adelaide http://www.grdc.com.au/~/media/A4C48127FF8A4B0CA7DFD67547A5B716.pdf

you continue to use herbicides with the same MOA and do not follow a resistance-management strategy, problems will arise.

6.5.1 MOA labelling

In order to facilitate management of herbicide-resistant weeds, all herbicides sold in Australia are grouped by MOA. The MOA is indicated by a letter code on the product label. The MOA labelling is based on the resistance risk of each group of herbicides. Australia was the first country to introduce compulsory MOA labelling on products, and the letters and codes used in Australia are unique. Labelling is compulsory and the letters and codes reflect the relative risk of resistance evolving in each group. Since the introduction of MOA labelling in Australia, other countries have adopted MOA classification systems; however, caution is advised if cross-referencing MOAs between Australia and other countries, as different classification systems are used. The herbicide MOA grouping and labelling system in Australia was revised in 2007. This is the first major revision of the classification system since its introduction.

The original groupings were made based on limited knowledge about MOAs. Groupings have been changed to improve the accuracy and completeness of the MOAs to enable more informed decisions about herbicide rotation and resistance management. The general intent of groups based on their risk has not changed.

6.5.2 Grouping by mode of action and ranking by resistance risk

Growers and agronomists are now better assisted to understand the huge array of herbicide products in the marketplace in terms of MOA grouping and resistance risk by reference to the MOA chart. All herbicide labels now carry the MOA group clearly displayed, such as:

Group	**G**	**Herbicide**

Know your herbicide groups to make use of this labelling.

Not all MOA groups carry the same risk for resistance development. Therefore, specific guidelines for Groups E, G, H, N, O, P and R have not been developed, because there are no recorded cases of weeds resistant to members of these groups in Australia.

Products represented in Group A (mostly targeted at annual ryegrass and wild oats) and Group B (broadleaf and grass weeds) are HIGH RESISTANCE RISK herbicides, and specific guidelines are written for use of these products in winter cropping systems.

Specific guidelines are also available for the MODERATE RESISTANCE RISK herbicides: Group C (annual ryegrass, wild radish and silver grass), Group D (annual ryegrass and fumitory), Group F (wild radish), Group I (wild radish and Indian hedge mustard), Group J (serrated tussock and giant Parramatta grass), Group L (annual ryegrass, barley grass, silver grass and cape weed), Group M (annual ryegrass, barnyard grass, fleabane, liverseed grass and windmill grass), Group Q (annual ryegrass), and Group Z (wild oats and winter grass).

Specific guidelines for Group K have been developed due to the reliance on this MOA to manage annual ryegrass, and the possibility of future resistance development. [13]

6.5.3 Specific guidelines for Group A herbicides

High resistance risk.

13 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Group A resistance exists in Australia in the grass weeds, including annual ryegrass, wild oats, phalaris, brome grass, crab grass, goose grass and barley grass. Resistance has developed in broadacre and vegetable situations.

Research has shown that as few as six applications to the same population of annual ryegrass can result in the selection of resistant individuals. A population can go from a small area of resistant individuals to a whole paddock failure in one season.

Fops, dims and dens are Group A herbicides and carry the same high resistance risk. Where a Group A herbicide has been used on a particular paddock for control of any grass weed, avoid using a Group A herbicide to control the same grass weed in the following season, irrespective of the performance it gave.

Frequent application of Group A herbicides to dense weed populations is the worst scenario for rapid selection of resistance.

Where resistance to a member of Group A is suspected or known to exist, there is a strong possibility of cross-resistance to other Group A herbicides. Therefore, use other control methods and herbicides of other MOA groups in a future integrated approach.

The above recommendations should be incorporated into an integrated weed management (IWM) program. In all cases, try to ensure that surviving weeds from any treatment do not set and shed viable seed. Keep to integrated strategies, including rotation of MOA groups.

The following charts have been compiled from chemical labels on the APVMA website and PIRSA Spraying charts and in consultation with chemical companies (Table 4).

Table 4: *Active ingredients of Group A MOAs.*

Chemical family	Active constituent (first registered trade name)
Group A. Inhibitors of acetyl coA carboxylase (inhibitors of fat synthesis/ACCase inhibitors)	
Aryloxyphenoxypropionates (fops)	Clodinaafop (Topik®), cyhalofop (Barnstorm®), diclofop (Cheetah® Gold, Decision®*, Hoegrass®, Tristar® Advance*), fenoxaprop (Cheetah® Gold*, Tristar® Advance*, Wildcat®), fluazifop (Fusilade®, Fusion®*), haloxyfop (Motsa®*, Verdict®), propaquizafop (Shogun®), quizalofop (Targa®)
Cyclohexanediones (dims)	Butroxydim (Falcon®, Fusion®*), clethodim (Motsa®*, Select®), profoxydim (Aura®), sethoxydim (Cheetah® Gold*, Decision®*, Sertin®), tepraloxydim (Aramo®), tralkoxydim (Achieve®)
Phenylpyrazoles (dens)	Pinoxaden (Axial®)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

6.5.4 Specific guidelines for Group B herbicides

High resistance risk.

Group B resistance exists in Australia in the grass weeds, annual ryegrass, barley grass, brome grass, wild oats and crab grass, and in at least 16 broadleaf weeds including: wild radish, common sowthistle, climbing buckwheat, turnip weed, wild mustard, Indian hedge mustard, prickly lettuce, wild turnip and African turnip weed. Resistance has developed in broadacre, rice and pasture situations. With respect to rice, three broadleaf weeds have been discovered: dirty dora, arrowhead and starfruit.

Research has shown that as few as four applications to the same population of annual ryegrass can result in the selection of resistant individuals and as few as six applications for wild radish. A population can go from a small area of resistant individuals to a whole paddock failure in one season.

Avoid applying more than two Group B herbicides in any four year period on the same paddock.

Broadleaf weed control

If a pre-emergent application is made with a Group B herbicide for broadleaf weed control, monitor results and, if required, apply a follow-up spray with a non-Group B herbicide for control of escapes and to reduce seed-set.

If a post-emergent application is made with a Group B herbicide for broadleaf weed control, it should preferably be as an APVMA-approved tank-mix with another MOA that controls or has significant activity against the target weed. If no APVMA-approved tank-mix is available, then monitor results and if required, apply a follow-up spray with a non-Group B herbicide for control of escapes and to reduce seed-set.

A Group B herbicide may be used alone on flowering wild radish only if a Group B herbicide has not been previously used on that crop.

Grass-weed control

If there are significant escapes following the herbicide application, consider using another herbicide with a different mode of action or another control method to stop seed-set (Table 5).

Table 5: *Active ingredients for Group B MOAs.*

Chemical family	Active constituent (first registered trade name)
Group B. Inhibitors of acetolactate synthase (ASL inhibitors)	
Sulfonylureas (SUs)	Azimsulfuron (Gulliver®), bensulfuron (Londax®), chlorsulfuron (Glean®), ethoxysulfuron (Hero®), foramsulfuron (Tribute®), halosulfuron (Sempra®), iodosulfuron (Hussar®), mesosulfuron (Atlantis®), metsulfuron (Ally®, Harmony®*M, Trounce®*, Ultimate Brushweed®* Herbicide), prosulfuron (Casper®*) rimsulfuron (Titus®), sulfometuron (Oust®), sulfosulfuron (Monza®), thifensulfuron (Harmony®*M), triasulfuron (Logran®, Logran® B-Power*) tribenuron (Express®), trifloxysulfuron (Envoke®, Krismat®*)
Imidazolinones (imis)	Imazamox (Raptor®, Intervix®*), imazapic (Flame®, Midas®*, OnDuty®*), imazapyr (Arsenal Xpress®*, Midas®*, OnDuty®*, Intervix®*, Lightning®*), imazethapyr (Spinnaker®, Lightning®*)
Triazolopyrimidines (sulfonamides):	Flumetsulam (Broadstrike®), florasulam (Conclude®*, Torpedo®*, X-Pand®*), metosulam (Eclipse®), pyroxsulam (Crusader®)
Pyrimidinylthiobenzoates	Bispyribac (Nominee®), pyrithiobac (Staple®)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

6.5.5 Specific guidelines for Group C herbicides

Moderate resistance risk.

Group C resistance exists in Australia in the weeds annual ryegrass, wild radish, liverseed grass, silver grass, stinging nettles and barnyard grass. Resistance has developed in broadacre, horticultural and non-crop situations.

CropLife Australia gives specific guidelines for the use of Group C herbicides in TT canola and in winter legume crops, following increasing reports of resistance development.

Avoid using Group C herbicides in the same paddock in consecutive years. Growing TT canola in a paddock treated with triazine herbicides in the previous season is a high resistance risk and is not recommended.

Watch and record for weed escapes, especially in paddocks with a long history of Group C use.

Consult the 'Integrated Weed Management Strategy for TT Canola' for further details. The resistance status of the 'at-risk' weeds should be determined prior to sowing. Always use the label rate of herbicide, whether a single active ingredient (e.g. bromoxynil) or combination of active ingredients is applied (e.g. bromoxynil/MCPA, pyrasulfotole/bromoxynil). Apply to weeds at the labelled growth stage and ensure that no weeds set and shed viable seed. To prevent seed-set, control survivors with a herbicide of different MOA from Group C, or use another weed-management technique (Table 6).

Table 6: *Active ingredients in Group C MOAs.*

Chemical family	Active constituent (first registered trade name)
Group C. Inhibitors of photosynthesis at photosystem II (PS II inhibitors)	
Triazines	Ametryn (Amigan®*, Primatol Z®, Gesapax® Combi*, Krismat®), atrazine (Gesaprim®, Gesapax® Combi*, Primextra® Gold*), cynazine (Bladex®), prometryn (Gesagard®, Cotoguard®*, Bandit®*), propazine (Agaprop®), simazine (Gesatop®) terbuthylazine (Terbyne®), terbutryn (Amigan®*, Igran®, Agtryne® MA*)
Triazinones	Hexazinone (Velpar® L, Velpar® K4*), metribuzin (Sencor®)
Uracils	Bromacil (Hyvar®, Krovar®*), terbacil (Sinbar®)
Pyridazinones	Chloridazon (Pyramin®)
Phenylcarbamates	Phenmedipham (Betanal®)
Ureas	Diuron (Karmex®, Krovar®*, Velpar® K4*), fluometuron (Cotoran®, Cotoguard®*, Bandit®*), linuron (Afalon®), methabenzthiazuron (Tribunil®), siduron (Tupersan®), tebuthiuron (Graslan®)
Armides	Propanil (Stam®)
Nitriles	Bromoxynil (Buctril®, Buctril® MA*, Barrel®*, Jaguar®*, Velocity®*, Flight®*), ioxynil (Totril®, Actril DS*)
Benzothiadiazinones:	Bentazone (Basagran®, Basagran® M60*)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

6.5.6 Specific guidelines for Group D herbicides

Moderate resistance risk.

Resistance to Group D herbicides is known for an increasing number of populations of annual ryegrass and fumitory. Resistance has generally occurred after 10–15 years of use of Group D herbicides.

Where possible, avoid the use of Group D herbicides on dense ryegrass populations. Consider using alternative methods of weed control to reduce weed numbers before applying herbicides.

Rotate with herbicides from other MOA. For annual ryegrass, consider rotating trifluralin with products such as Boxer Gold®.

These recommendations should be incorporated into an IWM program (Table 7). Try to ensure that surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies, including rotation of MOA groups.

Table 7: *Active ingredients of Group D MOAs.*

Chemical family	Active constituent (first registered trade name)
Group D. Inhibitors of microtubule assembly	
Dinitroanilines (DNAs)	Oryzalin (Surflan®, Rout®*), pendimethalin (Stomp®), prodiamine (Barricade®), trifluralin (Treflan®)
Benzoic acids	Chlorthal (Dacthal®, Prothal®*)
Benzamides	Propyzamide (Kerb®)
Pyridines	Dithiopyr (Dimension®), thiazopyr (Visor®)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

6.5.7 Specific guidelines for Group F herbicides

Moderate resistance risk.

Resistance to Group F herbicides is known for a small number of populations of wild radish. Resistance has generally occurred after a long history of use of Group F herbicides. The number of populations with Group F resistance is increasing following increased use of these herbicides.

Group F includes herbicides that reduce carotenoid biosynthesis through inhibition of phytoene desaturase (PDS).

Avoid applying Group F herbicides in any two consecutive years unless one application is a mixture with a different MOA that is active on the same weed, or a follow-up spray is conducted (using a different MOA) to control escapes. Always use the label rate of herbicide, whether a single active ingredient (e.g. diflufenican) or combination of active ingredients is applied (e.g. diflufenican/MCPA, picolinafen/MCPA). Apply to weeds at the labelled growth stage and ensure that no weeds set and shed viable seed. To prevent seed-set, control survivors with a herbicide of different MOA from Group F, or use another weed-management technique.

If applicable, apply a follow-up spray with a non-Group F herbicide for control of escapes and to reduce seed-set. Aim to ensure that surviving weeds from any treatment do not set and shed viable seed.

These recommendations should be incorporated into an IWM program. Try to ensure that surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies including rotation of MOA groups (Table 8).

Table 8: *Active ingredients for Group F MOAs.*

Chemical family	Active constituent (first registered trade name)
Group F. Bleachers: Inhibitors of carotenoid biosynthesis at the phytoenede saturase step (PDS inhibitors)	
Nicotinanilides	Diflufenican (Brodal®, Jaguar®*, Tigrex®*, Chipco Spearhead®*)
Picolinamides	Picolinafen (Paragon®*, Sniper®, Flight®)
Pyridazinones	Norflurazon (Solicam®)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

6.5.8 Specific guidelines for Group I herbicides

Moderate resistance risk.

Resistance to Group I herbicides is known for a number of populations of wild radish and Indian hedge mustard. Resistance has occurred after a long history of use of Group I herbicides. The number of populations with Group I resistance is increasing.

It is of particular concern that in addition to Group I resistance in wild radish—which is the most important broadleaf weed in broadacre agriculture—some populations are cross-resistant to other MOAs, e.g. Group F herbicides, which can be important for control of wild radish in lupins where other selective, non-Group I options are limited. Because of the long soil life of wild radish seed, measures to reduce the return of seed to the soil would be useful for this weed. Wild radish seed that is confined to the top 5 cm soil has a shorter life than seed buried deeper.

As a rule, in situations of high resistance risk:

- Avoid applying two applications of Group I herbicides alone onto the same population of weeds in the same season.
- Where possible, combine more than one MOA in a single application. Each product should be applied at rates sufficient for control of the target weed alone to reduce the likelihood of weeds resistant to the Group I herbicide surviving.

These recommendations should be incorporated into an IWM program. Try to ensure that surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies, including rotation of MOA groups (Table 9).

Table 9: *Active ingredients of Group I MOAs.*

Chemical family	Active constituent (first registered trade name)
Group I. Disruptors of plant cell growth (synthetic auxins)	
Phenoxycarboxylic acids (phenoxys)	2,4-D (Amicide®, Actril DS®*, Pyresta®*), 2,4-DB (Trifolamine®), dichlorprop (Lantana 600®), MCPA (MCPA, Buctril® MA*, Banvel M®*, Conclude®*, Midas®*, Paragon®*, Tigrex®*, Barrel®*, Tordon 242®*, Basagran® M60*, Chipco Spearhead®*, Agtryne® MA*, Precept®*, Flight®*) MCPB (Legumine®), mecoprop (Mecopropamine®, Mecoban®, Methar Tri-Kombi®*)
Benzoic acids	Dicamba (Banvel®, Banvel M®*, Barrel®*, Mecoban®, Methar Tri-Kombi®*)
Pyridine carboxylic acids (pyridines)	Aminopyralid (Hotshot®*,Grazon Extra®*), clopyralid (Lontrel®, Torpedo®*, Chipco Spearhead®*), fluroxypyr (Starane®, Hotshot®*), picloram (Tordon®, Tordon 242®*, Grazon®*, Grazon Extra®*), triclopyr (Garlon®, Grazon®*, Grazon Extra®*, Ultimate Brushweed®* Herbicide)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

6.5.9 Specific guidelines for Group J herbicides

Moderate resistance risk.

There are isolated cases of weeds resistant to Group J in Australia. Two populations of serrated tussock and six populations of giant Parramatta grass are confirmed resistant to flupropanate.

To assist in delaying the onset of resistance, consider alternating with herbicides from other MOA.

The recommendations should be incorporated into an IWM program. Try to ensure surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies, including rotation of MOA groups (Table 10).

Table 10: *Active ingredients of Group J MOAs.*

Chemical family	Active constituent (first registered trade name)
Group J. Inhibitors of fat synthesis (not ACCase inhibitors)	
Chlorocarbonic acids	2,2-DPA (Dalapon®), flupropanate (Frenock®)
Thiocarbamates	EPTC (Eptam®), molinate (Ordram®), pebulate (Tillam®), prosulfocarb (Boxer® Gold*), thiobencarb (Saturn®), triallate (Avadex®), vernolate (Vernam®)
Phosphorodithioates	Bensuilde (Prefar®)
Benzofurans	Ethofumesate (Tramat®)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

6.5.10 Specific guidelines for Group K herbicides

Moderate resistance risk.

Resistance to Group K herbicides is possible in Australia and may develop in broadacre situations.

Where possible, avoid the use of Group K herbicides on dense populations of ryegrass. Consider using alternative methods of weed control to reduce weed numbers before applying herbicides.

Rotate with herbicides from other modes of action (Table 11). The recommendations should be incorporated into an IWM program. Try to ensure surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies, including rotation of MOA groups.

Table 11: *Active ingredients for Group K MOAs.*

Chemical family	Active constituent (first registered trade name)
GROUP K. Inhibitors of cell division/inhibitors of very long chain fatty acids (VLCFA inhibitors).	
Acetamides	Napropamide (Devrinol®)
Chloroacetemides	Dimethenamid (Frontier®-P), metolachlor (Boxer® Gold*, Dual® Gold, Primextra® Gold*), propachlor (Ramrod®, Prothal®*)
Isoxazoline	Pyroxasulfone (Sakura®)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

6.5.11 Specific guidelines for Group L herbicides

Moderate resistance risk.

Group L resistance exists in Australia in annual ryegrass, barley grass (two species), silver grass, cape weed and square weed. Most instances have occurred in long-term lucerne stands treated regularly with a Group L herbicide, but Group L-resistant barley grass has also occurred in no-till situations.

The following factors are common to all cases of Group L resistance:

- A Group L herbicide is the major or only herbicide used.
- A Group L herbicide has been used for 12–15 years or more.
- There has been minimal or no soil disturbance following application.

The risk of resistance to Group L herbicides is higher in no-tillage broadacre cropping. Other situations of high resistance risk include irrigated clover pivots, orchards, vineyards or pure lucerne stands where frequent applications of a Group

L herbicide are made each season, cultivation is not used and there is reliance on a Group L herbicide alone for weed control.

Below are strategies to reduce the risk of Group L resistance developing in situations of high resistance risk.

No-tillage

Rotate Group L herbicides with other knockdown herbicides with a different mode of action.

Consider utilising the double-knock technique, with glyphosate sprayed first followed within 1–7 days by a paraquat application. A full label rate for the weed size targeted should be used for the paraquat application for resistance management. Consider occasional mechanical cultivation to aid weed control.

Lucerne

If using a Group L herbicide for winter cleaning, where possible include another MOA, e.g. diuron (Group C).

Use alternative MOA to selectively control grass and broadleaf weeds. Rotate Group L herbicides with other knockdown herbicides with a different MOA prior to sowing lucerne and prior to sowing future crops in that paddock.

Horticulture

Rotate Group L herbicides with other knockdown herbicides with a different MOA. Where possible use residual herbicides (that are effective on the same weeds as the Group L herbicides) where applicable, either alone or in mixture with Group L herbicides. Where possible, use an alternative MOA to selectively control grass and broadleaf weeds. Consider using the double-knock technique, with glyphosate sprayed first followed within 1–7 days by a paraquat application. A full label rate for the weed size targeted should be used for the paraquat application for resistance management.

These recommendations should be incorporated into an IWM program. Try to ensure surviving weeds from any treatment do not set and shed viable seed. Always try to apply herbicides to the smallest weed density. Use integrated strategies, including rotation of MOA groups (Table 12).

Table 12: *Active ingredients of Group L MOAs.*

Chemical family	Active constituent (first registered trade name)
Group L. Inhibitors of photosynthesis at photosystem I (PSI inhibitors)	
Bipyridyls	Diquat (Reglone®, Spray.Seed®*), paraquat (Gramoxone®, Spray.Seed®*, Alliance®*)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

6.5.12 Specific guidelines for Group M herbicides

Moderate resistance risk.

Group M resistance occurs in Australia in annual ryegrass, awnless barnyard grass, fleabane, liverseed grass and windmill grass.

Herbicide resistance to glyphosate was first discovered in annual ryegrass in Australia in 1996. Since then, several new cases of glyphosate resistance in annual ryegrass, awnless barnyard grass, fleabane, liverseed grass and windmill grass have been confirmed.

The following factors are common to all cases of Group M resistance:

- A Group M herbicide is the major or only herbicide used.
- A Group M herbicide has been used for 12–15 years or more.

- There has been minimal or no soil disturbance following application.

Given the important role of glyphosate in Australian farming systems, the Australian agricultural industry has developed strategies for sustainable use of glyphosate.

For more information, refer to the Australian Glyphosate Sustainability Working Group website.

All cases of glyphosate resistant weeds confirmed to date share three common factors:

- Intensive (year-to-year) use of glyphosate.
- Lack of rotation of other herbicide modes of action.
- Little or no tillage or cultivation following the application of glyphosate.

Several cases of ryegrass resistance to glyphosate have occurred in horticultural and non-cropping situations (e.g. firebreaks, fence lines, driveways, irrigation ditches), with the balance occurring in no-till, broadacre cropping systems.

Given the demonstrated propensity of annual ryegrass to develop resistance to multiple herbicide classes, IWM principles should be incorporated wherever possible to minimise the risk of selecting for glyphosate-resistant ryegrass. Strategies may include the use of cultivation, the double-knock technique (using a full-cut cultivation OR the full label rate of a paraquat-based product (Group L) following the glyphosate (Group M) knockdown application), strategic herbicide rotation, grazing and baling.

Try to ensure that surviving weeds from any treatment do not set and shed viable seed. Always try to apply herbicides to the smallest weed density. Use the integrated strategies mentioned, including rotation of MOA groups (Table 13).

Table 13: *Active ingredients of Group M MOAs.*

Chemical family	Active constituent (first registered trade name)
Group M. Inhibitors of EPSP synthase	
Glycines	Glyphosate (Roundup®, Trounce®*,Illico®*, Arsenal Xpress®*, Broadway®*)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

6.5.13 Specific guidelines for Group Z herbicides

Moderate resistance risk.

Group Z resistance exists in Australia in wild oats resistant to flamprop. Many of these flamprop-resistant wild oats also show cross-resistance to Group A herbicides. Resistance to endothal is confirmed in winter grass.

To assist in delaying the onset of resistance, rotate with herbicides from other MOAs. Consider using alternative methods of weed control to reduce weed numbers before applying herbicides. These may include summer crop rotations, delayed sowing to control wild oats with a knockdown herbicide, higher seeding rates and brown manuring to stop seed-set.

The recommendations should be incorporated into an IWM program. Try to ensure that surviving weeds from any treatment do not set and shed viable seed. Use integrated strategies, including rotation of MOA groups (Table 14).

Table 14: *Active ingredients of Group Z MOAs.*

Chemical family	Active constituent (first registered trade name)
Group Z. Herbicides with unknown and probably diverse sites of action	
Arylaminopropionic acids	Flamprop (Mataven L®)
Dicarboxylic acids	Endothal (Endothal®)
Organoarsenicals	DSMA (Methar®), MSMA (Daconate®)

*This product contains more than one active constituent
Source: CropLife Australia 'Herbicide Resistance Management Strategies—September 2011'

Refer to the APVMA website to obtain a complete list of registered products from the PUBCRIS database.

6.5.14 Herbicide use according to growth stage

It is important to consider growth stage of the chickpea crop before applying herbicides (Table 15).

Table 15: *Herbicide use according to growth stage in chickpeas.*

Herbicide	Use	Growth stage
Group A		
butroxydim	Do not graze or cut for stockfeed within 14 days of application	Vegetative growth stage, prior to flowering, podding and seven weeks prior to harvest
butroxydim + fluazifop	Up to seven weeks before harvest	Vegetative growth stage, prior to flowering, podding and seven weeks prior to harvest
clethodim	Up to full flowering	Vegetative growth stage, prior to flowering, podding
fluazifop	Up to seven weeks before harvest	Vegetative growth stage, prior to flowering, podding and seven weeks prior to harvest
haloxyfop	Second branch through to flowering	Vegetative growth stage, prior to flowering, podding
propaquizafop	Up to 12 weeks before harvest	Vegetative growth stage
sethoxydim	Up to prior to flowering	Vegetative growth stage, prior to flowering, podding
tepraloxydim	Up to 12 weeks before harvest	Vegetative growth stage
Group B		
flumetsulam	Apply from four to six branches and no later than six weeks after emergence	Vegetative growth stage

Source: DPI NSW

NOTE: For chickpea, 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 chickpea crop safety for most Group As is not influenced by growth stage up to at least flowering.

For up-to-date chemical Withholding Periods and other label information, see the APVMA search facility.

6.5.15 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, waterlogging, 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 (>10–15 km/hr) 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.
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. [14]

6.6 Summer fallow weed control

In a winter cropping system, the return on investment from managing weeds in summer fallow (i.e. the period between crops) is high. Economic benefits flow from both extra amounts of high value water and nitrogen, crop establishment benefits and reduced issues with weed vectored disease and insect pests.

Stopping weed growth in the fallow can lead to yield increases in the following crop via several pathways. These include:

- Increased plant available water
- A wider and more reliable sowing window
- Higher levels of plant available N
- Reduced levels of weed vectored diseases and nematodes
- Reduced levels of rust inoculum via interruption of the green bridge
- Reduced levels of diseases vectored by aphids that build in numbers on summer weeds, and
- Reduced weed physical impacts on crop establishment.

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

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

14 GRDC (2008) Grain Legume Handbook—Weed control

MORE INFORMATION

Summer fallow weed management for growers in the Southern and Western region

Shorter term management decisions can have an equal or even greater impact on how much plant available water (PAW) is stored at sowing. These include decisions such as crop sequence/rotation that dictate the length of the fallow and amount of stubble cover, how effectively fallow weeds are managed, stubble management and decisions to till/not to till at critical times.

While many factors influence how much plant available water is stored in a fallow period, good weed management consistently has the greatest impact. [15]

6.7 Double knock strategies

Getting the best bang for your buck

The use of glyphosate as the first knock followed within one to seven days with the second knock application of paraquat or paraquat + diquat is increasing in southern Australia. A well-timed and executed double knock is a very useful first step to reducing weed pressure and keeping a lid on glyphosate resistant annual ryegrass. Building the double knock treatment into a whole-of-season weed management plan provides opportunities to get more 'bang for your buck'.

The first knock is to kill all plants still susceptible to glyphosate—applying a lower rate risks higher survival rates, increasing the pressure on the second knock products. The second knock of Spray.Seed® or paraquat is to kill plants that survived the glyphosate. Reducing the rate of the second knock risks survival of potentially glyphosate resistant individuals and damages the integrity of the double knock tactic. Remember that paraquat and Spray.Seed® are contact herbicides and require robust water rates to ensure adequate coverage, and allow for losses on stubble.

If the main weed problem is annual ryegrass then using paraquat on its own as the second knock is an appropriate choice. If there are also broadleaf weeds present, then the paraquat + diquat combination (e.g. Spray.Seed®) will be more effective overall. Mixing the glyphosate and paraquat together is both ineffective and not registered. Applying the two sprays between one and seven days apart is optimum timing.

If there is a mix of weeds present it can be useful to include a compatible herbicide 'spike' such as 2-4D low volatile ester, carfentrazone, or oxyflouren to enhance control of broadleaf weeds. Be very mindful of plant-back requirements of some herbicide 'spikes' before planting sensitive crops such as pulses and canola.

Don't rely on a pre-sowing double knock alone. Use pre-emergent herbicides, and focus on increasing the level of crop competition with narrow row spacing and varieties with vigorous early growth. Sow crops at the optimal time to maximise competitiveness.

In weedy paddocks, consider the value of break crops such as pulses, canola, or hay as a way of incorporating other in-crop and non-chemical options to manage annual ryegrass, such as grass-selective post-emergent herbicides, crop-topping, desiccation, spraying under the swath or narrow windrow burning where appropriate. [16]

6.8 Pre-emergent herbicides

Pre-emergent herbicides are applied to the soil either before or directly after sowing and prior to weed emergence.

The pre-emergent herbicides alone will not adequately control large weed populations, and so they need to be used in conjunction with paddock selection and pre-seeding weed control.

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

16 WeedSmart. 2015. How can I get the best best for my buck with a double knock? http://www.weedsmart.org.au/ask-an-expert/how-can-i-get-the-best-bang-for-my-buck-with-a-double-knock/

Selection of the appropriate pre-emergent herbicide can only be made after assessing such factors as weed spectrum, soil type, farming system and local experience. For best results, refer to the complete product label for directions for use, application rates, weeds controlled and conditions.

Pre-sowing application is possible with some products and is often safer than post-sowing application, because the sowing operation removes a certain amount of the herbicide from the crop row. Higher rates can often be used pre-sowing, but in both cases the rate must be adjusted to soil type, as recommended on the product label.

6.8.1 Standard pre-sowing weed control practice—WA

Paddocks are generally selected at the end of a long cereal rotation where the pH is suitable for growing chickpeas. Ryegrass, wild turnip, mustard, wild radish and doublegee are generally the troublesome weeds to contend with. Standard pre-sowing weed control generally consists of a 'double knock' of glyphosate and Esteron™LV followed by Spray.Seed®, Diuron and Simazine or Terbuthylazine immediately before sowing (IBS), followed by Balance® Herbicide post sowing pre-emergent (PSPE). [17] Note that plant-back periods of 24D prior to planting can be an issue and that growers might want to reconsider adding this active ingredient unless specific in of the plant-back labels is mentioned. Table 16 lists products registered for pre-sowing application in kabuli chickpeas.

Table 16: *Registered herbicides for use with kabuli chickpea crops at pre-sowing stage (2005).*

Herbicide	Rate	Comments
Cyanazine (Bladex®)	2 L/ha	Pre-sowing. Most grasses and broadleaved weeds. May suppress rather than kill.
Simazine 50% flowable	1–2 L/ha	Pre-sowing or post-sowing pre-emergent. Most grasses and broadleaved weeds.

Source: DAFWA

6.8.2 Why use pre-emergent herbicides?

Pre-emergent herbicides are an essential part of a conservation farming system for a number of reasons:

- They can offer alternative modes of action to post-emergent knockdown herbicides.
- Many are very effective on hard-to-kill weeds such as annual ryegrass and barley grass.
- Pre-emergent herbicides control weeds early in crop life and potentially over multiple germinations, maximising crop yield potential.
- They suit a no-till seeding system with knife points and press wheels and/or disc seeders.
- They can be cost effective. [18]
- There is also limited options for post emergent weed control in pulses. [19]

Whilst pre-emergent herbicides can be used in conservation farming systems, they must be used in conjunction with herbicide/crop rotation management plans and other non-chemical weed control techniques (Figure 2). These methods usually aim to minimise weed seed production and may include fallows, crop rotations including pastures and/or cutting hay, burning full paddocks or windrows, chaff carts, and weed seed destructors. [20]

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17 Dow AgroSciences. http://msdssearch.dow.com/PublishedLiteratureDAS/dh_08bc/0901b803808bc88f.pdf?filepath=au/pdfs/noreg/012-10811.pdf&fromPage=GetDoc

18 Haskins, B. NSW DPI. Using pre-emergent herbicides in conservation farming systems.

19 Stuchbery J. (2016) Personal communication.

20 B Haskins. NSW DPI. Using pre-emergent herbicides in conservation farming systems.

Figure 2: *Trials have identified pre-emergent product combinations that provided significantly better control (right) than the district standard practice (left) for herbicide resistant annual ryegrass.*

Source: WeedSmart

6.8.3 Herbicide options

Chickpea is late maturing compared to other pulses, hence crop-topping to prevent ryegrass and other weed seed set is not often possible, even in the earliest of maturing varieties (e.g. GenesisTM 079). Chickpea is relatively slow to emerge with slow early growth during the colder winter months. As a consequence, it is a poor competitor with weeds. Even moderate weed infestations can cause large yield losses and harvest problems.

The weed control strategy for growing a successful chickpea crop depends on substantially reducing the viable weed seed bank in the soil before the crop emerges. Control the majority of weeds before seeding, either by cultivation or with knockdown herbicides such as glyphosate or Spray Seed®.

A technique used with varying success by growers has been to sow chickpea and then use a knockdown herbicide tank mixed with a pre-emergent herbicide to control germinating weeds before the crop emerges. Chickpea crops may take up to 21 days to emerge under cool, drying soil conditions but under favourable warm, moist soil conditions plants may emerge after 7 days. Growers considering this option should sow deeper (10–15 cm) and carefully check their paddocks for the emergence of the chickpea immediately before spraying. Done correctly, this can be an effective weed control option.

The pre-emergent herbicides will not adequately control large weed populations by themselves, and so they need to be used in conjunction with paddock selection and pre-seeding weed control. Incorporation by sowing (IBS) is generally considered safer on the crop than post-sowing pre-emergence with most herbicides used in modern no-till sowing systems. Most of these products work best if thoroughly incorporated with soil either mechanically or by irrigation or rainfall. The aim of incorporation is to produce an even band of herbicide to intercept germinating weed seeds.

Simazine is the most widely used herbicide for broadleaf weed control, and can provide relatively cheap control of cruciferous weeds. Efficacy is very dependent on receiving rainfall (20–30 mm) within 2–3 weeks of application, and consequently weed control is often disappointing under drier conditions.

Balance® (isoxaflutole) is a systemic herbicide belonging to the relatively new class of isoxazole herbicides (Group H). Balance provides more consistent and reliable control of susceptible weeds for longer and across a broader range of seasonal conditions. Ideally it is applied to a level seedbed post sowing pre emergence. This prevents rainfall moving herbicide treated soil into the furrows. Balance® is used specifically in chickpeas for broadleaf weed control in broadacre cropping situations. It provides a weed control option unique to chickpea and enables rotation of herbicide groups across the cropping sequence.

Terbyne is the newest triazine herbicide to be introduced in Australia and is registered for pre-emergent weed control in chickpeas, lupin, field peas, faba beans, lentils and triazine tolerant canola. Terbyne can be applied pre or post sowing.

Terbyne controls a wide range of broadleaf weeds, with some suppression of grasses, particularly if there is good soil moisture. Sufficient rainfall (20–30 mm) to wet the soil through the weed root zone is necessary within 2–3 weeks of application.

Spinnaker® (700 g/kg imazethapyr) works for the pre- or post-emergence control of certain weeds in centrosema (Cavalcade), chickpeas, faba beans, field peas, lucerne, mung beans, peanuts, serradella, soybeans and subterranean clover as per the directions for use table. On lighter sandy soils, some herbicide damage can be observed early in the crops growth.

In chickpea crops sown on wide rows, there is increasing adoption of 'directed sprays' of Broadstrike®, either alone or in tank-mixes with simazine. This largely avoids the problem of crop damage and improves weed control through the ability to safely add wetters or mineral oils to the spray mix.

While chickpea does have a degree of tolerance to glyphosate during the vegetative stage, caution is still required as the lower branches arising from the main stem contribute a large proportion of the total chickpea yield. Upright varieties such as Amethyst and Jimbour are more suited to this technique than the more prostrate types, and small chickpea plants are more susceptible to damage than older plants. [21]

Contact the Department of Agriculture, Western Australia (DAFWA) or your local consultant for up-to-date information on herbicide registrations.

An early series of trials were conducted to evaluate the selectivity of a range of herbicides in chickpeas (Table 17). Trifluralin had a narrow safety margin and rates in excess of 0.56 kg/ha were damaging. Pendimethalin produced similar damage at rate of 0.99 kg/ha and 1.98 kg/ha to trifluralin at rate of 0.84 kg/ha and 1.12 kg/ha. These herbicides reduced plant establishment by 15–38% with the greatest reduction at the higher rates. Where trifluralin reduced chickpea stands to below 40 plants/m^2 a significant yield reduction of 14.5% occurred. The wild oat herbicide triallate, was safe on chickpea at rate of up to 2.24 kg/ha. When trifluralin was added to triallate damage tended to be slightly worse than with trifluralin alone. [22]

Table 17: *Tolerance of chickpeas to pre-plant incorporation of herbicides.* [23]

Herbicide	Rate (kg a.i./ha)	No. of experiments (all harvested)	Significant reductions*	Average Yield (s.e.) (% site maximum)	Tolerance rating
Tri-allate	0.56-0.8	2	0	90.5 92.1)	T
	1.12-2.24	2	0	89.5 (9.2)	T
Pendimethalin	0.99	1	0	100	MT
	1.98	1	0	79	MS
Trifluralin	0.56	4	0	89.8 (5.0)	T-MT
	0.84	2	0	87.5 (4.9)	MT-MS
	1.12	2	1	85.5 (9.2)	MS
Trifluralin + Tri-allate	0.56+0.56	2	0	84.5 (12.0)	MT
Cyanazine+Trifluralin	2.0+0.40	1	0	89	T
Prodiamine	0.398	1	0	100	T
Unweeded control	-	4	1	86.3 (8.4)	
Handweeded control	-	3	0	96.3 (3.2)	-

* Number of experiments where yield < site maximum ($P = 0.05$)

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

22 G Kay, M, McMillan (1990) Pre and post emergent herbicides in chickpeas I. Crop tolerance. Proceedings of the 9th Australia Weed Conference.

23 G Kay, M, McMillan (1990) Pre and post emergent herbicides in chickpeas I. Crop tolerance. Proceedings of the 9th Australia Weed Conference.

6.8.4 Application

Most products work best if incorporated into soil, either mechanically or by irrigation or rainfall. The aim of incorporation is to produce an even band of herbicide to intercept germinating weed seeds. Some herbicide incorporation occurs when sowing is done with knife-points, provided sowing speed is adequate to throw soil into the inter-row without throwing into the adjacent seed furrow. Hence, these products are still compatible with the shift to minimum tillage and reduced-tillage farming practices. However, there may be insufficient soil throw with some low-disturbance, disc seeding systems. Typically, a follow-up, post-emergent grass weed herbicide is still required to provide the level of grass weed control desired by growers, particularly in the seed furrow.

WATCH: GCTV16: Spray application workshop.

WATCH: Over The Fence West: Summer weed management drives quality, yield returns.

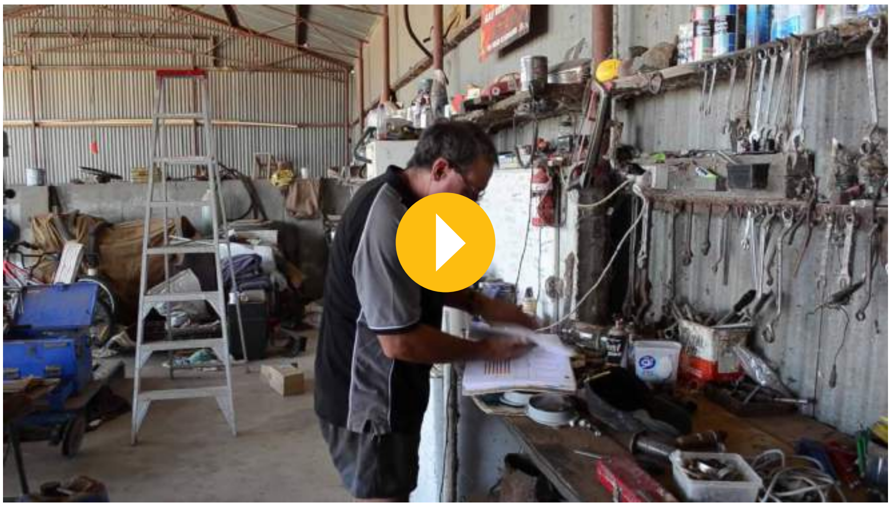


Table 18 lists products for application at sowing for kabuli chickpeas.

Table 18: *Registered herbicides for use with kabuli chickpea crops, to be incorporated at sowing stage (2005).*

Herbicide	Rate	Comments
Pendimethalin (Stomp®)	2 L/ha	Annual ryegrass and wireweed, and suppression of silvergrass and wild oat.
Triallate (e.g. Avadex®)	1.6 L/ha	Immediately before sowing. Wild oat.
Trifluralin (400 ai/L)	1–2 L/ha	Wire-weed, fumitory and annual ryegrass. Suppression of wild oat and brome grass.

Source: DAFWA

6.9 Post-plant pre-emergent herbicides

Post sowing pre-emergent (PSPE) is when a pre-emergent herbicide is applied after sowing (but before crop emergence) to the seedbed (Table 19).

These herbicides are primarily absorbed through the roots, but there may also be some foliar absorption (e.g. Terbyne®). 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. 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.

The absence of cost-effective and safe post-emergent herbicides effectively limits broadleaf weed control options in chickpea to a small number of pre-emergent herbicides. Most of these chemicals are very dependent on rainfall soon after application, and as a consequence often result in inconsistent or partial weed control under drier conditions. [24]

Table 19: *Registered herbicides for use with kabuli chickpea crops, post-sowing pre-emergent (after levelling the seeding furrows). (2005).*

Herbicide	Rate	Comments
Isoxaflutole (Balance®)	100 g/ha	Post-sowing pre-emergent. Mustard, radish and capeweed.
Simazine 50% flowable	1–2 L/ha	Most grasses and broadleaved weeds.
Metribuzin (Lexone®)	150–300 g/ha	Most grasses, brassicas, capeweed, doublegee, fumitory, toadrush, wireweed. Use lower rates on coarser textured soil types. Results from 2005 suggest that lower rates need to be used for Almaz⌽. Check rates – products vary in ai concentration.

Source: DAFWA

An early series of trials were conducted to evaluate the selectivity of a range of herbicides in chickpeas (Table 20). The herbicides which performed best under post-plant pattern were all triazines. In one experiment, mixtures with simazine were more damaging than herbicides applied alone at comparable total rate of the active triazine. Chickpea has consistently shown a high tolerance to registered herbicide cyanazine at rates up to 3.0 kg/ha and to prometryn at rates of 2.0 kg/ha or less. Damage symptoms were temporary and did not affect yields. Metribuzin was usually safe at a rate of 0.21 kg/ha but in one weed-free experiment a significant yield reduction occurred at this rate.

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

Table 20: *Tolerance of chikpea post-sowing, pre-emergence herbicides.* [25]

Herbicide	Rate (kg a.i./ha)	No. of experiments (all harvested)	Significant reductions*	Average Yield (s.e) (% site maximum)	Tolerance rating
Acifluorfen	0.224-0.896	7 (7)	0	93.8 (5.4)	T-MT
Atrazine	1.0	3 (3)	2	49.0 (40.0)	T
Cynazine	1.5	9 (8)	0	4.9 (4.9)	T
	2.0	5 (4)	0	88.0 (1.6)	T-MT
	3.0	1 (1)	0	98	T-MT
Dimethazone	0.9	1 (1)	1	59	HS
Imazaquin	0.3	1 (1)	1	41	HS
Imazethapyr	0.05-0.07	2 (2)	2	77.5 (3.5)	S
Linuron	1.5	1 (1)	0	92	MT
Methabenzthiazuron	1.75	2 (1)	0	94	T-MT
Metribuzin	0.21	10 (8)	2	88.9 (10.6)	T-MT
	0.28	3 (3)	3	61.0 (26.2)	MT-MS
	0.42	1 (1)	1	70	MS
Prometryn	0.75	3 (3)	0	95.3 (4.0)	T
	1.5	9 (8)	1	92.8 (5.8)	T
	2.0	2 (2)	0	94.5 (7.8)	T-MT
	3.0	1 (1)	0	87	MS
Simazine	0.75	6 (5)	1	87.8 (6.3)	T
	1.0	3 (3)	1	88.7 (1.2)	T
	1.25	1 (1)	1	85	T-MT
	1.5	6 (5)	2	87.0 (8.5)	T-MT
	2.5	1 (1)	1	55	MS
Terbutryn	2.0	2 (2)	1	78 (2.8)	T-MT
Cyanazine + metolachlor	2.0 + 1.44	1 (1)	0	82	T
Cyanazine + simazine	0.75-1.0+0.75	6 (5)	1	89.4 (8.7)	T-MT
Metribuzin + simazine	0.105-0.14+0.75	6 (5)	0	91.6 (6.2)	MT
Prometryn + simazine	0.75+0.75	6 (5)	1	91 (6.5)	T-MT
	1.5+0.75	3 (3)	0	89 (4.2)	MT
Unweeded control	-	13 (12)	5	76.9 (23.0)	-
Handweeded control	-	10 (9)	0	94.6 (4.7)	-

* Number of experiments where yield < site maximum (P = 0.05)

Results with simazine suggest that chickpeas were tolerant to rates less than 1 kg/ha (of active ingredient) but significant yield reductions due to poor weed control occurred at these rates in two experiments. Some variation was found on different soil types. In one trial on grey clay soils chickpea yield was reduced by 0.4 t/ha in the simazine 1.25 kg/ha treatment but on other soil types, no yield reduction occurred at 1.5 kg/ha. Damage symptoms developed slowly and usually increased as the season

25 G Kay, M, McMillan (1990) Pre and post emergent herbicides in chickpeas I. Crop tolerance. Proceedings of the 9th Australia Weed Conference.

progressed. Yield losses from simazine were greater than would be expected from visual damage ratings. [26]

More recently, the herbicide tolerance of two desi chickpea varieties (Howzat⁽ᴰ⁾ and ICCV96836) were compared to Tyson. All three varieties showed similar tolerance to a range of herbicides (Table 21). Simazine, Balance + Simazine and Spinnaker applied PSPE had little effect on yield, whereas Broadstrike applied Early Post Emergent on stressed plants it suppressed yield. For the main weeds in the trial (prickly lettuce, milk thistle) the best weed control option was Balance + Simazine. In paddocks where musk is a problem the best control option will be Spinnaker. [27]

Table 21: *Crop yields for three chickpea varieties following application of a range of herbicides.*

Herbicide	Cost $/ha	Tyson	Howzat⁽ᴰ⁾	ICCV96836
Control		1.3	1.1	1.2
Simazine 1L	6.25	1.6	1.5	1.4
Simazine 2L		1.8	1.7	1.6
Balance 100g + Simazine 1L	XXX	1.9	1.8	1.7
Balance 200g + Simazine 1L		2.0	1.8	1.8
Spinnaker 0.2L	22.00	1.7	1.6	1.5
Spinnaker 0.4L		1.6	1.4	1.4
Broadstrike 25g	14.50	1.1	1.2	1.1
Broadstrike 50g		0.9	0.9	0.9
Significant difference		P<0.001 LSD=0.2	P<0.001 LSD=0.2	P<0.001 LSD=0.1

Source: Online Farm Trials

See Section 6.12 Herbicide tolerance ratings for more information.

IN FOCUS

Effect of row spacing, nitrogen and weed control on crop and weed in a wheat—lupin or wheat—chickpea rotation in WA.

Key messages:

- Despite a very dry season in 2012, dimethenamid (e.g. Outlook®) herbicide in a chickpea crop was more effective on annual ryegrass than simazine in the two long-term rotational trials at Merredin.
- Sakura® reduced annual ryegrass head numbers more effectively than trifluralin at $N_2$5 and flexi N50 compared to N50 at Merredin.
- Grain yields of both crops at Merredin were very poor. Despite poor grain yields of crops at Merredin, yields of both crops were greater at 44 cm row spacing than at 22 cm row spacing.

In 2012, rotation trials of three years duration were initiated at Merredin (wheat – chickpea) to examine the effect of crop row spacing, herbicides and applied nitrogen (in wheat only) on crops and weeds. In the wheat – chickpea rotation at Merredin, wheat crop (cv. Wyalkatchem) was sown at two row spacings (22 cm and 44 cm) with two herbicides (trifluralin 2 L/

26 G Kay, M, McMillan. (1990). Pre and post emergent herbicides in chickpeas I. Crop tolerance. Proceedings of the 9th Australia Weed Conference.

27 Birchup Cropping Group. (2001). Herbicide tolerance of new chickpea varieties. Online Farm Trials. http://www.farmtrials.com.au/trial/13615

ha and Sakura® 118 g/ha) and three nitrogen treatments: $N_2$5 (25 kg N/ha drilled in front of tynes as urea), N50 (50 kg N/ha drilled in front of tynes as urea) and Flexi N50 (50 kg N/ha placed at about 7 to 8 cm depth as flexi N). Chickpea (cv. PB Slasher(b) was sown at two row spacings (22 cm and 44 cm) with two herbicides (simazine 2 L/ha and Outlook® (dimethenamid) 1 L/ha)). Both crops at Merredin were sown on 14 June 2012.

Results

The season of 2012 was very dry with significantly less than average rainfall during the growing season. During the 2012 growing season, the Merredin site had 60% of the average rainfall of 193 mm from April to September. As such crop growth, particularly wheat, was very poor.

Weed control: In the wheat crop, annual ryegrass was the main weed species but the average weed density of annual ryegrass was only 2 plants/m^2. This means that both herbicides effectively controlled annual ryegrass with no significant difference between trifluralin and Sakura®.

Despite no difference in initial weed control efficacy, Sakura® reduced annual ryegrass head numbers more effectively than trifluralin, particularly at $N_2$5 and flexi N50 compared to N50 (Figure 3). It may be possible that under low rainfall situations, surviving ryegrass plants had greater access to applied N at N50 than $N_2$5 or flexi N50, resulting in a greater number of annual ryegrass heads produced per unit area. No influence of crop row spacing was found on weed control.

In the chickpea crop, Outlook® controlled annual ryegrass plants measured at 4 weeks after emergence, more effectively than simazine (Outlook® 2 plants/m^2 versus simazine 8 plants/m^2 of annual ryegrass).

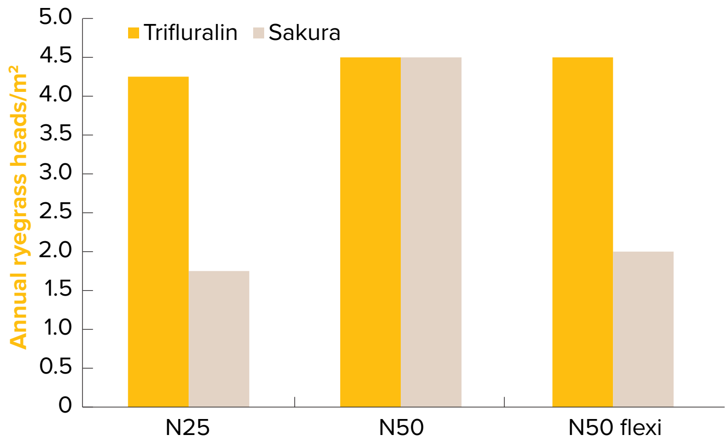


Figure 3: *Effect of herbicides and applied nitrogen on the head numbers of annual ryegrass in wheat, at seed filling stage of crop, at Merredin in 2012.* [28]

Crop grain yield: The overall grain yield of both wheat and chickpea crops was very low due to extremely poor crop growth. It was also too difficult to lift and harvest such a short crop with the harvester.

28 A Hashem, W Vance, R Brennan, R Bell (2013) DAFWA 2013 Crop Updates. Effect of row spacing, nitrogen and weed control on crop and weed in a wheat – lupin or wheat – chickpea rotation.

MORE INFORMATION

Wide rows and stubble management.

On the average, wheat grain yield was 257 kg/ha and chickpea grain yield was 90 kg/ha. Despite very poor crop growth, wheat and chickpea grain yields at 44 cm row spacing were significantly greater than at 22 cm, indicating the benefit of wide row cropping in low rainfall areas (data not presented). No effect of herbicides or applied nitrogen was found on wheat yield.

Conclusions

Rainfall was extremely low in the 2012 season, leading to very poor crop growth. Dimethenamid (e.g. Outlook®) herbicide was more effective on annual ryegrass than simazine in chickpea crops. Even though grain yields of crops were very low, yields of both crops at Merredin were greater at 44 cm row spacing than at 22 cm row spacing. These results show the benefit of wide row spacing in a dry season like 2012 in low rainfall areas such as Merredin. [29]

6.10 In-crop herbicides: knockdowns and residuals

Chickpea can be grown in wider rows in a stubble system that allows inter-row herbicide application with shielded sprayers.

Problem weeds or situations that require special attention include:

- Group A ('dims' and 'fops') resistant wild oats (and other grass species).
- Late germinations of weeds (e.g. ryegrass, brome grass) that would normally be prevented from setting seed in other pulses through croptopping.
- Snail medic, which can escape Balance®.
- hoary cress, soursob, tares, wild vetch, bedstraw, bifora, muskweed, wild radish and volunteer pulses [30]

Table 22 lists herbicides registered for use in kabuli chickpeas in WA.

Table 22: *Registered herbicides for use with kabuli chickpea crops, post-emergent (2005).*

Herbicide	Rate	Comments
Flumetsulam (Broadstrike®)	25 g/ha	Apply at the 4–6 leaf stage. Capeweed, doublegee, brassicas (suppression only).
Pyridate (Tough®)	2 L/ha	Capeweed, fumitory.
Fusion®, Select®, Motsa®, Fusilade®, Verdict®, Correct®, Shogun®, Targa®, Aramo®, Sertin®	—	A range of grass selective herbicides are available. Refer to label for use.

Source: DAFWA

Broadstrike® usually causes some transient crop yellowing and can cause reddish discoloration and height suppression. Flowering may be delayed (Figure 4), resulting in yield suppression.

29 A Hashem, W Vance, R Brennan, R Bell (2013) DAFWA 2013 Crop Updates. Effect of row spacing, nitrogen and weed control on crop and weed in a wheat – lupin or wheat – chickpea rotation.

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

Figure 4: *To control turnip weed, a single boom width of Broadstrike® was applied. Flowering and maturity of treated chickpeas (left) was delayed significantly, so they are still green compared with the untreated chickpeas that have matured (right).*

Photo: G Cumming, Pulse Australia

Broadstrike® is used mainly in salvage situations (as a last resort), and even then should be applied only under good growing conditions. Figure 5 depicts effective use of Broadstrike® against turnip weed adjacent to a chickpea crop.

With the shift into row-crop chickpeas, some growers are successfully using Broadstrike® as a directed spray into the inter-row area. This keeps a large proportion of the herbicide off the chickpea foliage and minimises crop damage.

Figure 5: *The same single boom width of Broadstrike® applied along the chickpea crop edge (centre) alongside the unsown, weedy headland (right) and untreated crop (far left). Broadstrike® did an excellent job on the turnip weed (centre and unsown front) compared with the untreated headland (right).*

Photo: G Cumming, Pulse Australia

6.10.1 Directed sprays

Though row-cropping chickpeas on wide rows in the Western region is less common, it provides an opportunity for the use of 'directed sprays' of Broadstrike®, either alone or in tank-mixes with simazine. This largely avoids crop damage and improves weed control through the ability to add wetters or mineral oils safely to the spray mix.

6.10.2 Shielded sprayers

Shielded sprayers are becoming increasingly more common in some areas, as they provide very cheap control of grass and broadleaf weeds with glyphosate. Although chickpea does have a degree of tolerance to glyphosate during the vegetative stage, caution is still required as the lower branches arising from the main stem make a large contribution to the total chickpea yield. Issues that need to be considered include:

- Selection and operation of spray shields (speed, nozzle type, etc.).
- Height of the crop (small chickpea plants are more susceptible).
- Variety (upright types are more suited to this technique than the more prostrate types). [31]

6.11 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
- 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 (Figure 6). 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 nitrogen
- 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

31 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited

Figure 6: *Boom spray on crop.*

Photo: Brad Collis, Source: GRDC

Ensure that grass weeds have fully recovered before applying grass herbicides.

Group A herbicides can occasionally cause leaf spotting in chickpea (Figure 7). This is usually associated with either frost or high temperatures occurring soon after spray application. [32]

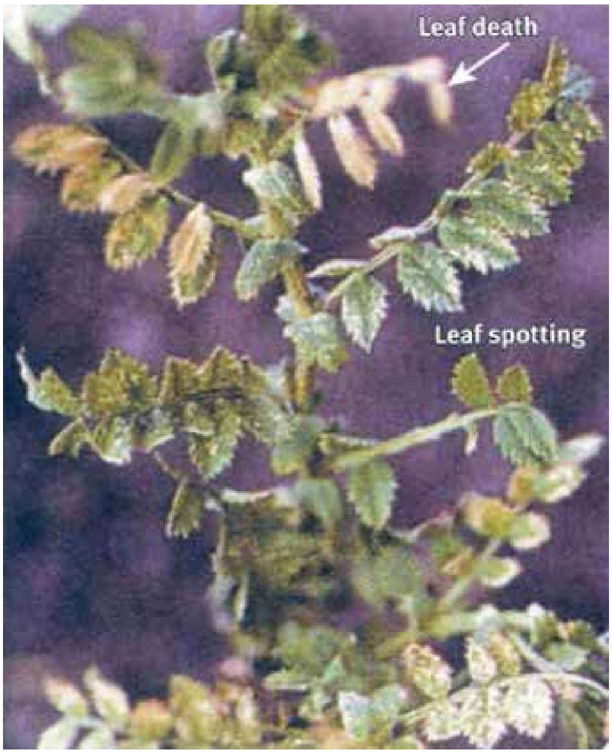


Figure 7: *Group A grass selective herbicide injury.*

Photo: T Bretag

32 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited

6.11.1 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.

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 <28°C.
- 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.

6.11.2 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.

6.11.3 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 23 is a guide to the more common herbicide active ingredients that are marketed with more than one formulation.

Table 23: *Relative herbicide volatility.*

Form of active	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 Amine 500 Low Odour®
2,4-D ipa	Isopropylamine salt	Surpass® 300
2,4-D tipa	Triisopropanolamine	Tordon® 75-D
2,4-DB dma	Dimethylamine salt	Buttress®
Dicamba dma	Dimethylamine salt	Banvel® 200
Triclopyr tea	Triethylamine salt	Tordon® Timber Control
Picloram tipa	Triisopropanolamine	Tordon® 75-D
Clopyralid dma	Dimethylamine	Lontrel® Advanced
Clopyralid tipa	Triisopropanolamine	Archer®
Aminopyralid K salt	Potassium salt	Stinger®
Aminopyralid tipa	Triisopropanolamine	Hotshot®
Other salts		
MCPA Na salt	Sodium salt	MCPA 250
MCPA Na/K salt	Sodium & potassium salt	MCPA 250
2,4-DB Na/K salt	Sodium & potassium salt	Buticide®
Dicamba Na salt	Sodium salt	Cadence®
SOME VOLATILITY		
Ester		
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	Meptyl ester	Starane® Advanced

Source: Mark Scott, former Agricultural Chemicals Officer, NSW Agriculture

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 24). 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.

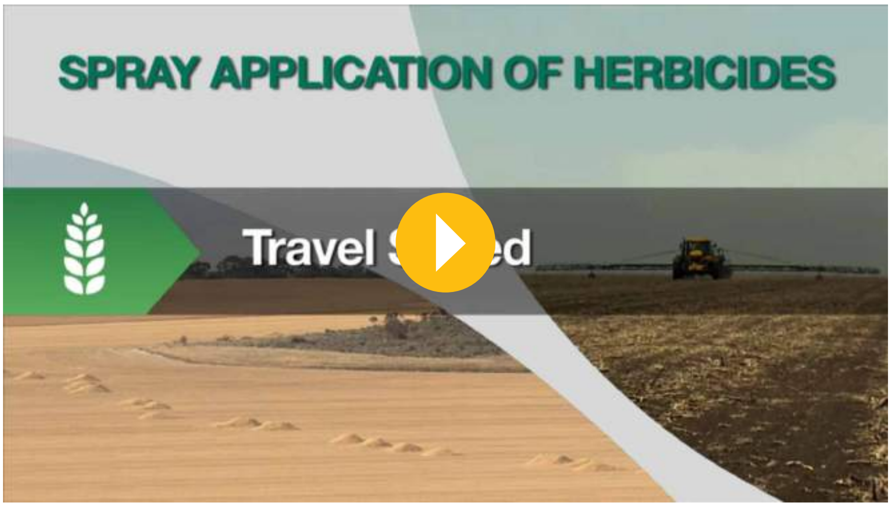
Table 24: *Nozzle selection guide for ground application.*
Volume median diameter (VMD): 50% of the droplets are less than the stated size and 50% greater. For flat-fan nozzle size, refer to manufacturers' selection charts as droplet size range will vary with recommended pressure; always use the lowest pressure stated to minimise the small droplets.

Distance downwind to susceptible crop	<1 km	1 to >30 km
Risk	High	Medium
Preferred droplet size (British Crop Protection Council) (to minimise risk)	Coarse to very coarse	Medium to coarse
Volume median diameter (µm)	310	210
Pressure (bars)	2.5	2.5
Flat-fan nozzle size	11,008	11,004
Recommended nozzles (examples only)	*Raindrop:* Whirljet® *Air induction:* Yamaho Turbodrop®, Hardi Injet®, AI Teejet®, Lurmark Drift-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. Require higher spray volumes	Suitable for grass control at recommended pressures. Some fine droplets

Adapted from P Hughes, DPI, Queensland
Source: DPI NSW

WATCH: Nozzle Selection

WATCH: Travel Speed



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.

WATCH: Spray deposition

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.

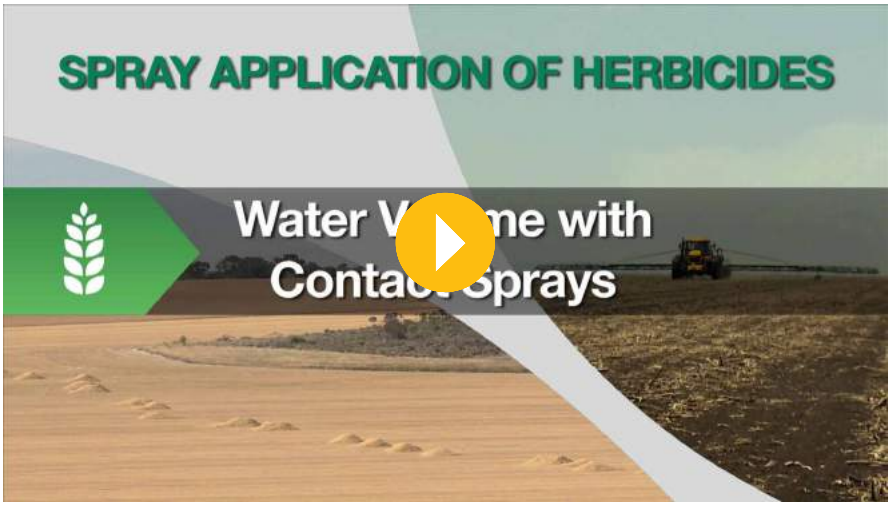
Capture surface

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.

WATCH: Water volume with contact sprays



WATCH: Application volume in stubble

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 (ΔT) 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 <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.)

Inversions

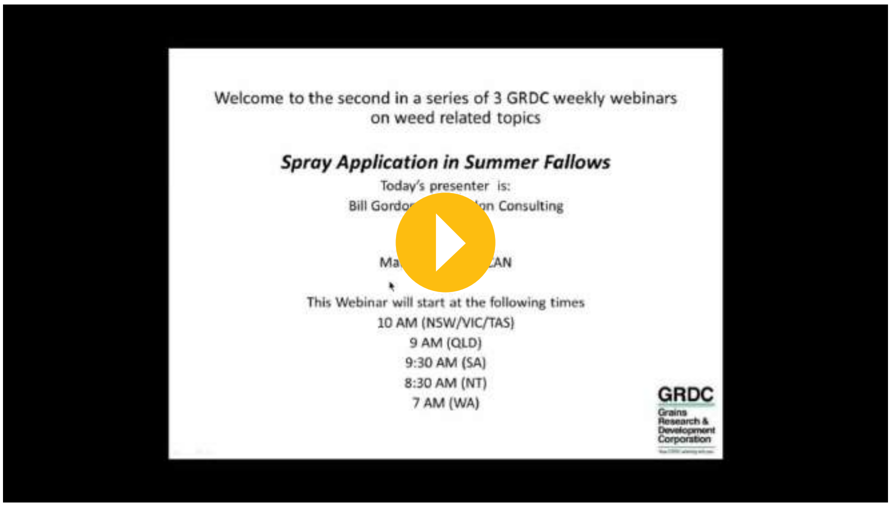
The most hazardous condition for herbicide spray drift is an atmospheric inversion, especially when combined with high humidity. An inversion exists when temperature increases with altitude instead of decreasing. An inversion is like a cold blanket of air above the ground, usually less than 50 m thick. 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'. [33]

WATCH: Advances in weed management—Webinar 2—Spray application in summer fallows



6.12 Herbicide tolerance ratings

Within many broad acre crop species, cultivars have been found to vary in sensitivity to commonly used herbicides and tank mixes, thereby resulting in potential grain yield loss, and hence reduced farm profit. With funding from GRDC and State Government Agencies across Australia, a series of cultivar by herbicide tolerance

33 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

MORE INFORMATION

Cultivar herbicide tolerance trial protocols

National Variety Trials

trials are conducted annually. The trials aim to provide grain growers and advisers with information on cultivar sensitivity to commonly used in-crop herbicides and tank mixes for a range of crop species including chickpeas, lupins, peas, lentils and faba beans. The intention is to provide data from at least two years of testing at the time of wide scale commercial propagation of a new cultivar. [34]

IN FOCUS

Herbicide tolerance of new chickpea varieties 2013 trial report, WA

Summary: Simazine, Outlook® and Balance® at the label rates were tolerated well with good crop safety margin, by all the varieties. Terbyne® and Lexone® registered low crop safety margin across all the varieties. Broadstrike® (with basal simazine or Terbyne®) reduced grain yield of Neelam⦻ and CICA 1016 (Table 25).

Table 25: *Trial details.*

Property	Darrin Lee's, Mingenew – Morawa Road.
Soil type (0–10 cm)	Red loam with soil pH 5.5 ($CaCl_2$) and organic carbon 0.67%
Crop/varieties	Chickpea, varieties - Neelam⦻, PBA Striker⦻ and CICA 1016
Paddock rotation	2012: wheat
Treatments	See Table 2
Replicates	Three with systematic untreated control plots
Plot size	12 m x 1.1 m. To convert plot yield to kg/ha, 1.8 m plot width used (plot to plot centre)
Seed treatment before sowing	P-Pickle T 200 mL/100 kg seed
Sowing date	17 May 2013
Seeding rate	120 kg/ha
Fertiliser	17 May 2013–seeding: DAP 70 kg/ha
Rhizobium inoculation	ALOSCA® group N granular inoculant 10 kg/ha applied with seed
Seeding machinery	Coneseeder with knife points and press wheels followed by rollers
Seeding depth	4–5 cm
Soil moisture at seeding (Gravimetric method)	7% (0–10 cm), 11% (10–20 cm)
Herbicide application machinery	Spray rig fitted with Teejet AIXRI11002 nozzles which produce very course droplets and 80 L/ha water volume used
Treatment application dates	16 May 2013–pre-seeding 22 May–immediately post plant/post seeding pre-emergence (IPP/PSPE) 13 June: 4–6 nodes

34 Ramsey C, Wheeler R, Churchett J, Walker S, Lockley P, Dhammu H, Garlinge J. (2010). Cultivar herbicide tolerance trial protocols. http://www.nvtonline.com.au/wp-content/uploads/2013/02/Herbicide-Tolerance-Protocols.pdf

Property	Darrin Lee's, Mingenew – Morawa Road.
Blanket spray(/s)	27 June 2013: Select® 0.5 L/ha and Bravo® 1.5 L/ha 26 August 2013: Bravo® 1.5 L/ha 10 September 2013: Dimethoate 400 mL/ha
Harvesting date	8 November 2013
Growing season rainfall	392 mm (May to October) 8% higher than the last five years' average (2009–13)

Source: DAFWA

Higher than label rates of the herbicides were included in the trial to determine the crop safety margin of the herbicides at the maximum label rates.

Good crop safety margin means that a herbicide at its maximum label rate and at the higher rate was tolerated well by a crop variety.

Whereas, a narrow crop safety margin for a particular herbicide indicates that the variety tolerated the maximum label rate well, but at higher than the label rate there was significant yield loss.

A low or narrow crop safety margin also implies that when spraying at the label rate under less than optimal conditions, herbicide damage and yield loss may occur.

For example, when: overlapping herbicide, spraying under wet conditions (for soil active and residual herbicides) or when there are stressed plants due to abiotic/biotic factors.

Table 26: *Effect of herbicides on grain yield (% of control) of chickpea varieties at Mingenew during 2013.*

Number	Herbicides	Rate/ha	Timing	Neelam⦸ grain yield (kg/ha)	PBA Striker⦸ grain yield (kg/ha)	CICA 1016 grain yield (kg/ha)
0 (untreated control)	–	–	–	100 1,267	100 1,457	100 1,212
1	Simazine 500	2.0 L	PS1	99.0	103.3	106.1
2	Simazine 500	Higher rate	PS1	108.2	102.9	107.8
3	Terbyne® (Terbuthylazine)	1.4 kg	PS1	95.0	96.5	100.7
4	Terbyne®	Higher rate	PS1	85.8*	83.7*	89.9*
5	Outlook® (Dimethenamid-P)	1 L	PS1	102.1	100.4	105.4
6	Outlook®	Higher rate	PS1	96.3	98.2	110.0
7	Simazine fb2 Balance®	1.5 L + 100 g	PS fb IPP/PSPE3	101.0	102.4	97.6
8	Simazine fb2 Balance®	1.4 kg + 100 g	PS fb IPP/PSPE3	97.0	93.7*	98.8

Number	Herbicides	Rate/ha	Timing	Neelam⟑ grain yield (kg/ha)	PBA Striker⟑ grain yield (kg/ha)	CICA 1016 grain yield (kg/ha)
9	Balance® (Isoxaflutole)	100 g	IPP/PSPE3	102.5	99.6	107.0
10	Balance®	Higher rate	IPP/PSPE3	97.9	97.4	102.6
11	Lexone® (Metribuzin)	280 g	IPP/PSPE3	92.6*	99.5	99.0
12	Lexone®	Higher rate	IPP/PSPE3	84.2*	85.2*	88.7*
13	Simazine fb2 Broadstrike®	2.0 L + 25 g	PS fb 4–6 nodes	89.3*	94.6	94.8
14	Simazine fb2 Broadstrike®	1.4 kg +25 g	PS fb 4–6 nodes	87.7*	96.2	90.3*

1PS = pre-seeding,
2 fb = followed by,
3 IPP/PSPE = immediately post plant/post seeding pre-emergence
* Figures are significantly lower than the untreated control. The names in parentheses are the herbicide chemical names.
Broadstrike = Flumetsulam. Simazine 500 2 L = Simazine 900 1.1 kg

Source: DAFWA

Results

The effect of herbicides during early crop growth stages, at flowering and on grain yield (Table 26, above) of chickpea varieties was as follows:

- Simazine and Terbyne® at the higher rate, applied before crop seeding, caused around 10–15% necrosis across all the varieties. These symptoms were outgrown by the time crop reached flowering stage; however, Terbyne® (at the higher rate) resulted in significant yield reduction across all varieties.
- Lexone® at the higher rate, applied PSPE, caused visible necrosis and yellowing across all the varieties and the yellowing or light green colour continued to be visible up to flowering stage. This treatment also recorded around 20% less pods (per plant or on area basis) and resulted in significant yield loss across the varieties.
- Lexone® at the label rate also registered significant yield loss in Neelam⟑.
- Balance® at 100 g/ha and at the higher rate continued to be safe to all the varieties.
- Simazine 1.5 L/ha or Terbyne® 1.4 kg/ha applied pre-seeding followed by Balance® at 100 g/ha PSPE were also safe to all the varieties except that the Terbyne® and Balance® combination caused significant yield loss in PBA Striker⟑.
- Broadstrike® at 25 g/ha applied at 4–6 node stage (with basal simazine 2 L or Terbyne® 1.4 kg/ha) caused significant yield loss in Neelam⟑ and CICA 106.

Conclusion

Simazine, Outlook® and Balance® were tolerated well with good crop safety margin by all the varieties.

Lexone® (Metribuzin) and Broadstrike® (especially sequential application with simazine) results were in line with the previous results.

Terbyne® at 1.4 kg/ha registered low crop safety margin for all the varieties. These results are contrary to the previous three years' results.

During 2010 at Mingenew on sandy loam soil, Simazine at the higher rate caused significant yield loss across all the varieties under heavy rainfall situations that filled the seeding furrows soon after seeding. In that trial Terbyne® at the label and the higher rate was safe to all varieties. [35]

WATCH: GCTV16: Pulse Herbicide Tolerance.

6.13 Monitoring

Monitoring of weed populations before and after any spraying is an important part of management:

- Keep accurate records.
- Monitor weed populations and record results of herbicide used.
- If herbicide resistance is suspected, prevent weed seed-set.
- If a herbicide does not work, find out why.
- Check that weed survival is not due to spraying error.
- Conduct your own paddock tests to confirm herbicide failure and determine which herbicides remain effective.
- Obtain a herbicide resistance test on seed from suspected plants, testing for resistance to other herbicide (MOA) groups.
- Do not introduce or spread resistant weeds in contaminated grain or hay.

Regular monitoring is required to assess the effectiveness of weed management and the expected situation following weed removal or suppression. Without monitoring, we cannot assess the effectiveness of a management program or determine how it might be modified for improved results. Effective weed management begins with monitoring weeds to assess current or potential threats to crop production, and to determine best methods and timing for control measures.

Regular monitoring and recording the details of each paddock allows the grower to:

- spot critical stages of crop and weed development for timely cultivation or other intervention;

35 H Dhammu, DAFWA (2015) Herbicide tolerance of new chickpea varieties 2013 trial report. https://www.agric.wa.gov.au/chickpeas/herbicide-tolerance-new-chickpea-varieties-2013-trial-report?page=0%2C0

- identify the weed flora (species composition), which helps to determine best short- and long-term management strategies; and
- detect new invasive or aggressive weed species while the infestation is still localised and able to be eradicated.

Watch for critical aspects of the weed-crop interaction, such as:

- weed seed germination and seedling emergence;
- weed growth sufficient to affect crops if left unchecked;
- weed density, height, and cover relative to crop height, cover, and stage of growth;
- weed impacts on crops, including harbouring pests, pathogens, or beneficial organisms; or modifying microclimate, air circulation, or soil conditions; as well as direct competition for light, nutrients, and moisture;
- flowering, seed-set, or vegetative reproduction in weeds; and
- efficacy of cultivations and other weed management practices.

Information gathered through regular and timely field monitoring helps growers to select the best tools and timing for weed-control tactics. Missing vital cues in weed and crop development can lead to costly efforts to rescue a crop—efforts that may not be fully effective. Good paddock scouting can help the grower to obtain the most effective weed control for the least fuel use, labour cost, chemical application, crop damage and soil disturbance.

6.13.1 Tips for monitoring

To scout weeds, walk slowly through the paddock, examining any vegetation that was not planted. In larger paddocks, walk back and forth in a zigzag pattern to view all parts of the paddock, noting areas of particularly high or low weed infestation. Identify weeds with the help of a good weed guide or identification key for your region, and note the weed species that are most prominent or abundant. Observe how each major weed is distributed through the paddock. Are the weeds randomly scattered, clumped or concentrated in one part of the paddock?

Keep records in a field notebook. Prepare a page for each paddock or crop sown, and take simple notes of weed observations each time the paddock is monitored. Over time, your notes become a timeline of changes in the weed flora over the seasons and in response to crop rotations, cover crops, cultivations and other weed control practices. Many growers already maintain separate records for each paddock. Weed observations (species, numbers, distribution, size) can be included with these.

When to scout, and what to look for in a new paddock or farm

When purchasing farmland, it is important to look at the weeds. Presence of highly aggressive or hard-to-kill weeds, intense weed pressure, stressed and nutrient-deficient weeds, or a weed flora indicative of low or unbalanced soil fertility or pH or salt may foretell problems that should be considered when deciding whether to buy or rent, or how much to offer.

During your first year or two on a new farm or paddock, study the weeds carefully throughout the season, and be sure to get correct identification of the 5–10 most common weeds.

Note the weeds that emerge, grow or reproduce at different times of the annual cropping cycle:

- over winter
- after primary tillage and during seedbed preparation
- after crop planting
- during crop growth and maturation
- after harvest
- over summer or during cover crop emergence and establishment

Questions to ask include:

- What are the main weed species present at different times of year?
- When does each weed species emerge, flower, and set seed?
- What paddocks or areas have the worst weed pressure? The least?

6.14 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.

Leaching

Some soil active herbicides used for weed control in pulses can damage crops where conditions favour greater activity and leaching.

Herbicides move more readily in soils with:

- low organic matter
- 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. The pH of a soil can also strongly influence the persistence of herbicides. Many labels have warnings about high pH (≥8.0) and the need to reduce application rates to avoid crop damage. Heavy rainfall following application may cause crop damage. This will be worse if the crop has been sown shallow (less than 3-5 cm), where there is light soil and where the soil surface is ridged. The soil surface should not be ridged as this can lead to herbicides being washed down and concentrated in the crop row. [36]

Whilst trifluralin is relatively immobile in the soil, Boxer Gold may move from the point of placement, particularly in sandy soils prone to leaching. Therefore care must be taken in soils with a higher leaching potential and where previous history has shown potential for damage from herbicides with a higher leaching index such as Dual Gold, metribuzin and the triazine herbicides. [37]

Metribuzin leaches at almost three times the rate of simazine and seven times the rate of diuron. The relative tolerance of the crop type and variety will also affect crop damage from these herbicides. For example, lupins are more tolerant to simazine than are the other pulses. For more specific details on soil active herbicides and the risk of crop damage in your cropping situation seek advice from an experienced agronomist.

Herbicide 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.

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 (Figure 8). The risk of residue damage is greater in the presence of grass-selective herbicides. 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.

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36 GRDC (2008). Grain Legume Handbook – Weed control.

37 Douglas A. (2008) Weeds Update, Western Australia.

Figure 8: *Hygiene between spraying operations is essential. After using herbicide, make sure the boom spray is cleaned out with chlorine before starting on grass control in legumes. The effect, as shown above, is dramatic.*

Source: GRDC

Spray Drift

Pulse crops can be severely damaged by some herbicide sprays, such as 2,4-D ester, drifting into the crop (Figure 9). 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 neighbouring pulse crop. [38]

38 GRDC (2008). Grain Legume Handbook—Weed control.

Figure 9: *Severe metsulfuron-methyl damage in chickpea plants.*

Source: DAFQ in Crop IT

6.14.1 Avoiding herbicide damage

Some herbicides can severely damage chickpea crops through residues in soil, contaminants in spray equipment, spray drift onto the crop or by incorrect use of the herbicide.

The importance of cleaning and decontaminating spray equipment before the application of herbicides cannot be overstressed. Traces of sulfonylurea herbicides (such as chlorsulfuron, metsulfuron or triasulfuron) in spray equipment can cause severe damage to chickpea and other legumes when activated by grass control herbicides.

Taking some general precautions can help to reduce the likelihood of crop damage with residual herbicide use at planting:

- Do not apply residual herbicides if rain is imminent.
- Maintain at least 7.5–10 cm soil coverage.
- Avoid leaving a furrow or depression above the seed that could allow water (and chemical) to concentrate around the seed or seedling.
- Avoid leaving an exposed, open slot over the seed with disc-openers and avoid a cloddy, rough tilth with tined-openers. [39]

6.14.2 Plant-back intervals

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

Some herbicides have a long residual. The residual is not the same as the half-life. Although the amount of chemical in the soil may break down rapidly to half the original amount, what remains can persist for long periods (e.g. sulfonylureas (chlorsulfuron)). This is shown in the Table 27 and 28 where known. Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the "Protection of crops etc." heading in the "General Instructions" section of the label.

MORE INFORMATION

Field crop herbicide injury: The Ute Guide

Chickpea Disorders: The Ute Guide

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

Part of the management of herbicide resistance includes rotation of herbicide groups. Paddock history should be considered. Herbicide residues (e.g. sulfonyl urea, triazines etc.) may be an issue in some paddocks. Remember that plant-back periods begin after rainfall occurs. [40]

Table 27: *Residual persistence of common pre-emergent herbicides, and note residual persistence in broad-acre trials and paddock experiences.* [41]

Herbicide	Half-life (days)	Residual persistence and prolonged weed control
Logran® (triasulfuron)	19	High. Persists longer in high pH soils. Weed control commonly drops off within 6 weeks.
Glean® (chlorsulfuron)	28-42	High. Persists longer in high pH soils. Weed control longer than Logran.
Diuron	90 (range 1 month to 1 year, depending on rate)	High. Weed control will drop off within 6 weeks, depending on rate. Has had observed longlasting activity on grass weeds such as black/stink grass (Eragrostis spp.) and to a lesser extent broadleaf weeds such as fleabane.
Atrazine	60–100, up to 1 year if dry	High. Has had observed long lasting (>3 months) activity on broadleaf weeds such as fleabane.
Simazine	60 (range 28–149)	Med./high. 1 year residual in high pH soils. Has had observed long lasting (>3 months) activity on broadleaf weeds such as fleabane.
Terbyne® (terbulthylazine)	6.5–139	High. Has had observed long lasting (>6 months) activity on broadleaf weeds such as fleabane and sow thistle
Triflur® X (trifluralin)	57–126	High. 6–8 months residual. Higher rates longer. Has had observed long lasting activity on grass weeds such as black/stink grass (Eragrostis spp.).
Stomp® (pendimethalin)	40	Medium. 3–4 months residual.
Avadex® Xtra (triallate)	56–77	Medium. 3–4 months residual.
Balance® (isoxaflutole)	1.3 (metabolite 11.5)	High. Reactivates after each rainfall event. Has had observed long lasting (> 6 months) activity on broadleaf weeds such as fleabane and sow thistle.
Boxer Gold® (prosulfocarb)	12–49	Medium. Typically quicker to break down than trifluralin, but tends to reactivate after each rainfall event.
Sakura® (pyroxasulfone)	10–35	High. Typically quicker breakdown than Trifluralin and Boxer Gold, however, weed control persists longer than Boxer Gold.

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

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

Table 28: *Minimum re-cropping intervals and guidelines (NOTE: always read labels to confirm).*

Group and type	Product	pH (H2O) or product rate (ml/ha) as applicable	Minimum re-cropping interval (months after application), and conditions
B, sulfonyl urea (SU)	Chlorsulfurons eg Glean®, Seige®, Tackle®	<6.5	3 months
		6.6–7.5	3 months, minimum 700 mm
		7.6–8.5	18 months, minimum 700 mm
B, sulfonyl urea (SU)	triasulfuron, eg Logran®, Nugrain®	7.6–8.5	12 months, >250 mm grain, 300 mm hay
		>8.6	12 months, >250 mm grain, 300 mm hay
B, Sulphonamide	Flumetsulam eg Broadstrike®		0 months
B, sulfonyl urea (SU)	metsulfuron eg Ally®, Associate®	5.6–8.5	1.5 months
		>8.5	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area.
B, sulfonyl urea (SU)	Metsulfuron + thifensulfuron Eg Harmony® M	7.8–8.5 Organic matter >1.7%	3 months
		>8.6 or organic matter <1.7%	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area.
B, sulfonyl urea (SU)	Sulfosulfuron eg Monza®	<6.5	0 months
		6.5–8.5	10 months

Source: Pulse Australia

Herbicides with long residuals can affect subsequent crops, especially if they are effective at low levels of active ingredient, such as the sulfonylureas. On labels, this will be shown by plant-back periods, which are usually listed under a separate plant-back heading or under the "Protection of crops etc." heading in the "General Instructions" section of the label. [42]

Conditions required for breakdown

Warm, moist soils are required to breakdown most herbicides through the processes of microbial activity. For the soil microbes to be most active they need good moisture and an optimum soil temperature range of 18°C to 30°C. Extreme temperatures above

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

MORE INFORMATION

Avoiding crop damage from residual herbicides

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.

For up-to-date plant-back periods, see Weed control in winter crops.

6.15 Herbicide residues

Pulse growers need to be aware of possible herbicide residues that may affect crop rotation choices or cause crop damage. Herbicide residue impacts are more pressing where rainfall has been minimal. After a dry season, herbicide residues from previous crops could influence choice of crop and rotations more than disease considerations. The opposite occurs after a wet year.

Pulse crop types differ in their sensitivity to residual herbicides, so check each herbicide used against each pulse type. 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.

Picloram (e.g. Tordon® 75-D) residues from spot-spraying can stunt any pulse crop grown in that area. This damage is especially marked in faba beans, where plants are twisted and leaves are shrunken. In more severe cases, bare areas are left in the crop where this herbicide had been used, in some cases more than five years ago. Although this damage is usually over a small area, correct identification of the problem avoids confusion and concern that it may be some other problem such as disease.

In wheat–chickpea rotations, the use of fallow and in-crop residual herbicides such as Broadstrike®, Eclipse®, Flame® Grazon®DS, Lontrel® and metsulfuron (Ally®, Associate®, Lynx®) Harmony®M should be avoided.

The use of long-term residual sulfonylurea herbicides such as Monza®, chlorsulfuron (Glean®, Lusta®), and Logran® in wheat should be avoided when re-cropping to chickpeas. [43]

Stay up to date with chemical labels and recommendations by visiting the APVMA and PubCRIS websites.

6.15.1 Sulfonylurea residues, Group B

Sulfonylurea products include:

- metsulfuron (Ally®, Associate®, Lynx®)
- thifensulfuron plus metsulfuron (Harmony®M)
- sulfosulfuron (Monza®)
- chlorsulfuron (Glean®, Lusta®, Logran®)

Usually, Glean® or Logran® damage is not serious when these products are used as directed, although there is an increased risk of damage given:

- very dry or drought conditions;
- highly alkaline (pH >8.5) soils; or
- excessive overlapping during application.

Sulfonylurea breakdown occurs by hydrolysis, and is favoured by warm, moist conditions in neutral to acid soils. Residues will tend to persist for longer periods under alkaline and/or dry conditions. Persistence of residues is greater for Glean® and Logran®, than for Ally® or Harmony®M.

Residues are root absorbed and translocated to the growing points; therefore, both roots and shoots are affected.

43 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Moderate residue levels

Plant emergence will be patchy, and the first true leaves elongated and narrow. Plants remain stunted, with severe chlorosis of the uppermost leaves (Figure 10).

Figure 10: *Yellowing of new growth (left) and plant stunting (right).*

Photo: A Storrie, NSW DPI

Seedlings develop symptoms as the roots reach the sulfonylurea residue layer in the soil. This may occur in the early seedling stage on heavy clay soils, or slightly later on light sandy soils due to movement of residues down the soil profile. Symptoms are often more severe where there is soil compaction, e.g. in wheel tracks.

Symptoms include:

- Spear-tipping of lateral roots (root pruning).
- Yellowing of uppermost leaves, which can progress to older, lower leaves in severe cases.
- Development of zinc-deficiency symptoms—narrow, cupped leaves.
- Stunted growth.

Highly sensitive crops (in order of susceptibility)

- lentils
- chickpea (0.5 ppb)

Highly susceptible indicator weeds

- brassicas (turnip, mustard, radish)
- red pigweed, mintweed
- native jute
- parthenium weed
- paradoxa grass

Strategy

Avoid using Glean® or Logran® on very high pH soils (pH >8.5) if you intend growing chickpea after wheat. Reassess risk if Glean® or Logran® has been used and drought conditions have been experienced during the wheat crop and in the subsequent fallow. [44]

44 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

6.15.2 Imidazolinone (imi) residues, Group B

Imidazolinone products include:

- imazapic + imazapyr (Midas®, OnDuty®)
- imazamox + imazapyr (Intervix®)
- imazapic (Flame®)
- imazethapyr (Spinnaker®, various imazethapyrs)
- imazamox (Raptor®)

Figure 11: *Spinnaker injury to the emerging new chickpea growth.*

Photo: G Cumming, Pulse Australia

Imazethapyr (e.g. Spinnaker®) can be damaging (Figure 11). Damage from residues of other 'imi' products should not be serious when used as directed, although there is an increased risk of damage where:

- plant-back periods or rainfall requirements are not adhered to;
- very dry or drought conditions have prevailed (often 150–200 mm rainfall required);
- soils are highly alkaline (pH >8.5);
- extensive overlapping has occurred during application; or
- heavy rainfall after application concentrates treated soil in plant furrows.

Persistence of imi residues is greater for Intervix® and Midas® or OnDuty® than for Flame®.

Residues are root-absorbed and translocated to the growing points; therefore, both roots and shoots are affected.

Moderate residue levels

Plant emergence will be patchy, and the first true leaves elongated and narrow. Plants remain stunted, with severe chlorosis of the uppermost leaves.

Low residue levels

Seedlings develop symptoms as the roots hit the imi residue layer in the soil. This may occur in the early seedling stage on heavy clay soils, or slightly later on light sandy soils due to movement of residues down the soil profile. Symptoms are often more severe where there is soil compaction, such as in wheel tracks.

Symptoms include:

- Spear-tipping of lateral roots (root pruning).
- Yellowing of uppermost leaves, which can progress to older, lower leaves in severe cases.
- Development of zinc-deficiency symptoms—narrow, cupped leaves.
- Stunted growth.

Highly sensitive crops (in order of susceptibility)

- conventional canola
- lentil
- safflower
- oats

Strategy

Avoid using imi products on very acidic soils if you intend growing chickpeas after a Clearfield® wheat or canola in an area with marginal rainfall. Reassess risk if imi products have been used and drought conditions have been experienced during the prior wheat, canola crop or fallow. Be wary of using imi products in short-term chemical fallows or for summer weed control where chickpeas are to be sown. [45]

6.15.3 Triazine residues (atrazine), Group C

Chickpeas have some tolerance to very low rates of atrazine, but triazine carry-over from previous crops should be avoided (see Figure 12). Atrazine significantly increases the frost sensitivity of the crop. Risk of damage increases where there are low levels of subsoil moisture. Crops in this situation are largely surface-rooted and vulnerable to damage when there is herbicide recharge after each rainfall event.

Figure 12: *Narrowing of the leaflets and multiple branching are signs of triazine residues (left). Similar distortion is seen in the roots (right).*

Photo: G Cumming, Pulse Australia

Atrazine breakdown is strongly influenced by soil type and climatic conditions. Rates of breakdown slow considerably under dry conditions, and can stop altogether under drought.

Atrazine is more persistent under the following conditions:

- alkaline soils (especially pH >8.0)
- increasing clay content (i.e. black earths)
- low soil temperatures
- low soil moisture levels.

Atrazine is root-absorbed and translocated up into the shoots, where it accumulates and inhibits photosynthesis. Plants usually emerge, but begin to show symptoms of stunting and chlorosis at 2–6 weeks of age. Atrazine initially accumulates in the tips and margins of the lower leaves. This results in bleaching and necrosis of the leaf

45 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

margins. Plants are often stunted and plant growth is slow. Other Group C herbicides such as diuron and fluometuron cause similar symptoms, mainly on the older, lower leaves.

Highly susceptible indicator weeds

- mintweed (turnip, mustard, radish)
- brassicas
- black pigweed [46]

6.15.4 Group I

Products include:

- 2,4-D products (amines, esters)
- dicamba (e.g. Cadence®)
- triclopyr (e.g. Garlon®)
- fluroxypyr (e.g. Lontrel®)

Residues of 2,4-D persist for a relatively short period, and they can be overlooked. Figure 13 shows residual damage from 2,4-D. Table 29 shows the plant-back period for various rates of products. The most important value here is the minimal rainfall requirement prior to sowing. In 2006 there was significant 2,4-D damage in chickpea resulting from an application of a 2,4-D product as a late fallow spray and/or knockdown spray prior to sowing. The re-cropping interval was not the cause; rather, the damage was due to not having received the minimal rainfall requirement of 15 mm before this period commenced. [47]

Figure 13: *Residual 2,4-D damage, showing narrowing and thickening of leaflets on younger growth.*

Photo: J Flemming, NSW DPI

46 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

47 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Table 29: *Chickpea plant-back intervals and conditions after spikes in Group I knockdown herbicides.*

Active Ingredient	Products	Rates (/ha)	Period	Comments
2,4-D	2,4-D amine (625 g/L)	Up to 0.56 L	7 days	At least 15 mm of rain must fall prior to commencement of the plant-back period
	2,4-D ester (800 g/L)	Up to 0.35 L		
	Baton® (800 g/kg) (amine)	Up to 0.4 kg		
	2,4-D amine (625 g/L)	0.56–1.1 L		
	2,4-D ester (800 g/L)	0.35–0.7 L	14 days	
	Surpass® (300 g/L) (amine)	1.1–2.3 L		
	Baton® (800 g/kg) (amine)	0.4–0.9 kg		
	2,4-D amine (625 g/L)	1.1–17 L		
	2,4-D ester (800 g/L)	0.7–1.1 L	21 days	
	Surpass® (300 g/L) (amine)	2.3–3.4 L		
	Baton® (800 g/kg) (amine)	0.9–1.3 kg		
	Cadence®	140 g		
Dicamba (700 g/kg)	Cadence®	200 g	Not determined	When applied to dry soil, at least 15 mm of rainfall is required prior to commencement of the plant-back period
	Dicamba 500	400 g	21 days	
		200 mL	28 days	
Dicamba (500 g/L)	Dicamba 500	280 mL	Not determined	
	Garlon® 600, Invader® 600	560 mL	21 days	
	Safari® 600	Up to 160 mL	28 days	
Triclopyr (600 g/L)	Starane® 200, Flagship®	Up to 375 mL	7 days	
Fluroxypyr (200 g/L)			7 days	

Source: Pulse Australia

6.15.5 Group I residual herbicides

Products include:

- clopyralid (Lontrel®)
- picloram (Tordon® 75-D, Tordon® 242, Grazon® DS)
- aminopyralid + fluroxypy (e.g. Hotshot®)

These products are used for in-crop or fallow weed control and can persist for long periods under dry conditions. Lontrel® is used in canola, wheat, barley, triticale and oats, so care with a subsequent chickpea crop is required. It can persist on crop stubble for long periods and then it can become activated when leached into the soil following rainfall. Lontrel® is being used more often for residual control of fleabane. Picloram residues are relatively stable in the soil, with residues fixed onto clay particles and remaining concentrated in the top 10–15 cm of soil. Residues are slowly broken down by microbial action, with decomposition slowing during the colder, winter months. Up to 25% of the applied dose can persist for up to 12 months, or longer under very dry conditions.

Some symptoms of low-level residue damage are not always readily visible in chickpeas, for example:

- retarded, slow growth;
- thickening and callousing of the lower stem, usually just above ground level, which can be accompanied by cracking and splitting of the stem in more severe cases; or
- proliferation of short, lateral roots.

There may also be some slight twisting and bending of the main stem. Higher rates of residue can also affect leaf shape, with a narrowing and thickening of leaflets. A severe reaction may cause cupping and stunting of leaflets.

Strategy

Avoid using Lontrel® or Grazon® DS in the fallow period prior to chickpeas. [48]

> *Caution needs to be taken when using Lontrel before cereal and canola crops. Make sure to adhere to re-cropping guidelines, and be cautious of rate and stubble retention.*

Agronomist's view

6.15.6 Management of herbicide residues in the soil

Using soil-persistent herbicides can provide very effective weed control; however, issues can arise when sensitive crops are planted in the next season. The main factors that influence whether crop damage occurs are: rainfall from application to sowing, temperature when the soil is wet, soil pH, soil organic matter, the sensitivity of the crop to the herbicide, and the relative persistence of the herbicide in the soil. Risk of damage to subsequent crops is greatest when conditions after application are dry from spring until autumn.

Herbicides can be broken down by chemical and/or microbial means. Both require moisture and temperature to be effective. Herbicides break down more slowly in winter when moisture may be available, but temperatures are low. In a Mediterranean climate, there is usually little or no herbicide breakdown over summer, where temperature is high, but there is no moisture available in the top soil. Most herbicide breakdown will occur in spring and autumn.

To achieve sustained breakdown of herbicides, the top 2 cm of the soil needs to be moist for a period of seven days or more. This is because in summer, the soil microbes shut down due to lack of water and it takes time for their populations to build up again. Small rainfall events in summer will be quickly evaporated from the topsoil, so as a general rule the rainfall events of less than 10 mm in summer should not be counted towards the amount of rainfall required for herbicide breakdown. It is those larger events, typically those of 25 mm or more, which will contribute most to herbicide breakdown.

Soil type and soil pH are also important, as they will affect how far the herbicide moves down the soil profile. Most of the microbial activity occurs in the top few centimetres of the soil and if the herbicide moves below this layer, it may be broken down more slowly. For example, sulfonylurea herbicides are much more mobile in alkaline soils, and this contributes to their longer persistence in alkaline soils. Soil organic matter is important as it provides food for the microbes. Microbial populations are typically smaller in soils with low organic matter than in those with higher organic matter.

48 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Following a dry spring and summer, it is generally those large rainfall events in autumn that do most of the work in breaking down herbicides. The larger these events are and the earlier they occur, the lower the risk of crop damage. One added risk is that the first large rainfall event after a long dry summer will release herbicides into the soil water quickly. Planting too soon after that first large rainfall event can result in greater crop damage than waiting for a week to sow. The re-cropping intervals on product labels are a good guide to the likely risks of crop damage. When in doubt, it is good practice to sow a more tolerant crop. [49]

6.16 Herbicide resistance

Herbicide resistance fact box

- Resistance is the inherited ability of an individual plant to survive and reproduce following a herbicide application that would kill a 'wild type' individual of the same species.
- Thirty-six weed species in Australia currently have populations that are resistant to at least one herbicide mode-of-action (MOA).
- As at June 2014, Australian weed populations have developed resistance to 13 distinct MOAs (click here for up to date statistics).
- Herbicide-resistant individuals are present at very low frequencies in weed populations before the herbicide is first applied.
- The frequency of naturally resistant individuals within a population will vary greatly within and between weed species.
- A weed population is defined as resistant when a herbicide at a label rate that once controlled the population is no longer effective (sometimes an arbitrary figure of 20% survival is used for defining resistance in testing).
- The proportion of herbicide resistant individuals will rise (due to selection pressure) in situations where the same herbicide MOA is applied repeatedly and the survivors are not subsequently controlled.
- Herbicide resistance in weed populations is permanent as long as seed remains viable in the soil. Only weed density can be reduced, not the ratio of resistant-to-susceptible individuals. The exception is when the resistance gene(s) carry a fitness penalty so that resistant plants produce less seed than susceptible ones, but this is rare. [50]

Herbicide resistance is the inherited ability of an individual plant to survive a herbicide application that would kill a normal population of the same species. During the 1940s and '50s, Australian agriculture relied heavily on the use of broad-spectrum pesticides to control pests. Selective herbicides began to appear in the mid-1970s and have been a fundamental tool for cropping and pasture since. However, as reliance on chemicals has grown over the years we are continuing to see more weeds that have developed resistance to herbicides. In other words, a number of chemicals that we have available to us have become less useful. Herbicide resistance was first recognised in Australia in 1981 where some annual ryegrass developed resistance to diclofop-methyl (Figure 14). [51]

49 GRDC Update Papers. (2016). Can we beat grass weeds or will they beat us. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/08/Can-we-beat-grass-weeds-or-will-they-beat-us

50 GRDC. Integrated weed management hub – Section 1: Herbicide resistance. https://grdc.com.au/Resources/IWMhub/Section-1-Herbicide-resistance

51 Agriculture Victoria. HERBICIDE RESISTANCE AND INTEGRATED WEED MANAGEMENT (IWM) IN CROPS AND PASTURE MONITORING TOOLS. http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/herbicide-resistance

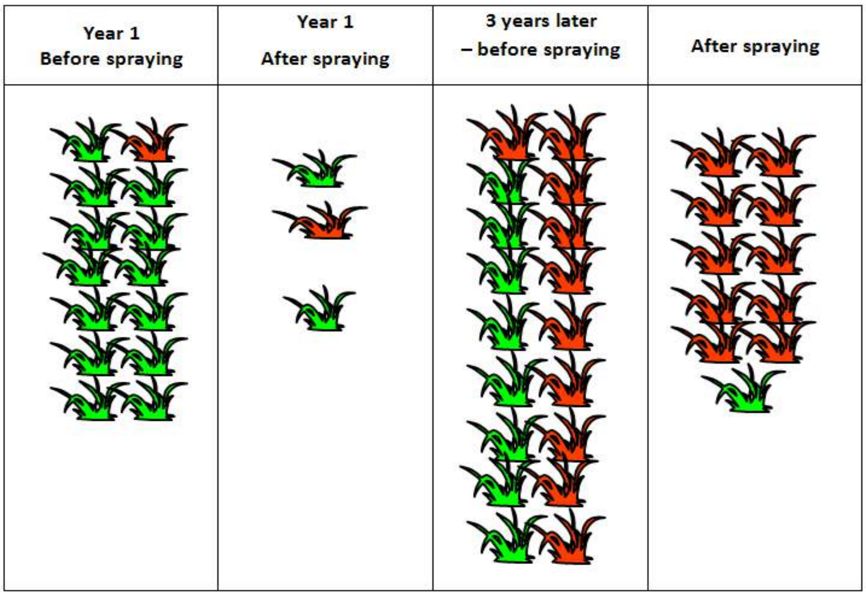


Figure 14: *How a weed population becomes resistant to herbicides.*

Source: GRDC

Herbicide use since the 1980s has seen the development of herbicide resistance across Australia in a range of cropping weeds, including annual ryegrass, wild oats, Indian hedge mustard, wild radish, wild turnip, and prickly lettuce as well as barley grass and capeweed (Table 30). Herbicide resistance is a major threat to Australian grain growers, but whilst herbicide resistance is here to stay, it need not spell the end of profitable cropping. Delaying the onset and/or reducing the impact of herbicide resistant weed populations calls for the implementation of a wide range of weed control strategies, that will in turn help sustain profitable grain production. [52]

Table 30: *Resistance status of a number of weeds. Note: Resistance status will vary from paddock to paddock and not all populations have these characteristics.*

Weed species	Resistance status
Annual Ryegrass *(Lolium rigidum)*	Very high resistance to Group A (e.g. Diclofop) and Group B herbicides (Sulfonylureas). Some resistance to Group D (Trifluralin) and Glyphosate (Group M herbicides).
Wild Oat *(Avena fatua)*	Diclofop-methyl (Group A herbicides) resistance Resistance to Group K (flamprop-methyl)
Barley grass (*Hordeum leporinum*)	Paraquat and Diquat resistance
Capeweed *(Arciotheca calendula)*	Paraquat and Diquat resistance
Barnyard Grass *(Echinochloa crus-galli)*	Resistance to Group C herbicides
Wild Radish	Resistance to chlorosulfron has increased threefold over last four years. Some resistance to Atrazine and 2, 4-D-amine.
Brome grass (*Bromus spp.*)	Resistant to Group A (Verdict) and Group B imi resistance.
Indian hedge mustard, prickly lettuce, wild turnip, sow thistle, black bindweed, silvergrass, summer grass, salvation jane.	New additions of resistant weeds with resistance to one or more groups of herbicides.

Source: AgVic

52 GRDC (2008). Grain Legume Handbook – Weed control

Annual ryegrass herbicide resistance

A number of weed species have developed resistance to herbicides. Of the greatest concern is Annual Ryegrass (*Lolium rigidum*) because it has developed cross-resistance to a number of different herbicide groups. Annual Ryegrass is one of the most significant weeds for cropping enterprises—and we are rapidly running out of chemical options to deal with it. Table 31 shows the resistance status of Annual Ryegrass to a number of Group A, B, D, and M herbicides—a herbicide program made up of two to three years use of any of these can fail due to cross resistance. Resistance to trifluralin is increasing rapidly.

Table 31: *Estimated number of herbicide applications before resistance develops.*

Product	Low ryegrass number	High ryegrass numbers
Group A	7 to 10	4
Group B		4
Group D (trifluralin)	15	10
Group L		12
Group M		15
Double Knock		30 +

Source: PIR.SA

Thirty-six weed species in Australia currently have populations that are resistant to at least one herbicide 'mode of action' (MOA) group (Figure 15).

Figure 15: *Pots of annual ryegrass tested for plyphosate resistance; susceptible (left) and strongly resistance (right).*

Photo: Peter Boutsalis, Source: DAFWA

Herbicide resistance is normally present at very low frequencies in weed populations before the herbicide is first applied. Variation exists within every population, with some individuals having the ability to survive the herbicide application.

A weed population is defined as resistant when a herbicide that once controlled the population is no longer effective (sometimes an arbitrary figure of 20% survival

MORE INFORMATION

DAFWA – Herbicide resistance.

is used). The proportion of herbicide resistant individuals will rise due to selection pressure in situations where one herbicide MOA group is applied repeatedly. [53]

Glyphosate resistance

Glyphosate resistance was first documented for annual ryegrass (Lolium rigidum) in 1996 in Victoria. Since then glyphosate resistance has been confirmed in 11 other weed species (Figure 16).

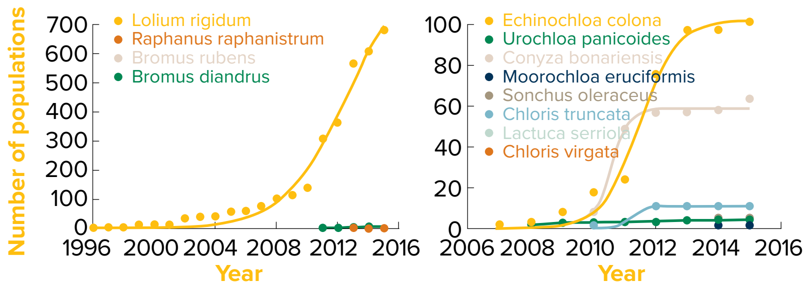


Figure 16: *Increase in confirmed cases of Glyphosate resistance in winter weeds (left) and summer weeds (right) between 1996 and 2016.*

Source: AGSWG

Resistance is known in eight grass species and four broadleaf species. There are four winter-growing weed species and eight summer-growing weed species. The latter have been selected mainly in chemical fallows and on roadsides.

The most number of resistant populations is for annual ryegrass (Tables 32 and 33) followed by barnyard grass and then fleabane.

Table 32: *Number of Glyphosate resistance weed populations recorded in WA.*

Glyphosate resistant weed	Number of population found in WA
Annual ryegrass	164
Barnyard grass	1
Windmill grass	1

Source: AGSWG

53 DAFWA (2016) Herbicide resistance. https://www.agric.wa.gov.au/grains-research-development/herbicide-resistance?page=0%2C0

Table 33: *Glyphosate resistant annual ryegrass has occurred in the following situations.*

Situation		Number of Sites	States
Broadacre cropping	Chemical fallow	34	NSW
	Winter grains	393	WA, SA, Vic, NSW
	Summer grains	1	NSW
	Irrigated crops	1	SA
Horticulture	Tree crops	10	SA, NSW
	Vine crops	25	WA, SA
	Vegetables	2	Vic
Other	Driveway	6	WA, SA, Vic, NSW
	Fenceline/crop margin	91	WA, SA, Vic, NSW
	Around buildings	2	NSW
	Irrigation channel/drain	14	SA, Vic, NSW
	Airstrip	1	SA
	Railway	2	WA, NSW
	Roadside	95	WA, SA, NSW
	Pasture	1	WA

Source: AGSWG

All of the glyphosate resistant weed populations have occurred in situations where there has been intensive use of glyphosate, often over 15 years or more, few or no other effective herbicides used and few other weed control practices are used. This suggests the following are the main risk factors for the evolution of glyphosate resistance:

- Intensive use of glyphosate—every year or multiple times a year for 15 years or more.
- Heavy reliance on glyphosate for weed control.
- No other weed controls. [54]

WATCH: GCTV9: Glyphosate resistant weeds.

54 Australian Glyphosate Sustainability Working Group (2016) Glyphosate resistant weeds in Australia. http://glyphosateresistance.org.au/RegisterSummary.pdf

An evaluation of farming systems in low rainfall areas has found that (Table 34):

- As cropping intensity increased, higher average returns are possible, but it is imperative to reduce the number of ryegrass to a very low level prior to, or as soon as possible in the rotation and then using a full range of practices to keep the number low.
- The initial reduction in ryegrass numbers must be carried out with as little selection for resistance as possible. Selective herbicide can be used without the population of ryegrass increasing its resistance if spray topped or green manured before seed set.
- To avoid the build-up in resistance to Group M (glyphosate), the additional cost of the double knock system is justified, particularly in more intensive systems that rely on glyphosate for early weed control in rotations.
- Ryegrass numbers also compete strongly with the crop limiting yield and returns (Figure 17).

Table 34: *Percent Ryegrass Control with different management treatments.*

Treatment	Average % Control Resistant Population	Average % Control
Trifluralin	30 to 40	80
Trifluralin + Avadex	75	85
Boxer Gold	80 to 90	80 to 90
Sakura	80 to 90	80 to 90
Double knock (application of glyphosate followed by Sprayseed three days later)	40%	40%
Crop topping		75%
Spray topping (low rate of paraquat or glyphosate) at flowering / milky dough		70%
Brown manure (high rate of glyphosate)		95%
Hay cutting		85%
Stubble burning – grazed		40%
Stubble burning – standing stubble ungrazed		75%
Windrow burning in canola, lupins and beans	85	85% plus
Wheat stubbles from < 2.5 t/ha grain crops		85% plus
Burning chaff dumps		90%
Seed catching		60%
Harrington seed destructor		95%

Source: PIR.SA

Figure 17: *Glyphosate resistant annual ryegrass in crop paddock.*

Source: GRDC

6.16.1 Practices to minimise herbicide resistance

The threat of herbicide resistance does not mean that herbicides should not be used; however, it does mean farmers should avoid over reliance on herbicides that have the same action on plants ('mode of action'). All herbicide labels now indicate what herbicide group the active ingredient belongs to. Cases of glyphosate resistance in annual ryegrass and of paraquat resistance in barley grass in direct-drill cropping systems sounds a warning on heavy reliance on even 'low risk' herbicides.

Growers should aim to use as many different methods of weed control as practical in the overall paddock management including the following:

- rotation of cultivation and herbicide groups
- crop competition
- use of knockdown
- pasture topping herbicides for seedset
- hay making preparation
- grazing
- burning
- seed capture
- crop-topping
- weed wiping (short crops)

Care must be taken when introducing control methods into the overall paddock plan. For example, weed numbers, especially resistant populations, can increase dramatically under pulses due to the poor competition offered by these crops.

Monitoring of weed populations before and after spraying is an important management tool.

Field testing and/or seed testing, as well as planning management strategies, can provide a guide to the resistance status of weed populations. [55]

55 GRDC (2008). Grain Legume Handbook – Weed control

6.16.2 WeedSmart farming

The Australian grain industry stands at a crossroads. Which direction will it take?

One road leads to every grower making herbicide sustainability their number one priority, so that it influences decision -making and practices on all Australian grain farms. Armed with a clear 10–point–plan for what to do on-farm, grain growers have the knowledge and specialist support to be WeedSmart.

On this road, growers are capturing and/or destroying weed seeds at harvest. They are rotating crops, chemicals and modes of action. They are testing for resistance and aiming for 100% weed kill, and monitoring the effectiveness of spray events.

In addition, they are not automatically reaching for glyphosate, they do not cut on-label herbicide rates, and they carefully manage spray drift and residues. Growers are planting clean seed into clean paddocks with clean borders. They use the doubleknock technique and crop competitiveness to combat weeds.

On this road, the industry stands a good chance of controlling resistant weed populations, managing difficult-to-control weeds, prolonging the life of important herbicides, protecting the no-till farming system, and maximising yields.

The other road leads to growers thinking that resistance is someone else's problem, or an issue for next year, or something they can approach half-heartedly. If herbicide resistance is ignored, it will not go away. Managing resistance requires an intensive, but not impossible, effort. Without an Australia-wide effort, herbicide resistance threatens the no-till system, land values, yields and your hip pocket. It will drive down the productivity levels of Australian farms.

WeedSmart 10-point plan

1. Act now to stop weed seed set

- Research and plan your WeedSmart strategy.
- Understand the biology of your weeds.
- Be strategic and committed.

2. Capture weed seeds at harvest

- Consider your options—chaff cart, narrow windrow burning, baling, Harrington Seed Destructor.
- Compare the financial cost per hectare.

3. Rotate crops and herbicide modes of action

- Protect the existing herbicide resource.
- Repeated application of effective herbicides with the same MOA is the single greatest risk factor for herbicide resistance evolution.

4. Test for resistance to establish a clear picture of paddock-by-paddock farm status

- Resistance continues to evolve.
- Sample weed seeds prior to harvest for resistance testing.

5. Never cut the rate

- Always use the label rate.
- Weeds resistant to multiple herbicides can result from below the rate sprays.

6. Don't automatically reach for glyphosate

- Consider diversifying
- Consider post-emergent herbicides where suitable.
- Consider strategic tillage.

7. Carefully manage spray events

- Use best management practice in spray application.
- Patch spray area of resistant weeds if appropriate
- No escapes

8. Plant clean seed into clean paddocks with clean borders

MORE INFORMATION

WeedSmart website.

- Plant weed-free crop seed
- The density, diversity, and fecundity of weeds is generally greatest along paddock borders and areas such as roadsides, channel banks and fencelines.

9. Use the double knock technique

- Any combination of weed control that involves two sequential strategies
- A second application to control survivors from the first

10. Employ crop competitiveness to combat weeds

- Increase your crop's competitiveness to win the war against weeds.
- Row spacing, seeding rate, and crop orientation can all be tactics to help crops fight. [56]

6.16.3 Testing for herbicide resistance

There are a number of different methods of testing for herbicide resistance. Tests can be performed in situ (in the paddock during the growing season), on seed collected from the suspect area, or by sending live plant samples to a testing service.

Testing can be conducted on-farm or by a commercial resistance testing service.

In-situ testing

An in-situ test can be performed following herbicide failure in a paddock. The test should be done at the earliest opportunity, remembering that the weeds will be larger than when the initial herbicide was applied. Test strips should be applied using herbicide rates appropriate to the current crop growth stage and weed size, plus a double rate. The test strips should only be applied if the weeds are stress free and actively growing. To more accurately assess the level of control, conduct weed plant counts before and after application. Green or dry plant weights can be calculated for more accurate results.

Herbicide resistance seed tests

Seed tests require collection of suspect weed seed from the paddock at the end of the season. This seed is generally submitted to a commercial testing service.

There are two commercial seed testing services in Australia:

- Peter Boutsalis, Plant Science Consulting
- John Broster, Charles Sturt University, +61 (0)2 6933 4001

Approximately 3,000 seeds of each weed (an A4-sized envelope full of good seed heads) are required for a multiple resistance test. This equates to about one cup of annual ryegrass seed and six cups of wild radish pods.

Syngenta herbicide resistance Quick-Test™

The Syngenta herbicide resistance Quick-Test™ (QT) uses whole plants collected from a paddock rather than seeds, eliminating the problem of seed dormancy and enabling a far more rapid turnaround time. In addition, the tests are conducted during the growing season rather than out of season over the summer. A resistance status result for a weed sample is possible within 4–6 weeks. The QT, which was developed by Dr Peter Boutsalis while working for Syngenta in Switzerland, is patented in Australia.

For each herbicide to be tested, 50 plants are required. To reduce postage costs, plants can be trimmed to remove excess roots and shoots. Upon arrival at the testing service, plants are carefully trimmed to produce cuttings and transplanted into pots. After appearance of new leaves (normally 5–7 days), plants are treated with herbicide in a spray cabinet. The entire procedure, from paddock sampling to reporting results, takes between 4–6 weeks, depending on postage time and the herbicides being tested. Unlike paddock tests, the QT is performed under controlled conditions, so it is not affected by adverse weather conditions. The age of the plants is also less critical

56 WeedSmart 10 point plan. http://www.weedsmart.org.au/10-point-plan/

to the testing procedure. Trimming the plants prior to herbicide application means that herbicides are applied to actively growing leaves, thus mimicking chemical application to young seedlings. The Quick-Test™ has been used to test resistance in both grass and broadleaf weed species. During testing, both known sensitive and resistant biotypes are included for comparison.

Quick-Tests can be done with Peter Boutsalis, Plant Science Consulting. [57]

6.17 Grazing for weed control

Grazing is an alternative non-chemical option in weed control (Figure 18). Most weeds are susceptible to grazing. Weed control is achieved through reduction in seed-set and competitive ability of the weed. The impact is optimised when the timing of the grazing is early in the life cycle of the weed.

Figure 18: *Sheep grazing crop in Condingup, WA.*

Photo: A Fowler, Source: GRDC

Plants vary in their palatability, and under the 'right' stocking rate, animals will selectively graze the more palatable plants. This knowledge is useful when previously grown crops volunteer in the sown crop and herbicides are not available, or their use would damage the crop. For example, graze peas in a chickpea crop. The relative palatability for some crops has been determined by the University of Adelaide and is shown in Table 35. The palatability was rated as: highly palatable (most of the crop eaten) or low palatability (very little of the crop eaten).

For best results:

- Introduce sheep early, before crop canopy closes.
- Use older sheep.
- Use low stocking rates.
- Spray weeds along fence line to concentrate sheep in crop.
- Remove sheep before they do much damage to crop.
- Remove sheep before flowering.

Observe grazing withholding periods if any chemicals are used in crop. [58]

57 DAFWA (2016) Herbicide resistance. https://www.agric.wa.gov.au/grains-research-development/herbicide-resistance?page=0%2C0

58 GRDC (2008) Grain Legume Handbook—Weed control

Table 35: *Relative palatability of various crops to sheep.*

Highly palatable	Moderately palatable	Low palatability
9 weeks after sowing		
Field peas, lathyrus, fenugreek, lentils, canola, wheat, safflower, lupin, blanchefleur and Languedoc vetch.	Chickpeas	Coriander, faba bean, narbon bean
13 weeks after sowing		
Field peas, lathyrus, canola	Lentils, lupins	Chickpeas, coriander, faba beans, narbon bean, fenugreek

Source: GRDC

6.17.1 Grazing stubbles or failed crops

When putting stock onto crop stubbles or failed crops, there are several considerations, the most important being:

- pulpy kidney
- acidosis, also known as grain poisoning
- nitrates or cyanides in weeds
- wind erosion of soil, and
- withholding periods.

Some simple actions can overcome these issues:

- Ensure that stock have had their 5-in-1 vaccinations and boosters.
- Pulpy kidney is the weakest of the vaccines in 5-in-1, and it is cheap insurance to vaccinate again.
- Ensure that stock have a full rumen prior to going onto a crop.
- This can be easily done by providing hay or stubble as gut-fill.
- This will avoid over gorging on weeds or grain and give the rumen time to adjust to the change in feed.
- Spread large piles of grain out to minimise excessive intakes and risk of acidosis.
- Double-check previous crop chemical treatments and make sure all withholding periods are met before introducing stock.
- Slowly introduce stock to feed by allowing increasing periods over a week, starting with two hours.

Watch stock closely for the first week to ensure no problems occur, including unpalatability, which will result in decreased intake and loss of condition. [59]

59 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Insect control

Key messages

- Native budworm (*Helicoverpa punctigera*) is a major pest of pulse crops in the south west of Western Australia.
- Chickpea is highly susceptible to native budworm. Crops need to be monitored from flowering through to pod fill. Small grubs less than 1 cm are damaging. Economic threshold for control can be as low as 1 grub per 10 sweeps of a sweep net.
- The crop will need to be sprayed with an appropriate insecticide if caterpillars are present and pods have started to form.
- Regular monitoring will help determine whether the crop needs to be sprayed. An insecticide application will be necessary if one caterpillar is found in 10 sweeps of the crop. Sweeps should be made while walking through the paddock and consist of a standard sweep of around two metres, sampling the top 15 cm of the crop canopy.
- Synthetic pyrethroids are most effective for native budworm control and will prevent reinfestation for up to six weeks after application.
- Chickpeas are less susceptible to red legged earth mite, lucerne flea and aphids than other pulses, though these pests should be monitored and controlled. [1]

Chickpea has only one major pest, the native budworm caterpillar *Helicoverpa punctigera.* Caterpillars do most damage at pod set through to maturity, and can reduce both grain yield and quality (Table 1).

Insects other than native budworm are rarely a problem in chickpeas post establishment. Chickpeas secrete an organic acid (malic acid) from hairs on their leaves, stems and pods, making the crop unattractive to insects.

Seedlings are most vulnerable to damage:

- before they develop three to four 'true' leaves;
- during periods of moisture stress; and
- when other factors such as low soil temperature or soil compaction limit plant growth.

Table 1: *Chickpea crop stage vulnerability to insect pests.*

Pest	Crop stage				
	Emergence/ Seedling	Vegetative	Flowering	Podding	Grainfill
RLEM	Damaging	Present	Present		
Lucerne flea	Damaging				
Cutworms	Damaging				
Aphids	Damaging	Present	Present		
Thrips	Present	Present	Present		
Native budworm		Present	Present	Damaging	Damaging

Present: Insect pest present in crop but generally not damaging
Damaging: Crop susceptible to damage and loss caused by insect pest

Source: IPM Guidelines

1 DAFWA. Production packages for kabuli chickpea in Western Australia—post planting guide. https://www.agric.wa.gov.au/chickpeas/production-packages-kabuli-chickpea-western-australia-post-planting-guide

Insect ID: The Ute Guide

The Insect ID Ute Guide is a comprehensive reference guide for insect pests commonly affecting broadacre crops and growers across Australia, and includes the beneficial insects that may help to control them. Photos have been provided for multiple life-cycle stages, and each insect is described in detail, with information on the crops they attack, how they can be monitored and other pests that they may be confused with. Use of this app should result in better management of pests, increased farm profitability and improved chemical usage. [2]

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.

7.1.1 Key Integrated pest management (IPM) strategies for chickpeas

- Tolerate early damage. Chickpeas can compensate for early damage by setting new buds and pods to replace those damaged by pests. Excessive early damage can reduce yields and delay harvest.
- Damage to pods is of more concern than damage to the plant. The grubs chew holes into the soft pod and feed on the developing and filling seed. Yield loss will occur at larval densities lower than those causing a reduction in grain quality (% defective seed). This is because *Helicoverpa* consumes most of a chickpea seed—the remaining damaged seed is generally lost during harvest.
- Monitor larval infestations as mortality of small larvae can be high. Refer to records from successive checks to help interpret check data and make decisions about the need for, and timing of, control.
- Aim for one well-timed spray: chickpea can tolerate moderate to high numbers of native budworm larvae (10–20 larvae/m^2) through late vegetative and early flowering stages. Yield loss is sustained from damage at pod fill—the most critical stage for protecting the crop.
- Post-treatment checks are critical to determine efficacy and possible reinfestation prior to harvest. [3]
- Chickpea is unique in that it does not host significant numbers of beneficial insects. Small numbers of parasitic flies (tachinids) have been recorded on

2 Insect ID, The Ute Guide: https://grdc.com.au/Resources/Apps

3 GRDC. IPM Guidelines. Chickpea—Southern region. http://ipmguidelinesforgrains.com.au/crops/winter-pulses/chickpea-southern-region/

chickpea, but little else. Therefore, in relation to IPM, there are no in-crop management opportunities via beneficial insects.

7.2 Pest management process

Figure 1 outlines the steps in the pest management process.

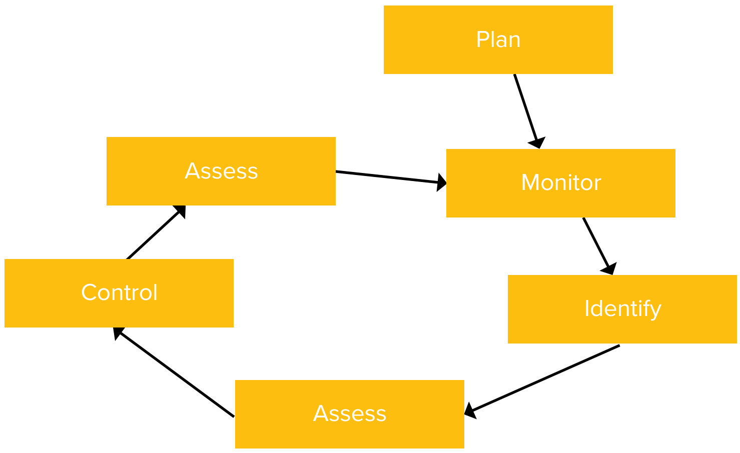


Figure 1: *Pest management process.*

1. Planning

- Be aware of which pests are likely to attack the crop in your region and become familiar with when to monitor for particular pests, what the pests look like, and damage symptoms.
- Assess sampling protocols and plan how you will cope with the logistics of sampling.
- Be aware of the latest management options, pesticide permits and registrations in chickpeas, and any use and withholding-period restrictions.

2. Monitoring

- Scout crops thoroughly and regularly during 'at-risk' periods, using the most appropriate sampling method.
- Record insect counts and other relevant information with a consistent method to allow comparisons over time.

3. Correct identification of insect species

- Identify the various insects present in your crop, whether they are pests or beneficial species, and their growth stages.
- Identify the different larval instars of *Helicoverpa* (very small, small, medium, large).
- Other minor pests of chickpeas should be recorded. These might include locusts, aphids, cutworms, false wireworms, thrips and loopers.

4. Assessing options

- Use the information gathered from monitoring to decide on the control action (if any) required.
- Make spray decisions based on economic threshold information and your experience. Other factors such as insecticide resistance and area-wide management strategies may affect spray recommendations.

5. Controlling

- Ensure that your aerial operators and ground-rig spray equipment are calibrated and set up for best practice guidelines.
- If a control operation is required, ensure that application occurs at the appropriate time of day.
- Record all spray details, including rates, spray volume, pressure, nozzles, meteorological data (relative humidity, temperature, wind speed and direction, inversions and thermals) and time of day.

6. Re-assessing and documenting results

- Assess crops after spraying and record data for future reference.
- Post-spray inspections are important in assessing whether the spray has been effective, i.e. if pest levels have been reduced below the economic threshold. [4]

7.3 Legal considerations of pesticide use

Information on the registration status, rates of application and warnings related to withholding periods, occupational health and safety (OH&S), residues and off-target effects should be obtained before making decisions about which pesticide to use. This information is available from state government department chemical standards branches, chemical resellers, the Australian Pesticide and Veterinary Medicine Authority (APVMA), and the pesticide manufacturer.

This section provides background to some of the legal issues surrounding insecticide usage, but it is not exhaustive. Specific questions should be followed up with the appropriate staff from your local state department.

7.3.1 Registration

All pesticides go through a process called registration, where they are formally authorised (registered) by APVMA for use:

- against specific pests;
- at specific rates of product;
- in prescribed crops and situations;
- where risk assessments have evaluated that these uses are:
- effective (against the pest, at that rate, in that crop or situation), and
- safe, in terms of residues not exceeding the prescribed maximum residue level (MRL); and
- not a trade risk.

7.3.2 Labels

A major outcome of the registration process is the approved product label—a legal document that prescribes the pest and crop situation in which a product can be legally used, and how.

MSDS

Material Safety Data Sheets are also essential reading. These document the hazards posed by the product, and the necessary and legally enforceable handling and storage safety protocols.

Permits

In some cases a product may not be fully registered but is available under a permit with conditions attached, which often requires the generation of further data for eventual registration.

4 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Always read the label

Apart from questions about the legality of such an action, the use of products for purposes or in manners not on the label involves potential risks. These risks include reduced efficacy, exceeded MRLs and litigation. Pesticide-use guidelines are on the label to protect product quality and Australian trade by keeping pesticide residues below specified MRLs.

Residue limits in any crop are at risk of being exceeded or breached where pesticides:

- are applied at rates higher than the maximum specified;
- are applied more frequently than the maximum number of times specified per crop;
- are applied within the specified withholding period (i.e. within the shortest time before harvest that a product can be applied); or
- are not registered for the crop in question. [5]

7.4 Native budworm

The native budworm (*Helicoverpa punctigera* or, as it was known, *Heliothis punctigera*) is indigenous to Australia and is distributed, particularly during spring, throughout much of the central and southern regions of the country. Native budworm is a major pest of pulse and canola crops in the south west of Western Australia and can develop large populations over extensive areas on native plants. In 2014 large populations swept through the southern wheatbelt, found in pulse and canola crops from Boyanup to Kojonup and Esperance. [6] These populations often migrate into agricultural regions in late winter and spring, causing damage to crops. Migratory flights are unpredictable, as moths may be carried hundreds of kilometres from breeding areas by high altitude air currents.

Effective control requires understanding when the crop is at risk and the economic threshold for when to spray. In terms of production losses, chickpeas, field peas, lentils, faba beans, tomatoes and lucerne are probably the most important hosts. [7]

Eggs

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 on close inspection of the plant. They are white when first laid but change colour to yellow and brown as they get closer to hatching (Figure 2).

5 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

6 DAFWA (2014) Native budworm sweeps southern wheatbelt. https://www.agric.wa.gov.au/news/media-releases/native-budworm-sweeps-southern-wheatbelt

7 DAFWA. Management and economic thresholds for native budworm. https://www.agric.wa.gov.au/grains/management-and-economic-thresholds-native-budworm

Figure 2: *Left to right: fresh white, brown ring and black larval head in nearly hatching eggs.*

Source: QDAF

Larvae/caterpillars

The newly hatched caterpillars (larvae) are very small and are often easily missed when inspecting a crop. When first hatched, they are about 1.5 mm long with dark brown heads and white bodies. The young caterpillars feed on leaf or pod material for about two weeks before they become large enough (5 mm long) to be noticed in the crop.

It takes a further four weeks until they are fully grown (40 mm long), which is about seven weeks from the time of egg laying.

These development times are based on average spring temperatures when caterpillars are active in central cropping areas of Western Australia. Later in the season, or in more northerly areas, developmental rates for caterpillars will be faster.

The caterpillars vary greatly in colour from green through orange to dark brown and are often seen with their heads inside pods. They usually have dark stripes along the body and are sparsely covered with fine bristles. [8]

During full development they will pass through six or seven growth stages, or instars, until they are 35 to 40 mm long (Figure 3).

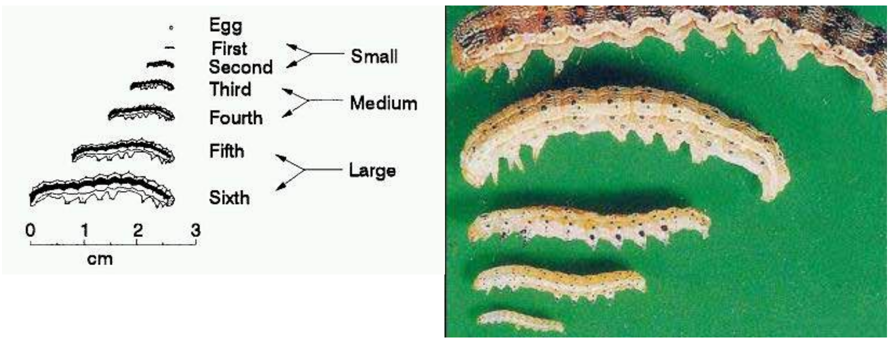


Figure 3: *Approximate instar sizes of the budworm.*

Source: Agriculture Victoria, DAFWA

8 DAFWA. Management and economic thresholds for native budworm. https://www.agric.wa.gov.au/grains/management-and-economic-thresholds-native-budworm

When fully grown, their colour ranges from green, yellow, buff, red or brown to almost black, with a broad yellow-white stripe down each side of the body and a dark stripe down the centre of the back. The skin of the caterpillars feels rough to touch, due to long dark hairs on prominent bumps on the body surface (Figures 4 and 5).

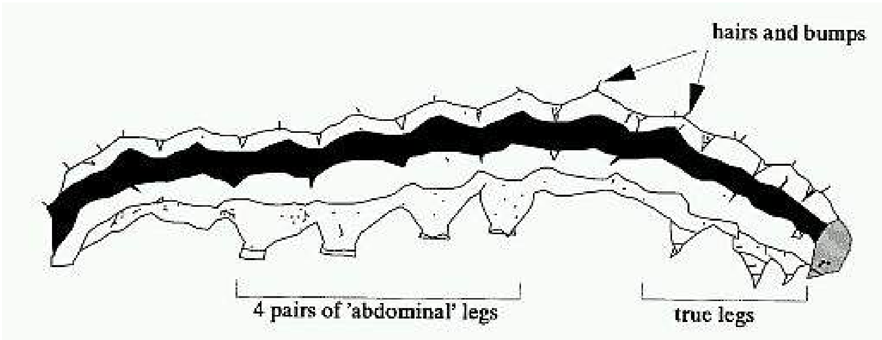


Figure 4: *Distinguishable features of native budworm larva.*

Source: Agriculture Victoria

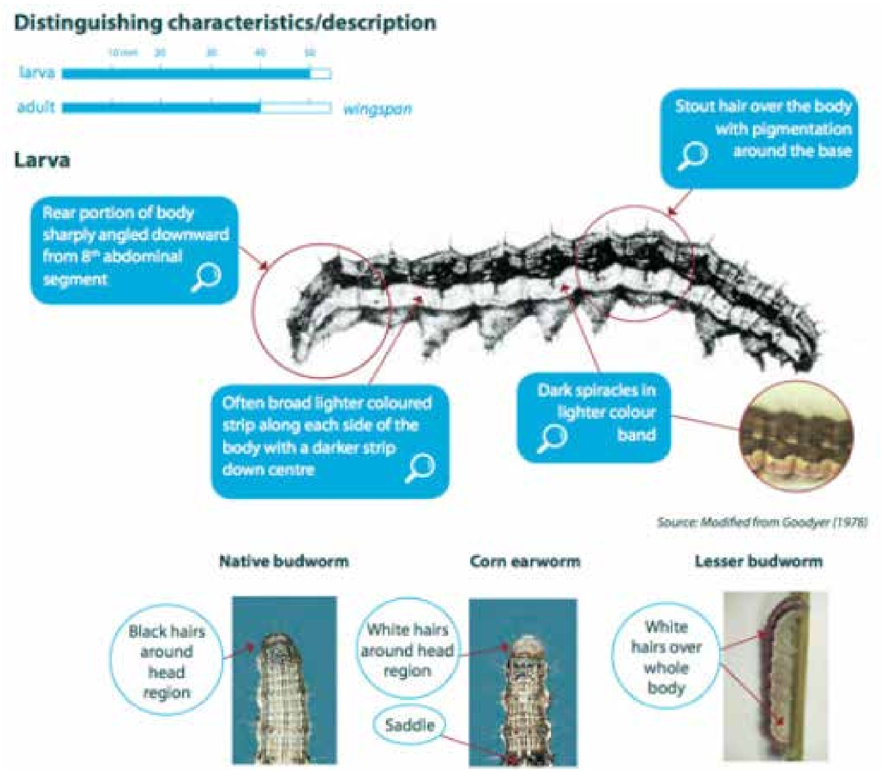


Figure 5: *Distinguishing characteristics/description of native budworm*

Source: cesar - Bellati *et al.* 2012

New moth flights and egg laying will result in caterpillars of varying sizes in a crop. Caterpillars eat increasing quantities of seed and plant material as they grow, with the last two growths stages (fifth and sixth instar) responsible for eating over 90% of their total grain consumption.

Pupa

When fully mature, the caterpillars crawl to the ground, burrow from 20–150 mm in depth into the soil, and pupate. Pupae are cigar-shaped, 12–22 mm long, and during development change in colour from a yellow-orange to a shiny dark brown. The length of the pupal stage depends on several environmental factors and varies from two weeks to several months.

Adult

Adult moths are medium-sized (wingspan 30–40 mm) and stout-bodied. The forewings are buff-olive to red-brown with numerous dark spots and blotches (Figures 6 and 7). The hind wings are pale gray with dark veins and a dark band along the lower edge. Moths are usually active during the evening and night.

Figure 6: *Native budworm larvae showing prominent hairs (left) and buff coloured adult (right)*

Source: cesar

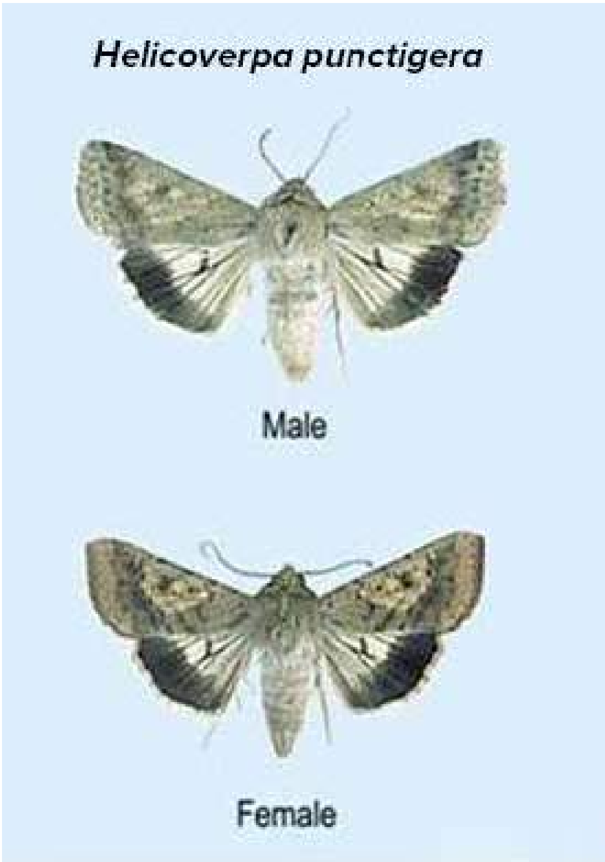


Figure 7: *Helicoverpa punctigera male (top) and female (bottom).*

Source: GRDC

Mortality of eggs and caterpillars

Only a small proportion of eggs laid by moths survive to the damaging large caterpillar stage. Eggs may be dislodged and small caterpillars may become stuck or drown due to wet weather.

Predators and parasitoids also affect population numbers and can suppress them below economic damage thresholds. If numbers of native budworm are high, populations can crash due to viruses and disease. [9]

7.4.1 Varietal resistance or tolerance

Crops vary in their attractiveness to moths as sites for egg laying. Crop density and crop growth stage (flowering and podding) will affect the number of eggs laid by the native budworm moths. The feeding behaviour of caterpillars also changes according to the type of crop the caterpillars are feeding upon.

Chickpea, field pea, lentil and faba bean crops:

- Are very susceptible to all sizes of caterpillars during the formation and development of pods.
- Tiny caterpillars can enter emerging pods and damage developing seed or devour the entire contents of the pod.

7.4.2 Damage caused by native budworm

Native budworm caterpillars most frequently attack the fruiting parts of plants (Figure 8) but also feed on the terminal growth, flowers and leaves. All pulse crops grown in Western Australia are susceptible to attack, especially when pods are present. This includes chickpea, field pea, faba bean, lentil, lupin and canola.

Figure 8: *Large helicoverpa larva feeding on a chickpea pod.*

Source: QDAF in CropIT

Cost of native budworm

Losses attributed to native budworm come from direct weight loss through seeds being wholly or partly eaten. Grain quality may also be downgraded through unacceptable levels of chewed grain or fungal infections introduced via caterpillar entry into pods. The percentage of broken, chewed and defective seed found in

9 DAFWA. Management and economic thresholds for native budworm. https://www.agric.wa.gov.au/grains/management-and-economic-thresholds-native-budworm

grain samples affects the final price of pulse crops marketed for human consumption. This applies particularly to the large-seeded crops such as kabuli chickpea, faba bean, lentil and field pea. [10]

7.4.3 Conditions favouring development

Native budworm is the major pest of grain legumes in spring (Table 2). At this time of year, the adult moths fly from inland breeding areas, on weather systems, and lay eggs in pulse and canola crops. Early spring is the time when grain growers should be checking all pulse and canola crops for native budworm eggs and larvae as crops reach the susceptible flowering and podding stages.

Table 2: *Conditions leading to risk of damage and loss from native budworm in chickpeas.*

High risk	Moderate risk	Low risk
Wet winters in breeding areas of central Australia + suitable weather conditions that bring moths in spring migrations. Repeated influxes of moths over long periods, resulting in need for continuous monitoring and potentially repeat infestations.	Broadleaf weeds hosting cutworm and helicoverpa that move into the crop as large, damaging larvae. Hot weather in spring can cause small larvae to burrow into pods. Wet harvest weather resulting in pods that are 'softer' for longer and susceptible to damage right up to harvest.	Dry winters in breeding areas. Low source population. Absence of frontal wind systems that provide opportunities for migration.

Source: IPM Guidelines

Species composition in the crop will be influenced by a number of factors, such as:

- Winter rainfall in inland Australia, which drives populations of *H. punctigera*, and the occurrence and timing of wind systems that carry *H. punctigera.*
- Relative timing of flowering–podding (attractive and susceptible) stages and the immigration of *H. punctigera* and emergence of *H. armigera* from overwintering diapause.
- Geographic location. In temperate regions, most of the *H. armigera* population overwinters from mid-March onwards and emerges during September–October. *H. punctigera* is usually the dominant species through September when moths are migrating into eastern cropping regions. Seasonal variation can lead to *H. armigera*-dominant early infestations in some years. [11]

7.4.4 Thresholds for control

Thresholds depend on crop value, cost of control and tolerance of feeding damage.

Suggested thresholds (check 5–10 sites) are:

- Chickpea (Kabuli): 2–3 larvae in 10 sweeps.
- Chickpea (Desi): 5 larvae in 10 sweeps (note that this threshold is subject to crop pricing).

10 DAFWA. Management and economic thresholds for native budworm. https://www.agric.wa.gov.au/grains/management-and-economic-thresholds-native-budworm

11 M Miles (2013) Chickpea insect pest management. Department of Agriculture, Fisheries and Forestry, Queensland, http://ipmworkshops.com.au/wp-content/uploads/Chickpea_IPM-Workshops_north-March2013.pdf

Threshold tables

The number of caterpillars present in a crop is the major factor determining whether economic damage will occur. Results from many trials conducted by DAFWA have been used to generate Figure 9 to give a personalised and more precise measure of potential loss from native budworm damage.

Crop loss (kg per hectare) for each caterpillar netted in 10 sweeps (or found per m^2) is shown in Figure 9. For one caterpillar netted in 10 sweeps is equivalent to about 20,000 caterpillars per hectare for most pulse crops.

The losses given in Figure 9 are for the number of caterpillars netted in crops during early pod formation for all crops except lupins and canola.

To use the table you need to substitute:

- control costs with your own actual costs;
- expected grain price per hectare based.

This will calculate the economic threshold or the number of caterpillars that will cause more financial loss than the cost of spraying.

The on-farm value of field peas is $185 per tonne (t)
The cost of control is $12 per hectare (ha)

ET = C ÷ (K x P)
Where:
ET = Economic threshold (numbers of grubs in 10 sweeps)
C = Control cost (includes price of chemical + application) ($ per ha)
K = Kilogram per hectare (ha) eaten for every one caterpillar netted in 10 sweeps or per square metre (see Table 2)
P = Price of grain per kg (price per tonne ÷ 1000)

Therefore economic threshold for field pea = 12 ÷ (50 x (185 ÷ 1000)) = 1.3 grubs per 10 sweeps

Figure 9: *Example to calculate the economic threshold or the number of caterpillars that will cause more financial loss than the cost of spraying.*

Source: DAFWA

Economic thresholds for the control of native budworm in chickpea crops is given in Table 3.

Table 3: *Economic thresholds (ET) for native budworm on chickpeas.*

P Grain price per tonne	C Control costs including chemical + application	K Loss for each grub in 10 sweeps (kg/ha/grub)	ET Grubs in 10 sweeps	ET Grubs in 5 lots of 10 sweeps	ET Grubs (>15 mm) per m^2
420	10	30	0.8	4	-

Note: Growers using this table to calculate spray thresholds should substitute their own control costs and the current on-farm grain price expected.

Where:
ET = Economic threshold (numbers of grubs in 10 sweeps)
C = Control cost (includes price of chemical + application) ($ per ha)
K = Kilogram per hectare (ha) eaten for every one caterpillar netted in 10 sweeps or per square metre
P = Price of grain per kg (price per tonne ÷ 1000).

Source: DAFWA

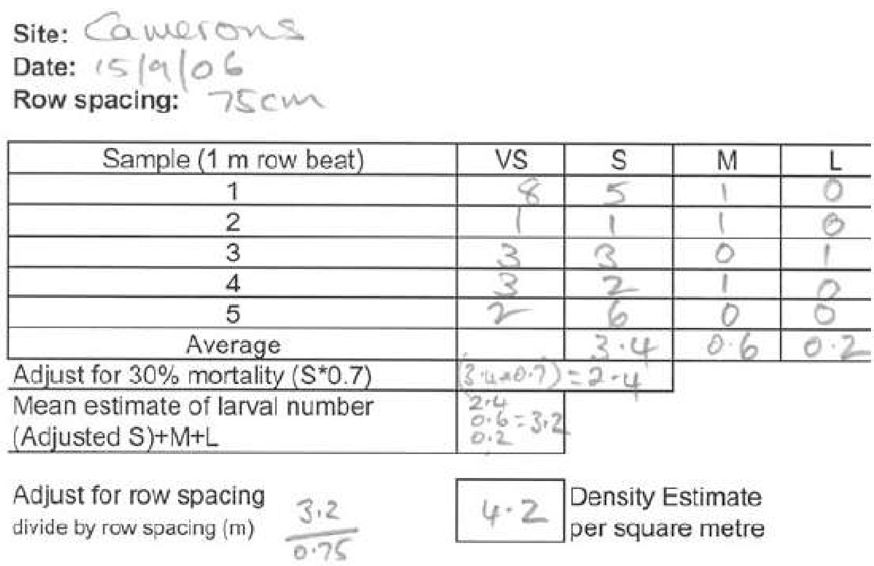
The ready-reckoner table (Table 4) works for a range of larval densities, and crop prices. Putting a dollar value on the predicted yield loss if nothing is done to control the *Helicoverpa* infestation is a useful way to assess the economic benefit (or otherwise) of spraying.

Table 4: *The value of yield loss ($/ha) caused by Helicoverpa larvae in chickpea for a range of larval densities (determined by beat sheet sampling) and grain prices.* [12]

Chickpea price ($/t)	1 larva/m^2	2 larva/m^2	3 larva/m^2	4 larva/m^2	5 larva/m^2
200	4	8	12	16	20
300	6	12	18	24	30
400	8	16	24	32	40
500	10	20	30	40	50
600	12	24	36	48	60

NOTE: Control is warranted if the cost of control is less than the value of the yield loss predicted.

In Figure 10, the field has an average of 4.2 larvae per m^2 (adjusted for mortality of small larvae). Assuming a chickpea price of $400/t, the table of potential yield loss (refer to Table 4) shows the cost of not controlling to be $32/ha. In this example, if the cost of control is less than $32/ha then it is economic to spray.


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 10: *Example of a field check sheet with sampling data recorded for Helicoverpa larvae in chickpea.*

Source: DAFF

Adjusting thresholds

Use of the table and calculations will provide a personalised and more precise measure of potential loss from native budworm damage. Sometimes the loss would turn out to be less than predicted, if, for example, the season is shortened by a lack of moisture.

Premiums paid for exceeding quality standards for high value and large-seeded pulses (like Kabuli chickpea) may necessitate even lower thresholds than those provided in the table. [13]

7.4.5 Making a decision to control

Several factors (in addition to number of larvae) will influence a decision on whether to spray, timing and product choice:

12 M Miles (2013) Chickpea insect pest management. Department of Agriculture, Fisheries and Forestry, Queensland, http://ipmworkshops.com.au/wp-content/uploads/Chickpea_IPM-Workshops_north-March2013.pdf

13 DAFWA. Management and economic thresholds for native budworm. https://www.agric.wa.gov.au/grains/management-and-economic-thresholds-native-budworm

- Age structure of the larval population may need to be considered in relation to time to desiccation or harvest. For example, a late egg-lay is unlikely to result in economic damage if the crop is 7–10 days away from harvest.
- Proportions of *H. punctigera* making up the total population are important and can be determined by visual identification, time of year, pheromone trap catches and local experience.
- Spray conditions and drift risk must be considered.
- Information on insecticide options, resistance levels for *Helicoverpa* and recent spray results in the local area should be sought.
- Residual of the products may have implications.

Selecting control options

Growers depend on insecticides for the management of *Helicoverpa* in chickpea, and the high usage of a limited group of compounds against successive pest generations imposes severe selection pressure. Invariably, selection is for individuals in a population that are not killed by normal application rates of insecticides. With continued insecticide application, the frequency of resistant individuals in the population increases, leading to field-control failures.

The potential for natural enemies of *Helicoverpa* (predators, pathogens and parasitoids) to limit the development of damaging populations of larvae—while typically low in chickpea—may also influence product selection.

'Spray small or spray fail'

Spraying should be carried out promptly once the threshold has been exceeded. Insects grow rapidly under warm spring conditions, and a few days' delay in spraying can result in major crop damage and increased difficulty in control.

If a spray application is delayed for more than two days, for any reason, the crop should be rechecked and reassessed before any control action is implemented. [14]

7.4.6 Management of helicoverpa

Monitoring

All crops should be scouted weekly during flowering for moth activity and eggs, then at least two times per week during pod-fill for eggs and larvae. The main egg-laying period is often around the flowering period when moths can be quite abundant. Eggs can often be found on the vegetative or floral growing points, new leaves, stems, flowers, flower buds and young pods. They may not be obvious to the untrained eye unless there is a heavy egg-lay or until small larvae can be found. [15]

Sampling of crops to determine the abundance of caterpillars is essential. Light traps & pheromone traps can indicate presence of adults in spring. Monitor crops 1–2 weekly until podset, then increase frequency when moths and/or larvae are detected:

- Use beat sheet (wide rows), sweep net (narrow rows) and/or visual sampling (Figure 11). Where border sprays were used to control pea weevil, start sampling well into the crop.
- Look for eggs on leaves, buds and flowers. Start looking for eggs in mid-August or when the crops start flowering and moths are detected.
- Repeat sampling at 5–10 sites across the field; more sites give greater level of confidence.
- Assess pod burrowing by looking for holes and splitting open 20–40 pods and look for larval damage.
- Record number, sizes, and crop development stage. Record /m^2 to compare numbers with appropriate thresholds. In southern grain regions, average

14 M Miles (2013) Chickpea insect pest management. Department of Agriculture, Fisheries and Forestry, Queensland, http://ipmworkshops.com.au/wp-content/uploads/Chickpea_IPM-Workshops_north-March2013.pdf

15 Bray T (2010) Managing native budworm in pulse crops. Pulse Australia, Southern Pulse Bulletin PA 2010 #18, http://www.pulseaus.com.au/storage/app/media/crops/2010_SPB-Pulses-native-budworm.pdf

number of caterpillars per 10 sweeps of an insect sweep net is the standard for comparison and thresholds.

The quickest and easiest method to sample most crops is to sweep with an insect net, taking 2 m long sweeping arcs, using the standard net size (380 mm diameter).

Multiples of 10 sweeps should be taken in several parts of the crop. If more than 10 consecutive sweeps are made, there are likely to be too many dead flowers and leaves in the sample to locate the small caterpillars easily.

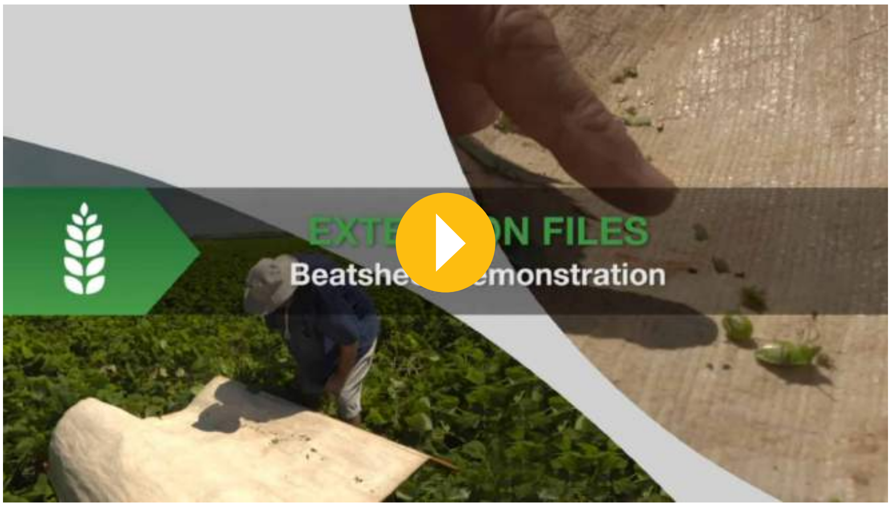
Netting is most efficient in short and thin crops and less efficient in tall dense crops. It is very important to keep the lower leading edge of the sweep net slightly forward of the net opening, so that dislodged grubs are picked up and carried into the net.

Figure 11: *Sweep-netting a chickpea crop (left) and use of a beatsheet (right).*

Source: DAFWA and The Beatsheet

In years of large moth influxes or wet springs where crops continue to flower/pod, monitoring should continue until pods are dry and no longer able to be penetrated by larvae.

WATCH: GCTV16: Extension files – IPM Beatsheet Demo.



WATCH: How to use a sweep net to sample for insect pests.

How to use a beat sheet

Place the beat sheet with one edge at the base of a row. On 1 m row spacing, spread the sheet out across the inter-row space and up against the base of the next row. Draping over the adjacent row may be useful for row spacing less than 1 m, or where there is canopy closure. It also minimises the chance of larvae being thrown off the far side of the sheet. With a 1 m long stick (dowel, heavy conduit), shake the row vigorously 10 times to dislodge larvae from the plants. Measure and count larvae on the sheet. A standard beat sheet is made from plastic or tarpaulin material with heavy dowel on each end to weigh down the sheet. The beat sheet is typically 1.3 m wide by 1.5 m long. The extra 0.15 m on each side catches insects thrown out sideways.

Using a sweep net to monitor Helicoverpa

A standard sweep net has a cloth bag and an aluminium handle. With heavy use, the aluminium handle can shear off; more robust, wooden handles are often fitted by agronomists.

Where crops are sown on narrow row spacings and it is not possible to get a beat sheet between the rows, a sweep net can be used to sample *Helicoverpa*. Hold the sweep net handle in both hands and sweep it across in front of your body in a 180° arc. Take a step with each sweep. Keep the head of the net upright so the bottom of the hoop travels through the canopy. Use sufficient force in the sweep to pass the hoop through the canopy and dislodge larvae. Take 10 sweeps and then stop and check the net for larvae. Record the number and size of larvae in each set of 10 sweeps. Repeat at additional sites across the field. [16]

Monitoring for adult moths

Male moths are easily captured in pheromone (female sex scent) traps (Figure 12). These traps are maintained by Department of Agrilculture and Food, Western Australia (DAFWA) staff and volunteer farmers and provide an early warning of moth arrival and abundance.

Results from native budworm traps together with other pest and disease alerts are published weekly throughout the growing season in PestFax. The PestFax newsletter is distributed via email and requests for free subscription can be sent to pestfax@agric.wa.gov.au.

16 M Miles (2013) Chickpea insect pest management. Department of Agriculture, Fisheries and Forestry, Queensland, http://ipmworkshops.com.au/wp-content/uploads/Chickpea_IPM-Workshops_north-March2013.pdf

Pheromone trap used for detecting moths.

Source: Pulse Australia

Pheromone trap catches—data updates

Stay up to date with native budworm numbers in your local areas. Weekly trap catch data for *H. punctigera* and *H. armigera* from locations across all states can now be viewed online. The adjustable bar below the map allows selection of a time period (1 week, 2 weeks, 1 month etc.). [17]

Recording of monitoring data for decision-making

Keeping records should be a routine part of insect checking. Successive records of crop inspections will show whether pest numbers are increasing or decreasing, and will help in deciding whether a control is necessary.

Records of insect checking should include as a minimum:

- date and time of day
- crop growth stage
- average number of pests detected, and their stage of development
- checking method used and number of samples taken
- management recommendation (economic threshold calculation)
- post spray counts

The *Helicoverpa* size chart (Table 5) is an essential reference for decision-making, particularly in chickpea where larval size is taken into account in the economic threshold (beat sheet threshold), and is important in ensuring that any control action is well targeted against susceptible larvae.

Eggs and very small larvae are not included in the economic threshold for *Helicoverpa* (beat sheet threshold) due to high natural mortality.

17 The Beatsheet. https://jamesmaino.shinyapps.io/MothTrapVis/

Table 5: *Helicoverpa larval size categories and actual sizes.*

Helicoverpa larval size categories and actual sizes		
Actual larval size	Larval length (mm)	Size category
	1-2 mm	very small
	4-7	small
	8-23	medium
	24-30+	large

Source: IPM Guidelines for Chickpeas)

Chemical control

Key points:

- Aim to control larvae before they enter pods—target small larvae less than 7 mm.
- Synthetic pyrethroids are very effective but their broad spectrum activity has a negative impact on any beneficial insects present.
- Commercially available NPV gives up to 80% control in chickpeas.
- Bt (*Bacillus thuringiensis*) is a naturally occurring bacteria which produces spores that contain a toxin. It is effective against *Helicoverpa,* but can be broken down in high light intensity conditions.
- There is usually a range of rates on the insecticide label to allow for varying conditions such as the size of the caterpillars. The choice of rate should not be solely driven by the lowest price. Also consider the impact of chemical use on other pests and beneficial species.
- Inspect crops after spraying to ensure chemical applications have been effective and to detect further infestations until the crop is no longer susceptible. [18]

The decision to spray for chickpea needs to be considered from the time of first podding.

If caterpillar numbers are below the threshold levels provided, the decision to spray should be delayed and periodic sampling continued. One well-timed spray to control native budworm caterpillars should be sufficient in most situations.

Sweep netting of the crop should be carried out after spraying to confirm that the required level of control has been obtained. One well-timed spray with a synthetic pyrethroid should prevent reinfestation for up to six weeks after spraying. Late season hatchings are often too late to cause economic damage. [19]

Synthetic pyrethroid insectides are very effective but their broad spectrum activity impacts negatively on beneficial insects. [20]

Refer to the beneficial impact table for more information.

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.

18 GRDC, IPM Guidelines. Native budworm in winter pulses. http://ipmguidelinesforgrains.com.au/pests/helicoverpa/native-budworm-in-winter-pulses/

19 DAFWA. Management and economic thresholds for native budworm. https://www.agric.wa.gov.au/grains/management-and-economic-thresholds-native-budworm

20 GRDC. Budworm in Western Australia. https://grdc.com.au/Media-Centre/Hot-Topics/Budworm-in-Western-Australia

The crop should be re-inspected 2–4 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. [21]

Be aware of insecticide withholding periods (WHP) close to harvest and remember that windrowing is classified as harvest.

Many traditional pyrethroid insecticides (e.g. alpha-cypermethrin) have a 21-day WHP in canola, however there are newer generation pyrethroids available (e.g. Trojan®or Karate®) with a shorter 7-day WHP. [22]

Unlike other parts of Australia or overseas where *Helicoverpa armigera* is abundant (the cotton bollworm or corn earworm), the control of native budworm poses no great problem in southern winter-growing areas of WA. There is no known resistance to chemicals, and temperatures during the growing season do not allow for a high level of activity until the crop is podding.

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.

Beneficials

- Be aware of key beneficials before larvae infest the crop.
- *Trichogamma* wasps parasitise helicoverpa eggs and *Microplitis*, *Heteropelma*, *Netelia* sp. and other wasps parasitise helicoverpa larvae.
- Predatory bugs such as *Geocorris* and *Nabis* prey on eggs and small larvae while *Cermatulus* and *Oechalia* also attack larger larvae.
- Ants and spiders also eat helicoverpa eggs and larvae.
- NPV is a virus which only infects *Helicoverpa* species. This occurs naturally but can also be applied— see chemical control. [23]

7.4.7 Management nearing dessication and harvest

Hot, dry weather will rapidly advance a chickpea crop (Figure 13) which means that very small and small larvae are unlikely to survive on leaves of rapidly deteriorating quality. As the pods dry they also become more resistant to damage by small to medium larvae. In summary, this means that the major source of damage in a senescing crop is late medium and large larvae.

21 Cesar. Native Budworm. www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/Native-budworm

22 GRDC. Budworm in Western Australia. https://grdc.com.au/Media-Centre/Hot-Topics/Budworm-in-Western-Australia

23 GRDC. IPM Guidelines. Native budworm in winter pulses. http://ipmguidelinesforgrains.com.au/pests/helicoverpa/native-budworm-in-winter-pulses/

Figure 13: *Chickpea crop nearing desiccation and harvest.*

Source: The Beatsheet

Therefore, the recommended approach to managing *Helicoverpa* populations in the later stages of a chickpea crop is to continue to monitor both number and size of larvae. If the population of medium and large larvae exceeds the economic threshold, and the crop is still susceptible, then treatment may be warranted.

At this stage of the crop, a wait-and-see approach (continue checking the crop 1–2 times a week) is recommended, principally because it is difficult to predict a week or two ahead how fast a crop will dry down, and what the *Helicoverpa* population will be whilst the crop is still susceptible. The alternative approach is to treat above threshold populations of small larvae when they are detected. This approach is likely to result in treatment of fields that subsequently would not have been at risk of damage, particularly if the crop dries faster, or larval mortality is higher than expected.

The options available for the treatment of *Helicoverpa* infestations late are limited because of withholding periods (WHP). Methomyl has a 1-day WHP while thiodicarb has a 21-day WHP. Indoxacarb (StewardTM) has a 21-day WHP, but no more than one application is permitted per crop growth cycle. Check with others in your local area on their experience with the efficacy of options when making a choice. [24] Dow Trojan® has a shorter WHP to harvest of only 7 days.

7.4.8 Broader management considerations

Close monitoring can pay off. In many cases, the larval infestation may not progress past the 'small' stage and, therefore, control is unwarranted. Regular close checking, and reference to records from successive checks, will enable you to determine larval survival.

Aim for one well-timed spray. Chickpea can tolerate moderate to high numbers of *Helicoverpa* larvae (10–20 larvae/m^2) through late-vegetative and early-flowering growth stages. However, agronomists may suggest that numbers this high during flowering would warrant immediate spraying. Even with mortality, an economic threshold may be exceeded as soon as podset begins. This situation potentially leads to high numbers of advanced stage larvae, resulting in more costly and less reliable control.

24 The BeatSheet (2008) Managing Helicoverpa larvae in chickpea crops close to dessication and harvest. http://thebeatsheet.com.au/crops/pulses/chickpeas/managing-helicoverpa-larvae-in-chickpea-crops-close-to-dessication-and-harvest/

Most yield loss will be sustained from damage caused during pod-fill, and this is the most critical stage for crop protection. Larval infestations are likely to be of mixed ages by the time the crop is well into podding. Products such as Steward™ and Larvin® will adequately control a wide range of larval sizes, and offer around 10–14 days of residual protection if applied to plants that are not actively growing. [25]

7.4.9 Checking compatibility of products used in mixtures

With the fungicide spray programs recommended for Ascochyta blight control, mixing of fungicides with insecticides is becoming more common. However, some product formulations are NOT compatible with available fungicides.

Check compatibility of potential mixing partners before recommending and applying.

Always read the label supplied with each product before use.

Compatibility of insecticides with mancozeb formulations

It is the responsibility of the agronomist ultimately to ensure that any recommendation is safe for the crop.

Table 6 outlines some considerations when using chlorothalonil within 10 days of an insecticide application. These lists are by no means exhaustive. Always check with individual companies and read product labels for specific information.

Note that formulations can vary between companies or they may be changed without notice. Compatibilities provided are a guide only and should be followed up with companies if problems occur.

Always read the label supplied with the product before each use.

Always ensure that a product (or mixture) is safe for the crop before recommending and applying. [26] Microencapsulated insecticides like Karate Zeon® or FMC Trojan® at very low use rates may not affect fungicide efficacy or crop effects.

25 M Miles (2013) Chickpea insect pest management. Department of Agriculture, Fisheries and Forestry, Queensland, http://ipmworkshops.com.au/wp-content/uploads/Chickpea_IPM-Workshops_north-March2013.pdf

26 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Table 6: *Compatibilities of various insecticides with chlorothalonil.*

Product	Chlorothalonil compatibility	Considerations
Steward™ (indoxacarb)	Yes. Widely used with chlorothalonil and no know compatibility issues	
Oil-based emulsifiable or flowable pesticides	Some incompatibilities. The excerpt (right) is from the Crop Care Barrack 720 label. Also see labels of other chlorothalonil products available under permit.	DO NOT tank mix Crop Care Barrack 720 with EC formulations when spraying after shuck fall. COMPATIBILITY: This product is compatible with wettable powderformulations of the most commonly used fungicides, insecticdes and miticides. Do not combine with oil-based emulsifiable or flowable pesticides, unless prior experience has shown the combination to be physically compatible and non-injurous to your crop. This product should not be mixed with spraying oils or sprayed on to crops that have been sprayed with oil for at least 10 days after the oil spray. Oils should not be sprayed on crops treated with this product for at least 10 days after the last spray. Wetting agents have not improved performance. Under some conditions, certain surfactants may cause injury.

Source: compiled with the assistance of Bayer CropScience, Sumitomo Chemical Australia, DuPont, Crop Care Australasia and Infopest

7.4.10 Post spray assessments

After applying a spray to control a pest infestation, a post-spray assessment or follow-up check is essential to ensure that pest numbers were successfully reduced to below the threshold.

Sometimes sprays fail to work as effectively as required or expected. This can occur for a variety of reasons, such as inadequate application (coverage, timing), insecticide resistance, or too-high expectations of the product selected. Poor application is sometimes mistaken as resistance.

Where a spray failure is suspected, detailed records can assist in determining the cause of the apparent failure.

With products such as Steward™, the phenomenon of growth dilution is often evident in chickpea. That is, the growth that was present at the time of application may still have residual activity from the insecticide but new growth will not. It has been observed that small larvae can feed on this new growth but incur no crop damage. Rechecking fields sprayed with Steward™ or Larvin® can be complicated and will require regular assessment.

Record spray decision and re-check to confirm control success or failure. Record details of application equipment (nozzle size, etc.) as well as time of day and weather conditions. This may help interpret what might have gone wrong where poor control is achieved. [27]

7.5 Aphids

Aphids are small insect pests with oval-shaped green, brown or black bodies. Often occurring in colonies, aphids suck on sap, causing loss of vigour, and in some cases yellowing, stunting or distortion of plant parts (Table 7). Honeydew (unused sap) secreted by the insects can cause sooty mould to develop on leaves. When aphids

27 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

transmit viruses, the impact on crop growth and yield can be significant. The earlier the transmission of virus, the greater the potential impact.

Direct aphid feeding rarely causes major damage to broadacre crops, and control measures are generally unnecessary, as parasitoids and predators keep populations in check. Exceptions occur when aphid populations are extreme (particularly early) or the compensatory ability of the crop is compromised by stress (particularly moisture stress), and aphid impact on flowering or pod set/fill may be significant.

Pulse aphids

- Cowpea aphid *Aphis craccivora*
- Blue green aphid *Acyrthosiphon kondoi*
- Green peach aphid *Myzus persica*
- Pea aphid *Acyrthosiphon pisum*

Table 7: *Susceptibility of pulse crops to aphids according to growth stage.*

Pre-Plant/Plant	Seedling	Vegetative	Budding/ Flowering
Aphids can transmit viruses.	**Cowpea aphid:** colonies start in growing points. **Blue green aphid:** infest growing tips first then move down stems to the crown as numbers build up. Risk of large infestations is higher if weather conditions are mild and hosts abundant.	In lupins direct feeding during flowering can cause flower abortion and poor pod set. Heavily infested crops may show signs of wilting—more severe in water stressed crops. Early colonisation by virus-infected aphids may result in yield losses from virus infections; bean yellow mosaic virus infection (BYMV) or cucumber mosaic virus (CMV). Look for aphids on stems and lower leaves.	Most sensitive crop stage to damage**:** reduce flowering reduce or prevent pod-set and pod-fill Look for aphids on stems, lower leaves, buds and flowering heads.

Source: IPM Guidelines

Cowpea aphids are black, or dark grey-green, sometimes with a white ‘dust’ over them (Figure 14). Dense colonies can develop on individual plants, or in well-defined patches. Infestations start in the growing tip and spread down the stem, causing leaf bunching and stem twisting. Cowpea aphids tolerate warm dry weather, and can be severe on water-stressed plants. Water stress and warm weather before flowering can result in heavy, extensive infestations.

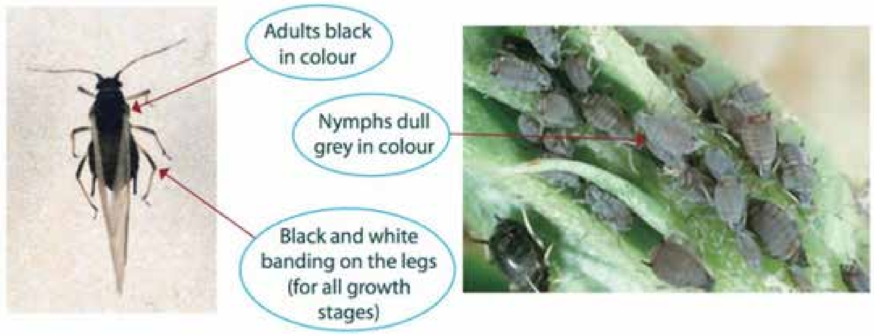


Figure 14: *Distinguishing characteristics/description of cowpea aphids*

Source: Bellati *et al.* 2012 in Cesar

Green peach aphids are waxy green (except the winged adults, which are almost black) (Figure 15). Occasionally, colours of individual wingless green peach aphids can range from a pale yellow-green to an orange-red. They usually feed in buds and flowers, and do not often form large dense colonies. Generally they are widespread, in low numbers, rather than in well-defined patches. They tolerate cool/moist and warm/dry conditions. Green Peach Aphids are often resistant to synthetic pyrethroids, Organophosphateas and carbamates. Check with your local agronomist or entomologist for the correct insecticide group choice.

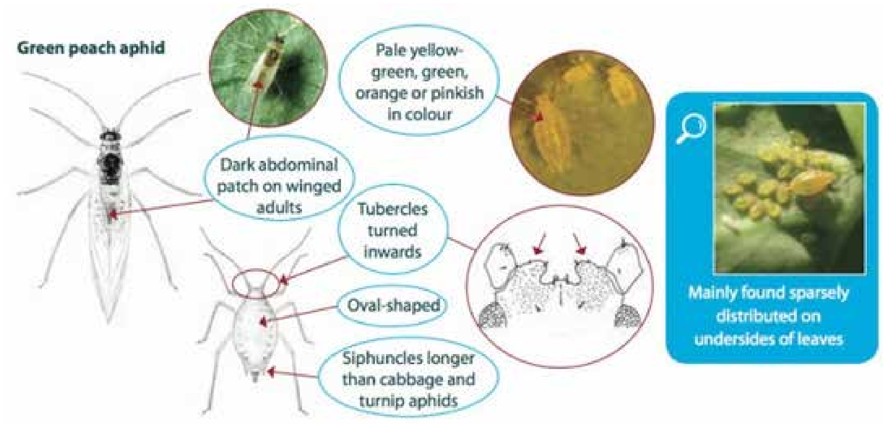


Figure 15: *Distinguishing characteristics/description of green peach aphid*

Source: Bellati et al. 2012, in Cesar

Life cycle

Winged aphids fly into lupin crops from surrounding vegetation and pastures. Spring population size depends on autumn and winter conditions. Long autumn growing periods allow early build-up and spread of aphids. Mild (not cold) winters allow further development and spread of winged aphids, which can establish many small colonies of wingless aphids throughout a crop. Reproduction is rapid if plant growth and spring weather is favourable, until the colonies are large, and winged aphids redevelop. All aphids are female and give birth to live young without mating. Viruses carried by flying aphids are transmitted to plants as they feed and establish colonies. Wingless aphids feeding on infected plants can also crawl to healthy plants (through the canopy or after falling to the ground) and spread disease. Viruses can be brought into crops from outside paddocks, or spread within a crop from infected plants.

Damage

Aphids feeding on lupins can cause yield loss before plant symptoms become obvious. Large colonies, with more than 40 aphids per stem, cause distortion of leaves, stems and flowers. By the time such symptoms are evident, there will have been yield loss that cannot be recovered by spraying to control the aphids. The crop should be treated before aphid numbers increase markedly. The economic loss over a paddock depends on the area infested, and on the numbers of aphids in each growing tip or bud. Yield losses are greater if virus transmission also occurs.

Virus infection causes additional plant symptoms. Aphid feeding slows growth, distorts flowers, and reduces pod set and fill. Viruses transmitted by the aphids cause a range of symptoms, including 'shepherds crook', stunting, and leaf yellowing. Low numbers of aphids can spread viruses, whereas larger widespread populations are needed to cause direct feeding loss. Virus diseases can cause significant yield loss in lupins. Aphids can carry and spread these diseases, at population levels that cause little damage from direct feeding.

WATCH: Green peach aphids and beet western yellows virus.

Control

Aphid numbers can rise and fall rapidly—mainly in response to weather conditions—so they are virtually impossible to predict beyond a few days. The potential for grain yield loss is high if five or more aphids are found in 30% of buds on the main stem or first branches of a plant, and 15% or more of the crop is affected at this level. Waiting until colonies are large, and plant damage symptoms are obvious, is too late; yield loss has occurred and cannot be recovered.

The type of aphid does not matter. Green peach aphid is more difficult to kill than the other aphids, and higher rates of aphicide should be used. An aphicide that does not kill beneficial insects (wasps, ladybeetles, lacewings, hoverflies) is preferred. It may be necessary to apply aphicide twice in a season, as each set of buds and flowers develop. Spot spraying may be effective.

Cucumber Mosaic Virus (CMV) is carried over in seed from infected plants, and can also be transmitted by aphids. Within a crop, aphids spread CMV from plants growing from infected seed. Usually the disease is localised and patchy, but yield losses due to the virus can exceed 50% if the infection spreads throughout a paddock early on. Recommended management strategies include early seeding, high seeding rates to generate dense stands, use of uninfected seed, and strategic application of aphicides to kill aphids in late winter/early spring.

Bean Yellow Mosaic Virus (BYMV) spreads into paddocks from neighbouring pastures. It is usually restricted to paddock edges, but occasionally widespread infections occur, resulting in severe yield loss. Sparse crops (low seeding rate, seedling loss) are especially vulnerable. Management strategies include high seeding rates to generate dense stands, cereal barriers around the crop, heavy grazing of adjoining pasture paddocks to reduce aphid numbers, and strategic aphicide sprays. [28]

7.5.1 Bluegreen aphid

Bluegreen aphids (BGA) are relatively large (up to 3 mm), matt blue-green, with a pair of slender tubes like exhaust pipes (cornicles) projecting from the back to beyond the tip of the abdomen (Figure 16). Winged aphids fly into pastures or crops and start colonies, which cause damage. Overcrowding or plant deterioration triggers the development of new winged aphids which migrate to establish new colonies. Winged aphids can spread viruses.

28 DAFWA. Lupin Aphids. http://agspsrv34.agric.wa.gov.au/ento/pestweb/Query1_1.idc?ID=1923328529

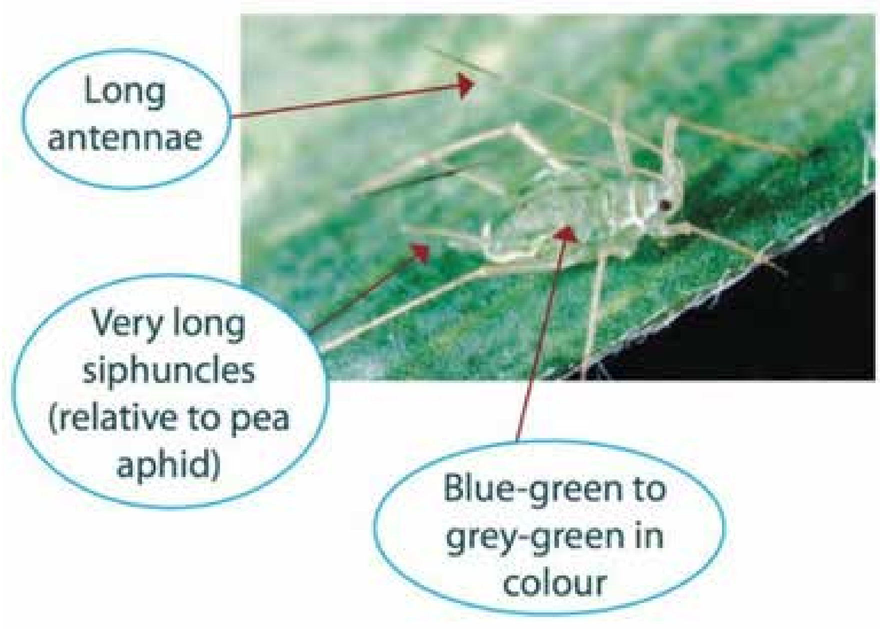


Figure 16: *Distinguishing characteristics/description of bluegreen aphid*

Source: Bellati *et al.* 2012 in Cesar

Life cycle

Like other aphids, all BGA are females and give birth to live young without having to mate. Reproduction rates are very high so numbers increase rapidly when conditions are favourable. BGA survive hot dry summers in low numbers on sheltered host plants, usually as winged aphids. Migration into germinating annual legumes or lucerne occurs in autumn, and large colonies can develop if it is warm and mild. Winter cold slows reproduction until spring, when populations grow rapidly on favourable plants. During heavy infestations, plants can be covered with white speckles, which are cast-off aphid skins. The number of winged aphids flying between paddocks also increases throughout spring; these can be caught with 'sticky' traps.

Damage

Annual medics, lucerne, subterranean clover and lupins are susceptible to bluegreen aphid. In lucerne and medics, heavy infestations cause stunted growth, leaf curling and leaf drop. Dry matter production can be reduced. In subterranean clover, leaves wilt before turning grey-brown and dying, becoming dry and 'crisp'. Pastures take on a patchy, burnt appearance. Seed yield of annual species can be reduced by 20–80%. The higher the legume content and the lighter the grazing pressure from flowering onwards, the greater the risk of aphid damage. Ungrazed swards with more than 50% legume dominance are at greatest risk in spring. BGA favour growing tips of medic or lucerne, while in subterranean clover they are widely dispersed under the canopy, particularly on flower/burr peduncles.

Control

For lucerne, sow resistant or tolerant cultivars. Parasitic wasps (Figure 17), ladybeetles, lacewings, hoverflies and fungal diseases exert useful biological control. Aphid-resistant annual medics and subterranean clover are not common, so insecticides may be needed in lightly or ungrazed spring pastures, if maximum seedset and spring drymatter production is wanted. Redlegged earthmite can cause similar spring losses, and may also be present. If BGA is the predominant pest, use insecticides that do not kill aphid parasites and predators; for mixed infestations, systemic chemicals that control aphids and mites should be used.

Figure 17: *Bluegreen aphid and parasitoid wasp*

Source: Cesar

7.5.2 Management of aphids

Monitoring

Monitor terminals/growing tips:

- Check at least 5 points in the field and sample 20 plants at each point.
- Check regularly at different locations across a field as populations are often patchy.
- Aphids are often first observed along the edges of crops. Inspect crops from crop edge to centre of paddock. Infestations may be patchy or in 'hot spots'.
- Infestations can be reduced by heavy rain. If rain occurs when spray decision is made but not carried out, monitor again to determine is spray still required.
- Record the number of large and small aphids (adults and juveniles), the number of beneficials as well as parasitised aphids (mummies), and the impact of infestation on crop.

Repeat sampling provides information on whether the population is increasing (lots of juveniles), stable or declining (lots of adults and winged adults). [29]

Table 8 summarises control strategies against aphids.

29 GRDC. IPM Guidelines. Aphids in pulses. http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-pulses/

Table 8: *Best Bet IPM strategies for controlling aphids in winter pulses in the southern growing region.*

	Post Harvest, pre-sowing	Establishment – vegetative	Flowering - maturity
Aphid vectors and virus source	Control green bridge (in fallows) Sow virus – free seed Sowing into standing stubble may reduce aphid landing	Asses risk of aphid outbreak High risk when: Warm, mild conditions Abundant weed hosts Nearby food sources eg. Clover/medic Aim to close canopy and minimise gaps to outcompete infected plants	Conserve and monitor beneficials that suppress aphids. Use of broad spectrum pesticides may flare aphids. Check post-application for signs of flaring
Aphids – direct damage (not virus) Cowpea Green peach Blue-green Pea aphid	Remove green bridge (aphid hosts) to minimise build up during autumn and spring. Sowing into standing stubble may reduce aphid landing and delay aphid build up in crops.	Control in-crop weeds to minimse sources of aphids Beneficials suppress low population and reduce the chance of outbreaks. High nitrogen may make the crop more attractive to aphids	Monitoring: Conserve and monitor beneficials that suppress aphids. If not control is required, use soft options (eg. Pirimicarb). Use of broad spectrum pesticides may flare aphids. Check post-application for signs of flaring. Note: knowledge of damaging levels is limited.

Source: IPM Guidelines

Chemical control

- Systemic insecticides are the preferred chemical control (aphids often shelter in spray-inaccessible areas of the plant). However in very dry conditions translocation of chemicals may be impaired, and insecticide will be less effective.
- If chemical control is required, consider aphid specific products (e.g. pirimicarb) to preserve beneficials. Refer to the beneficial impact table.
- If heavy rain and cool temperature are forecast, consider delaying spray decisions until after rain and monitor again.
- Seed treatments and border spraying (autumn/early winter) when aphids begin to colonise crop edges may provide sufficient control.
- Controlling aphids to prevent virus is not an economic proposition, as a small number of aphids can transmit virus and these populations could establish without being detected.
- Rotate chemicals to prevent resistance. GPA is known to have resistance to pirimicarb in WA, and potentially to SPs and OPs nationally. [30]

30 GRDC. IPM Guidelines. Aphids in pulses. http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-pulses/

Biological control

Beneficials

- Beneficials will suppress low to moderate aphid populations but will not control heavy infestations. Look for parasitoids (wasps, aphid mummies) and predators (ladybirds, hover flies and lacewings).
- The presence of bloated aphids with a pale gold/bronze sheen indicates parasitoid activity in the crop.
- Reviewing aphid and beneficial densities over time may provide information on the impact that natural enemies are making on the growth, or decline, of the aphid populations.
- Broad spectrum insecticides that target aphids will also kill beneficials.

Beneficials may not arrive early enough in the crop to prevent the build-up of aphids to above threshold. They are important to suppress populations after control, so determine impact of insecticides on beneficials before spraying. [31]

Cultural control

- Control alternative hosts (wet autumn and spring promotes the growth of weed hosts—when weed hosts dry off aphids move into crops). Legume pasture species are also hosts.
- Sow crops early where possible to enable plants to flower before aphid numbers peak.
- Sow clean seed tested for cucumber mosaic virus (CMV) in lupins or pea seed-borne mosaic virus (PsbMV) in field peas.
- Cover of bare ground through rapid canopy development assists in deterring aphids, e.g. narrow rows with high seeding rates.
- High intensity rain during crop growth can suppress aphids.
- Research in WA shows that high levels of reflective stubble may deter aphids, especially in crops with wide row spacing. [32]

7.5.3 Aphids and virus incidence

Aphids can damage crops by spreading viruses, or they can cause direct damage when feeding on plants. Feeding damage generally requires large populations, but virus transmission can occur before aphids are noticed. Pre-emptive management is required to minimise the risk of aphids and their transmission of viruses. Aphids are the principal, but not sole, vectors of viruses in pulses; some viruses are also transmitted in seed.

An integrated approach to aphid and virus management is required to reduce the risk of yield or quality loss.

Different aphid species transmit different viruses to particular crop types. Viruses are already transmitted before detection, but aphid species identification is important because management strategies can vary. Pulses are annual crops, whereas aphids and the viruses they spread have alternative hosts between seasons. 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.

Integrated management practices that aim to control aphid populations early in the season are important in minimising virus spread. Aphids can spread viruses persistently or non-persistently. Once an aphid has picked up a persistently transmitted virus, e.g. BWYV, it carries the virus for life, infecting every plant where it feeds on the phloem. Aphids carrying non-persistently transmitted viruses, e.g. CMV, carry the virus temporarily and only infect new plants in the first one or two probes.

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31 GRDC. IPM Guidelines. Aphids in pulses, http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-pulses/

32 GRDC. IPM Guidelines. Aphids in pulses, http://ipmguidelinesforgrains.com.au/pests/aphids/aphids-in-pulses/

Important vectors for non-persistent viruses in pulse crops include green peach aphid, pea aphid, cowpea aphid and blue-green aphid, which will colonise pulse crops (Table 9). Turnip aphid, maize aphid and oat aphid—which are non-colonising species in pulses—may also move through pulse crops, probing as they go, and potentially spreading pulse viruses. Green peach aphid and pea aphid are also important in spreading persistently transmitted viruses, depending on the virus involved. [33]

Table 9: *Differences in transmission of one persistent and two non-persistent viruses by four aphid species.*

Aphid species	Cucumber mosaic virus (non-persistent)	Pea seed-borne mosaic virus (non-persistent)	Beat western yellows virus (persistent)
Green peach aphid	Yes	Yes	Yes
Pea aphid	Yes	Yes	–
Cowpea aphid	Yes	Yes	Yes
Blue-green aphid	Yes	–	–

Source: GRDC

7.5.4 Integrated pest management and viruses

An integrated approach with crop, virus and insect management is required to control aphids and viruses in pulse crops.

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.

Source clean seed and test retained seed for viruses including CMV, BYMV, *Alfalfa mosaic virus* (AMV) and *Pea seed-borne mosaic virus* (PSbMV). Sow tested seed with less than 0.1% virus infection to reduce the pool of virus-infected material. Field pea seed should have less than 0.5% PSbMV. Where possible, choose a pulse variety that has virus resistance.

Resistance to CMV seed transmission has been bred into many new lupin varieties, including Jenabillup. Yarrum field pea has resistance to BLRV and PSbMV. Pulse Breeding Australia is increasing its emphasis on developing pulse crop lines with increased virus resistance. Faba bean lines with resistance to BLRV and field pea with resistance to BLRV and PSbMV have been identified and should be commercially available in the future.

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. This applies especially to minimising CMV spread in lupins and chickpea.

Seed dressings are probably the best aphid protection strategy compatible with an IPM approach, for example, Gaucho® 350SD insecticide seed dressing on other pulses to prevent aphids attacking emerging seedlings and spreading viruses (e.g. CMV, BLRV and BWYV). However, Gaucho® 350SD is not registered for use in chickpea.

Alternatively, a foliar insecticide can be applied early based on forecast reports of the degree of risk. Preferably use a 'soft' insecticide that targets the aphids and leaves beneficial insects unharmed. There is debate over the use of synthetic pyrethroids as a foliar application; they are recommended to prevent BLRV transmission because of so called 'anti-feed' properties that prevent early colonising of crops by pea aphids. However, discouraging colonisation may increase the spread of aphids and, potentially, virus through a crop.

33 GRDC (2010) Aphids and viruses in Pulse Crops—Factsheet. Western and Southern Region.

Synthetic pyrethroid insecticides should not be used to control green peach aphid, an important vector of BWYV, as most populations of green peach aphid are resistant. Monitor crops and neighbouring areas regularly. Identify the species of aphid present and their numbers. [34]

7.6 Red legged earth mite (RLEM)

The redlegged earth mite (RLEM) (*Halotydeus destructor*) is a major pest of pastures, crops and vegetables in regions of Australia with cool wet winters and hot dry summers. The RLEM was accidentally introduced into Australia from the Cape region of South Africa in the early 1900s. These mites are commonly controlled using pesticides, however, non-chemical options are becoming increasingly important due to evidence of resistance and concern about long-term sustainability. RLEM is a sap-sucking pest of crops and pastures. They often co-exist with blue oat mites. The mites are often gregarious and are found clumped together in large numbers. They disperse quickly when disturbed. [35]

WATCH: GCTV9: Redlegged earth mites.

7.6.1 Symptoms

What to look for

Insect Adult

- Adults are 1 mm long with a black body and eight red-orange legs (Figure 18).
- Newly hatched mites are 0.2 mm long with a pinkish-orange body and 6 legs.

34 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

35 Agriculture Victoria. Redlegged Earth Mite, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/redlegged-earth-mite

Figure 18: *Leathery cotyledons with adult RLEM.*

Source: DAFWA, 2013

Plant

- Feeding causes a silver or white discolouration of leaves and distortion. If damage is severe, plants shrivel and die (Figure 19).
- Damage is more severe when seedlings are stressed (e.g. cold waterlogged or very dry conditions).

Figure 19: *Silver leaf discolouration.*

Source: DAFWA, 2013

7.6.2 Damage caused by RLEM

Large numbers of RLEM are commonly found in annual pastures at the break of the season and may cause heavy loss of subterranean clover and annual medic seedlings. These species are susceptible throughout the growing season, and can suffer losses in dry matter (10–80%) and seed yield (20–80%) in spring. The greater the legume content of pastures and the lighter the grazing pressure, the higher the risk of loss from mites. They also attack lupins, rape, field peas, serradella (cotyledons only) and vegetables.

Mites rupture cells on the surface of leaves and feed on exuding sap; affected leaves look silvered, but do not have holes as with lucerne flea attack. Mite damage to seedlings is more severe if plant growth is slowed. This could be caused by cold and/or waterlogging, low seedling density after a false break, low seed banks after a crop, or if pastures or stubble are being reseeded. Capeweed increases their reproductive potential, and legumes in paddocks with a lot of capeweed may be severely damaged, especially where mites can attack smaller clover and medic seedlings from the shelter of large capeweed plants. [36]

RLEM effects:

- Will damage all field crops and pastures.
- Reduces production and quality of older plants during the growing season.
- Reduces seed yield of legumes in spring.
- Silvering of leaves, distortion of leaf shape in broadleaf crops.

36 DAFWA, Pest Web. Redlegged earth mite. http://agspsrv34.agric.wa.gov.au/Ento/pestweb/Query1_1.idc?ID=247419235

- Affected seedlings can die.
- Seedlings can be killed below ground before they emerge.

7.6.3 Conditions favouring development

Earth mites are active in the cool, wet part of the year, usually between April and November. During this winter-spring period, RLEM may pass through three (sometimes only two) generations, with each generation surviving six to eight weeks.

RLEM eggs hatch in autumn following exposure to cooler temperatures and adequate rainfall. It takes approximately two weeks of exposure to favourable conditions for over-summering eggs to hatch. This releases swarms of mites, which attack delicate crop seedlings and emerging pasture plants.

RLEM eggs laid during the winter-spring period are orange in colour and about 0.1 mm in length. They are laid singly on the underside of leaves, the bases of host plants (particularly stems) and on nearby debris. They are often found in large numbers clustered together. Female RLEM can produce up to 100 winter eggs, which usually hatch in eight to ten days, depending on conditions.

Towards the end of spring, physiological changes in the plant, the hot dry weather and changes in light conditions combine to induce the production of over-summering or 'diapause eggs'. These are stress resistant eggs that are retained in the dead female bodies. Diapause eggs can successfully withstand the heat and desiccation of summer and give rise to the autumn generation the following year. Autumn conditions trigger egg hatching. [37]

7.6.4 Management of RLEM

Key points:

- Spray only if you need to. RLEM have been detected that have resistance to synthetic pyrethroids. Rotate chemical groups in and between seasons, as this will help to reduce resistance occurring.
- Use insecticide seed treatments for crops and new pastures with moderate pest pressure rather than spraying whole paddocks. This allows for smaller quantities of pesticide to be used that will directly target plant feeding pests.
- Control weeds before seeding, particularly in late autumn or winter sown crops where RLEM are likely to hatch before seeding. At least one week of bare soil can 'starve out' most of the mite population before crops are sown.
- Control weeds in the crop and along fencelines that provide habitat for mites. A weed-free crop will have few mites and over-summering eggs to carry through to the following season.
- Controlled grazing of pasture paddocks that will be cropped the next year will reduce mite numbers to levels that are almost as effective as chemical sprays. Sustained grazing of pastures throughout spring to maintain them at levels below 2 tonnes per hectare. Feed On Offer (FOO) (dry weight) will restrict mite numbers to low levels.
- Apply insecticides to paddocks that are to be cropped during spring to prevent RLEM populations producing over-summering eggs. This will minimise the pest population for the following autumn. TIMERITE® is a free package that provides a date in spring for a spray application to stop female RLEM from producing over-summering eggs.
- Look at your cropping rotations to decrease reliance on pesticides. The risk is generally highest if paddocks have been in long- term pasture (with high levels of broadleafed plants) where mite populations have been uncontrolled. Lower risk paddocks that generally do not require mite control are often those which follow a weed-free chickpea or cereal crop. [38]

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37 P Umina (2007) Redlegged earth mite. Agriculture Victoria, Ag Note AG0414 January 2007, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/redlegged-earth-mite

38 DAFWA (2015) Diagnosing redlegged earth mite. https://www.agric.wa.gov.au/mycrop/diagnosing-redlegged-earth-mite

Monitoring

Carefully inspect susceptible pastures and crops from autumn to spring for the presence of mites and evidence of damage. It is especially important to inspect crops regularly in the first 3–5 weeks after sowing. Mites are best detected feeding on the leaves in the morning or on overcast days. In the warmer part of the day RLEM tend to gather at the base of plants, sheltering in leaf sheaths and under debris. They will crawl into cracks in the ground to avoid heat and cold. When disturbed during feeding they will drop to the ground and seek shelter.

RLEM compete with other pasture pests, such as blue oat mites, for food and resources. Competition within and between mite species has been demonstrated in pastures and on a variety of crop types. This means control strategies that only target RLEM may not entirely remove pest pressure because other pests can fill the gap. This can be particularly evident after chemical applications, which are generally more effective against RLEM than other mite pests.

Chemical control

Chemicals are the most commonly used control option against earth mites. While a number of chemicals are registered for control of active RLEM in pastures and crops, there are no currently registered pesticides that are effective against RLEM eggs.

Autumn sprays

Controlling first generation mites before they have a chance to lay eggs is the only effective way to avoid the need for a second spray. Hence, pesticides used at or after sowing should be applied within three weeks of the first appearance of mites, before adults begin to lay eggs. Timing of chemical application is critical.

1. Pesticides with persistent residual activity can be used as bare earth treatments, either pre-sowing or at sowing to kill emerging mites. This will protect seedlings which are most vulnerable to damage.
2. Foliage sprays are applied once the crop has emerged and are generally an effective method of control.
3. Systemic pesticides are often applied as seed dressings. Seed dressings act by maintaining the pesticide at toxic levels within the growing plant, which then affects mites as they feed. This strategy aims to minimise damage to plants during the sensitive establishment phase. However, if mite numbers are high, plants may suffer significant damage before the pesticide has much effect.

Spring sprays

Research has shown that one accurately timed spring spray of an appropriate chemical can significantly reduce populations of RLEM the following autumn. This approach works by killing mites before they start producing diapause eggs in mid-late spring. The optimum date can be predicted using climatic variables, and tools such as TIMERITE® can help farmers identify the optimum date for spraying. Spring RLEM sprays will generally not be effective against other pest mites.

Repeated successive use of the 'spring spray' technique is not recommended as this could lead to populations evolving resistance to the strategy. To prevent the development of resistance, the selective rotation of products with different Modes of Action is advised.

Biological control

There is evidence of natural RLEM populations showing resistance to some chemicals, therefore, alternative management strategies are needed to complement current control methods.

At least 19 predators and one pathogen are known to attack earth mites in Australia. The most important predators of RLEM appear to be other mites, although small beetles, spiders and ants also play a role in reducing populations. A predatory mite (*Anystis wallacei*) has been introduced as a means of biological control, however, it has slow dispersal and establishment rates. Although locally successful, the benefits of this mite are yet to be demonstrated.

Preserving natural enemies may prevent RLEM population explosions in established pastures but this is often difficult to achieve. This is mainly because the pesticides generally used to control RLEM are broad-spectrum and kill beneficial species as well as the pests. The chemical impact on predator species can be minimised by choosing a spray that has least impact and by reducing the number of chemical applications. Although there are few registered alternatives for RLEM, there are groups that have low-moderate impacts on many natural enemies such as cyclodienes.

Natural enemies residing in windbreaks and roadside vegetation have been demonstrated to suppress RLEM in adjacent pasture paddocks. When pesticides with residual activity are applied as border sprays to prevent mites moving into a crop or pasture, beneficial insect numbers may be inadvertently reduced, thereby protecting RLEM populations.

Cultural control

Using cultural control methods can decrease the need for chemical control. Rotating crops or pastures with non-host crops can reduce pest colonisation, reproduction and survival. For example, prior to planting a susceptible crop like canola, a paddock may be sown to cereals or lentils to help reduce the risk of RLEM population build up. Cultivation can also help reduce RLEM populations by significantly decreasing the number of over-summering eggs. Hot stubble burns can provide a similar effect.

Clean fallowing and controlling weeds around crop and pasture perimeters can also act to reduce mite numbers. Control of weeds, especially thistles and capeweed, is important, as they provide important breeding sites for RLEM. Where paddocks have a history of damaging, high density RLEM populations, it is recommended that sowing pastures with a high clover content be avoided.

Appropriate grazing management can reduce RLEM populations to below damaging thresholds, possibly because shorter pasture results in lower relative humidity, which increases mite mortality and limits food resources.

Other cultural techniques including modification of tillage practices, trap or border crops, and mixed cropping can reduce overall infestation levels to below the economic control threshold, particularly when employed in conjunction with other measures. [39]

7.6.5 RLEM insecticide resistance in WA

Western Australia is the only state to have RLEM that are resistant to commonly applied insecticides, including synthetic pyrethroids (Group 2A) (SPs) and the organophosphates (Group 1B) omethoate and chlorpyrifos. Resistant RLEM populations are likely to be present in more localities in WA and elsewhere in southern Australia, especially in paddocks that have a history of repeated insecticide applications.

How does resistance occur?

Repeated use of synthetic pyrethroids (SP) insecticides, within seasons and between seasons, can encourage RLEM to develop resistance to this chemical group. All SPs have the same molecular mode of action. Once RLEM develop resistance to one insecticide, they are then resistant to all insecticides in this chemical group (Group 3A).

The repeated cumulative exposure of RLEM to SPs is the main factor behind resistance developing. Even if a SP insecticide is used against pests such as weevils or aphids and is not targeting RLEM, they will also receive a dose of the chemical.

39 Agriculture Victoria. Redlegged Earth Mite. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/pest-insects-and-mites/redlegged-earth-mite

Chemical control options

Farmers with resistant RLEM have been able to control these mites by using insecticides from the organophosphate (OP) group (Group 1B), e.g. dimethoate or omethoate. However, residual populations of SP-resistant RLEM were found on weeds along fencelines and re-infested paddocks.

How long does resistance last?

Resistance in RLEM is heritable and mechanisms to switch it off have not been found. RLEM from one site have been tested each year for four years and are still resistant to SPs, even without further SP application. This indicates that resistance, once established, is likely to persist in RLEM populations over many years. Growers need to prevent further development of resistance by decreasing overall use of SPs.

Spread of resistance

Locations of resistance within southern WA are geographically quite distinct, suggesting that the resistance develops in isolated RLEM populations within each property. Resistant RLEM have been found on properties near Esperance, Cranbrook, South Stirlings, Tenterden and Boyup Brook, making it unlikely that resistant RLEM have spread between locations. However, resistant RLEM can move into adjacent paddocks from weeds on fencelines.

Managing resistance

Identify your mites

RLEM are often found with other mites, such as blue oat mite (BOM), bryobia (clover) mite or balaustium mite, but resistance has only been found in RLEM. In situations where spray failures have occurred, it is important to correctly identify the mite. Blue oat mites are controlled by all chemicals registered for RLEM control, whereas chemical controls for bryobia mite and balaustium mites differ.

Plan ahead to reduce mite numbers

If you prepare paddocks in the preceding season, there will be lower numbers of pests on your crops. Consider the following to reduce pest numbers:

- Control weeds in the crop and along fencelines. Weeds provide habitat for mites. Controlling weeds with herbicides, cultivation or heavy grazing will decrease mite numbers. A weed-free crop will have few mites and over-summering eggs to carry through to the following season.
- Controlled grazing of pasture paddocks in the year prior to a cropping year will reduce RLEM numbers to levels similar to chemical sprays. Sustained grazing of pastures throughout spring to maintain Feed On Offer (FOO) levels below two tonnes per hectare (t/ha) (dry weight) will restrict mite numbers to low levels. Control RLEM in spring.
- Applying insecticides to some paddocks during spring to prevent RLEM populations producing over-summering eggs will decrease the pest population in the following autumn. Only specific paddocks should be selected for spring spraying based on FOO levels, future grazing management options, seed production requirements and intended paddock use next season.
- Use cropping rotations to decrease reliance on pesticides. Some paddocks will have a higher or lower risk of RLEM damage depending on previous crop rotations. The risk is generally highest if paddocks have been in long term pasture (with high levels of broadleafed plants) where mite populations have been uncontrolled. Lower risk paddocks that generally do not require mite control are often those that follow a cereal or canola weed-free crop, where conditions are less favourable for mite increase.

What you can do this season

Spray only if you need to

Farmers that currently have populations of resistant RLEM have mostly used repeated applications of SP chemicals as 'insurance' sprays to minimise anticipated pest risks. To decrease the likelihood of resistance developing on your property apply insecticides only on paddocks that have damaging numbers of pests.

Where spraying is needed, rotate chemical groups

For example, rotate between Synthetic Pyrethoids (SP, Group 3A) and Organophosphate (OP, group (Group 1B), e.g. dimethoate or omethoate), in and between seasons, as this will help to reduce resistance build-up. If spraying other pests, such as aphids, try not to use SPs. Consider other chemical options such as pirimicarb.

Predict hatchings of RLEM on your property to target your control strategy

Knowing approximately when the first autumn hatchings of RLEM is occurring on your property will help to determine if they will coincide with seedling crops. RLEM hatch in autumn from their over-summering egg stage, after adequate rainfall and at least seven days of average temperatures below 20°C. Crops sown in seasons with 'early breaks' with maximum temperatures well above 20°C (for example, canola sown in April) will not be damaged by RLEM.

Use insecticide seed treatments

Use insecticide seed treatments for crops and sown pastures with moderate pest pressure rather than spraying whole paddocks. Seed treatments allow smaller quantities of pesticide to be used that directly target plant feeding pests, allowing any predatory insects to continue their important beneficial role.

Do you suspect you have resistant RLEM?

If you have RLEM that survive registered rates of insecticide treatments or suspect that you have mites resistant to chemicals, please contact the DAFWA's broadacre entomologists. Arrangements can be made to have mites sampled and tested for their level of resistance. [40]

7.7 Lucerne flea

The lucerne flea, *Sminthurus viridis*, is a springtail that is found in both the northern and southern hemispheres but is restricted to areas that have a Mediterranean-type climate. It is thought to have been introduced to Australia from Europe and has since become a significant agricultural pest of crops and pastures across the southern states. It is not related to the fleas which attack animals and humans.

The adult lucerne flea is approximately 3 mm long with light green-yellow colouring and an irregular pattern of darker patches over the body (Figure 20). Lucerne fleas are wingless, have globular abdomens and can jump large distances relative to their size. Their mottled colouration, small size and elusive habits can often make detection difficult.

40 DAFWA (2016) Prevent redlegged earth mite resistance. https://www.agric.wa.gov.au/mites-spiders/prevent-redlegged-earth-mite-resistance?page=0%2C2

Figure 20: *Yellow-green wingless and globular adults, sometimes with dark markings.*

Source: DAFWA, 2013

Eggs, which are laid in batches, are covered in a soil layer making them almost impossible to detect in the field. The eggs are yellow-cream in colour and about 0.3 mm in diameter. The newly hatched nymphs are approximately 0.75 mm long and are pale yellow in colour. Young nymphs resemble adults except that they are much smaller in size and will moult several times before reaching maturity.

Lucerne fleas have a characteristic ability to 'spring' off vegetation when disturbed. This is due to a stiff appendage folded under their abdomen called a furcula, which is unfolded with such speed and force that it launches the lucerne flea into the air. Lucerne fleas are commonly observed on loam-clay soils.

7.7.1 Symptoms

What to look for

Paddock

- Small jumping bugs that appear early in the season and chew young leaves on heavier textured soils.

Plant

- Cereals, canola and pasture legumes have chewed leaves with transparent 'windows' (Figure 21).
- Green material completely removed in severe infestations.

Figure 21: *Chewed leaves have transparent 'windows'.*

Source: DAFWA, 2013

Insect Adult

- Adults (3 mm) yellow-green, wingless and globular in shape sometimes with dark markings.
- Insects 'spring' off foliage when disturbed. [41]

7.7.2 Damage caused by Lucerne flea

- Lucerne flea can kill seedling crops and pastures and re-growth of lucerne.
- Yield loss varies with the growth stage of the plant.
- Broadleaf seedlings are most susceptible.
- Young nymphs feed on the soft tissue on the underside of leaves leaving transparent 'windows'.
- Adults and older nymphs chew irregular holes in leaves and can completely defoliate plants. [42]

7.7.3 Thresholds for control

The key to preventing yield loss from pest infestation is early control.

- Establishing pasture: 15 per 100 cm^2 (sampling method not established, but could use that proposed by Taverner et al. 1996).
- A suggested threshold for other crops—treat if 50% of leaf area is likely to be damaged. [43]

41 DAFWA. Diagnosing Lucerne flea. https://www.agric.wa.gov.au/mycrop/diagnosing-lucerne-flea

42 GRDC, IPM Guidelines. Lucerne Flea. http://ipmguidelinesforgrains.com.au/pests/lucerne-flea-in-winter-seedling-crops/

43 GRDC, IPM Guidelines. Lucerne Flea. http://ipmguidelinesforgrains.com.au/pests/lucerne-flea-in-winter-seedling-crops/

7.7.4 Conditions favouring development

The lucerne flea has a similar seasonal biology to other important pests of establishing crops, such as the redlegged earth mite (RLEM). Lucerne fleas generally hatch from over-summering eggs in March-April following soaking autumn rains. They reproduce sexually and, depending on favourable temperatures and moisture availability, may go through as many as 3–5 generations between autumn and spring. Each generation takes three to five weeks, with each female capable of laying up to three batches of eggs during this time.

Winter eggs are laid in moist crevices on the soil surface in batches of about 20–60, usually under vegetation and debris. Females then excrete a fluid substance containing ingested soil and glandular secretions over the eggs. This acts to both camouflage and protect the eggs.

At the onset of warmer and drier conditions, over-summering eggs are produced which are protected from desiccation by a clay cement layer excreted by females. Consequently, lucerne fleas are more common on heavier loam/clay soils and are rarely found on sandy soils. The protective coating also prevents eggs from hatching when rain is insufficient for lucerne flea development or for the establishment of host plants.

7.7.5 Management of Lucerne flea

Monitoring

Monitoring is the key to reducing the impact of lucerne flea. Crops and pastures grown in areas where lucerne flea has previously been a problem should be regularly monitored for damage from autumn through to spring. Susceptible crops and pastures should also be carefully inspected for the presence of lucerne fleas and evidence of damage.

It is important to frequently inspect winter crops, particularly canola and pulses, in the first 3–5 weeks after sowing. Crops are most susceptible to damage immediately following seedling emergence. Pastures should be monitored at least fortnightly from autumn to spring, with weekly monitoring preferred where there have been problems in previous years.

Lucerne fleas are often concentrated in localised patches or 'hot spots' so it is important to have a good spread of monitoring sites within each paddock. Examine foliage for characteristic lucerne flea damage and check the soil surface where insects may be sheltering.

Some sprays require application at a particular growth stage, so it is also important to note the growth stage of the population. Spraying immature lucerne fleas before they have a chance to reproduce can effectively reduce the size of subsequent generations.

Lucerne fleas compete for food and resources with other agricultural pests such as RLEM and blue oat mites. This means control strategies that only target one species may not reduce the overall pest pressure because other pests can fill the gap. It is therefore important to assess the complex of pests before deciding on the most appropriate control strategy.

Chemical control

Lucerne fleas are commonly controlled post-emergence, usually after damage is first detected. Control is generally achieved with an organophosphate insecticide (eg. omethoate). In areas where damage is likely, a border spray may be sufficient to stop invasion from neighbouring pastures or crops. In many cases spot spraying, rather than blanket spraying, may be all that is required.

If the damage warrants control, treat the infested area with a registered chemical approximately three weeks after lucerne fleas have been observed on a newly emerged crop. This will allow for the further hatch of over-summering eggs but will be before the lucerne fleas reach maturity and begin to lay winter eggs.

In pastures, a follow-up spray may be needed roughly four weeks after the first spray to control subsequent hatches, and to kill new insects before they lay more eggs. Grazing the pasture before spraying will help open up the canopy to ensure adequate spray coverage. The second spray is unlikely to be needed if few lucerne fleas are observed at that time.

Crops are most likely to suffer damage where they follow a weedy crop or a pasture in which lucerne flea has not been controlled. As such, lucerne flea control in the season prior to the sowing of susceptible crops is recommended.

Caution is advised when selecting an insecticide. Several chemicals registered for RLEM (i.e. synthetic pyrethroids such as cypermethrin) are known to be ineffective against lucerne flea. When both lucerne fleas and RLEM 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.

Information on the registration status, rates of application and warnings related to withholding periods, OH&S, residues and off-target effects should be obtained before making decisions on which insecticide to use. This information is available from the DPI Chemical Standards Branch, chemical resellers, APVMA and the pesticide manufacturer. Always consult the label and MSDS before using any insecticide.

Biological control

Several predatory mites, various ground beetles and spiders prey upon lucerne fleas. Snout mites (which have orange bodies and legs) are particularly effective predators of this pest (Figure 22). The pasture snout mite (Bdellodes lapidaria) and the spiny snout mite (Neomulgus capillatus), have been the main focus of biological control efforts against lucerne flea.

Figure 22: *Predatory adult snout mite.*

Photo: A. Weeks (CESAR). Source from AgVic

The pasture snout mite was originally found in Western Australia and there are some examples of this mite successfully reducing lucerne flea numbers. Although more rare, the spiny snout mite can also drastically reduce lucerne flea populations, particularly in autumn.

Three species of predatory mites feed on lucerne flea. They include:

- pasture snout mite (*Bdellodes lapidaria*);
- spiny snout mite (*Neomulgus capillatus*);
- French anystis mite *Anystis wallacei* can provide effective suppression of lucerne flea.

Some field experiments indicate a 70–90% control of lucerne fleas by predatory mites. Other reports suggest that predatory mite activity is rarely effective to reduce lucerne flea impact on seedling crops. Predatory mites are slow to spread and can only do so by crawling. Redistribution of predatory mites is possible using suction machines to collect and transfer mites from established to new sites.

Other beneficials include ground beetles and spiders. [44]

7.8 Cutworms

Cutworms are plump, smooth caterpillars of several moth species. They feed on all crop and pasture plants, damaging them near the ground. The caterpillars hide under the soil or litter by day. When mature, they pupate in the soil. Cutworm caterpillars grow to about 40 mm long, but they usually cannot be seen as they hide under soil or litter by day. Often they can be located by scratching the surface near damaged plants, where they can be seen curled up in a defensive position.

Caterpillars with a pink tinge belong to the pink cutworm, *Agrotis munda*, which has caused widespread damage in agricultural areas north of Perth. The dark grey caterpillars of the bogong moth, *Agrotis infusa*, have been extremely damaging in most parts of the agricultural areas from time to time. Large numbers of patterned caterpillars belonging to different genera, *Rictonis* and *Omphaletis*, have also been found attacking cereals in agricultural areas.

Adult cutworms are stout-bodied moths with patterned wings. They fly very well and may be seen on window panes at night as they are attracted to lights. [45]

7.8.1 Symptoms

What to look for

Insect Adult

Adult cutworms are stout-bodied moths with patterned wings (Figure 23).

Figure 23: *Cutworm moths.*

Source: DAFWA, 2013

44 GRDC, IPM Guidelines. Lucerne Flea. http://ipmguidelinesforgrains.com.au/pests/lucerne-flea-in-winter-seedling-crops/

45 DAFWA (2016) Cutworm: pests of crops and pastures. https://www.agric.wa.gov.au/pest-insects/cutworm-pests-crops-and-pastures

Insect Larvae

- Caterpillars are up to 50 mm long, hairless with a dark head.
- They vary in colour and can have:
- a dark grey to green body often with lines and/or dark spots running along length;
- a pale grey-green body with a pinkish tinge, often with lines and/or dark spots running along length; or
- an orange-brown body with diagonal markings (Figure 24).

Figure 24: *Larvae of the three main species of cutworm.*

Source: DAFWA, 2013

Paddock

Often patches will have plants with leaves lopped or cut off at the base (Figure 25).

Figure 25: *Damage often occurs in patches.*

Source: DAFWA, 2013

Plant

- Damage is worst at the seedling stage but can persist for several weeks.
- Larvae hide in the soil during the day, often at the base of lopped plants (Figure 26). [46]

Figure 26: *Lopped lupin and wheat (insert) plants.*

Source: DAFWA, 2013

7.8.2 Damaged caused by cutworms

- Small larvae cause skeletonised or scalloped leaves (damage may be confused with that of lucerne flea or pasture web worm).
- Large larvae sever seedling stems near ground level.
- Large larvae (40–50 mm) are the damaging stage. These larvae may remain below the soil surface feeding on the stem at or below ground level.
- Whilst generally a pest of seedlings (1 to 5 leaf stage), cutworms can occasionally cause damage at tillering and early stem elongation in winter cereals. [47]

Economic and financial considerations

To assist in assessing the economic risk and financial costs associated with various treatment strategies go to MyEconomicTool.

There may be other economic and financial implications that need to be considered when choosing a management option. These may include:

46 DAFWA (2015) Diagnosing Cutworm in Canola and Pulses. https://www.agric.wa.gov.au/mycrop/diagnosing-cutworm-canola-and-pulses

47 GRDC, IPM Guidelines. Cutworms. http://ipmguidelinesforgrains.com.au/pests/soil-insects/cutworms/

Pre-crop

- Understand the potential yield losses associated with cutworm feeding damage.
- Assess the costs and benefits of taking preventative action.
- Assess the cost and benefits of controlling summer weeds (green bridge) to reduce potential feed source.

In-crop

- Compare the costs, benefits and risk of each management option against doing nothing or delaying treatment.
- Ignore all previous treatment costs in assessing current management options.
- Undertake a 'what if' scenario analysis to see what impact changing variables, such as grain price and season, have on the net income.

Post-crop

- Consider using an integrated pest management system and include a resistance management strategy in your spray program to reduce the chance of cutworm and other non-target insects becoming resistant. [48]

View these economic considerations in more detail.

7.8.3 Conditions favouring development

Cutworm moths can fly large distances and favour bare or lightly vegetated areas for egg laying. Moths emerge in late spring or early summer and are often observed entering houses and buildings for shelter over summer. They have one generation per year.

They are most damaging in autumn when large caterpillars (>20 mm) transfer from summer and autumn weeds onto newly emerged crop seedlings.

7.8.4 Thresholds for control

Control is warranted when two larvae per 0.5 m of crop row is present under visual inspection.

7.8.5 Control

Cutworms are easily controlled by insecticides. They are most damaging in autumn when large caterpillars (>20 mm) transfer from summer and autumn weeds onto newly emerged seedlings.

Monitoring:

- Inspect crops regularly from emergence to establishment. Larvae are active from late afternoon through the night.
- Look for signs of feeding on leaves. If detected, search the soil and stubble in the areas that are damaged, or where the plant stand is thinned.
- Larvae may move into a crop from a neighbouring weedy fallow, particularly as the weeds start to dry off, or are sprayed. Be alert to sources of larvae from outside the field.

Chemical control

- Treat the crop when seedling loss is nearing minimal plant density crop requirements.
- Treat older plants if more than 50% of plants have 75% or more leaf tissue loss.
- Chemical control is most effective when applied late in the day to maximise likelihood of larvae contacting/ingesting insecticide when they emerge at night to feed.

48 DAFWA (2015) Diagnosing Cutworm in Canola and Pulses. https://www.agric.wa.gov.au/mycrop/diagnosing-cutworm-canola-and-pulses

- Ground rig applications may provide flexibility to treat just affected areas, or to apply a border spray where larvae are moving into the crop from neighbouring weeds.

Cultural control

- Control weeds in and around fields prior to planting to reduce potential cutworm infestations.
- Be aware of cutworm movement from sprayed weedy fallow into neighbouring crops.
- Prolonged green feed in autumn allows larvae to develop to a large size by the time crops emerge.
- Aim to control potential hosts at least two weeks prior to planting to ensure larvae do not survive to infest crops.

Biological control

Biological control agents, or beneficials, include fly and wasp parasites, predatory beetles and diseases, continually reduce cutworm numbers but cannot be relied on to give adequate control. Orange and two-toned caterpillar parasites and orchid dupe are key parasitoids. These beneficials may suppress cutworm populations, but are unlikely to prevent crop loss in the event of an outbreak. [49]

7.9 Locusts

Locusts and grasshoppers will cause damage to chickpeas in the same way that they will cause damage to any green material when in plague numbers. Chickpea may be less vulnerable in the seedling stages than lupins and lentils. However, sheer weight of numbers can lead to significant damage (Figure 27).

Figure 27: *Locust swarms can travel long distances on the wind. Landholders are required to report locust activity.*

Source: Pulse Australia

Though locusts plagues are infrequent, they can be unpredictable and cause serious damaged if not managed. Plagues are traditionally thought to occur once every decade, however, locust hatchings arrived in 2012, just five years after the previous plague in WA in 2007. There could be a number of reasons for the increased frequency of locust hatchings—changing weather patterns, low summer rainfall and widespread uptake of minimum-till cropping, resulting in less disturbance of beds. Whatever the cause, growers are urged to be vigilant over spring-summer period in monitoring and controlling locusts. [50]

49 IPM Guidelines (2016) Cutworms. GRDC, http://ipmguidelinesforgrains.com.au/pests/soil-insects/cutworms/

50 GRDC (2012) Early return for locusts in WA. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-101/Early-return-for-locusts-in-WA

7.9.1 Effect on growing crops

While it is well known that cereals are particularly vulnerable to locusts, the susceptibility of the various pulses is uncertain, but growers must assume that they could be attacked while they remain green. It is important to note that:

- Established green crops are susceptible to damage by adult locusts but tend to be avoided by hoppers (immature locusts), although crop edges can be damaged and may warrant a perimeter spray.
- Locusts cause little damage to crops that have dried off, but crops that are beginning to dry down when locusts begin to fly are still susceptible to attack.
- Even slight damage to pulse crops that have a high grain value or are destined for specific export markets could justify the cost of control (Figure 28).
- As a general rule, hopper and adult numbers should be closely monitored, and if any damage is seen, spraying should be commenced immediately.
- Comply with label directions for the chosen insecticide and pay particular attention to withholding periods (WHP) for harvest/windrowing or swathing, and for grazing/fodder. [51]

Figure 28: *Locust hatchlings cause the most damage when they form feeding bands that move across the land, eating anything that is green.*

Source: Pulse Australia

7.9.2 Locusts can impact on pulse deliveries

Key points:

- Locusts pose more than just a physical threat to pulse crop yields and quality.
- Controlling locusts before harvest is imperative to ensure marketable quality grain and to ensure successful delivery.
- Pulse growers need to make contact with their receival agent well in advance of harvest to discuss probable industry attitudes to high locust inclusion in the grain sample.
- Both receival agents and marketers may reject grain with high locust inclusion despite the sample technically meeting the receival standard for field insects.
- Grain staining, slimes and objectionable odours may arise from squashing live locusts during harvest. This material is difficult, if not impossible to remove.
- Objectionable material and odours in the sample will result in the product being rejected at the receival point.
- Only permitted chemicals are to be used for control of locusts.
- Maximum residue limits apply and grain samples may be collected and analysed for compliance with regulatory and market requirements.

MORE INFORMATION

Pulse Australia: Locusts can impact on pulse deliveries.

51 Pulse Australia. Australian pulse bulletin: Impact of locusts on pulse crops and grain quality. http://pulseaus.com.au/growing-pulses/publications/locust-control

7.9.3 Management of locusts

The decision on how locusts in crops are best managed is affected by a range of factors including:

- Growth stage of the crop, i.e. is there any green plant material or has the crop completely dried off?
- Ability to harvest early—desiccation may be an option to advance harvest.
- Delivery standards required for the specific pulse—discuss requirements with potential buyers.
- Risk to market from pesticide residues—WHP for windrowing/swathing is the same as harvest.
- Ability to clean physical locust contamination from harvested grain.

Control

The easiest and most effective way for landholders to control locusts is by ground spraying the hoppers when they have formed into dense aggregations called bands. This normally occurs from 1–2 weeks after hatching. The time available for controlling an outbreak is short with hoppers taking about five weeks to develop into swarming adults. Hoppers are most likely to hatch in pasture paddocks and along roadsides, fencelines and non-cultivated ground around the crop perimeter, but some hoppers may hatch from egg beds laid within crops particularly bare areas such as wheel tracks where tram lining is practiced.

It is critical in these situations that the correct insecticide is used to avoid residue issues. Australian grain produce must meet minimum residue levels (MRLs). Individual deliveries of grain will be tested for chemical residues, to detect the use of unapproved pesticides and to ensure that withholding periods have been followed.

- Only use an insecticide that is registered or has a permit for locust control in the specific pulse crop.
- Users must obtain, read and adhere to the conditions of APVMA permits prior to use.
- Follow label directions and pay attention to the WHP (withholding period). Following pesticide application, the relevant withholding period MUST expire BEFORE cutting for hay, windrowing, harvest or undertaking of any similar operation.
- Plan well ahead in choosing the most appropriate product(s) to suit your situation as availability may become an issue as the season progresses.
- Be aware of the receival standards that apply to insect contamination (alive or dead) and grain damage from locust feeding.
- Be aware of nil tolerance for odour and taints that could arise from crushing locusts during harvest, handling or while in storage.
- Avoid inadvertent contamination of grain with other chemicals not used in pulses. [52]

Spur-throated locust: insecticide spraying guide—WA

Spur-throated locusts are an infrequent but important pest of agriculture in parts of Western Australia (Figure 29). Damage to winter crops tends to occur in the autumn just after sowing when the locusts are fledging and at the late ripening stage in spring when the locusts are beginning to mature.

MORE INFORMATION

Impact of locusts on pulse crops and grain quality.

52 Pulse Australia. Australian pulse bulletin: Impact of locusts on pulse crops and grain quality. http://pulseaus.com.au/growing-pulses/publications/locust-control

Figure 29: *Spur throated locust.*

Source: DAFWA

Chemicals registered or permitted in Western Australia

There are many products with different trade names that contain the same active ingredient:

- Emulsifiable concentrate (EC), ultra low volume (ULV), suspension concentrate (SC).
- Withholding period (WHP): number of days are given for: Harvest withholding period (H) and export withholding periods (Export Slaughter Interval (ESI), Export Grazing Interval (EGI) and Export Animal Feed Interval (EAFI). For grazing WHP's refer to chemical label.
- Avoid overspraying stock. Refer to labels for withholding grazing periods for domestic markets. For animals destined for export: if overspraying does occur, withhold stock for slaughter until the ESI on clean feed is met. Or the EGI on treated crops/pasture.
- Many products are dangerous to fish and crustaceans. Do not contaminate ponds, rivers or waterways and do not spray flowering crops when bees are foraging.

MORE INFORMATION

DAFWA Spur throated locust: insecticide spraying guide.

7.10 Slugs and snails

7.10.1 Increase in WA

Numbers of slugs and snails have increased in broadacre cropping in Western Australia with the use of minimum tillage and stubble-retention practices (Figure 30). These systems increase the organic content of paddocks and the soil moisture content, leading to higher survival levels of slugs and snails.

Slug and snail pests in Australia have come from other countries, mainly the Mediterranean region. They damage plant seeds (mainly legumes), recently germinated seeds, seedlings and leaves and can be a contaminant of grain at harvest.

Figure 30: *Snails and slugs have increased in WA.*

Source: DAFWA

MORE INFORMATION

Identification and control of pest slugs and snails for broadacre crops in WA.

Distribution of slugs and snails

Slugs are pests of crops, especially emerging canola, in the higher rainfall regions of Western Australia. Slugs tend to be restricted to soils with a clay content.

Snails are found on all soil types. White Italian and vineyard snails prefer alkaline sandy soils, the small pointed snail is able to survive on all soil types, even acidic soils. Liming areas where there are snails will aid snail survival.

The small pointed snails are only known to cause economic crop damage in high rainfall areas, whereas the vineyard and white Italian snails are known to cause crop damage in the Greenough flats (which is the region between Dongara and Geraldton) and the Geraldton region. [53]

7.10.2 Damage caused by slugs and snails

Slug and snail pests damage plant seeds (mainly legumes), recently germinated seeds, seedlings and leaves and can be a contaminant of grain at harvest.

Snails are not known to damage seeds, but may damage germinated seeds close to the soil surface. However, slugs, especially black keeled slugs, will feed in the furrows on seeds of legumes. These slugs are not known to feed on ungerminated seeds.

Irregular pieces chewed from leaves and shredded leaf edges are typical of snail and slug presence. Damage to legume crops can be difficult to detect if seedlings are chewed down to the ground during emergence. Different species of slugs cause differing amounts of damage. [54]

7.10.3 Thresholds for control

Table 10: *Suggested thresholds for control of slugs and snails in broadacre crops.*

Species	Oilseeds	Cereals	Pulses	Pastures
Black keeled slug	1-2/m^2	1-2/m^2	1-2/m^2	5/m^2
Reticulated slug	1-2/m^2	5/m^2	1-2/m^2	5/m^2
Small pointed snail	20/m^2	40/m^2	5 per seedling	100/m^2
Vineyard snail	5/m^2	20/m^2	5/m^2	80/m^2
White Italian snail	5/m^2	20/m^2	5/m^2	80/m^2

Please note: the above thresholds are from limited data. It is essential to carefully monitor crops as distributions of snails and slugs are patchy.

Source: DAFWA

7.10.4 Management of slugs and snails

From a management point of view, slugs and snails have similar lifecycles. This means similar management techniques can be employed to control them in broadacre crops. Effective management requires applying controls that coincide with different phases of the pest's lifecycle (Figure 31).

53 DAFWA. Identification and control of pest slugs and snails for broadacre crops in WA. https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C0

54 Micic S. (2016). Identification and control of pest slugs and snails for broadacre crops in Western Australia. DAFWA. https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C0

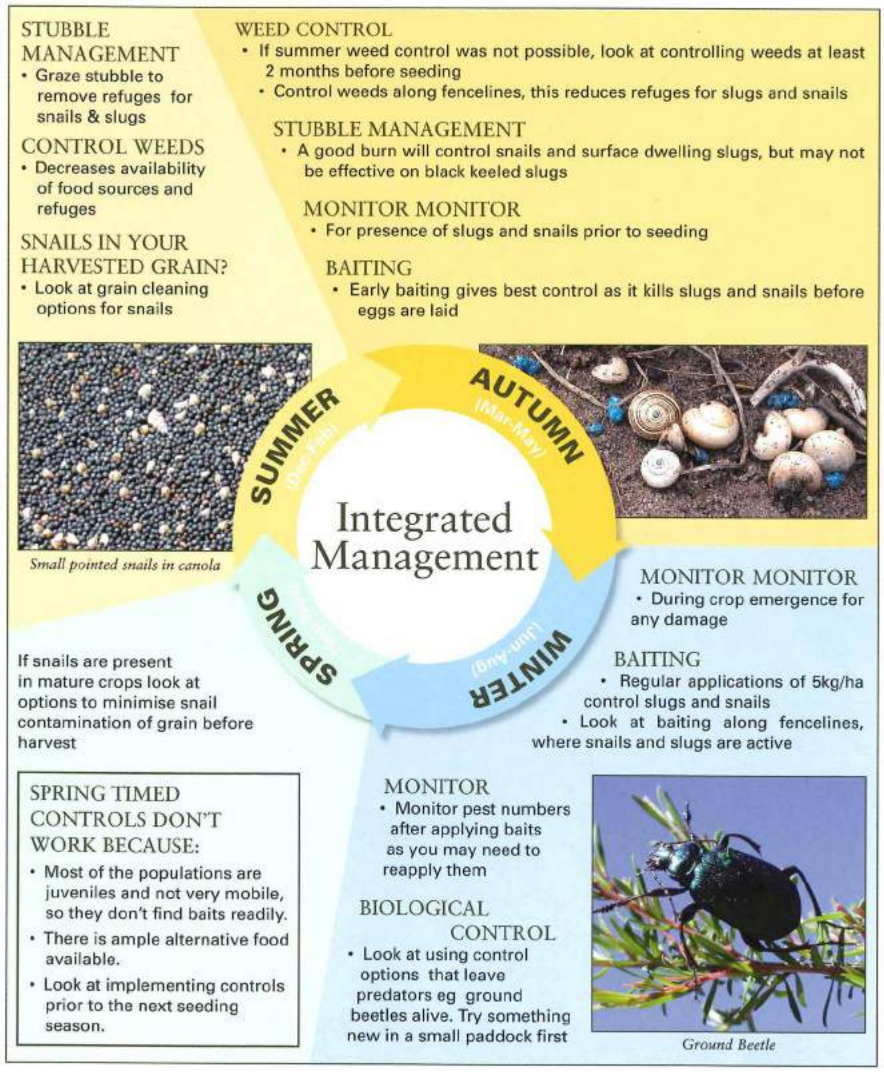

Figure 31: *Integrated control options that align with slug and snail lifecycles, breaking the cycle of reinfestation.*

Source: DAFWA

Chemical control

There are no sprays registered for snail and slug control in broadacre cropping. Be aware that insecticides commonly used to control insect pests of broadacre crops are not effective against slugs and snails.

Baits

Slugs and snails can only be controlled by baits if they are mobile and looking for food. Note that young snails; i.e. those less than 7 mm in diameter for round snails and 7 mm in height for conical snails are not likely to be controlled by baits. Young snails feed on decaying plant matter and are not likely to be attracted to baits.

Snail and slug numbers should be monitored to determine if there is a need to bait especially during crop emergence. Baiting will generally only kill 50% of a slug population at any one time and then mainly the larger ones. Younger slugs may emerge in successive waves. Monitoring numbers (refer to Table 10) will determine if there is a need for multiple bait applications. Based on this, baiting can be confined to areas of high snail/slug density.

All baiting must be stopped at least two months prior to harvest to ensure baits are broken down and do not become a contaminant of grain.

MORE INFORMATION

Snails: Bash'em Burn'em Bait'em

Biological control

There are a range of native ground beetles (family Carabidae: carabids) that are generalist predators, which attack slugs. These beetles would normally eat other prey, but some have been found to have a significant impact on slug populations. They can be important factor in controlling slugs, in combination with baiting.

The only biological control developed for snails (by the South Australian Research and Development Institute) is a parasitic fly, *Sarcophaga penicillata.* Its effectiveness has been limited.

Cultural control

Burning

Burning prior to seeding, is one of the most effective methods for pre-breeding snail control and provides some slug control. The burning itself kills snails but does not kill slugs. The lack of food and shelter following a burn makes it more likely that slugs will move elsewhere.

Before deciding to burn, soil type and weather conditions need to be taken into consideration. Also, summer weeds should be desiccated and browned off. Rocks also provide hiding places and these, if possible, should be turned by cabling or fire harrowing just prior to burning.

It is important to ensure that an even burn is applied across the paddock, as unburnt patches will provide habitats (refuges) especially for snails. An even burn causes 80-100% kill, patchy burn 50-80% kill. Burning on a warm day with little wind in a paddock that has a reasonable fuel load should achieve good control, can be less effective on small pointed snails if rocks are not turned.

When snail populations are large, a strategic burn every three or four years will assist in controlling snail numbers.

Grazing

Grazing animals will knock snails from stubble and may also trample them. Grazing will also decrease the stubble load into a paddock about to be seeded. Decreasing stubble ground cover will decrease refuges for slugs and snails.

Tillage

The most effective form of tillage to reduce numbers of snails and slugs is wide points or full-cut discs that are used in conventional tillage methods. Ploughing the soil to a depth of 5 cm or more will bury surface snails and slugs. Burying snails, especially small pointed snails, can reduce surface numbers of snails by around 40-60%.

Conventional tillage may have limited impact on black keeled slugs. Tillage will disrupt burrows made by these slugs and may cause some mortality. However, it is unlikely that tillage alone will decrease the number of black keeled slugs sufficiently to protect crops.

If tillage coincides with egg laying by slugs and snails, it may expose buried eggs to the environment. This may cause eggs to dry out and die, thereby decreasing slug and snail populations.

Cultivation of the soil does bury surface trash, disturbing potential shelters for slugs and snails. Ploughing trash residues after harvest has been found to remove over-summering habitat for slugs and snails. [55]

55 Micic S. (2016). Identification and control of pest slugs and snails for broadacre crops in Western Australia. DAFWA. https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C0

7.10.5 Monitoring

Monitoring regularly, means pests can be detected early, ideally before seeding as there are more control options available at this time. Once the crop has been seeded and germination is commencing, control options are limited to baiting. At this time crops should be examined at night for slug and snail activity.

It is best to look for slugs and snails on moist, warm and still nights. Fresh trails of white and clear slime (mucus) visible in the morning also indicate the presence of slugs or snails. However, prior to and after applying control measures, it is necessary to estimate how many slugs and snails are present.

It is a good idea to monitor in:

- January/February to assess stubble management options for slug and snail management
- March/April to assess options for burning and/or baiting
- May to August to assess options for baiting especially along fencelines
- For snails 3-4 weeks before harvest to assess risk of snail contamination of grain and if required, implement options to minimise the risk.

How to find slugs

A useful method to detect areas infested with slugs, prior to seeding or crop emergence, is to lay lines of slug pellets with a rabbit baiter. In infested areas, slugs are attracted to the freshly turned soil and pellets placed in the furrow. Very large numbers can be found dead or dying in the furrows or nearby. On sloping ground, furrows should be run along contours to reduce the risk of soil erosion in the event of heavy rain.

An alternative method to gain an indication of the numbers of slugs present in a paddock is to place wet carpet squares, hessian sacks or tiles on the soil surface. They should at least be 32x32 cm (10% of a square metre). Place pellets under them. After a few days, count the number of slugs under and around each square. Multiplying by 10 will give an estimate of slugs per square metre (/m^2).

How to find snails

Snails are usually found on stumps, fence lines and under stubbles. A good way to determine snail numbers on open ground is to use a 32x32 cm square quadrant and count all of the live snails in it. This is an area of 10% of a square metre so multiplying by 10 will give an estimate of snails/m^2. [56]

MORE INFORMATION

Snails – economic considerations for management

Slugs – economic considerations

56 Micic S. (2016). Identification and control of pest slugs and snails for broadacre crops in Western Australia. DAFWA. https://www.agric.wa.gov.au/grains/identification-and-control-pest-slugs-and-snails-broadacre-crops-western-australia?page=0%2C0

Nematode management

Key messages

- Nematodes are common soil pests that feed on the roots of a wide range of crop plants in all agricultural areas of Western Australia, irrespective of soil type and rainfall.
- Root-lesion nematodes are found over 5.74 million ha (or ~65%) of the cropping area of Western Australia (WA). Populations potentially limit yield in at least 40% of these infested paddocks.
- The main species found in broadacre cropping in WA are *Pratylenchus neglectus, P. quasitereoides* (formerly known as *P. teres*), *P. thornei* and *P. penetrans*.
- There are consistent varietal differences in Pt resistance within chickpea varieties
- Successful management relies on:
- farm hygiene to keep fields free of RLN;
- soil test to determine whether RLN are an issue and which species are present;
- growing tolerant varieties when RLN are present, to maximise yields; and
- rotating with resistant crops to keep RLN at low levels.

Nematodes are microscopic worms that are sometimes known as 'roundworms' or 'eelworms'. Those living in soil are generally small (less than 1 mm long and only 15–20 µm wide) and can only be seen with a microscope. Nematodes are common soil pests that feed on the roots of a wide range of crop plants in all agricultural areas of Western Australia, irrespective of soil type and rainfall. Nematodes multiply on susceptible hosts. Consequently, as nematode populations increase, crop production is limited. Damaged roots have less efficient water and nutrient uptake, and plants are also less able to tolerate other stresses such as drought. [1]

WATCH: GCTV6: Root lesion nematodes.

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

8.1 Root-lesion nematode (RLN)

Key points

- Root-lesion nematodes are found over 5.74 million ha (or ~65%) of the cropping area of Western Australia (WA).
- Populations potentially limit yield in at least 40% of these infested paddocks.
- The main species found in broadacre cropping in WA are *Pratylenchus neglectus*, *P. quasitereoides* (formerly known as *P. teres*), *P. thornei* and *P. penetrans*.
- The host range of RLN is broad and includes cereals, oilseeds, grain legumes and pastures, as well as many broadleaf and grass weeds. [2]
- *P. quasitereoides* is unique to WA, has a wide host range and is capable of causing significant yield damage.
- Crop rotation and resistant cultivar selection are the keys to management of Root-lesion nematode (RLN). Growers need to know which species of RLN are present as cultivars resistant to one nematode species may be susceptible to another, so suitable rotations will vary.
- Ongoing DAFWA research is developing rotational recommendations through the characterisation of wheat cultivar resistance and tolerance levels.
- Become familiar with root and crop symptoms associated with nematode damage.
- Make use of available testing services to determine nematode species and levels, but be aware that PreDicta-B™ cannot currently detect *P. quasitereoides* present in WA crops.
- AGWEST Plant Laboratories can conduct in-season nematode diagnosis.
- Consider the influence of soil nematode levels not only on the current, but also subsequent crops in the rotation. [3]

Figure 1: *Microscopic image of a root lesion nematode. Notice the syringe-like 'stylet' at the head end, which is used for extracting nutrients from the plant root. This nematode is less than 1 mm long.*

Source: DAFWA. Photo: Sean Kelly, DAFWA, Nematology

2 GRDC. Tips and tactics, Root Lesion Nematode–Western Region. https://grdc.com.au/Resources/Factsheets/2015/03/Root-Lesion-Nematodes

3 S Collins, S Kelly, H Hunter, B MacLeod, L Debrincat, J Teasdale, C Versteeg, X Zhang (2013) Pratylenchus teres–WA's home grown Root-lesion nematode (RLN) and its unique impacts on broadacre crops. DAFWA, GRDC.

Root-lesion nematodes (RLN, *Pratylenchus* spp.) are microscopic migratory endoparasites (Figure 1). This means that RLN enter roots, feed on cell contents then either remain to continue feeding within the same root or exit and move to nearby root systems. This process damages the root system making water and nutrient uptake less efficient, therefore plants are less able to tolerate other stresses. Currently, RLN damage is estimated to cause crop losses in the order of $190 million per annum in western and southern Australia. [4] These huge losses are put into perspective when the magnitude of the area affected by RLN in WA alone is considered. It is estimated that one or more species of RLN occur in at least 60% of WA cropping paddocks–that is over at least 5.3 million ha of the WA cropping zone (Figure 2).

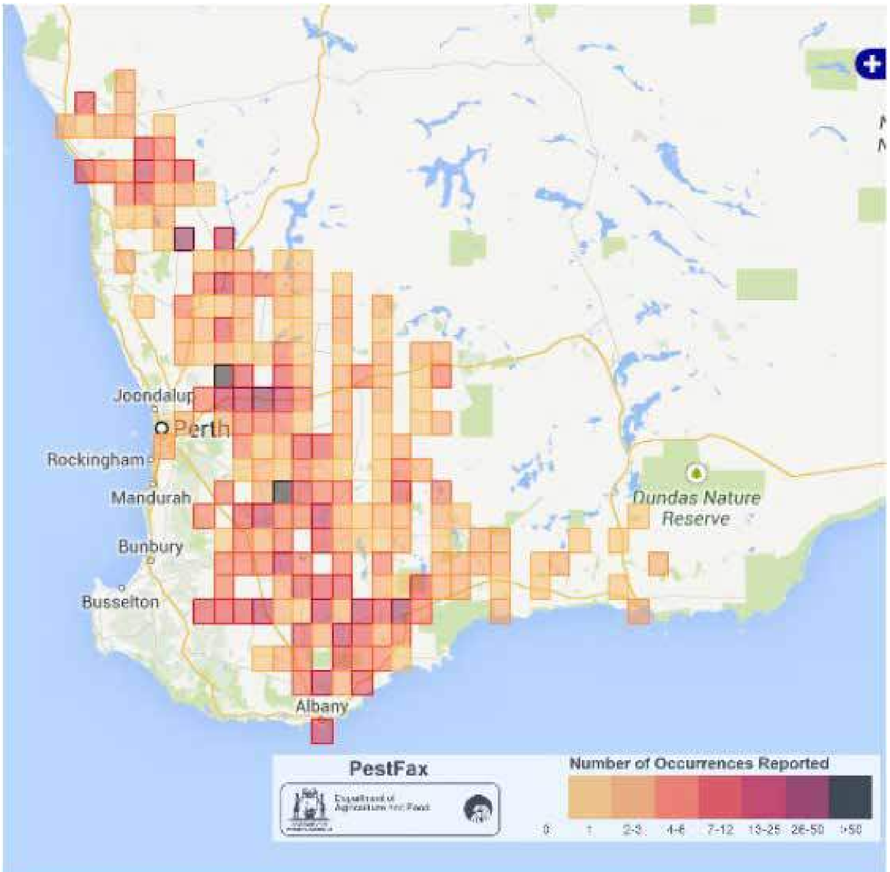

Figure 2: *Positive detection of root-lesion nematodes in Western Australian broadacre cropping between 1997 and 2013.*

Source: GRDC

Surveys also found that RLN is at yield limiting levels in at least 40% of paddocks. Several types of RLN are responsible and paddocks usually have one or more species: *P. neglectus* is the most frequent RLN identified in WA, occurring in at least 40% of paddocks; *P. thornei* occurs rarely (around 8% of paddocks); *P. quasitereoides* is unique to WA, can reach high populations and cause more significant and widespread damage within a crop than *P. neglectus*. Although *P. quasitereoides* is less frequent, crops resistant to *P. neglectus* can be highly susceptible to this species, requiring a different suite of rotational crops and cultivars for effective management. It is therefore imperative that in field diagnoses the species of RLN is correctly identified, to enable growers to deploy appropriate crop cultivars and species and minimise current and future losses. [5]

4 Vanstone et al. (2008) Australasian Plant Pathology 37, 220–234

5 S Collins, S Kelly, H Hunter, B MacLeod, L Debrincat, J Teasdale, C Versteeg and X Zhang. (2013). Pratylenchus teres—WA's home grown Root Lesion Nematode (RLN) and its unique impacts on broadacre crops. DAFWA, GRDC.

Pratylenchus penetrans is rare in broadacre crops but can cause severe damage to some crops. These estimates represent a compilation of more than 2,300 confirmed RLN reports gathered since 1997 by the Department of Agriculture and Food, Western Australia (DAFWA), including research trials, surveys and Agwest Plant Laboratory diagnostic samples. Yield losses in broadacre cropping caused by *P. quasitereoides* or *P. penetrans* are a problem unique to WA. Research is under way to learn more about these species and the rotations that will limit their population below damaging levels in cropping soils.

More than one RLN species can be found in the roots of an individual crop, although one species usually dominates (Figure 3).

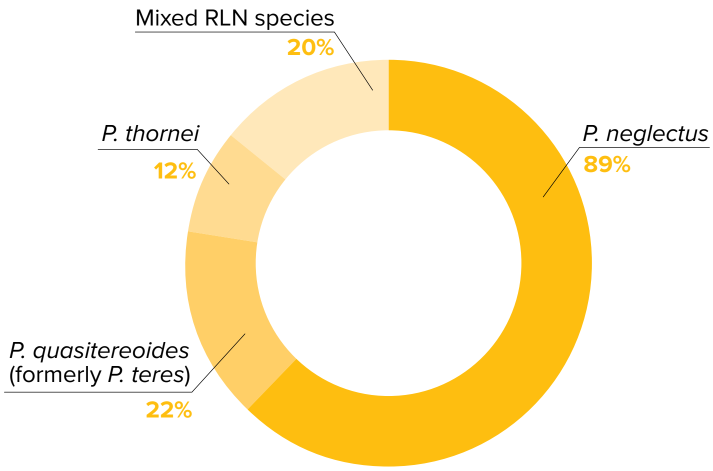

Figure 3: *Relative abundance of the main root-lesion nematode species identified in infested broadacre paddocks in Western Australia.*

Source: GRDC

DAFWA has been conducting research for nearly 20 years into the distribution, host range among crop species, variety resistance within crop species, and yield impacts of RLN on crops. During this time, 486 varieties across a wide range of crops have been assessed for resistance to the four main RLN species. All species of RLN have a wide host range. Identification of nematode species is important to management decisions because varieties and crop species differ in their resistance or susceptibility to different members of the *Pratylenchus* genus, with chickpea being susceptible to *P. neglectus* and *P. penetrans*.

8.1.1 *Pratylenchus quasitereoides* (formerly *teres*)—WA's home grown RLN

- *P. quasitereoides* is unique to WA, has a wide host range, and is capable of causing significant yield damage.
- Crop rotation and resistant cultivar selection are the keys to management of Root-lesion nematode (RLN). Growers need to know which species of RLN are present as cultivars resistant to one nematode species may be susceptible to another, so suitable rotations will vary.
- Ongoing DAFWA research is developing rotational recommendations through the characterisation of wheat cultivar resistance and tolerance levels.
- Become familiar with root and crop symptoms associated with nematode damage.
- Make use of available testing services to determine nematode species and levels, but be aware that PreDicta-B™ cannot currently detect *P. quasitereoides* present in WA crops.

- AGWEST Plant Laboratories can conduct in-season nematode diagnosis.
- Consider the influence of soil nematode levels not only on the current, but also on subsequent crops in the rotation.

8.1.2 Varietal resistance or tolerance

A tolerant crop yields well when large populations of RLN are present (in contrast to an intolerant crop). A resistant crop does not allow RLN to reproduce and increase in number (in contrast to a susceptible crop).

Chickpeas are susceptible to *P. neglectus*, *P. thornei* and *P. penetrans*. [6] Chickpea varieties differ in their resistance and tolerance to RLN but are generally considered more susceptible (allowing nematodes to multiply) than field pea, faba bean and lupin—but less so than wheat. While older chickpea varieties were a host for the root lesion nematode *(Pratylenchus neglectus, P. thornei)*, newer varieties are not as susceptible to root lesion nematode multiplication. [7]

Research in the Northern growing region indicates that there are consistent differences in *Pt* resistance between commercial chickpea varieties. Figure 4 shows a summary of key chickpea variety performance in eight trials sampled by DAFF QLD, NSW DPI or NGA.

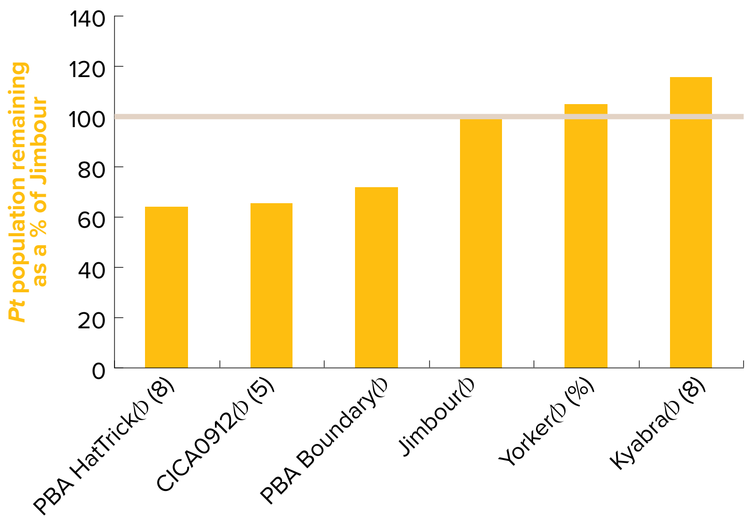

Figure 4: *Comparison of Pt population remaining as a % of Jimbour, 2010–2012 (Number) indicates the number of trials compared to Jimbour. The red broken line indicates the Pt level remaining after Jimbour.*

Source: GRDC

6 GRDC Tips and Tactics Root-Lesion nematode–Western region. http://www.grdc.com.au/TT-RootLesionNematodes

7 Pulse Australia. Chickpea production: Southern and Western Region. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/southern-guide

WATCH: Root-lesion nematodes. Resistant cereal varieties have surprising impact on RLN numbers.

8.1.3 Damage caused by RLN

Root-lesion nematodes cause poor plant growth in situations that otherwise appear favourable. They attack cereals and pulses and are thus a threat to the whole farming system. The nematodes feed and multiply on and in the roots of chickpea plants and, when in sufficient numbers, reduce growth and yield. Root-lesion nematode numbers build up steadily under susceptible crops and cause decreasing yields over several years. Intolerant chickpea varieties can lose up to 20% yield when nematode populations are high. [8]

8.1.4 Symptoms

Root-lesion nematodes cannot be seen with the naked eye in the soil or in plants. Aboveground symptoms are often indistinct and difficult to identify. The first signs are poor establishment, stunting, poor tillering of cereals, and plants possibly wilting despite moist soil. Nematodes are usually distributed unevenly across a paddock, resulting in irregular crop growth (Figure 5). Sometimes symptoms are confused with nutrient deficiency, and can be exacerbated by a lack of nutrients.

Figure 5: *Chickpea field infested with nematode.*

Source: IIPR

8 DAFQLD. Root-Lesion nematode management. https://www.daf.qld.gov.au/__data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf

When roots are damaged by RLN, the plants become less efficient at taking up water and nutrients, and less able to tolerate stresses such as drought or nutrient deficiencies. Depending on the extent of damage and the growing conditions, affected plants may partly recover if the rate of new root growth exceeds the rate at which nematodes damage the roots.

Chickpea roots can show distinct dark brown–orange lesions at early stages of infection, and the lateral roots can be severely stunted and reduced in number. The root cortex (or outer root layer) will be damaged and it may disintegrate.

Diagnosis is difficult and can be confirmed only with laboratory testing, particularly to identify the species, because all RLN species cause identical symptoms. The Predicta-BTM soil test (SARDI Diagnostic Services) is a useful tool for several nematode species and is available through accredited agronomists. [9]

Root-lesion nematodes are microscopic and cannot be seen with the naked eye in the soil or in plants. The most reliable way to confirm the presence of root-lesion nematodes is to test your farm soil. Nematodes are extracted from the soil for identification and to determine their population size. Look out for tell-tale signs of nematode infection in the roots and symptoms in the plant tops, and if seen, submit soil and root samples for nematode assessment. [10]

WATCH: How to diagnose Root-lesion nematode.

Root damage—dark lesions and poor root structure

Root-lesion nematodes invade the root tissue, resulting in light browning of the roots or localised deep brown lesions (Figure 6). However, these lesions can be difficult to see on roots. The damage to the roots and the appearance of the lesions can be made worse by fungi and bacteria also entering the wounded roots. Roots infected by root-lesion nematodes are poorly branched, lack root hairs and do not grow deeply into the soil profile. Such root systems are inefficient in taking up soil nutrients (particularly nitrogen, phosphorus and zinc under northern region conditions) and soil water.

9 GRDC Tips and Tactics Root-lesion nematode–Western region. http://www.grdc.com.au/TT-RootLesionNematodes

10 A Wherrett, V Vanstone The National Soil Quality Monitoring ProgramFact Sheets–Root Lesion Nematode. http://soilquality.org.au/factsheets/root-lesion-nematode

Figure 6: *Brown lesions indicate entry points of RLN on chickpea roots.*

Photo: Vivien Vanstone, DAFWA, Nematology

Plant tops—stunted, yellow lower leaves, wilting

When root-lesion nematodes are present in very high numbers, the lower leaves of the wheat plants are yellow and the plants are stunted with reduced tillering. There is poor canopy closure so that the crop rows appear more open. The tops of the plants may exhibit symptoms of nutrient deficiency (nitrogen, phosphorus and zinc) when the roots are damaged by root-lesion nematodes. Infected crops can wilt prematurely, particularly when conditions become dry later in the season because the damaged root systems are inefficient at taking up stored soil moisture. With good seasonal rainfall, wilting is less evident and plants may appear nitrogen deficient. [11]

8.1.5 Conditions favouring development

The adult root-lesion nematodes are nearly all self-fertile females. They lay eggs inside the roots and pass through a complete life cycle in about six weeks under favourable conditions (warm, moist soil), and so pass through several generations in the life of one host crop (Figure 7). The nematodes survive through fallow periods, particularly in the subsoil where they escape the hot, drying conditions of the surface soil. In drought or as plants and soil dry out in late spring, the nematodes can dehydrate (anhydrobiosis) to further aid their survival until favourable conditions return. [12]

11 DAFQLD. Root-Lesion nematode management. https://www.daf.qld.gov.au/__data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf

12 DAFQLD. Root-Lesion nematode management. https://www.daf.qld.gov.au/__data/assets/pdf_file/0010/58870/Root-Lesion-Nematode-Brochure.pdf

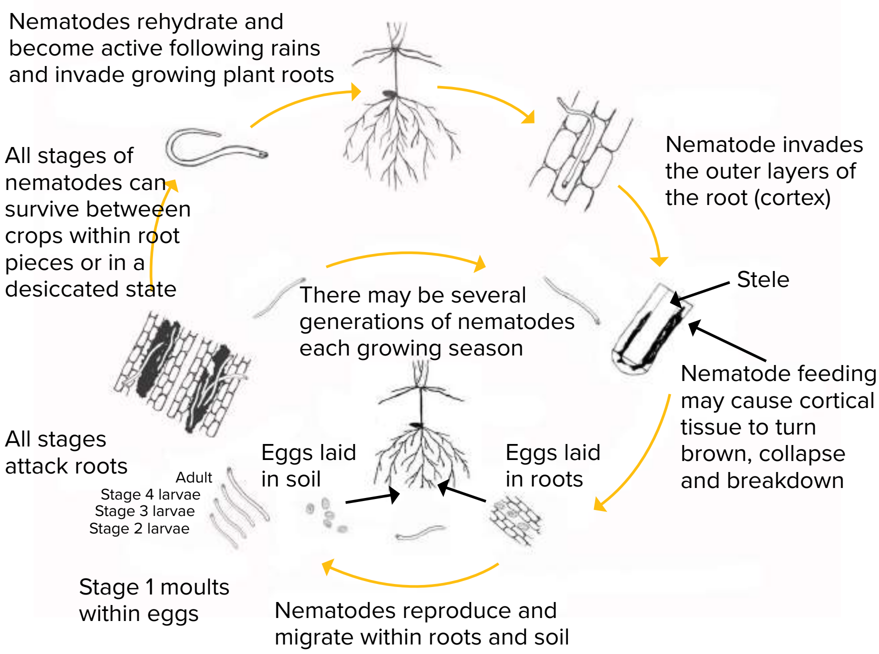

Figure 7: *Disease cycle and damage of root-lesion nematode, adapted from: GN Agrios (1997).*

Illustration: Kylie Fowler. Source: GRDC

8.1.6 Thresholds for control

The damage threshold has been estimated at 2,000 nematodes/kg soil (or 2/g soil). Control is warranted for paddocks with populations over this density threshold. [13]

8.1.7 Management of RLN

There are four key strategies for the management of RLN:

1. Test soil for nematodes in a laboratory.
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. Tolerant varieties grow and yield well when RLN are present. [14]
4. Rotate with resistant crops to prevent increases in RLN. When large 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 so that the yield potential of tolerant varieties is achieved.

Figure 8 is a simplified chart that highlights the critical first step in the management of RLN: to test your soil and determine whether or not you have an issue to manage.

13 GRDC. (2015). Tips and tactics: Root lesion nematodes Western region. www.grdc.com.au/TT-RootLesionNematodes

14 KJ Owen, J Sheedy, N Seymour (2013) Root-lesion nematode in Queensland. Soil Quality Pty Ltd Fact Sheet.

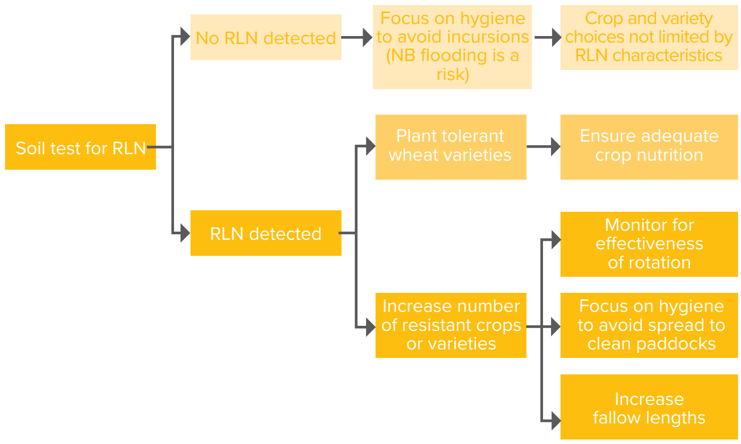

Figure 8: *RLN management flow chart.*

Source: GRDC

WATCH: What lies beneath—managing RLNs to combat yield loss

Monitoring

Observation and monitoring of above and below ground symptoms of plant disease, followed by diagnosis of the cause(s) of any root disease, is the first step in implementing effective management. Although little can be done during the current cropping season to ameliorate nematode symptoms, the information will be crucial in planning effective rotations of crop species and varieties in following seasons.

Commercial pre-season testing of soil by the Predicta-BTM root disease testing service determines levels of *P. neglectus* and *P. thornei* present using a DNA detection technique. Currently, this test is limited in its ability to detect levels of *P. penetrans* and *P. quasitereoides* in the soil, and any results from Western Australian soils using Predicta-BTM should be confirmed by traditional laboratory extraction and microscopic examination. During the season, plants with suspected RLN infections should be sent to a laboratory for extraction and identification. [15]

If RLN infestation is suspected, growers are advised to check the crop roots. Carefully digging up and washing the soil from the roots of an infected plant can

15 A Wherrett, V Vanstone The National Soil Quality Monitoring ProgramFact Sheets–Root Lesion Nematode. http://soilquality.org.au/factsheets/root-lesion-nematode

MORE INFORMATION

DDLS – Seed testing and certification services

Predicta-BTM - SARDI

reveal evidence of infestation in the roots, which warrants laboratory analysis. Testing services are available at the DAFWA Diagnostic Laboratory Services (DDLS). Growers are advised to contact their local DAFWA office for advice. [16]

Soil testing

When to collect samples

The best time for sampling varies between crops, and is related to the growth stage of the crop and the objective of sampling. Many species of nematodes increase to high levels during the growing season and reduce to low numbers during the dry season. This is more easily seen in annual crops than in perennial and tree crops.

Sampling Equipment

- Clean bucket for collecting samples
- Soil probe (Figure 9) or shovel/spade
- Plastic bags to hold 500 g of soil
- Labels
- Waterproof marker

Figure 9: *Soil sampling probe.*

How to sample

Fallow or bare fields:

Do not collect samples when the field is dry or extremely wet. For sampling, the field should be divided into 1–2 ha blocks. Take about 20–30 cores/sub-samples of soil, at 15–20 cm depth from an area of 1–2 hectares. Collect these sub-samples at every 10–20 m in a 'W' or in a 'Zigzag' pattern (Figure 10). Place sub-samples in a bucket and mix thoroughly with hands, and collect a 500 g composite sample in a labelled plastic bag.

16 GRDC Tips and Tactics Root-Lesion nematode—Western region. http://www.grdc.com.au/TT-RootLesionNematodes

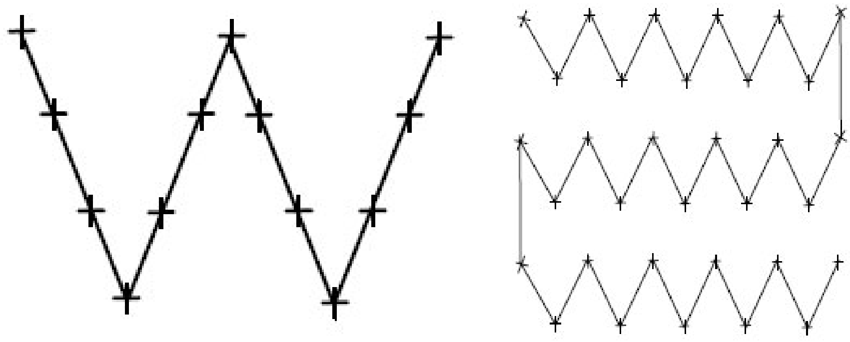

Figure 10: *'W' pattern (left) and 'Zigzag' pattern (right) for randomising soil sampling in a paddock.*

Source: AgVic

Field Crops:

Nematodes do not necessarily occur uniformly throughout a paddock, therefore several sub-samples must be taken from across the field and then combined. Collect 20–30 random sub-samples from each block of 1–2 ha. Samples should be taken directly from the root zone. Mix sub-samples thoroughly and place 500 g of soil, with roots, in a plastic bag for laboratory analysis. Because nematode damage within a crop can be patchy, collect samples from healthy plants as well as from plants showing symptoms of decline. Keep these samples separate and label them as 'good' and 'bad' samples.

Care of Samples

- Place all samples in plastic bags to prevent drying.
- Generally, plant-parasitic nematodes remain alive at temperature between 5°C and 40°C, and die within seconds when exposed to temperatures above 50°C.
- Keep samples in a cool place at all times.
- Do not refrigerate samples.
- Do not leave samples exposed in the field, or in a vehicle, on very hot days.
- Do not wrap roots or any other plant material in damp tissue.
- Leave roots with soil in bag.
- Place other plant material in a separate plastic bag.

Label and Information

Label samples with identification numbers and provide the following information on a separate sheet of paper:

- Name and address of the grower as well as sender.
- Crop plant, symptoms and estimated damage.
- A sketch map of the diseased area and the sampling site, and also an indication of the topography of the field.
- Cropping history of the field.
- Fertilisers, pesticides and herbicides applied.
- Relevant weather conditions and watering or drainage conditions.

It is necessary to provide the above information so that the results of the analysis can be interpreted correctly and satisfactorily. [17]

Strategies

- Well-managed rotations with resistant or non-host break-crops are vital. To limit RLN populations, avoid consecutive host crops.

17 Agriculture Victoria (2011) Collecting Soil and Plant Samples for Nematode Analysis. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/fruit-and-nuts/stone-fruit-diseases/collecting-soil-and-plant-samples-for-nematode-analysis

- Use a state department of agriculture Crop Variety Guide to choose varieties with high resistance ratings, which result in fewer nematodes remaining in the soil to infect subsequent crops.
- Reducing RLN can lead to higher yields in following cereal crops.
- Healthy soils and good nutrition can partly alleviate RLN damage through good crop establishment, and healthier plants may recover more readily from infestation under more suitable growing conditions.
- Observe crop roots to monitor development of symptoms.
- Weeds can host parasitic nematodes within and between cropping sequences, so choice of pasture species and control of host weed species and crop volunteers is important. [18]

Nematicides

Nematicides are not used commercially in broadacre cropping in Australia. They are not recommended because of their cost and mammalian toxicity, and because rotational crops are available for nematode management. If they were used commercially, their efficacy would likely be poor, particularly in situations where the nematode occurs at depth.

Currently, no nematicides are registered for use on broadacre crops in Australia. [19]

Varietal choice and crop rotation options

Varietal choice and crop rotation are currently our most effective management tools for RLN. The focus is on two different characteristics: tolerance, i.e. ability of the variety to yield under RLN pressure; and resistance, i.e. impact of the variety on RLN build-up. Note that varieties and crops often have varied tolerance and resistance levels to *P. thornei* and *P. neglectus*.

Chickpea grown in rotations with wheat (*Triticum aestivum*) can reduce the build-up of pathogens of cereals such as *Fusarium pseudograminearum* (responsible for crown rot), improve soil nitrogen (N) fertility, and facilitate control of grass weeds. Offsetting these benefits however is the fact that populations of root-lesion nematode (RLN; *Pratylenchus thornei*) increase with chickpea rotations, reducing its yield and negatively affecting the yield of subsequent intolerant wheat and other crops. [20]

Summer crops can play an important role in management of RLN. Crops that are partially resistant or poor hosts of *P. neglectus* include sunflower, mungbean, soybean and cowpea. When these crops are grown, populations of *P. neglectus* do not increase because the crops do not allow the nematode to reproduce. [21]

MORE INFORMATION

GRDC Tips and Tactics Root-Lesion Nematode Factsheet – Western Region.

IN FOCUS

Yield response in chickpea cultivars and wheat following crop rotations affecting population densities of Pratylenchus thornei and arbuscular mycorrhizal fungi.

In Australia, root-lesion nematode (RLN; *Pratylenchus thornei*) significantly reduces chickpea and wheat yields. Yield losses from RLN have been determined through use of nematicide; however, nematicide does not control nematodes in Vertosol subsoils in Australia. The alternative strategy of assessing yield response, by using crop rotation with resistant and susceptible crops to manipulate nematode populations, is poorly documented for chickpea. This research tested the effectiveness of crop

18 GRDC (2009) Plant Parasitic Nematodes Fact sheet Southern and Western region.

19 GRDC Tips and Tactics Root-Lesion nematode—Western region. http://www.grdc.com.au/TT-RootLesionNematodes

20 RA Reen, JP Thompson, TG Clewett, JG Sheedy, KL Bell (2014) Yield response in chickpea cultivars and wheat following crop rotations affecting population densities of Pratylenchus thornei and arbuscular mycorrhizal fungi. Crop and Pasture Science, 65(5), 428–441.

21 K Owen, T Clewett, J Thompson (2013) Summer crop decisions and root-lesion nematodes: crop rotations to manage nematodes—key decision points for the latter half of the year, Bellata. GRDC Grains Research Update, July 2013.

rotation and nematicide against *P. thornei* populations for assessing yield loss in chickpea. First-year field plots included canola, linseed, canaryseed, wheat and a fallow treatment, all with and without the nematicide aldicarb. The following year, aldicarb was reapplied and plots were re-cropped with four chickpea cultivars and one intolerant wheat cultivar. Highest *P. thornei* populations were after wheat, at 0.45–0.6 m soil depth. Aldicarb was effective to just 0.3 m for wheat and 0.45 m for other crops, and increased subsequent crop grain yield by only 6%. Canola, linseed and fallow treatments reduced *P. thornei* populations, but low mycorrhizal spore levels in the soil after canola and fallow treatments were associated with low chickpea yield. Canaryseed kept *P. thornei* populations low throughout the soil profile and maintained mycorrhizal spore densities, resulting in grain yield increases of up to 25% for chickpea cultivars and 55% for wheat when pre-cropped with canaryseed compared with wheat. Tolerance indices for chickpeas based on yield differences after paired wheat and canaryseed plots ranged from 80% for cv. Tyson to 95% for cv. Lasseter and this strategy is recommended for future use in assessing tolerance. [22]

Fallow

Populations of RLN will decrease during a 'clean' fallow, but the process is slow and expensive in lost 'potential' income. Additionally, long fallows may decrease arbuscular mycorrhiza (AM) levels and create more cropping problems than they solve. [23]

8.1.8 Breeding resistance

IN FOCUS

Hybridisation of Australian chickpea cultivars with wild Cicer spp. increases resistance to root-lesion nematodes (Pratylenchus thornei and P. neglectus)

Chickpea cultivars, germplasm accessions, and wild annual Cicer spp. in the primary and secondary gene pools, were assessed in glasshouse experiments for levels of resistance to the root-lesion nematodes *Pratylenchus thornei* and *P. neglectus*. Lines were grown in replicated experiments in pasteurised soil inoculated with a pure culture of either *P. thornei* or *P. neglectus*. The population density of the nematodes in the soil and roots after 16 weeks of growth was used as a measure of resistance. Combined statistical analyses of experiments (nine for *P. thornei* and four for *P. neglectus*) were conducted and genotypes were assessed. Australian and international chickpea cultivars possessed a similar range of susceptibilities through to partial resistance. Wild relatives from both the primary (*C. reticulatum* and *C. echinospermum*) and secondary (*C. bijugum*) gene pools of chickpea were generally more resistant than commercial chickpea cultivars to either *P. thornei* or *P. neglectus* or both. Wild relatives of chickpea have probably evolved to have resistance to endemic root-lesion nematodes whereas modern chickpea cultivars constitute a narrower gene pool with respect to nematode resistance.

22 RA Reen, JP Thompson, TG Clewett, JG Sheedy, KL Bell (2014) Yield response in chickpea cultivars and wheat following crop rotations affecting population densities of Pratylenchus thornei and arbuscular mycorrhizal fungi. Crop and Pasture Science, 65(5), 428–441.

23 R Daniel (2013) Managing root-lesion nematodes: how important are crop and variety choice? GRDC Update Paper, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Managing-root-lesion-nematodes-how-important-are-crop-and-variety-choice

Resistant accessions of *C. reticulatum* and *C. echinospermum* were crossed and topcrossed with desi chickpea cultivars and resistant F 4 lines were obtained. Development of commercial cultivars with the high levels of resistance to *P. thornei* and *P. neglectus* in these hybrids will be most valuable for areas of the Australian grain region and other parts of the world where alternating chickpea and wheat crops are the preferred rotation. [24]

IN FOCUS

Highly heritable resistance to root-lesion nematode (Pratylenchus thornei) in Australian chickpea germplasm observed using an optimised glasshouse method and multi-environment trial analysis

Pratylenchus thornei is a root-lesion nematode (RLN) of economic significance in the grain growing regions of Australia. Chickpea is a significant legume crop grown throughout these regions, but previous testing found most cultivars were susceptible to *P. thornei*. Therefore, improved resistance to *P. thornei* is an important objective of the Australian chickpea breeding program. A glasshouse method was developed to assess resistance of chickpea lines to *P. thornei*, which requires relatively low labour and resource input, and hence is suited to routine adoption within a breeding program. Using this method, good differentiation of chickpea cultivars for *P. thornei* resistance was measured after 12 weeks. Nematode multiplication was higher for all genotypes than the unplanted control, but of the 47 cultivars and breeding lines tested, 17 exhibited partial resistance, allowing less than two fold multiplication. The relative differences in resistance identified using this method were highly heritable (0.69) and were validated against *P. thornei* data from seven field trials using a multi-environment trial analysis. Genetic correlations for cultivar resistance between the glasshouse and six of the field trials were high (>0.73). These results demonstrate that resistance to *P. thornei* in chickpea is highly heritable and can be effectively selected in a limited set of environments. the improved resistance found in a number of the newer chickpea cultivars tested shows that some advances have been made in the *P. thornei* resistance of Australian chickpea cultivars, and that further targeted breeding and selection should provide incremental improvements. [25]

24 JP Thompson, RA Reen, TG Clewett, JG Sheedy, AM Kelly, BJ Gogel, EJ Knights (2011) Hybridisation of Australian chickpea cultivars with wild Cicer spp. increases resistance to root-lesion nematodes (Pratylenchus thornei and P. neglectus). Australasian Plant Pathology, 40(6), 601–611.

25 MS Rodda, KB Hobson, CR Forknall, RP Daniel, JP Fanning, DD Pounsett, JP Thompson (2016) Highly heritable resistance to root-lesion nematode (*Pratylenchus thornei*) in Australian chickpea germplasm observed using an optimised glasshouse method and multi-environment trial analysis. Australasian Plant Pathology, 45(3), 309–319.

8.2 Nematodes and crown rot

There is increasing evidence for the enhancing effect of nematodes on levels of crown rot. An extensive survey exploring the effect of crown rot on crops concluded that where RLN combines with high levels of crown rot (a common scenario), yield losses can be exacerbated if varieties are susceptible to the RLN. Instead of a 10% yield loss from RLN in a susceptible variety it could be 30–50% if crown rot is combined with a RLN-intolerant variety. [26]

8.2.1 Management

Variety choice is the key management option when it comes to managing nematode risk. However, when it comes to crown rot management, although varieties have some impact, rotation and stubble management are by far our most important management tools. Root lesion nematodes, need to be taken far more seriously and better factored into crop rotation considerations as well as variety choice. [27]

When including chickpea in cereal crop rotations to reduce crown rot, sow chickpea between the standing cereal rows. Sow the following cereal crop directly over the row of the previous year chickpea crop. [28]

Chickpea was thought to be one of the best break crops to use in crown rot management, however, recent trials have indicated that faba beans and canola are better break crops for crown rot than chickpeas. [29]

WATCH: GCTV9: Crown rot and root-lesion nematodes.

MORE INFORMATION

The additive yield impact of root-lesion nematode and crown rot

26 GRDC. 2010. Update paper. The additive yield impact of root lesion nematode and crown rot? https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/THE-ADDITIVE-YIELD-IMPACT-OF-ROOT-LESION-NEMATODE-AND-CROWN-ROT

27 B Freebairn. (2011). Nematodes and crown rot: a costly union. Ground Cover Issue 91, March-April 2011. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-91-March-April-2011/Nematodes-and-crown-rot-a-costly-union

28 A Verrell (2016). GRDC Update Papers: Integrated management of crown rot in a chickpea-wheat sequence. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Integrated-management-of-crown-rot-in-a-chickpea-wheat-sequence

29 S Simpendorfer. (2015). GRDC Update Papers: Crown rot, an update on latest research. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Crown-rot-an-update-on-latest-research

Diseases

Key messages

- Several foliar fungal diseases, some seedling root diseases, viruses and root lesion nematode can affect chickpea (Table 1).
- The most significant fungal disease of chickpea in Western Australia is Ascochyta blight. Disease management of chickpea should primarily focus on ascochyta blight.
- Chickpea crops in south-eastern Australia are being hit by a more virulent strain of ascochyta blight. This strain has not been detected in Western Australia (WA).
- The new varieties PBA HatTrick and PBA Boundary have improved resistance to Ascochyta and require fewer or no fungicide sprays. [1]
- The diseases Botrytis grey mould (BGM; *Botrytis cinerea*) and sclerotinia white mould (*Sclerotinia sclerotorium* and *S. minor*) were major diseases of chickpea in WA prior to the incursion of Ascochyta blight, and may again become significant diseases in chickpea varieties resistant to Ascochyta blight. [2]
- Integrated disease management in chickpeas involves paddock selection, variety choice, seed dressing, strategic fungicide use and hygiene.
- Stay up to date with local Crop diseases forecasts for your region.

Table 1: *Key features of the main chickpea disorders, at a glance.*

Disorder and cause	Seed-borne?	Symptoms	Distribution and occurrence	Survival and spread	Management
Seed-borne root rot: *Botrytis cinerea* *Ascochyta rabiei*	Yes	Seedlings wilt and die, epicotyl rots.	Random individual plants (not patches).	Seed.	Quality seed; seed treatment.
Phytophthora root rot (PRR): *Phytophthora medicaginis*	No	Rapid wilting and yellowing; defoliation from lower leaves; rotted roots; plants easy to pull up.	Patches; poorly drained areas; heavy rainfall; can occur at any time; history of medics, lucerne or PRR	Oospores in soil and residue persist for many years; survives saprophytically; spread by water and soil.	Varietal selection; avoid paddocks with history of PRR; rotation; seed treatment.
Waterlogging: root anoxia	No	Very rapid death; little defoliation; roots not rotted but may be dark; plants hard to pull up.	Patches; poorly drained areas; heavy rainfall; can occur at any time; history of medics, lucerne or PRR	Caused by insufficient supply of oxygen to roots.	Avoid low-lying or poorly drained paddocks or areas within paddocks.

1 GRDC Chickpea disease management fact sheet. (2013) Northern Region.

2 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

Disorder and cause	Seed-borne?	Symptoms	Distribution and occurrence	Survival and spread	Management
Sclerotinia root and stem rot: *Sclerotinia spp.*	Yes (ad-mixed)	Wilting and death; bleached root, collar and stem tissue; white cottony mould at site of lesion; sclerotia at lesions or inside stems.	Root and collar lesions result from direct infection from sclerotia; stem lesions result from airborne ascospores released from sclerotial apothecia, scattered or patches; favoured by denser canopies; wet events.	Sclerotia persist in soil for many years; wide host range including pulses, canola, sunflowers and broadleaf weeds but not cereals or grasses.	Avoid paddocks with history of Sclerotinia of its hosts; rotate with cereals; some varieties more susceptible.
Rhizoctonia rot: *Rhizoctonia solani*	?	Death of seedlings, stunting of survivors due to root damage, re-shooting after damping-off of epicotyl.	Can be a problem in irrigated crops grown immediately after cotton. Often occurs in 1–5 m stretches of row.	Survives as sclerotia and on decomposing trash. Probably present in most soils.	Allow time for decomposition of (preceding) crop debris. Tillage should help.
Ascochyta blight: *Ascochyta (Phoma) rabiei*	Yes	Ghosting of tissues; lesions with concentric rings of pycnidia; stem stumps; plant death.	Small patches enlarge rapidly in wet weather to kill large areas of crop.	Chickpea residue very important in spread especially header dust and surface water flow; infected seed; volunteers.	Follow chickpea Ascochyta blight management package published annually; includes foliar fungicides.
Boytrytis grey mould (BGM): *Botrytis cinerea.*	Yes/no	Stem, flower pod and leaf lesions covered in grey mould.	Occurs later in season when canopy closes and warm humid conditions persist; individual plants or patches.	Can flow-on from seed-borne root rot but pathogen has wide host range and airborne spores can blow around; dormant fungal remnants can survive in soil.	Avoid highly susceptible varieties; plant on wider rows; follow chickpea Ascochyta blight management package.
Root-Lesion nematodes. *Pratylenchus spp.*	No	General poor growth; small black lesions on lateral roots sometimes visible.	Often affects large parts of crop; P. thornei more prevalent on high clay soils.	Wide host range; survives and spreads in soil; anhydrobiosis allows nematodes to persist for prolonged dry periods.	Farm hygiene; rotate with resistant species; grow tolerant varieties.
Alfalfa Mosaic virus (AMV), Cucumber mosaic virus (CMV)	Yes	Initially bunching, reddening, yellowing, wilting or death of shoot tips; later discoloration.	Initially scattered plants often at edges of crop; more common in thin stands.	Viruses persist and multiply in weeds and pasture legumes; aphid-borne except for CpCDV (leafhopper).	Establish uniform stand by using recommended sowing rates and times; sowing into standing stubble.
Phloem-limited viruses (luteoviruses): BLRV (Bean leaf roll virus), SCRLV (Subterranean clover red leaf virus), BWYV Beet western yellows virus, SCSV (Subterranean clover stunt virus)	No	Death of entire plant; Luteovirus infected plants often have discoloured phloem.	Close to lucerne; seasons or districts with major aphid flights.		Cereal stubble deters aphids; grow resistant varieties.
CpCDV (Chickpea chlorotic dwarf virus)	-	Reddening, proliferation of axillary branching.	Individual or small clusters of plants. Maybe more at edges of crop.	Potentially via leafhopper transmission.	-

Source: K Moore, NSW DPI and M Fuhlbohm, Qld Gov

Table 2: *Key facts about the biology of major chickpea diseases.*

Disease	Survival	Spread	Infection by
Ascochyta blight	Stubble, seed, volunteers	Stubble, seed water-splashed spores	Water-splashed spores
Botrytis grey mould	Stubble, seed, sclerotia, alternative hosts	Stubble, seed, soil, airborne spores	Airborne spores
Phytophthora root rot	Oospores, alternative hosts	Soil and surface water	Waterborne spores
Sclerotinia rot	Sclerotia in soil and seed, alternative hosts	Soil and water, airborne spores	Airborne spores or directly into crowns

Table 3: *Resistance ratings of Western Australian Chickpea to common diseases.*

Variety	Ascochyta blight foliage	Botrytis grey mould	Root-Lesion nematode
Desi			
Ambar⌽	R	S	–
Neelam⌽	R	MS	–
PBA Slasher⌽	R	S	MRMS
PBA Striker⌽	MR	S	–
Genesis 510	R	MS	
Genesis 836	MS	MS	
Kabuli			
Genesis 079	R	MS	MR

NOTE: That these disease ratings for Ascochyta blight do not include the new strain impacting crops in the Southern cropping region.

Source: PIRSA

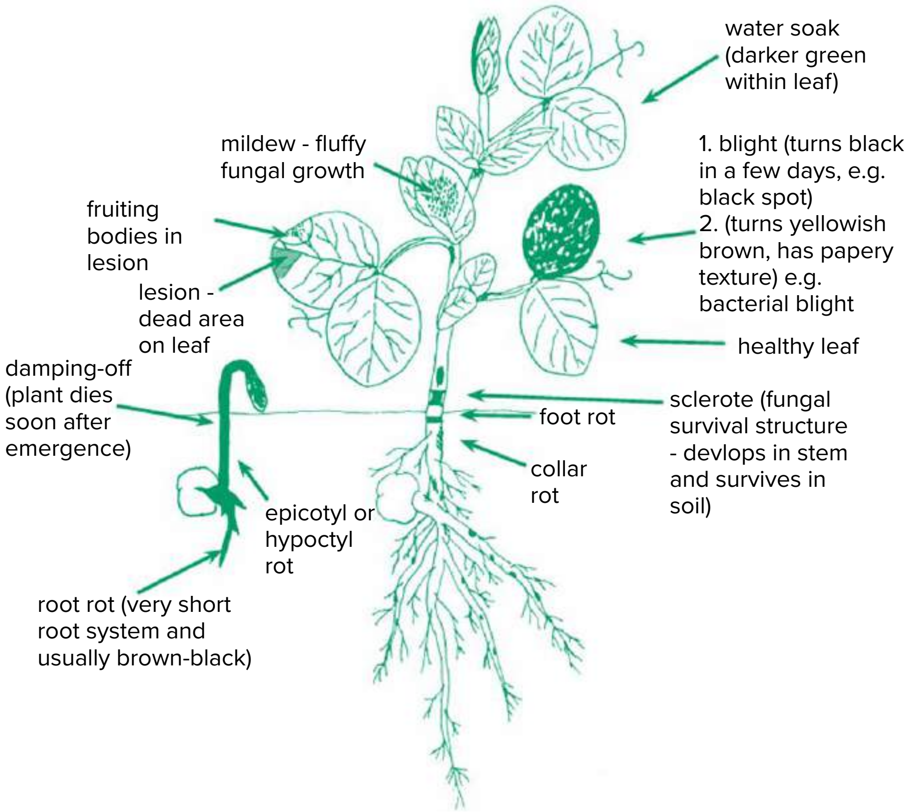

Figure 1: *Chickpea disease diagnosis terms.*

Source: Grain Legume Handbook

9.1 Key disease management strategies for chickpea

- Variety selection is critical. Ideally grow an ascochyta resistant variety.
- Paddock isolation from chickpea stubble is a high priority (greater than 500 m).
- Paddock history:Aim for a break of at least four years between chickpea crops.
- Seed source: Use seed from a paddock where disease was not detected.
- Fungicide seed dressing is effective and should be used, especially in high disease risk situations.
- Sowing date: Do not sow too early, even with an ascochyta resistant variety.
- Sowing depth: If using an ascochyta susceptible variety, sow deeper than normal.
- Sowing rate: Aim for 35–50 plants per square metre, depending on the situation and crop type (kabuli or desi).
- Hygiene: Reduce disease sources and prevent spread of disease.
- Foliar fungicides: Ascochyta resistant varieties still require foliar fungicide at podding. Success is dependent on monitoring, timeliness of spraying and correct fungicide choice. Early detection and correct disease identification are essential.
- Manage aphids and virus: Ground surface cover, healthy plants and crop canopy are important. Control aphids at their source (host) crop.
- Harvest management: Harvest early to minimise disease infection of seed.
- Crop desiccation enables even earlier harvest. [3]

3 Pulse Australia Ltd (2012) Southern Pulse Bulletin PA #08. Chickpea disease management strategy. http://pulseaus.com.au/storage/app/media/crops/2012_SPB-Chickpea-disease-management.pdf

9.2 Fungal disease management strategies

Disease management in pulses is critical, and relies on an integrated management approach involving variety choice, crop hygiene and strategic use of fungicides. The initial source of the disease can be from the seed, the soil, the pulse stubble and self-sown seedlings, or in some cases, other plant species. Once the disease is present, the source is then from within the crop itself.

Note that the impact of disease on grain quality in pulses can be far greater than yield loss. This must be accounted for in thresholds because the visual quality of pulses has a huge impact on price for food products. Examples are Ascochyta blight in most pulses and Pea seed-borne mosaic virus in field peas.

A plant disease may be devastating at certain times, yet under other conditions it may have little impact. The interactions of host, pathogen and environment are all critical points in disease development, and all can be represented by the disease triangle (Figure 2 and 3). Diseases such as Ascochyta blight and PRR rot can cause total crop failures very quickly. The effects of BGM and root-lesion nematodes on crop performance and yield usually unfold more slowly, however, they can cause damage quickly when conditions are suitable.

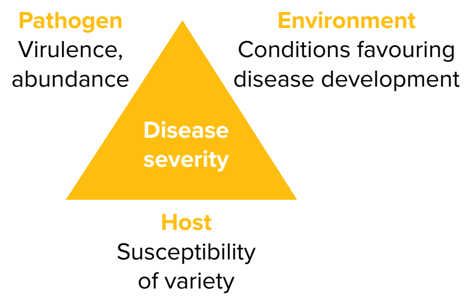

Figure 2: *The virus and some bacterial disease triangle*

Source: Jones 2012

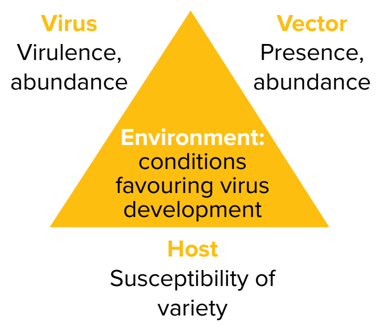

Figure 3: *The disease triangle*

Source: Agrios 1988

Disease management should be a consideration when planning any rotation, particularly at the beginning of the season. This is especially important for chickpea, where the first defence against disease begins with paddock selection. Other criteria such as seed quality and treatment are also vitally important. Determine which diseases have the highest priorities to control in the pulse crop being grown, and sow a variety that is resistant to those diseases if possible. Paddock selection and strategic fungicide use are part of the overall program to minimise disease impact. Fungicide disease control strategies alone may not be economic in high-risk situations, particularly if susceptible varieties are grown.

Key strategies:

- **Variety selection**. Growing a resistant variety reduces the need for foliar fungicides.
- **Distance**. Distance from any of last year's stubble of the pulse will affect the amount of infection for some diseases. Aim for a separation of at least 500 m.
- **Paddock history and rotation**. Aim for a break of at least four years between sowing of the same pulse crop. Having a high frequency of crops such as lentil, faba bean, vetch, field pea, chickpea, lathyrus or clover pasture puts pulses at greater risk of diseases such as Phoma blight, Sclerotinia rot and BGM. Ascochyta blight species are more specific to each pulse crop, but 3–4 year rotations are still important. Canola can also increase the risk of Sclerotinia rot.
- **Hygiene**. Take all necessary precautions to prevent the spread of disease. Reduce last year's pulse stubble if erosion is not a risk and remove self-sown pulses before the new crop emerges.
- **Seed source**. Use seed from crops in which there were low levels of disease, or preferably no disease, especially at podding. Avoid using seed with known disease infection, particularly with susceptible varieties. Have seed tested for disease status.
- **Fungicide seed dressings**. Dressings are partially effective early in situations of high disease risk, particularly for diseases such as BGM, Phoma blight and Ascochyta blight. They are also effective for seed-borne disease control but not effective on viruses and bacterial diseases.
- **Sowing date**. To minimise foliar disease risk do not sow too early, so avoiding excessive vegetative growth and early canopy closure. Early crop emergence also coincides with greater inoculum pressure from old crop residues nearby. Aim for the optimum sowing window for the pulse and the district.
- **Sowing rate**. Aim for the optimum plant population (depending on region, sowing time, crop type, variety), as denser canopies can lead to greater disease incidence. Adjust seeding rate according to seed size and germination.
- **Sowing depth**. Sow deeper than normal any seed lot that is infected with disease to help reduce emergence of infected seedlings. The seeding rate must be adjusted upwards to account for the lower emergence and establishment percentage.
- **Foliar fungicide applications**. Disease-resistant varieties do not require the same regular foliar fungicide program that susceptible varieties need to control foliar diseases. Some pulses may require fungicide treatment for BGM if a dense canopy exists. Successful disease control with fungicides depends on timeliness of spraying, the weather conditions that follow, and the susceptibility of the variety grown. Monitoring for early detection and correct disease identification is essential. Correct fungicide choice is also critical.
- **Controlling aphids**. This may reduce the spread of viruses, but not eliminate them. Strategic or regular insecticide treatments are unlikely to be successful or economical. Usually the virus spread has occurred by the time the aphids are detected.
- **Harvest management**. Early harvest will help to reduce disease infection of seed, and is also important for grain quality and to minimise harvest losses. Crop desiccation enables even earlier harvest. Moisture contents of up to 14% are allowable at delivery. Do not prematurely desiccate as this can affect grain quality. [4]

4 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013.

9.3 Integrated disease management

Disease management in chickpea is critical and relies heavily on an integrated management package involving paddock selection, variety choice, strategic fungicide use and crop hygiene.

Paddock selection based on Ascochyta blight infection is the first priority, followed by cropping history. The appropriate Ascochyta blight control strategy is adopted by determining the level of risk in combination with climatic conditions and the level of resistance afforded by the variety chosen.

Disease control strategies may not be economical in high-risk situations if varieties susceptible to Ascochyta blight are grown. [5]

Integrated disease management is an integrated approach of crop management to reduce chemical inputs and resolve ecological problems. Although originally developed for insect pest management, IDM programs now encompass diseases, weeds, and other pests.

Integrated disease management is performed in three stages: prevention, observation and intervention. It is aimed at significantly reducing or eliminating use of pesticides while managing pest populations at an acceptable level.

An IDM system is designed around six basic components:

1. Acceptable disease levels

- Emphasis is on economical control, not eradication.
- Elimination of the disease is often impossible, and can be economically expensive, environmentally unsafe, and frequently unachievable. IDM programs work to establish acceptable disease levels (action thresholds) and then apply controls if those thresholds are about to be exceeded. Thresholds are specific for disease and site. What is acceptable at one site may not be acceptable at another site or for another crop. Allowing some disease to be present at a reasonable threshold means that selection pressure for resistance pathogens is reduced.

2. Preventive cultural practices

- Use varieties best suited to local growing conditions and with adequate disease resistance.
- Maintaining healthy crops is the first line of defence, together with plant hygiene and crop sanitation. Crop canopy management is also very important in pulses; hence, time of sowing, row spacing and plant density and variety attributes become important.

3. Monitoring

- Regular observation is the key to IDM.
- Observation is broken into inspection and then identification. Visual inspection, spore traps, and other measuring tools are used to monitor disease levels. Accurate disease identification is critical to a successful program. Record keeping is essential, as is a thorough knowledge of the behaviour and reproductive cycles of target pests.
- Diseases are dependent on specific temperature and moisture regimes to develop (e.g. rust requires warm temperatures, Ascochyta blight often requires colder temperatures). Monitor the climatic conditions and rain likelihood to determine when a specific disease outbreak is likely.

4. Mechanical controls

- Should a disease reach unacceptable levels, mechanical methods may be needed for crop hygiene, for example, burning or ploughing in pulse stubble, removing hay, cultivating self-sown seedlings.

5. Biological controls

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5 Pulse Australia Ltd (2011) Chickpea Integrated Disease Managment. http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/idm-strategies

- Crop rotation and paddock selection is a form of biological control.
- Using crops and varieties with resistance to the specific disease is also important. Other biological products are not necessarily available for disease control.

6. Responsible fungicide use

- Synthetic pesticides are generally used only as required and often only at specific times in a disease life cycle.
- Fungicides applied as protection ahead of conditions that are conducive to disease (e.g. sustained rainfall) may reduce total fungicide usage. Timing is critical with foliar fungicides, and may be more important than rate used. Protection is better than cure, because once the disease is established in the canopy there is an internal source of infection that is difficult, or even impossible, to control with later fungicide applications.

9.4 Risk assessment

Prediction of likely damage from a chickpea disease can be used at the paddock, whole farm, regional, state or national level. The choices of variety and disease management options are some of the factors determining risk.

Knowledge of your paddock, its layout (topography), soil parameters, and cropping history will help you to assess the level of risk.

9.4.1 Steps in risk assessment

1. Identify factors that determine risk

- *Pathogen.* Exotic *v.* endemic; biotypes, pathogenicity, survival and transmission, amenable to chemical management
- *Host.* Host range; varietal reactions, vulnerability. Does susceptibility change with growth stage?
- *Environment.* Weather dependency, interactions with nutrition, herbicides, other diseases, agronomic factors, e.g. planting depth, row spacing, no-tillage, soil conditions.
- *Risk management.* Access to components of management plan; ease of implementing plan; how many options; cost of implementation.

2. Assess level of factors

- *Pathogen.* Level of inoculum, dirty seed, aggressiveness of isolate, weed hosts prevalent in paddock or nearby, paddock history.
- *Host.* How susceptible, nutritional status, frost susceptibility, herbicide susceptibility.
- *Environment.* Length of season; likelihood of rain, drought, waterlogging, irrigation; availability of spray gear; paddock characteristics; herbicide history.
- *Risk management.* Not yet considered; plan being developed; plan in place?

3. What risk level is acceptable?

- *High.* Grower is prepared to accept substantial yield loss because potential returns are high and financial situation sound; crop failure will not affect rotation or other components of farming system.
- *Low.* Grower needs cash flow and cannot afford to spend much or lose the crop; failure seriously affects farming system.

9.4.2 Paddock selection

The selection of the most appropriate paddock for growing chickpea involves consideration of several important factors, some of which are related to the modes of survival and transmission of pathogens such as *Ascochyta rabiei*.

1. Rotation

- Develop a rotation of no more than one year of chickpea in four years.

- Plant chickpea into standing stubble of previous cereal stubble to enhance crop height and reduce attractiveness of the crop to aphids (aphids may vector viruses).
- Consideration also needs to be given to previous crops that may host pathogens such as *Sclerotinia, Rhizoctonia*.
- *Ascochyta rabiei* is chickpea-specific, whereas *Botrytis cinerea* has a wide host range including sunflower, bean, lentil, pea, and weeds (e.g. Euphorbia spp., groundsel and emufoot).
- Lucerne, medics and chickpea are hosts for *Phoma medicaginis var. pinodella* can be hosted by lucerne, clover, field pea, lupin and chickpea, as can *Phaseolus spp*.

2. History of chickpea diseases

- Previous occurrence of soil-borne diseases (Sclerotinia stem rot, PRR or *Pratylenchus* nematodes) constitutes a risk for subsequent chickpea crops for up to 10 years.
- Plant chickpea at least 500 m from the previous year's chickpea crop.

3. Weeds

- Almost all broadleaf weeds host *Sclerotinia spp.*
- Some of the viruses affecting chickpea also have wide host ranges. Weeds, particularly perennial legumes, host viruses and their aphid and leafhopper vectors (e.g. Cucumber mosaic virus).

4. Herbicide history

- Have triazine, sulfonylurea or other residual herbicides been applied in the last 12 months?
- The development of some diseases is favoured in herbicide-weakened plants. The presence of these herbicide residues in soil may cause crop damage and thus confusion over in-field disease diagnosis.

9.4.3 Regular crop monitoring

The two main diseases for which monitoring is necessary are Ascochyta blight and BGM. Following the monitoring process recommended for these diseases will provide the opportunity to assess the impact or presence of other diseases or plant disorders. To be effective, crop monitoring needs to include a range of locations in the paddock, preferably following a 'V' or 'W' pattern.

For Ascochyta blight

The initial symptoms will be wilting of individual or small groups of seedlings, or lesions on the leaves and stems of young plants, often in patches. Monitoring should commence 2–3 weeks after emergence, or 10–14 days after a rain event. This is because the initially infected seedlings soon die and symptoms are difficult to separate from other causes. Plant parts above the lesion may also break off, making symptoms difficult to detect. Timing is critical! After the initial inspection, subsequent inspections should occur every 10–14 days after a rain or heavy dew event. During dry periods, inspections should occur every 2 weeks. When monitoring, look for signs of wilting in upper foliage (the 'ghosting' phenomenon) or small areas of dead or dying plants and, if present, examine individual affected plants for symptoms of infection. This method will allow more of the crop to be inspected than a plant-by-plant check.

For Botrytis grey mould

Botrytis grey mould (BGM) is more likely to occur in well-grown crops where there is canopy closure. The critical stage for the first inspection will be at the commencement of flowering and then regularly through the flowering period. Lesions occur on stems, leaves and pods, and flower abortion and drop can occur; a fluffy grey fungal 'bunch of grapes' growth develops on affected tissue. Normal pod set will occur when daily temperature exceeds 15°C; BGM ceases to affect the plant once the maximum daily temperature exceeds ~28°C.

More regular crop monitoring may also be required if:

- high-risk situations exist such as non-optimal paddock selection
- shortened rotation
- immediately adjacent to last year's crop
- high disease pressure experienced last year
- a more susceptible variety is planted

9.4.4 Services and resources available to assist with disease forecasts, disease occurrence and identification

Crop disease forecasts

From an understanding of the biology of key plant pathogens it is possible to estimate the risks associated with particular diseases in key crops in Western Australia and Southern Australia. Research undertaken by DAFWA and collaborators from southern Australia has been used to develop tools to allow risk assessments to be made in the lead up to the cropping season. Keep up to date with the most recent DAFWA crop disease risk forecast.

Crop disease forecast estimates the risk of certain crop diseases during the cropping season for specific locations. For some diseases, it offers management practices to avoid potential yield losses.

Each weekly forecast, where relevant, accounts for varietal resistance, chemical options, agronomic yield potentials and losses, agronomic constraints (frost and terminal drought), risks of spore showers, disease severity and disease-related yield losses.

Inputs

No inputs from growers are required.

Outputs

A disease forecast report may include, for each location:

- forecast risk in tables or maps
- estimated severity or spore maturity
- sowing guide
- rainfall to date and stubble moisture
- suggested management practices

Reliability

The forecasts are updated regularly as part of ongoing research projects by the Grains Research & Development Corporation and the Department of Agriculture and Food Western Australia. [6]

PestFax

PestFax is a free weekly informative and interactive reporting service during the growing season. It provides risk alerts, current information and advice on pests and diseases threatening crops and pastures throughout the grain belt of Western Australia during each growing season. Subscribe and view the latest newsletter on the Pestfax page.

The PestFax map allows users to report pest and disease finds and view historic maps of past insect and disease reports.

6 Climate Kelpie. Crop disease forecast. GRDC, http://www.climatekelpie.com.au/manage-climate/decision-support-tools-for-managing-climate/crop-disease-forecast

Diagnosis tools and services

Correct diagnosis is crucial for successful management of crop diseases. DDLS Seed Testing and Certification (formally AGWEST Plant Laboratories) provides a wide range of chargeable services to assist with identification of crop foliar diseases, viruses, nematodes and root diseases. These include plant disease diagnostics (on leaves, whole plants, roots and soil), seed disease testing and weed and insect identification.

Refer to the DDLS page for more information and to request submission forms, sampling and postage instructions. For more information on sampling refer to the How to take a plant sample YouTube video.

The MyCrop app is available to assist you to correctly diagnose a constraint in your crop yourself. For more information refer to the How to diagnose crop constraints YouTube video, or visit the MyCrop page to download the MyCrop app. [7]

9.5 Ascochyta blight

Ascochyta blight, caused by the fungus *Phoma rabiei* (formerly *Ascochyta rabiei*), is a serious disease of chickpea in Australia. The fungus is different from the species of Ascochyta that infects faba beans, lentils and field peas. The fungus can infect all above ground parts of the plant and is most prevalent when cool, cloudy and humid weather occurs during the crop season. *Didymella rabiei*, the teleomorph of *Phoma rabiei,* has also been found in chickpea stubble in WA. [8]

In Western Australia, Ascochyta blight was first detected in 1998 in a single seed production paddock in the Walkaway area near Geraldton. This crop was subsequently destroyed and a 20 km chickpea exclusion zone was placed around the property. In addition, a quarantine restriction was placed on the import of chickpea seed into Western Australia, both from interstate and overseas. In this same year, Ascochyta blight was found in chickpea crops throughout eastern Australia, resulting in significant losses.

The first outbreak of Ascochyta blight in commercial chickpea crops in Western Australia was detected in July 1999. By the end of 1999, over 70 crops were found to be infected with all but two being in the Northern and Central agricultural regions. Due to the difficulty in detecting low levels of the disease, it is expected that many parts of the wheatbelt that now appear free of the disease may have a low level of infection. [9]

Ascochyta blight is now considered to be endemic in all growing regions with the exception of central Queensland. Unlike some insect control strategies, there is no economic threshold for Ascochyta. Management strategies are aimed at preventing the occurrence of disease and limiting its spread. [10]

Chickpea crops in southern Australia have recently been damaged by a more virulent strain of Ascochyta blight. Pulse pathologists in Victoria and South Australia have noted a marked decline in the resistance of several varieties of chickpeas, with varieties previously rated as moderately resistant performing like susceptible lines. There has not been any reported cases of the new strain in WA.

Ascochyta blight is managed through crop rotation, hygiene, seed treatment, prophylactic fungicide application and growing varieties with improved resistance. All growers and advisers need to regularly inspect their crops from emergence, through flowering, right up to plant maturity. Inspections should be undertaken 10–14 days after rain events, when new infections will be evident as lesions on plant parts.

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7 DAFWA (2016) Crop diseases: Forecasts and management. https://www.agric.wa.gov.au/barley/crop-diseases-forecasts-and-management?page=0%2C0

8 J Galloway, WJ MacLeod (2003) Didymella rabiei, the teleomorph of Ascochyta rabiei, found on chickpea stubble in Western Australia. Australasian Plant Pathology, 32(1), 127–128.

9 I Pritchard (2000) Managing Ascochyta blight. Journal of the Department of Agriculture, WA, Series 4, Vol 41. DAFWA, http://researchlibrary.agric.wa.gov.au/cgi/viewcontent.cgi?article=1010&context=journal_agriculture4

10 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

Economic importance

The widespread occurrence of this disease in 1998 had a negative impact on the chickpea growing industry. To successfully grow varieties with an Ascochyta disease rating less than moderately resistant, foliar fungicides need to be applied throughout the growing season to avoid serious yield losses. Varieties rated as moderately resistant (such as PBA SLASHER and Genesis™ 509) still require at least one fungicide at early pod set, but the risk of yield loss is minimal. When selecting varieties the added cost of fungicide applications needs to be considered before selecting and growing susceptible to moderately resistant varieties. [11]

9.5.1 Varietal resistance or tolerance

See Table 3 at the start of this chapter for varietal disease ratings.

Table 4 estimates gross margins for chickpeas with Ascochyta-susceptible versus Ascochyta-resistant varieties. Fungicide costs are based on eight applications at $20/ha per application for the susceptible variety versus one for the resistant variety. Assuming variety yields are the same, desi gross margin of $130 versus $270/ha may be achieved from a 1.5 t/ha grain yield. A $180 versus $420/ha return could be obtained from a kabuli yield of 1.0 t/ha. If choosing a variety susceptible to Ascochyta blight, growers should consider kabuli production in preference to desi where conditions are suitable. [12]

Table 4: *Estimated desi and kabuli returns.*

Grain yield (t/ha)	Grain price ($/t)	Fungicide cost Susceptible variety ($/ha)	Fungicide cost Resistant variety ($/ha)	Other costs All varieties ($/ha)	Gross margin Susceptible variety ($/ha)	Gross margin ($/ha) Resistant variety ($/ha)
Desi						
0.5	300	160	20	160	-170	-30
1.0	300	160	20	160	-20	120
1.5	300	160	20	160	130	270
2.0	300	160	20	160	280	420
Kabuli						
0.5	500	160	20	160	-70	70
1.0	500	160	20	160	180	420
1.5	500	160	20	160	430	570
2.0	500	160	20	160	680	820

Source: Pulse Australia

9.5.2 Damage caused by disease

WA's chickpea industry grew rapidly from the mid-1990s and rose to be a significant 70,000 hectare grain legume crop until the arrival of the fungal disease Ascochyta blight in 1999 devastated the industry. Currently production is less than 10,000 tonnes. [13] Unlike some insect control strategies, there is no economic threshold for Ascochyta. Management strategies are aimed at preventing the occurrence of disease and limiting its spread. [14] The high-risk and increased cost of controlling

11 Agriculture Victoria (2016) Ascochyta Blight of Chickpea. DEPI, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/ascochyta-blight-of-chickpea

12 Pulse Australia Ltd (2007) Chickpeas in South Australia and Victoria. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpeas-SA-Vic.pdf

13 https://www.agric.wa.gov.au/pulses/western-australian-pulse-industry

14 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

Ascochyta blight often makes desi chickpea production unprofitable but higher value kabuli types may remain profitable. [15]

9.5.3 Symptoms

Phoma rabiei infects the leaves, stems and pods of chickpea plants, causing tan/brown, rounded lesions on affected plant parts. This disease is usually first noticed in late winter when small patches of blighted plants appear throughout the paddock (Figure 4). Usually the first symptoms are the wilting of individual or small groups of seedlings. Plants appear as if premature haying-off has occurred. Initially Ascochyta blight appears on the younger leaves as small water-soaked pale spots. These spots rapidly enlarge under cool and wet conditions, joining with other spots on the leaves and blighting the leaves and buds. [16]

Figure 4: *Wilting of individual or small groups of seedling.*

Source: Pulse Australia

Ascochyta leaf ghosting symptoms may appear 4–7 days after rainfall or heavy dew (Figure 5). [17]

15 L McMurray, J Brand, J Davidson, K Hobson, M Materne, (2006, September). Economic chickpea production for southern Australia through improved cultivars and strategic management to control Ascochyta blight. In Proceedings of 13th Australian Agronomy Conference (p. 65).

16 Agriculture Victoria (2016) Ascochyta Blight of Chickpea. DEPI, http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/ascochyta-blight-of-chickpea

17 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

Figure 5: *Ghosting symptoms of chickpea.*

Source: Pulse Australia.

Lesions usually begin as a pale green-yellow discolouration on leaves and stems and progress into small, round lesions with dark brown margins and pale grey to tan sunken centres (Figure 6). Note the concentric circles of brown-black dots in the centre of the lesions. These small black spots (pycnidia), or fruiting bodies are unique to Ascochyta blight. Pycnidia, less than 1 mm in diameter, can be seen in the affected areas. Pycnidia are also present in stem lesions. In severe cases of infection the entire plant dries up suddenly.

Figure 6: *Lesions on chickpea leaves caused by Ascochyta blight.*

Source: Pulse Australia

Lesions on stems at first tend to be oval shaped, with brown centres and a darker margin. Elongated lesions can often form and girdle the stem (Figure 7). The stem may die and break off. Regrowth may occur from the broken stem. Affected areas on the pods tend to be round and sunken, with pale centres and dark margins.

Figure 7: *Stem lesion of chickpea leading to girdling and breakage of stem.*

Source: Pulse Australia

- Leaf lesions: Lesions usually begin as a pale green-yellow discolouration on leaves and stems and progress into small round lesions with dark-brown margins and pale grey to tan sunken centres. Toward the centre of the lesion, fruiting bodies called pycnidia develop (appearing as black specks), often in concentric rings. These pycnidia produce spores, which spread on wind-borne stubble and/or water (rain-splash) to infect other plants. Note the concentric circles of brown-black dots in the centre of the lesions. These are the pycnidia or fruiting bodies that are unique to ascochyta blight. Ascochyta leaf ghosting may appear 4–7 days after infection following rainfall or heavy dew.
- Stem lesions: Lesions on stems at first tend to be oval shaped, with brown centres and a darker margin. Lesions often girdle the stems of the plant, causing them to weaken and subsequently break off.
- Pod lesions: Pod lesions are similar in appearance to leaf lesions. They lead to infection of the seed. DO NOT keep planting seed from any crop that has been identified as having Ascochyta blight (Figure 8). [18]

Figure 8: *Pod lesions look similar to leaf lesions and lead to infection of the seed.*

Source: Pulse Australia

The fungus can penetrate the pod and infect the seed. Pod lesions are similar in appearance to leaf lesions. Severe pod infection usually results in reduced seed set and infected seed. When infected seeds are sown, the emerging seedlings will develop dark brown lesions at the base of the stem. Affected seedlings may collapse and die.

9.5.4 Conditions favouring development

Initial crop infection is due to the introduction of either infected planting seed or from movement of infected trash by wind, machinery or animals. Spores of the fungus can survive for a short time on skin, clothing and machinery. Subsequent in-crop infection and spread occurs when inoculum is moved higher in the canopy or to surrounding plants by wind or rain-splash during wet weather. The disease spreads during cool, wet weather from infected plants to surrounding plants by rain splash of spores. This creates large blighted patches within crops. Pycnidia produce spores, which infect other plants through wind-borne stubble and/or water (rain-splash). There are no other known hosts of *Phoma rabiei* in Australia. [19,20]

Ascochyta blight-infected stubble blown about during and after harvest is a major cause of short–medium–distance dispersal (metres to kilometres) along with movement of infected trash by water, machinery or animals.

18 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

19 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

20 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

Ascochyta blight can increase rapidly on volunteer chickpeas if wet weather occurs during spring–summer–autumn. Paddocks with chickpea stubble should be regarded as a source of inoculum even if Ascochyta blight was not observed in last season's chickpea crop. The pathogen can survive at least three years in the paddock.

Ascochyta blight can develop over a wide range of temperatures (5–30°C) and needs only 3 hours of leaf wetness to infect (Figure 9). However, the disease develops fastest when temperatures are 15–25°C and relative humidity is high (the longer relative humidity remains high, the more severe will be the infection).

Subsequent in-crop infection occurs when spores are moved higher in the canopy or to surrounding plants by rain-splash during wet weather. Multiple cycles of infection will occur during the growing season whenever environmental conditions are favourable.

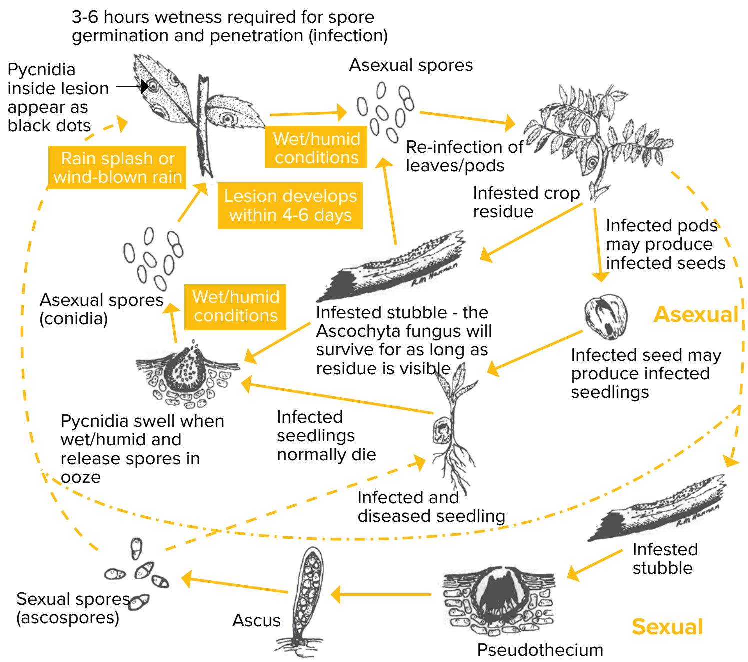

Figure 9: *Life cycle of Ascochyta blight pathogen. Note: Only the asexual phase is known to occur in Australia at this time.*

Drawings by RM Hannan. Source: Can. J. Pl. Path. 19:215–224, 1997

9.5.5 Management of disease

Monitoring

- 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' 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.

Take extra care when inspecting crops that are growing:

- under centre pivot or lateral-move irrigators;
- from seed whose ascochyta status is unknown; and
- from seed that was not treated with a registered fungicide seed dressing. [21]

21 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

If Ascochyta is suspected

If Ascochyta is suspected mark the spot and take samples for diagnosis. DO NOT enter other chickpea paddocks wearing the same clothing. All other chickpea crops on the property need to be inspected for Ascochyta blight. Be sure to follow the hygiene practices outlined below.

- Place samples of suspected Ascochyta-infected plants into a plastic bag then seal the bag and keep the samples cool.
- Suspect samples should be referred to a plant pathologist or agronomist familiar with the disease for identification.
- Unnecessary movement within a suspected Ascochyta-infected crop should be avoided until the sample has been fully assessed.
- Most importantly, do not visit other chickpea crops until all clothing has been disinfected or changed and machinery has been washed of all plant material and dirt. [22]

Hygiene

The spores of Ascochyta can adhere to clothing, machinery, vehicles, people and animals when moving through infected paddocks, so hygiene is a vital component of IDM when Ascochyta is found in a crop. Wear waterproof pants, overboots or rubber gum boots when entering a suspected infected paddock, then decontaminate immediately after exiting.

- Farmers and advisors should take precautions to prevent spreading Ascochyta blight via clothing, footwear and vehicles.
- The recommended protocol is for clothing to be washed, changed or disinfected when moving between chickpea paddocks.
- Wash boots in a mixture of 10% bleach and 90% water solution or methylated spirits upon leaving an infected chickpea crop.
- Clothing must be machine-washed in hot water before being worn when entering another chickpea crop.
- Extra care should be taken to remove soil and plant material from boots and vehicles.
- Hands and arms should be washed in warm soapy water or a suitable disinfectant.
- The use of heavy-duty plastic bags to cover boots and legs is a common practice when checking crops. After inspecting the crop, remove these plastic covers and place them in another bag and seal. Use another set of covers if you need to enter another chickpea crop.
- Farmcleanse® can be used to clean equipment. [23]

During harvest

Harvest Ascochyta -free paddocks before infected paddocks and preferably use your own harvester. Do not run the straw spreaders when harvesting, which will reduce the spread of small pieces of Ascochyta-infected stem and pods.

Thoroughly clean and decontaminate all machinery associated with harvesting in a well-defined and identifiable area before moving to another paddock or property.

Post-harvest

All grain harvested from an Ascochyta-infected paddock should be transported off-farm to receival sites in well-sealed trucks. If kept for a period on-farm it should be stored in well-sealed and labelled silos which must be thoroughly cleaned after the grain has been removed. Grain harvested from an Ascochyta-infected crop must not be retained as planting seed for other crops. Consideration may be given

22 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

23 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

to incorporation of infected crop residues by the use of off-set discs immediately after harvest to enhance the rate of breakdown. Chickpea volunteers in the infected paddock, along fence lines and near sheds must be controlled. Chickpeas should not be grown in or adjacent to an Ascochyta-infected paddock for at least three years. [24]

Control

Follow the principles of Integrated Disease Management (IDM), which include:

- crop rotation and paddock selection
- clean seed and fungicide seed dressings
- regular crop monitoring
- strict hygiene on and off farm
- strategic use of foliar fungicides

Note: Chickpea seed dressings only protect the emerging seedling from seed-borne Ascochyta and seed-borne botrytis. Seed dressings will not protect the emerged seedling from raindrop-splashed Ascochyta or wind-borne botrytis. [25]
See Section 3 Planting, 3.2 Seed treatments for more information.

9.5.6 Ascochyta blight management in Kabuli

Paddock selection

Keep at least a three-year break between chickpea crops in the same paddock. Equally importantly, sow new chickpea crops at least 500 m from any paddock (yours or your neighbours) in which chickpea was grown in the previous season. Ascochyta spores from infected chickpea stubble from the previous season are released in mid-winter and can be blown hundreds of metres, or even kilometres. Small pieces of infected chickpea trash (leaf, pod and stem) may be blown considerable distances during harvest and may also be moved about by winds throughout the summer and autumn. It is important to consider the risks from wind-blown trash prior to the break of the season and wind-borne spores after crop emergence when selecting paddocks to sow to chickpea. [26]

Seed

Test your seed for germination and Ascochyta blight infection. Do not sow seed if the Ascochyta infection level is above 0.25%. All kabuli seed should be treated with a fungicide seed dressing; this will reduce the transmission of seed-borne fungal infections and also help to protect the emerging seedling from soil-borne pathogens and seedling rots. Seed testing and seed dressing are complementary: seed testing ensures that seed with an unacceptably high level of infection is not being sown while seed dressing reduces, but does not eliminate, seed-borne infection. Seed dressing highly infected seed reduces the level of transmission, but may still result in high levels of initial infection of the emerged crop. [27]

Fungicide timing

Where crops of ALMAZ and KALKEE have been established following the above recommendations, growers should budget for two or three strategic fungicide sprays (chlorothalonil 720 g/L applied at 1.0–2.0 L/ha). This is a significant improvement over the regular spray schedule (every three to four weeks) previously recommended.

The fungicide spray is required four weeks after emergence (chlorothalonil 720 g/L applied at 1.5 L/ha). This early prophylactic spray is required to contain the spread from any Ascochyta blight infections resulting from wind-blown spores from last

24 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

25 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

26 DAFWA (2016) Production packages for kabuli chickpea in Western Australia—post planting guide. https://www.agric.wa.gov.au/chickpeas/production-packages-kabuli-chickpea-western-australia-post-planting-guide

27 DAFWA (2016) Production packages for kabuli chickpea in Western Australia—post planting guide. https://www.agric.wa.gov.au/chickpeas/production-packages-kabuli-chickpea-western-australia-post-planting-guide

year's stubble, seed-borne infections or infected trash that has been carried into the paddock. The level of infection that requires application of a fungicide spray this early in the crop's life is very low and is below the level that can be reliably identified, even by a person who has considerable experience in identifying this disease in field crops. Additionally, application of an early spray will protect the crop against wind-borne spores released from chickpea stubble during the two to three weeks following the spray application.

A second spray (chlorothalonil 720 g/L applied at 1.0–2.0 L/ha) is recommended at full flowering to protect the developing pods and minimise the risk of reduced quality. The rate of fungicide application depends on the level of Ascochyta blight infection detected in the crop prior to spraying. The high rate (2.0 L/ha) would be appropriate where Ascochyta blight can be easily identified in the crop and the low rate (1.0 L/ha) where only minor disease infection is evident after close inspection. If Ascochyta blight is not identified, even after close inspection of more than ten locations throughout the crop, a fungicide application may not be required at this time. A fungicide spray (chlorothalonil 720 g/L applied at 1.5 L/ha to 2.0 L/ha) may be required during pod filling if Ascochyta blight becomes evident in the canopy during late flowering or podding. [28]

9.5.7 Foliar fungicide programs

Differing spray programs have been developed based on each variety's Ascochyta rating (see Table 5). Chickpea Ascochyta fungicides are protectants only. Unlike wheat stripe rust fungicides, they have no systemic or kick-back action, and they will not eradicate an existing infection. To be effective, they must be applied before infection; i.e. before rain. The key to a successful Ascochyta spray program is regular monitoring combined with timely application of registered fungicides (Table 5). [29]

Table 5: *Foliar fungicides for the control of Ascochyta and Botrytis grey mould.*

Active ingredient	Example trade name	Rate	
		Ascochyta blight	Botrytis grey mould
Chlorothalonil (720 g/L)	Crop Care Barrack 720# Barrack Betterstick # Nufarm Unite 720#	1.0–2.0 L/ha	Not registered
Mancozeb (750 g/kg)	Dithane TM RainshieldTM	1.0–2.2 kg/ha	1.0–2.2 kg/ha
Mancozeb (420 g/L)	Penncozeb SC	1.8–3.95 L/ha	Not registered
Carbendazim (500 g/L)	Spin Flo	Not registered	500 mL/ha

These are the only registered chlorothalonil products. It is an offence to use any other product. Refer to current product label for complete 'Direction for use' prior to application.

Source: Pulse Australia

Note: Observations in 2010 Tamworth trials indicated that the natural resistance all plants have to pathogens and pests is compromised when plants are stressed from waterlogging, and that this reduced the ability to manage Ascochyta with a fungicide strategy that worked in less stressed plots. In a season when repeated cycles of infection occur, even MR varieties can have yield-reducing levels of disease. [30]

28 DAFWA. (2016) Production packages for kabuli chickpea in Western Australia - post planting guide. https://www.agric.wa.gov.au/chickpeas/production-packages-kabuli-chickpea-western-australia-post-planting-guide

29 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

30 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

IN FOCUS

Economic chickpea production for southern Australia through improved cultivars and strategic management to control Ascochyta blight.

Experiments were sown at four locations over two seasons in southern Australia to assess fungicide (chlorothalonil or mancozeb) application timing and efficacy in controlling Ascochtya blight in cultivars varying in Ascochyta blight resistance. Resistant (R) cultivars were successfully grown with two or less fungicide applications during podding. Moderately resistant (MR), moderately susceptible (MS) and susceptible (S) cultivars always required at least three and up to nine fungicide applications to prevent yield loss. In all experiments the podding treatment of chlorothalonil had equivalent or greater grain yields than the mancozeb podding treatment. The use of resistant cultivars with one or two strategic foliar fungicide applications ensures chickpeas are a low risk, profitable option in medium rainfall (350–450 mm) cropping areas of southern Australia. [31]

Resistant (R) *(e.g. Genesis™ 090, Genesis™ 425)*

- Fungicide sprays are unlikely to be required before podding. Despite good foliar resistance to Ascochyta, the flowers and pods of R varieties can be infected, which can result in poor quality, discoloured seed or seed abortion and, in extreme situations, yield loss.
- Monitor the crop 10–14 days after each rain event.
- If Ascochyta is detected, apply a registered fungicide at early podding prior to rain. In high rainfall or high risk situations and where there is an extended pod filling period, further applications may be required.

Moderately Resistant to Resistant (MR/R) *(e.g. PBA HatTrick⍱, PBA Boundary⍱)*

- In most seasons, disease development will be slow and there will be no or minimal yield loss. In such seasons there is no cost benefit in applying a fungicide during the vegetative stage. Despite good foliar resistance to Ascochyta, the flowers and pods of MR/R rated varieties can be infected which can result in poor quality, discoloured seed or seed abortion and yield loss in severe situations.
- However, under high disease pressure, a reactive foliar fungicide strategy may be warranted during the vegetative period of the crop.
- Monitor the crop 10–14 days after each rain event.
- If Ascochyta is present in the crop apply a registered fungicide at early podding prior to rain to ensure pods are protected, and high quality, disease free seed is produced.

Moderately Resistant (MR) *(e.g. Flipper⍱)*

- In most seasons of low to moderate disease pressure, there is no cost benefit in applying a fungicide until after Ascochyta blight is detected.
- Monitor the crop 10–14 days after each rain event and if Ascochyta is detected apply a registered fungicide just before the next likely rain event.

31 L McMurray, J Brand, J Davidson, K Hobson, M Materne (2006) Economic chickpea production for southern Australia through improved cultivars and strategic management to control ascochyta blight. In Proceedings of the 13th Australian Agronomy Conference (65).

- Continue monitoring and spray again if weather and disease levels indicate Ascochyta is likely to spread.

Moderately Susceptible to Moderately Resistant (MS/MR) *(e.g. Yorker⍉, Almaz⍉)*

- For all situations apply a registered fungicide before the first rain event after crop emergence, or three weeks after emergence or at the three branch stage of development, whichever occurs first.
- Monitor the crop 10–14 days after each rain event.
- If Ascochyta is found, apply a registered fungicide just before the next rain event.
- Continue monitoring and spray again if weather and disease levels indicate Ascochyta blight is spreading.

Susceptible (S) varieties *(e.g. Jimbour, Kyabra⍉, Moti, PBA Pistol)*

- If the season favours Ascochyta, regular fungicide sprays will be needed from emergence until four weeks before maturity. Do not wait until you find the disease.
- Timing of the first two sprays is critical, because control is difficult or impossible after the disease has taken hold. The first spray must be applied before the first post emergent rain event, or three weeks after emergence or at the three leaf stage whichever occurs first. The second spray should be applied three weeks after the first spray. However, apply the second spray if two weeks have elapsed since the first spray and rain is forecast.
- Mancozeb is often the preferred fungicide for these first two applications as it can be applied with a Group A grass herbicide.
- Continue monitoring the crop 10–14 days after each rain event. If Ascochyta is found additional sprays will be required. If it has been two weeks or longer since the last application, spray again just before the next rain event. [32]

IN FOCUS

Management options for minimizing the damage by Ascochyta blight in chickpea

Ascochyta blight, a fungal disease caused by *Ascochyta rabiei (Pass.) Labrousse*, is the major constraint for chickpea production worldwide. Current cultivars only possess partial resistance to the pathogen, and this level of resistance can breakdown easily because the pathogen is highly variable due to potential for sexual recombination. The development of integrated disease management is the key for successful chickpea production. In this research the key crop management practices from the major chickpea growing areas in the world were summarised. Emphasis is on strategies and options that can be used to minimize the damage caused by this disease. The use of Ascochyta blight-free seed and seed dressing with effective fungicides reduces the probability of transmitting seed-borne disease to the seedlings. Deep-burying or burning of chickpea stubble minimizes stubble-borne inoculum. One to two years of non-host crops for warm and wet areas and 3–4 year crop rotation for cold and dry areas are required to reduce the levels of stubble-borne inoculum. The use of field isolation and sowing chickpea at a distance from previous chickpea crops will reduce the density of airborne ascospores released from infected debris. Optimum sowing date, deep sowing, optimising plant density, balanced nutrition, and alternative sowing patterns should be considered as a means of reducing Ascochyta blight pressure wherever

32 K Moore, M Ryley, G Cumming, L Jenkins. Chickpea: Ascochyta blight management. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

MORE INFORMATION

Chickpea: Ascochyta blight management.

possible. Sprays at seedling stage or before the occurrence of infection are crucial in short-season areas or where ascospores are the major sources of inoculum. Chickpea growers are strongly encouraged to adopt an integrated approach that combines all agronomic options, including cultivar selection, if they are to manage this disease economically and effectively. [33]

9.6 Botrytis grey mould

Botrytis grey mould (BGM) in chickpea is caused by the fungus *Botrytis cinerea*. *B. cinerea* is a significant pathogen of pulse crops, particularly lentils, ornamental plants grown under glasshouse conditions, and fruit including grapes, strawberries and apples. Flowers are especially vulnerable to BGM infection. *B. cinerea* does not infect cereals or grasses.

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. This makes management of BGM different from chickpea Ascochyta, which is more dependent on inoculum, at least in the early phases of an epidemic.

B. cinerea also causes pre and post-emergent seedling death. This happens when chickpea 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. [34]

Economic importance

Botrytis grey mould is a serious disease of chickpeas in southern Australia and can cause total crop failure. Discoloured seed may be rejected or heavily discounted when offered for sale. If seed infection levels are >5% then it may be worth grading the seed. Crop losses are worst in wet seasons, particularly when crops develop very dense canopies.

9.6.1 Varietal resistance or tolerance

See Table 3 at the start of this chapter for varietal disease ratings.

9.6.2 Damage caused by BGM

Botrytis grey mould is the second most important disease of chickpeas and can infect plants at any stage of development. Under favourable conditions, the disease can develop rapidly, spread widely and cause complete yield loss. Chickpea genotypes with vigorous seedling growth, early canopy closure and early flowering are more likely to develop disease than other varieties. Use of badly infected seed can result in total crop failure where seed is not dressed with a fungicide. Crop losses are greatest in wet seasons, particularly when crops develop very dense canopies. [35]

33 YT Gan, KHM Siddique, WJ MacLeod, P Jayakumar, P (2006) Management options for minimizing the damage by ascochyta blight (Ascochyta rabiei) in chickpea (Cicer arietinum L.). Field Crops Research, 97(2), 121–134.

34 M Ryley, K Moore, G Cumming, L Jenkins. Chickpea: Managing Botrytis Grey Mould. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

35 CropPro. Botrytis grey mould of Chickpeas. http://www.croppro.com.au/crop_disease_manual/ch05s06.php

9.6.3 Symptoms

The first symptom of BGM infection in a crop is often drooping of the terminal branches. If groups of plants are infected, these may appear as yellow patches in the crop (Figure 10). The diagnostic feature is a grey 'fuzz' which, under high humidity, develops on flowers, pods, stems and on dead leaves and petioles.

Figure 10: *If groups of plants are infected, these may appear as yellow patches in the crop.*

Photo: Phil Davies. Source: Pulse Australia.

Lesions can develop anywhere along the stem but are usually first found on the lower part of the stems, often starting in leaf axils (Figure 11). Infected seeds are usually smaller than normal and are often covered with white to grey fungal growth.

Figure 11: *Lesions are usually first found on the lower part of the stems often starting in leaf axils.*

Source: Pulse Australia.

Infected seeds are usually smaller than normal and are often covered with white to grey fungal growth (Figure 12).

Figure 12: *Botrytis grey mould on seed.*

Photos: G. Cumming. Source: Pulse Australia

When a severely BGM-infected canopy is opened, clouds of spores are evident (avoid inhaling these). During dry weather the 'fuzz' is not obvious, but it develops again when wet weather returns (Figure 13). Small, dark brown/black resting bodies (sclerotes) of *B. cinerea* may develop on infected dead tissue, and are capable of producing spores on their surface.

Figure 13: *BGM on a chickpea flower.*

Photo: Phil Davies. Source: Pulse Australia.

The stem lesions caused by BGM can be confused with those caused by *Sclerotinia sclerotiorum* (at and above ground level) and by *Sclerotinia minor* (at ground level), but neither of these pathogens produce the grey 'fuzz' typical of BGM. Also, sclerotinia lesions tend to remain white, and are covered by a dense cottony fungal growth, in which irregular shaped black sclerotes develop.

In contrast, the sclerotes of *B. cinerea* are more rounded and usually develop after the stems die. They are smaller than the sclerotes of *S. sclerotiorum*, but larger than the angular sclerotes of *S. minor*. [36]

9.6.4 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.

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.

Over 10 million spores can be produced on a single 2 cm-long lesion on a chickpea stem. Consequently, *B. cinerea* has the capacity to rapidly develop during conducive weather conditions. The spores can be blown many kilometres, and if deposited on chickpea plants they can remain dormant until conditions favour spore germination.

Free moisture is necessary for germination and infection. Lesions and the grey 'fuzz' are evident 5–7 days after infection under ideal conditions.

B. cinerea is favoured by moderate temperatures (20–5°C) and frequent rainfall events. It does not become a risk until the average daily temperature (ADT) is 15°C or higher. The combination of early canopy closure, prolonged plant wetness and overcast weather results in high relative humidity and rapid leaf death in the canopy, conditions which are ideal for *B. cinerea*.

B. cinerea can survive on and in infected seeds, in infected stubble, on alternative hosts, in dead plant tissue and as sclerotes. The relative importance of these in Australia is unknown, but recent research in Victoria demonstrated that *B. cinerea* can survive for up to 18 months on infected stubble under field conditions. Other research from Western Australia suggests that sclerotes of *B. cinerea* cannot survive over summer because they lose their viability during hot weather. [37]

9.6.5 Management of BGM

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.

36 M Ryley, K Moore, G Cumming, L Jenkins. Chickpea: Managing Botrytis Grey Mould. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

37 M Ryley, K Moore, G Cumming, L Jenkins. Chickpea: Managing Botrytis Grey Mould. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

Burying or burning stubble can significantly increase the risk of soil erosion and reduce water infiltration. [38]

Volunteer control (the green bridge)

Volunteer chickpea 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. [39]

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. [40]

See Section 3 Planting, 3.2 Seed treatments for more information.

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 chickpeas and water if necessary.
- Count the number of seedlings that have emerged after one, two and three weeks and note their appearance. Do they look healthy or are they stunted and distorted?
- If you want 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. [41]

Paddock selection

Paddocks in which chickpeas were affected by BGM should not be re-sown to chickpea, faba bean or lentil the following season. Nor should chickpea be sown beside paddocks where BGM was an issue the previous season.

As for Ascochyta blight, chickpea should be grown as far away from paddocks in which BGM was a problem as is practically possible.

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. [42]

Sowing time and row spacing

If long-term weather forecasts suggest a wetter-than-normal year (La Niña), consider sowing in the later part of the suggested sowing window for your district and on wider rows. Keep in mind, however, that WA soil types may not have enough nutrients to support very wide rows, and that wide rows may increase the risk of weeds, against which chickpeas are poor competitors. Planting on wider rows results in increased air movement through the crop and reduced humidity within the canopy.

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38 M Ryley, K Moore, G Cumming, L Jenkins. Chickpea: Managing Botrytis Grey Mould. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

39 M Ryley, K Moore, G Cumming, L Jenkins. Chickpea: Managing Botrytis Grey Mould. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

40 M Ryley, K Moore, G Cumming, L Jenkins. Chickpea: Managing Botrytis Grey Mould. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

41 M Ryley, K Moore, G Cumming, L Jenkins. Chickpea: Managing Botrytis Grey Mould. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

42 M Ryley, K Moore, G Cumming, L Jenkins. Chickpea: Managing Botrytis Grey Mould. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

Varietal resistance

All current commercial varieties suitable for the northern region are susceptible to BGM, although Howzat⒟ is reported to have slightly better resistance than other varieties.

Fungicide treatment

In areas outside central Queensland, spraying for BGM is not needed in most years.

However, in seasons and situations favourable to the disease, a preventative spray of a registered fungicide immediately prior to canopy closure, followed by another application two 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 (Table 6).

None of the fungicides currently registered or under permit for the management of BGM on chickpea have eradicant activity, so their application will not eradicate established infections. Consequently, timely and thorough application is critical. [43]

Table 6: *Foliar fungicides for the control of Ascochyta and Botrytis grey mould.*

Active ingredient	Example trade name	Rate	
		Ascochyta blight	Botrytis grey mould
Chlorothalonil (720 g/L)	Crop Care Barrack 720# Barrack Betterstick # Nufarm Unite 720#	1.0–2.0 L/ha	Not registered
Mancozeb (750 g/kg)	Dithane TM RainshieldTM	1.0–2.2 kg/ha	1.0–2.2 kg/ha
Mancozeb (420 g/L)	Penncozeb SC	1.8–3.95 L/ha	Not registered
Carbendazim (500 g/L)	Spin Flo	Not registered	500 mL/ha

These are the only registered chlorothalonil products. It is an offence to use any other product. Refer to current product label for complete 'Direction for use' prior to application.

Source: Pulse Australia

9.7 Sclerotinia

Sclerotinia, caused by *Sclerotinia sclerotiorum* and *trifoliorum*, is an occasional disease of chickpeas but has caused significant crop losses in Australia. Sclerotinia can cause serious crop losses where a substantial number of plants within a crop are affected. Kabuli chickpeas appear more susceptible to this disease than Desi chickpeas, but both types can be seriously damaged under favourable conditions. Dense crops are likely to be the most severely affected, particularly under moist conditions. Grain quality can be decreased when infected with sclerotinia, which causes poor colour and shrivelled seed.

In WA, sclerotinia infection was prevalent in crops throughout the west midlands area in trials between 2011 and 2012, with 25% of canola crops infected. On average this has been at a level of 20% of plants although the range was 0 to 82%. In contrast, 14% of lupin paddocks have been infected with an average of 13% of plants infected. Canola is a good host for sclerotinia and its host ability may increase the risk of this disease for all broadleaf crops. [44]

43 M Ryley, K Moore, G Cumming, L Jenkins. Chickpea: Managing Botrytis Grey Mould. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould

44 W Parker (2013) Profitable crop and pasture sequencing 2013 trial report. DAFWA, https://www.agric.wa.gov.au/grains-research-development/profitable-crop-and-pasture-sequencing-2013-trial-report?page=0%2C0

9.7.1 Varietal resistance or tolerance

There are no grain legumes that are resistant to sclerotinia. [45]

9.7.2 Damage caused by disease

Sclerotinia can cause serious crop losses where a substantial number of plants within a crop are affected. This disease has caused total crop failure where chickpeas were sown in the same paddock in successive years. However in many situations it only affects a small proportion of plants within the crop. Kabuli chickpeas appear more susceptible to this disease than desi chickpeas but both types can be seriously damaged under favourable conditions. Dense crops are likely to be the most severely affected, particularly under moist conditions. Grain quality can be decreased when infected with sclerotinia, which causes poor colour and shrivelled seed. [46]

9.7.3 Symptoms

There are two *Sclerotinia spp* that attack chickpeas and they can be distinguished by the size of their sclerotes (survival structures).

- *S. sclerotiorum* produces large irregular shaped sclerotes 5–10 mm in diameter as high up as 20–30 cm on the stem
- *S. minor* produces sclerotes that are angular and much smaller, rarely larger than 2–3 mm in diameter

What to look for:

A small number of dead plants scattered throughout a paddock. Affected plants first wilt and rapidly die, often without turning yellow. Later, as the plant dries out the leaves turn a straw colour (Figure 14).

Figure 14: *Plants killed by S. sclerotiorum (left). Fungal weft of sclerotinia in the lower canopy of a chickpea crop (right).*

Photos: Kevin Moore

On the surface of the root, just below ground level, small black fungal bodies called sclerotia (which are irregular in size and shape), can sometimes be seen mingled with white cottony fungal mycelium (Figure 15).

45 G Thomas. (2010). Sclerotinia and grain legumes – is it an issue? http://www.australianoilseeds.com/__data/assets/pdf_file/0018/8244/9_Thomas_-_Sclerotinia.pdf

46 CropPro. (2014). Sclerotinia of chickpeas. http://www.croppro.com.au/crop_disease_manual/ch05s03.php

Figure 15: *Early symptoms of stem infection by sclerotinia. Whit mycelial growth starting to develop (left). Comparison of stem infections caused by sclerotinia (top stem) and botrytis (lower stem) (right). Note the different colour of fungal growth.*

Source: http://www.croppro.com.au/crop_disease_manual/ch05s03.php

In spring, water-soaked spots may appear on the stems and leaves. Affected tissues develop a slimy soft rot from which droplets of a brown liquid may exude. Infected tissues then dry out and may become covered with a web of white mycelium of the fungus (Figure 16).

Figure 16: *Sclerotinia stem infection of chickpeas. White fluffy mycelium and sclerotia formation evident.*

Source: CropPro

9.7.4 Conditions favouring development

The disease is usually established from sclerotia (survival bodies of the fungus) present in the soil or introduced with contaminated seed. Outbreaks are more common when very wet conditions occur in July.

The sclerotia germinate in moist soil and either directly infect roots or produce air-borne spores (Figure 17) which attack the above ground parts of the plant. Once established, the fungus rapidly moves to adjacent healthy tissue. Within a few days of infection, plants start to wither then die.

Figure 17: *Ascospore infection of chickpea stem by S. sclerotiorum*

Photo: G. Cumming. Source: Pulse Australia

Sclerotia formed on infected plants enable the fungus to survive to the following year. Individual seeds can be contaminated with the fungus and/or sclerotia may be present in the seed sample. Sclerotia can remain viable in the soil for up to eight years.

Soil-borne sclerotia are the most important disease source for establishing disease in following crops. Seeds infected with sclerotinia can be the cause of disease establishment in otherwise sclerotinia-free areas. [47]

9.7.5 Management of sclerotinia

Before sowing

Use clean seed

Use of disease-free seed minimises the risk of disease and prevents establishment into a new area. It is important to avoid sowing chickpea in areas where the disease is known to be present. The seed harvested from infected crops should not be used for sowing.

47 Crop Pro. Sclerotinia of Chickpeas. GRDC, http://www.croppro.com.au/crop_disease_manual/ch05s03.php

Crop rotation

Crop rotation is the best method of control once the disease has become established. Cereal crops are not affected by sclerotinia and provide a good disease break. Pulse crops, oilseeds, legume based pastures and capeweed are all good hosts to this disease.

If a severe sclerotinia problem does occur, at least a four-year break from susceptible crops is required to substantially reduce the number of sclerotia in the soil. A longer break may be required as sclerotes can survive in the soil for up to eight years. The most practical option is to use legumes such as field peas or vetch which have some resistance to sclerotinia. In addition, burning of the disease infected stubble should be considered. Deep ploughing (5 cm) will also reduce the number of sclerotia, and so minimise disease carry over. Where a minor sclerotinia problem occurs, a two-year break from susceptible crops is advisable.

No commercial seed treatments or fungicides are known to manage this disease in crop. [48]

9.8 Phytophthora root rot

Phytophthora root rot (PRR) is a disease of chickpea caused by the fungus-like oomycete *Phytophthora medicaginis*. It can cause significant yield losses in wetter than normal seasons or following periods of soil saturation in normal seasons. Lucerne, perennial and annual medics (*Medicago* species) and other leguminous plants including sulla (*Hedysarum* species) and sesbania (*Sesbania* species) can also host *P. medicaginis*. [49]

In northern New South Wales this disease is a serious constraint to production but is much less common in WA.

PRR is soil and water-borne and can establish permanently in a paddock. Fungicide treatment is expensive and will not provide season-long control of this disease. It can only be managed with pre-planting decisions in commercial situations—planting into low risk paddocks and sowing the most resistant variety available if sowing into a medium or high risk paddock. [50]

9.8.1 Varietal resistance or tolerance

See Table 3 at the start of this chapter for varietal disease ratings.

9.8.2 Damage caused by PRR

Damage is greatest in wetter than normal seasons or during periods of soil saturation in normal seasons. Only one saturating rain event is needed for infection. Once a plant or crop is infected with PRR, nothing can be done to treat the current crop. [51]

9.8.3 Symptoms

Infection by *P. medicaginis* can occur at any growth stage, causing seed decay, pre- and post-emergence damping off, loss of lower leaves, and yellowing, wilting and death of older plants (Figure 18). The disease is usually observed late in the season but may also affect young plants. Badly affected seedlings suddenly wither and die with no obvious disease symptoms.

48 Agriculture Victoria (2012) Sclerotinia of Chickpeas. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/sclerotinia-of-chickpea

49 K Moore, M Ryley, M Schwinghamer, G Cumming, L Jenkins. Chickpea: Managing Phytophthora root rot. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

50 GRDC. (2015). Phytophthora root rot in chickpea. https://grdc.com.au/Media-Centre/Hot-Topics/Phytophthora-root-rot-in-chickpea

51 GRDC. (2015). Phytophthora root rot in chickpea. https://grdc.com.au/Media-Centre/Hot-Topics/Phytophthora-root-rot-in-chickpea

Figure 18: *Cultivated areas killed by phytophthora. Only plants on tops of contours survived (left) and phytophthora in water course (right). (Photos: Mark Schwinghamer.*

Source: Pulse Australia

Infected plants are often stunted with obvious yellowing and drying of the foliage. They have few lateral roots and the lower portion of the tap root is often decayed (Figure 19). The remaining tap root is usually discoloured dark brown to black. Sometimes the discolouration can extend to the base of the plant. The advancing margins of the lesions may also have a reddish-brown discolouration.

Figure 19: *Severely affected plants have no lateral roots (right) and defoliation below tips of stems.*

Photo: Joe Wessels. Source: CropProp

Symptoms are sometimes delayed if temperatures are cool and the soil is moist. Lateral roots and tap root die, or dark brown/black lesions girdle the taproots (Figure 20).

Figure 20: *New roots forming from the top of the taproot.*

Photo: Mike Fuhlbohm. Source: Pulse Australia

On young plants the lesions may extend up the stem for 10 mm or more above ground level (Figure 21).

Figure 21: *PRR basal lesions extending up the plant stem.*

Photo: Mal Ryley. Source: Pulse Australia

Plants with Phytophthora can be easily pulled from the soil. If conditions are mild, affected plants may partially recover by producing new roots from the upper part of the tap root. [52]

9.8.4 Phytophthora and waterlogging

PRR and waterlogging have similar symptoms (Table 7) and are both induced by transient or prolonged soil saturation and surface water. They usually occur in low lying areas of paddocks, or where water accumulates such as on the low side of contour banks or in watercourses, or where the soil has been compacted or has hard pans. However, under very wet conditions, entire paddocks can be affected.

Table 7: *Symptoms of PRR and waterlogging.*

Phytophthora root rot	Waterlogging
Organism kills roots	Low oxygen kills roots
Chickpea, medics, lucerne are hosts	No link with cropping history or weed control
Occurs any time of year	Usually occurs later in the year
Symptoms onset occurs after a week or more	Symptoms onset occurs quite rapidly
Lower leaves often yellow and fall off	Plants die too fast for leaves to yellow or fall
Roots always rotted and discoloured	Initially roots not rotted or discoloured (tips black)
Plants easily pulled up and out	Plants not easily pulled up initially
Manage through paddock rotation varietal choice	Manage through paddock selection, no irrigation in reproductive phase

Source: Pulse Australia

Symptoms of waterlogging can be confused with those of phytophthora but differ in that:

- Plants are most susceptible to waterlogging at flowering and early pod fill.
- Symptoms develop within two days of flooding compared to at least seven days for phytophthora.
- Roots are not rotted and are not easily pulled from the soil at first.
- Plants often die too quickly for the lower leaves to drop off.

9.8.5 Conditions favouring development

Phytophthora medicaginis survives in soil mainly as thick-walled oospores, but some strains also survive as chlamydospores. Oospores can survive in soil for at least 10 years. In saturated soil the exudates from the roots of chickpea and other hosts stimulate the oospores to germinate and produce lemon-shaped sporangia. Inside these sporangia, zoospores develop and are released into the soil and surface water, where they are carried by moving water and 'swim' towards the roots and collars of chickpea plants.

Zoospores encyst on the root surfaces and germinate to produce hyphae that invade the roots. New sporangia develop from infected roots, enabling further cycles of infection to occur. Later, oospores are formed in the infected roots.

Zoospores are only capable of 'swimming' for a few millimetres, so long distance dispersal of *P. medicaginis* is by physical movement of soil and water infested with

52 K Moore, M Ryley, M Schwinghamer, G Cumming, L Jenkins. Chickpea: Managing Phytophthora root rot. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

oospores, sporangia, zoospores and/or chlamydospores during floods and irrigation or by machinery. [53]

9.8.6 Management of PRR

Once a plant or crop is infected with PRR, there is nothing a grower can do.

There are no effective chemical sprays as there are for Ascochyta and Botrytis. Therefore, Phytophthora can only be managed by pre-sowing decisions and assessing risks for individual paddocks.

Development of the disease requires both the pathogen in the soil, and a period of soil saturation with water. Losses in a Phytophthora-infested paddock may be minor if soil saturation does not occur.

The most effective control strategy is to not sow chickpeas in high-risk paddocks, which are those with a history of:

- Phytophthora noted in previous chickpea or lucerne crops;
- lucerne or annual or perennial medics;
- waterlogging or poorly drained paddocks or prone to flooding; and/or
- metalaxyl-based seed dressings.

Do not flood irrigate after podding has commenced, especially if the crop has been stressed.

If you choose to sow chickpeas in high-risk paddocks, grow a chickpea variety with the highest level of resistance. Particularly in medium risk situations, where medic, chickpea or lucerne crops have been grown in the past 5–6 years. [54]

9.9 Root rots including Damping off (*Fusarium, Rhizoctonia* and *Pythium spp.)*

All fungi responsible for root rot are soil dwellers. They can survive from crop to crop in the soil, either on infected plant debris or as resting spores. In wet soils, these fungi can invade plant roots and cause root rot. Wet conditions also encourage the spread of disease within a field.

9.9.1 Economic importance

Root rot diseases can occasionally be serious, especially when soils are wet for prolonged periods. The reduced root development causes the plants to die when they are stressed.

9.9.2 Symptoms

Affected seedlings gradually turn yellow and leaves droop. The plants usually do not collapse. The taproot may become quite brittle, except in Pythium root rot when they become soft. When plants are pulled from the ground the portion of the root snaps off and remains in the soil. The upper portion of the taproot is dark, shows signs of rotting, and may lack lateral roots. Distinct dark brown to black lesions may be visible on the taproot (Figure 22). The leaves and stems of affected plants are usually straw-coloured, but in some cases may turn brown. Older plants dry-off prematurely and are often seen scattered across a field. In some cases, especially with Kabuli, seeds may rot before they emerge.

53 K Moore, M Ryley, M Schwinghamer, G Cumming, L Jenkins. Chickpea: Managing Phytophthora root rot. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

54 K Moore, M Ryley, M Schwinghamer, G Cumming, L Jenkins. Chickpea: Managing Phytophthora root rot. Pulse Australia Ltd, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

Figure 22: *Rhizoctonia root rot. Optimum soil temperature is 24–26°C; disease is worse on light sandy soils.*

Source: CropIT

9.9.3 Management options

Root rot disease can be reduced by crop rotation. As this disease may also affect other pulses, chickpea should be sown in rotation with another non-legume crop. Chickpea should not be grown in areas subject to waterlogging. Damping-off in Kabuli chickpeas can be controlled using fungicide seed treatment.

9.10 Collar rot (Sclerotium rolfsii)

9.10.1 Economic importance

Collar rot is generally a minor disease in chickpea. However, the disease has been particularly severe in irrigated Macarena (Kabuli).

9.10.2 Symptoms

This disease is commonly observed at very low levels in chickpea crops sown during warmer conditions (up to six weeks after sowing) as isolated dead seedlings with a coarse web of white fungal threads encasing the tap root. However, in irrigated systems, the fungus can kill significant numbers of plants. The coarse threads of the fungus can be seen on or just under the soil surface, colonising decomposing trash or on the plant itself (Figure 23); these webs of mycelium can cover quite a substantial area around plants. On chickpea, plants will be killed outright and quite rapidly as the fungus invades around the soil level and girdles the vascular tissue. Plants will wilt and become bleached (a result of a toxin produced by the fungus). Younger seedlings may collapse but older plants may simply dry (without collapse). The characteristic signs of the pathogen will be the webs of coarse mycelium and the small (~1–2 mm) spherical brown sclerotia (survival and resting structures) of the fungus that attach to the fungal threads. The sclerotia look like canola seeds.

Figure 23: *Webs of Sclerotium rolfsii mycelium at the base of an infected chickpea plant.*

Photo: K. McCosker

9.10.3 Conditions favouring development

The fungus has a very wide host range including monocots (such as millet and barley) and dicots (such as cotton). The pathogen is also the causal agent of white mould in peanuts.

The pathogen rarely occurs where average winter temperatures fall below 0°C. The fungus survives in the soil mainly as sclerotia that remain viable for 2–3 years, but occasionally persists as mycelium in infected tissues or plant residues. Sclerotia germinate by hyphal or eruptive germination. Hyphal germination is characterised by the growth of individual hyphae from the sclerotial surface, while eruptive germination is characterised by plugs or aggregates of mycelium bursting through the sclerotial surface.

9.10.4 Management options

The disease is favoured by the presence of undecomposed organic matter on the soil surface and excessive moisture. If possible, avoid wetting and drying cycles during warmer periods, as this promotes germination of the sclerotia, and try to minimise inter-row cultivation, which pushes soil up around the base of plants. The fungus is a very effective saprophyte of cotton trash, so allowing time for cotton trash to break down prior to planting will reduce the activity of the fungus. Similarly, trash from other crops such as barley and millet are attractive substrates for the fungus.

9.11 Fungal disease control

9.11.1 When to spray

Sprays will control fungal disease, but when and how often to spray will depend on the varietal resistance, amount of infection, the impending weather conditions and the potential yield of the pulse crop.

Fungal disease control is geared around protection rather than cure. The first fungicide spray must be applied as early as necessary to minimise the spread of the disease. Additional sprays are required if the weather conditions favour the disease.

9.11.2 Principles of spraying

A fungicide spray at the commencement of flowering protects early podset. Additional protection may be needed in longer growing seasons until the end of flowering. Fungicides last around 2–3 weeks.

Remember that all new growth after spraying is unprotected. Coverage and canopy penetration is critical, as only treated foliage will be protected. Translocation is very low in most products.

In periods of rapid growth and intense rain (50 mm over several days), the protection period will reduce to ~10 days.

Timing of fungicide sprays is critical (Table 8). As Ascochyta blight and BGM can spread rapidly, DO NOT DELAY spraying. A spray in advance of a rainy period is most desirable.

Despite some fungicide washing off, the disease will be controlled. Delaying until after a rainy period will decrease the effectiveness of the fungicide as the disease has started to spread.

Repeat fungicide sprays depend on:

- amount of unprotected growth
- rainfall since spraying
- likelihood of a further extended rainy period

Unprotected crops can lose more than 50% in yield. In severe cases, the crop may drop all of its leaves.

Table 8: *Principles of when to spray for fungal disease control in chickpea.* [55]

Disease	Occurrence	When to spray
Ascochyta blight	First appears under wet conditions	Resistant variety. Fungicide sprays are unlikely to be required before podding. Despite good foliar resistance to Ascochyta blight, the flowers and pods of resistant varieties can be infected which can result in poor quality, discoloured seed or seed abortion and, in extreme situations, yield loss. Moderately resistant variety. In most seasons, disease development will be slow and there will be no or minimal yield loss. In such seasons there is no cost benefit in applying a fungicide during the vegetative stage. Despite good foliar resistance to Ascochyta blight, the flowers and pods of MR/R rated varieties can be infected, which can result in poor quality, discoloured seed or seed abortion and yield loss in severe situations. However, under high disease pressure, a reactive foliar fungicide strategy may be warranted during the vegetative period of the crop. If Ascochyta blight is present in the crop, apply a registered fungicide at early podding prior to rain to ensure pods are protected, and high quality, disease free seed is produced. Susceptible variety. If the season favours Ascochyta blight, regular fungicide sprays will be needed from emergence until four weeks before maturity. Do not wait until you find the disease. Timing of the first two sprays is critical, because control is difficult or impossible after the disease has taken hold. The first spray must be applied before the first post-emergent rain event, or three weeks after emergence or at the 3-leaf stage, whichever occurs first. The second spray should be applied three weeks after the first spray. However, apply the second spray if two weeks have elapsed since the first spray and rain is forecast. Continue to monitor the crop 10–14 days after each rain event. If Ascochyta blight is found, additional sprays will be required. If it has been ≥2 weeks since the last application, spray again just before the next rain event. For all varieties regardless of resistance. If Ascochyta blight is detected, apply a registered fungicide at early podding prior to rain. In high-rainfall or high-risk situations and where there is an extended pod-filling period, further applications may be required
Boytrytis grey mould	Develops during warm (15–20°C), humid (>70%) conditions, usually at flowering.	During early to mid-flowering as a protective spray. Additional sprays may be necessary through flowering and pod-filling if disease progresses. Disease is favoured by warm weather (15–20°C) and high humidity (>70% RH)

55 K Moore, M Ryley, G Cumming, L Jenkins. (2015) Chickpea: Ascochyta blight management. Pulse Australia, Australian Pulse Bulletin, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight

Table 9: *Carryover of major pulse diseases, showing relative importance as sources of infection.*

Disease	Stubble	Seed	Soil
Ascochyta blight	***	**	*
Botrytis grey mould	***	***	*
Phytophthora root rot			***
Sclerotinia	*	*	***

9.12 Viruses

Key points

- Chickpea is distinct from other pulses in respect to virus diseases and how viruses spread in crops.
- Aphicide sprays and some other control strategies that are effective in other pulses are less effective.
- At present, the best control options for chickpea are the current best agronomic practices: retaining standing stubble, using optimal sowing rates and times, and controlling in-crop and fallow weeds [56]
- Virus management aims at prevention through integrated management practice that involves controlling the virus source, aphid populations and virus transmission into pulse crops.
- Rotate legume crops with cereals to reduce virus and vector sources and where possible avoid close proximity to perennial pastures (e.g. lucerne) or other crops that host viruses and aphid vectors.
- Eliminate summer weeds and self-sown pulses 'green bridge' that are a host for viruses and a refuge for aphids.
- Aphid activity is influenced by seasonal conditions and will require early monitoring in nearby crops and pastures and possible use an aphicide or cultural controls to reduce numbers.
- Sow directly into cereal stubbles, (preferably standing) and encourage rapid canopy cover through early planting, high planting density as bare soil is more attractive to some aphid species.
- Purchase virus tested seed or have farmer seed virus tested as PSbMV, CMV, BYMV and AMV depend largely on seed transmissions for survival.
- Gaucho® 350SD is now registered and when applied as seed treatment will help protect faba bean, field pea and lentil seedlings from early season aphid attack and reduce virus spread.

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. [57]

There are more than 14 species of virus that naturally infect chickpea. These viruses are spread by airborne insects, with aphids being the predominant vector. The occurrence of virus in chickpea is episodic and changes dramatically from season to season and location. Clovers, medics, canola/mustard, weeds and other pulses can host viruses that infect chickpea. The best control strategies to reduce risk of viruses are agronomic. These include retaining cereal stubble, sowing on time, establishing a

56 Pulse Australia Ltd (2009) Australian Pulse Bulletin PA #10. Virus control in chickpea–special considerations.

57 Pulse Australia Ltd (2015) Australian Pulse Bulletin: Managing viruses in pulses. http://www.pulseaus.com.au/growing-pulses/publications/manage-viruses

uniform closed canopy and controlling weeds. [58] Seed and foliar insecticides are not recommended for chickpea viruses. [59]

9.12.1 Symptoms

Viruses exhibit a varied range of symptoms and severity from relatively unapparent to plant death. The intensity and symptoms depend on virus and pulse species and to a lesser extent on virus strain, pulse variety, climatic conditions and plant stage at infection. Plants infected at an early stage or through seed will usually show more uniform discoloration and stunting, but when infected at the later stage discolouration will usually occur at the leaf tip before the whole plant starts to deteriorate (Figure 24).

Figure 24: *Kabuli Chickpea (centre) with low plant stand and high virus infection compared to kabuli (right) and desi (left) with good canopy.*

Source: Pulse Australia. http://www.pulseaus.com.au/growing-pulses/publications/manage-viruses

Foliage symptoms are often more visible on young leaves and can include yellowing (sometimes reddening), vein clearing, leaf mottle, leaf distortion, curling of leaves, reduced size, chlorotic or necrotic spotting, or more widespread necrosis. Shoot symptoms may be seen as bunching of young leaves, growth of auxiliary shoots, bending over of the growing point, tip or apical necrosis, streaking of stems, stunting and wilting or plant death.

Symptoms such as leaf yellowing, veining, mottling, and wilting can often be confused with nutrient deficiencies, herbicide damage or water stress unless sufficiently distinct. It is also difficult to tell which virus is present without resorting to laboratory tests on plant samples.

It is best to collect living tissue samples, and collection and packaging of fresh samples is simple. Instructions from local agronomists or Pulse Australia need to be heeded. Immediately place the sample with paper towelling into a plastic bag, seal it and refrigerate it until dispatched. Send the sample by priority post and do not leave it sitting around. [60]

58 M Schwinghamer, T Knights, K Moore (2009). Virus control in chickpea--special considerations. Australian Pulse Bulletin PA 2009 #10

59 A Verrell (2013) Virus in chickpea in northern NSW 2012. GRDC Update Papers. 26 Feb 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Virus-in-chickpea-in-northern-NSW-2012

60 Pulse Australia Ltd (2015) Australian Pulse Bulletin: Managing viruses in pulses. http://www.pulseaus.com.au/growing-pulses/publications/manage-viruses

9.12.2 Conditions favouring development

High levels of virus infections have occurred in recent years, resulting from infected plants in the previous spring as a virus source and a 'green bridge' of summer plant material to carry over these viruses and as a refuge for aphids. Warm dry conditions during autumn have favoured increased aphid activity and virus transmission.

Some aphid species prefer to land on plants surrounded by bare ground, and favour thin crop stands or areas within the crop which have low plant densities.

Stressed plants are also more attractive to aphids, possibly due to a higher level of plant sugars, and are vulnerable to colonisation and can become a source of virus spread. Environmental factors that impacted on chickpeas in 2009 were extremely dry conditions early in the season that favoured aphid build. This was particularly evident in vetch crops. Then followed cold and wet conditions that included some transient water logging that stressed plants, making them more venerable to root diseases and aphid attack.

Chickpea that border lentil, canola or lucerne crops can be subjected to larger numbers of aphids, as they can readily colonise these crops and multiply quickly. Controlling aphids in these nearby host crops can potentially decrease aphid numbers moving through chickpea crops.

Types of transmission

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.

Persistently transmitted viruses

- Bean leafroll virus (BLRV)
- Beet western yellows virus (BWYV) (Figure 25)
- Subterranean clover red leaf virus (SCRLV)
- Subterranean clover stunt virus (SCSV)

Figure 25: *Beet Western Yellows Virus in kabuli (top) and in desi (bottom).*

Source: CropPro.

The general symptoms of BLRV on pulses are interveinal chlorosis, yellowing, stunting and leaf rolling (Figure 26). These symptoms could easily be confused with subterranean clover stunt virus (SCSV) or other luteoviruses such as beet western yellows virus (BWYV) and subterranean clover red leaf virus (SCRLV) or nutrient stress symptoms. [61]

61 Agriculture Victoria. (2013). Temperate pulse viruses: Bean leafroll Virus. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/temperate-pulse-viruses-bean-leafroll-virus-blrv

Figure 26: *Chickpeas develop tip yellowing and stunting.*

Photo: S Kumari, ICARDA, Source: AgVic.

Persistent transmission means that once the insect becomes infectious, it remains so for the rest of its life. After an insect vector feeds on an infected plant, the virus has to pass through its body and lodge in the salivary glands before it can be transmitted to healthy plants. Not all aphid species are vectors of this kind of virus in pulses, so the identification of aphid species is very important.

BWYV is the main virus most commonly occurring in chickpea and lentil crops. It has a diverse natural host range including canola, pasture plants, lucerne and many weeds such as paddy melons, wild radish and some native legumes. BLRV is another, but is limited to fabacae (faba bean, field pea, chickpea, and lentil), lucerne, clovers and summer legumes.

Persistently transmitted viruses typically start with a random distribution of infected plants in autumn and increases during the season as vectors colonise the crop. Transmission rates can dramatically increase with large aphid flights that will often coincide with aphid activity and build up prior to sowing.

Non-persistently transmitted viruses

- Alfalfa mosaic virus (AMV)
- Bean yellow mosaic virus (BYMV)
- Cucumber mosaic virus (CMV)
- Pea seedborne mosaic virus (PSbMV)

Non-persistently transmitted viruses can be seed-borne (depending on the virus/crop combination), but require aphid vectors to spread during the season. [62]

9.12.3 Management of viruses

A virus management strategy to reduce the risk of infection may require a number of control measures relevant to the various virus and pulse types.

Better agronomy—better chickpeas

Field trials from 2012 and 2013 have shown that chickpea crops are at risk of increased damage from viruses when plant density is less than 20 plants/m^2. Significantly fewer plants are infected when plant densities are higher, and it is recommended to aim for over 25 plants/m^2.

62 Pulse Australia Ltd (2015) Australian Pulse Bulletin: Managing viruses in pulses. http://www.pulseaus.com.au/growing-pulses/publications/manage-viruses

Trial crops deficient in nitrogen, potassium, phosphorus or all three have been shown to have significantly more virus-affected plants than a crop with adequate nutrition.

Inter-row planting into standing wheat stubble significantly reduced virus incidence in small trial plots of PBA HatTrick⁽ᴰ compared with the same amount of stubble slashed low to the ground. The mechanism for this difference is unclear, but these results are in agreement with many field observations in large crops during virus outbreaks.

Although differences in virus resistance have been observed for different varieties, further screening is needed to strengthen confidence in these results under high disease pressure in different growing regions, and to identify for which virus species resistance is effective. Under low virus pressure in field trials, some of the better performing varieties included Flipper⁽ᴰ and PBA HatTrick⁽ᴰ. However, both these varieties have been observed with high rates of infection under high disease pressure. The variety Gully is very susceptible to Ascochyta blight, but has moderate virus resistance so may be useful for breeding resistance into future varieties.

While a link could not be confirmed in the 2013 season between BWYV infections in canola and subsequent spread into nearby chickpea crops (van Leur et al. 2014), the sometimes high incidence of BWYV in canola indicates it may be prudent to avoid planting chickpea and other pulse crops next to canola. [63]

Best agronomic management can help to reduce damage by viruses and includes:

- Retain standing stubble, which can deter migrant aphids from landing. Where possible, use precision agriculture to plant between stubble rows. This favours a uniform canopy, which makes the crop less attractive to aphids.
- Plant on time and at the optimal seeding rate. These practices result in early canopy closure, which reduces aphid attraction (Figure 27).
- Ensure adequate plant nutrition.
- Control in-crop, fence line and fallow weeds. This removes in-crop and nearby sources of vectors and virus.
- Avoid planting adjacent to lucerne stands. Lucerne is a perennial host on which legume aphids and viruses, especially AMV and Bean leaf roll virus (BLRV), survive and increase.
- Seed treatment with insecticides, e.g. imidacloprid, are not effective for non-persistently transmitted viruses but may be effective for luteoviruses. Unfortunately, local data supporting seed treatment is lacking.
- Given the high incidence of Beet western yellows virus (BWYV) sometimes found in canola, consider growing chickpeas (and other pulse crops) away from canola. [64]

63 M Sharman, K Moore, J van Leur, M Aftab, A Verrell (2014) Viral diseases in chickpeas—impact and management. GRDC Update Papers 4 March 2014, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Viral-diseases-in-chickpeas-impact-and-management

64 K Moore, M Ryley, M Sharman, J van Leur, L Jenkins, R Brill (2013) Developing a plan for chickpeas 2013. GRDC Update Papers 26 Feb 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Developing-a-plan-for-chickpeas-2013

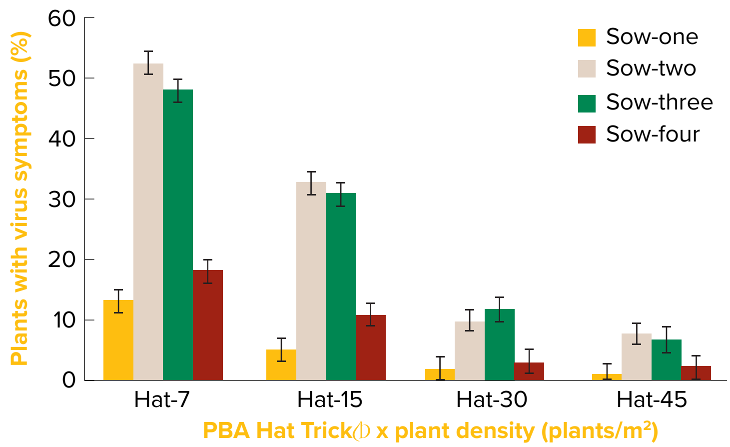

Figure 27: *Proportion of plants with virus symptoms for sowing date by plant density for PBA HatTrick⫯.*

Source: A Verrell (2013) Virus in chickpea in northern NSW 2012. GRDC Update Papers. 26 Feb 2013

Row spacing and incidence of plants with virus symptoms

Row spacing had a significant effect on incidence of plants with virus symptoms in a 2013 trial. On 11 October 2013, there were more than twice as many symptomatic plants/m^2 in plots with 40 cm rows compared to those with 80 cm rows (Figure 28). Both row configurations were sown at 30 plants/m^2 so plant density per unit area cannot account for the difference. Rather, plant density within each row appears to be responsible (12 plants/m row at 40 cm and 24 pl/m row at 80 cm).

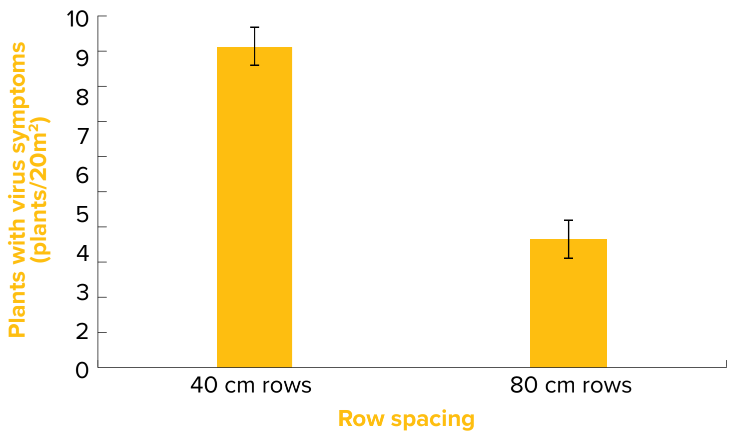

Figure 28: *Effect of row spacing on incidence of chickpea plants with virus symptoms.*

Source: GRDC

Stubble management and incidence of plants with virus symptoms

Planting into standing cereal stubble is known to help reduce risk of virus in lupin crops. Retaining standing cereal is believed to be useful in reducing risk of virus in chickpea crops, though research providing such evidence is limited.

Two trials were conducted in 2013 to compare standing versus flat (slashed) wheat stubble on incidence of plants with virus symptoms. One trial was sown at 80 cm row spacing; the other at 40 cm spacing; both were sown with PBA HATTRICK chickpea at 30 plants/m^2. The 80 cm trial was assessed on 11 October and the 40 cm trial was assessed on 9 October and again on 16 October. In both trials, incidence of plants with virus symptoms was lower where the chickpeas had been sown into standing stubble (Figure 29). Individual plots in these trials were small, 2 m × 10 m for the 80 cm trial and 4 m × 10 m in the 40 cm trial. [65]

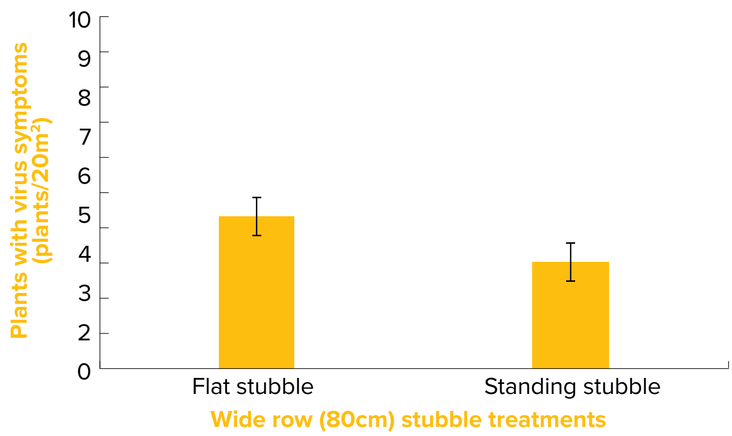

Figure 29: *Effect of stubble management (flat v. standing) on incidence of chickpea plants with virus symptoms.*

Source: GRDC

Non-persistently transmitted viruses

With non-persistently transmitted viruses (e.g. CMV, BYMV, AMV, and PSbMV) the initial and main source of infection is contaminated seed, with further transmission in-crop by aphids.

Management steps include:

- Source healthy seed that has been tested free of CMV, BYMV, AMV and PSbMV virus. Tested seed should have less than 0.1% virus infection and field peas should have less than 0.5% for PSbMV.
- Farmer-retained seed should only come from crops with no visible virus symptoms and seed testing should be a priority.
- Some cultivars have virus resistance such as CMV in many new lupin varieties and in Jenabillup (available in 2011). Yarrum field pea has resistance to BLRV and PSbMV. Increased emphasis on virus resistance is a priority of Pulse Breeding Australia.
- Controlling aphids in-crop is not an effective means of controlling non-persistently transmitted types of viruses.
- Sow direct into retained cereal stubble and preferably standing, as some aphid species are attracted to bare earth. This has been effective in minimising CMV spread in lupins.

Persistently transmitted viruses

Persistently transmitted viruses (e.g. BLRV, BWYV, SCSV) are not seed-borne. The virus is transmitted from live infected plants to healthy plants primarily by aphids or other insect vectors.

65 K Moore K, A Verrell, M Aftab (2014) Reducing risk of virus disease in chickpeas through management of plant density, row spacing and stubble. GRDC Update Papers 04 March 2014, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/03/Reducing-risk-of-virus-disease-in-chickpeas

An integrated management strategy involves the use of both cultural and chemical measures that aim to eliminate any virus sources, minimise aphids and deter aphids from entering the crop. Often by the time aphids are detected, the virus spread has already occurred.

Management steps include:

- Minimise the 'green bridge' for virus and aphid survival over summer. Control volunteer pulses, legumes and weeds well before sowing and early crop weeds that may carry viruses and aphids.
- Minimise bare earth through sowing into previous cereal stubbles and early sowing with adequate plant population (germ and vigour test seed). Use narrow rows in the absence of stubble to minimise exposed bare soil to deter aphids entering the crop.
- Avoid crop stress through good paddock selection (soil type, no hard pan, low weed burden) adequate nutrition, no herbicide stresses and good inoculation.
- Avoid sowing pulses close to each other and broadleaf crops such as canola, and be aware of proximity to perennials (e.g. lucerne).
- Monitor crops and neighbouring areas using a sweep net or beat sheet. Yellow sticky traps on crop perimeters can also be a handy check for aphid presence. Identify the species present and be prepared to use a 'soft' insecticide such as pirimicarb if there is a chance of localised flights.
- Use of 'soft' insecticides soon after emergence has been shown to help control persistently transmitted viruses only. Use of an SP is controversial as while it prevents early colonisation due to 'anti feed' properties, it can also agitate aphids not controlled and increase virus spread. It should not be used when green peach aphid is present as this major vector for BWYV has resistant populations. Impact on natural beneficials could also lead to higher aphid build-up. [66]

MORE INFORMATION

[Impact and management of viral diseases in chickpeas]

[Virus control in chickpea – special considerations]

[Managing viral diseases in chickpeas through agronomic practices]

66 Pulse Australia Ltd (2015) Australian Pulse Bulletin: Managing viruses in pulses. http://www.pulseaus.com.au/growing-pulses/publications/manage-viruses

Plant growth regulators and canopy management

Not applicable for this crop.

Crop desiccation/spray out

Key messages

- Chickpeas often mature unevenly and require herbicides to ripen more evenly.
- Desiccation assists production by taking out late weeds (such as thistles) that can stain the seed; allowing for earlier harvesting, which lessens the weather risk at harvest; and browning out green stems, which can gum up knives in headers.
- The correct timing for desiccation is when 80%–85% of the seeds in the pod have turned yellow and are firm, and the remaining 15%–20% have yellow 'beaks' on the seed, or are starting to turn yellow in colour.
- A high water rate is advised to get coverage, if using a contact herbicide.
- After desiccation, plants become more brittle, so it's advised not to delay harvesting.

11.1.1 Benefits of desiccation

Desiccation is the strategic termination of crop growth using herbicides. Desiccation is an established technique to improve the rotational fit, benefits and profitability of pulse crops. Desiccation provides important benefits such as reducing weed seedset, allowing faster harvest and improving grain quality, all leading to improved profitability in pulses. Desiccation prepares the pulse crop for harvesting by removing moisture from plants and late maturing areas of the paddock. Desiccation is an aid to a timely harvest, particularly where uneven ripening occurs across a paddock, and is now a common practice in growing chickpeas. Desiccation enables a timely harvest to avoid weather damage. Application timing is based on the crop when the grain is 75%–90% mature, to avoid reducing the quality of the harvested grain. Windrowing can be similar to desiccation in timing and benefits to harvest, and may be considered as an alternative to desiccation. The timing of windrowing is similar to desiccation. [1]

Desiccating a crop overcomes problems with green weeds at harvest. It also improves harvest efficiency by eliminating many of the problems associated with green stems and gum build-up, such as uneven feeding and drum chokes. Minimising these problems enables drum speeds to be reduced in many cases, with a reduction in cracked or damaged grain. It allows harvesting of a crop that will not naturally shut down due to high soil moisture, stops chickpeas reshooting and reflowering after preharvest rain, and makes crops with uneven maturity more uniform, allowing earlier harvesting. [2]

While desiccation is often not necessary under very hot conditions where the crop is under terminal moisture stress, it can be a very useful harvest management tool in situations where:

- there has been rain during grainfill, and the crop is uneven in maturity. Chickpeas are very indeterminate, and will continue to flower and set up pods late in the season. Crop maturity tends to be very uneven and slow in situations of reasonable moisture supply
- podset has been very uneven due to agronomic factors such as low plant population, poor native budworm management, uneven plant establishment in some deep-sown crops, wheel tracks through crops etc
- there is a problem with actively growing weeds in the crop

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

2 DAFF. Chickpea – harvesting and storage. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/harvesting-and-storage

In these situations, desiccation is a valuable management tool for maximising yield and quality through early harvesting. It also improves harvest efficiency by eliminating many of the problems associated with putting green, sappy plant material through theheader; i.e. uneven intake and drum chokes. Minimising these problems enables drum speeds to be reduced, with less likelihood of cracking grain. [3]

11.2 Croptop, desiccate, harvest or manure?

All pulse growers face the decision between croptopping, desiccation, harvesting or manuring, and their decision is dictated by weed pressures, weed type and the nitrogen demands of the rotation.

11.2.1 When weeds are not the priority

Option 1

Management: natural maturation and grain harvest

Goal: to maximise grain yield and profit while at the same time providing rotational benefits

Method: This is a traditional and widespread practice for cultivating pulses and is based on well-developed agronomy and crop management strategies from sowing through to harvest. This option assumes weeds are fully managed by conventional rotation and herbicides.

Option 2

Management: brown manuring

Goal: to maximise N2 fixation, N-benefit and to conserve soil moisture

Method: The amount of N2 fixed is linked closely to dry matter (DM) production of the legume, therefore 'manure' the weed-free pulse close to its maximum DM.

11.2.2 When weeds are the priority, particularly if herbicide resistance exists

Option 1

Management: brown manuring

Goal: total control of weeds including herbicide resistance, and to fix some N and conserve soil moisture

Method: It is imperative to desiccate the crop at or before the milky dough stage of the targeted weed. This often coincides with the flat pod stage of the pulse, and inevitably falls well short of the crop's peak DM. At this stage the crop is growing at its maximum rate (about 80–100 kg DM/ha/day), so the amount of N fixed will be proportionally reduced according to its growth stage at desiccation. This cost is non-negotiable and essential to ensure complete weed control.

Option 2

Management: crop topping/desiccation followed by grain harvest

Goal: to maximise grain yield and profit while at the same time providing rotational benefits

Method: This is the 'have your cake and eat it' scenario. It is a good option for cleaning up scattered weeds and to eliminate weed seedset in all weedy situations, including herbicide resistance. It uses the conventional approach of grain harvest, plus croptopping/desiccation at the critical growth stage of the weed.

3 Pulse Australia. (2007). Chickpea harvest and seed storage. www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

Timing is critical – it depends on the pulse variety reaching physiological maturity at or before the time of croptopping/desiccation. Most pulse varieties (chickpeas, lupins and kaspa field peas) are unsuitable, as they are too late and lose too much grain yield. [4]

11.3 Timing of desiccation

Chickpea are an indeterminate plant, with flowering commencing in the lower canopy and gradually progressing up the branches (towards the top of the plant) over a 20–30-day period. The problem that growers and agronomists are confronted with is how to maximise yield and quality through the optimal timing of the desiccant spray. This can be difficult when you have various stages of seed maturity present on individual plants as well as variability across the paddock.

The optimal stage to desiccate the crop is when the majority (90–95%) of seeds have reached physiological maturity (when seeds are below 35% moisture content). The best guide at present is to base this on a visual inspection of seeds—by cracking open pods on each main fruiting branch. Maximum harvest yield is normally reached when 75% of seeds on each main fruiting branch have turned totally yellow, and are in various stages of drying down (turning yellow to brown).

Desiccation should occur when:

- pods in the top 25% of the canopy are mainly in the final stages of grainfill; i.e. when the yellow colouring is moving from the 'beak' down through the seed; and
- the bottom 75% of pods should have all reached, or dried down below, this stage of maturity (seeds have turned totally yellow, and the pod has been bleached to a very light green-yellow colour) (Figure 1).

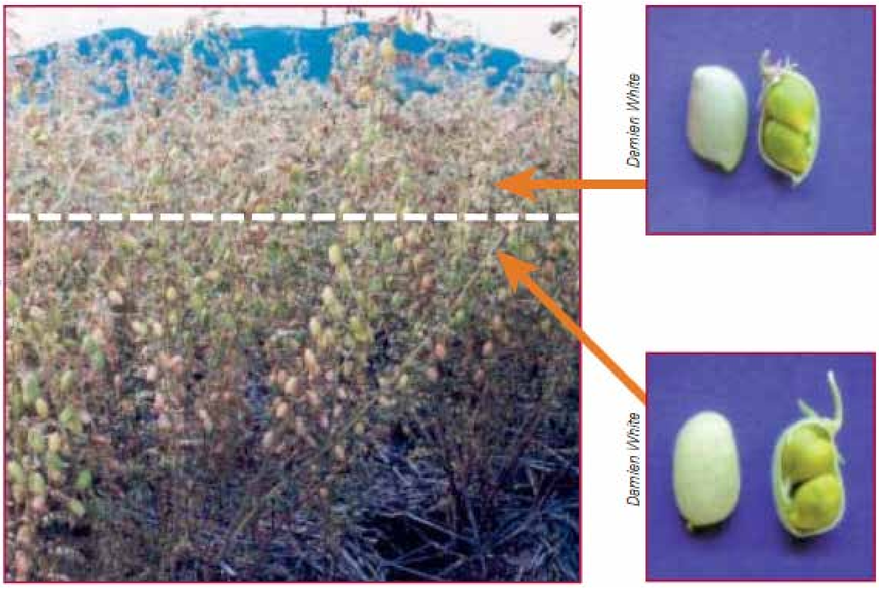

Figure 1: *Chickpea seeds mature progressively from the bottom to the top of the plant.*

Source: Pulse Australia

Monitoring for desiccation timing

Careful monitoring is needed to determine the correct timing for desiccation in both chickpea species. Yield reductions of 10%–20% can occur if applied too early. Quality can also be adversely affected. The optimal stage to desiccate chickpeas is when the vast majority of seeds have reached physiological maturity; i.e. 90–95%

4 Armstrong E. GRDC, (2015). Weigh up the risks, benefits of pulse harvest. Ground cover issue 115 – Profitable pulses and pastures. https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-115-Profitable-pulses-and-pastures/Weigh-up-the-risks-benefits-of-pulse-harvest

of the crop. Inspect the seeds within the upper 20% of pods on each main fruiting branch (Figure 2).

Figure 2: *Correct desiccation timing based on inspection of uppermost pods of each fruiting branch.*

Photo: G. Cumming, Pulse Australia

Seeds are considered to be physiologically mature when the green seed colour begins to lighten—normally when the pod wall begins to yellow The Western Australian recommendation for physiological maturity is 'when the pod wall begins to yellow' (Figure 3, right).

Figure 3: *LEFT: Pods in the top 25% of the canopy should mainly be in the final stages of grainfill, where the yellow colouring is moving from the 'beak' down through the seed. RIGHT: The bottom 75% of pods should have reach maturity. Seeds have turned yellow and the pod has been bleached to a very light, green-yellow*

Photos: G. Cumming, Pulse Australia

To avoid the need to inspect seeds, desiccate when 80–85% of pods within the crop have turned yellow-brown (Figure 4). This is usually too late for the control of ryegrass survivors. [5]

Figure 4: *Full maturity, known as 'rattle pod', where the seed has detached from the pod wall and will rattle when shaken*

Photo: G. Cumming, Pulse Australia

Seed and pod development

Chickpea plants are indeterminate and the period of flowering can extend from 20 to 50 days depending on levels of flower abortion and the impact of moisture stress on the plant. Causes of flower abortion and poor podset have been discussed previously and they include:

- low mean daily temperature (below 15°C)
- frost
- Botrytis grey mould
- extended periods of overcast weather

Flowering commences on the main stem and basal branches, and proceeds upward at intervals of ~2 days between successive nodes on each fruiting branch.

Under favourable conditions, the time taken from flowering to the visual appearance of the pod (podset) is ~6 days. After podset, the pod wall grows rapidly for the next 10–15 days to assume full pod size. The seeds start to develop at about the same time as the growth of the pod wall ceases.

Seed growth occurs over the next 20 days. Pod and seed maturation is also very staggered along each fruiting branch, although it is generally more compressed and of shorter duration than flowering due to the effects of higher temperatures and varying degrees of moisture stress on the plant. The problem faced by agronomists and growers in a commercial paddock situation is how to optimise the timing of the desiccant spray when there are various stages of seed maturity present on individual plants, as well as variation across the paddock. This can be compounded by variation in soil type or paddock micro-relief, adding to the problem of uneven crop maturity. Some agronomists use a rule of thumb that when 90% of the field is 90% mature, they will advise growers to spray it out. Alternatively, when larger areas are involved, they may split soil types and test them separately for desiccation timing. Often, inspection of commercial crops nearing desiccation reveals that while the lower 30% of pods have dried to below 15% seed moisture (seeds detached from pod and rattle when shaken—see Figure 4), the upper 30% of pods on each fruiting branch are still at 30–40% moisture content and in varying stages approaching physiological maturity. [6]

5 Pulse Australia. Australian Pulse Bulletin: Desiccation and croptopping in pulses PA 2010 #14. http://www.pulseaus.com.au/growing-pulses/publications/desiccation-and-croptopping

6 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

Effect of desiccants on immature seeds

Desiccants should not be applied too early, as they can affect green seeds. The result can be a reduction in grain size and yield, an increase in immature seeds, an increase in greenish discolouration of the seed coat, and a reduction in seed viability (Table 1).

Table 1: *Effects of desiccation timing on seed viability.*

Trial and treatment	Crop stage	Normal seed (%)	Abnormal seed (%)	Dead seed (%)
None	Mature pods	87	9	4
Roundup®	Mature pods	84	14	2
Ally® & Roundup®	Mature pods	85	13	2
Ally® & Roundup®	Mature pods	76	20	4
Ally® & Roundup®	70% green pods	15	63	22
Ally® & Roundup®	All green pods	22	60	18

Source: Qld DPI (1999)

11.3.1 Products for the desiccation of chickpea

1. Reglone® is registered at 2–3 L/ha
2. Reglone® provides quick leaf drydown, but the chickpea plant and weeds can quickly regrow if moisture is available.
3. Roundup PowerMAX® is the only glyphosate registered for chickpea desiccation.
4. For chickpea desiccation: Roundup PowerMAX® at 0.68 to 1.8 L/ha.
5. For additional weed and chickpea desiccation: Roundup MAX® at 0.5 to 1.1 L/ha plus Ally® at 5 g/ha.
6. Roundup PowerMAX® and Roundup PowerMAX®/Ally® will kill the plants reducing the likelihood of regrowth. [7]

Table 2 lists options available to growers for desiccating chickpeas.

7 Pulse Australia. (2007). Chickpea harvest and seed storage. www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

Table 2: *The following table details the registered herbicides for use when croptopping or desiccating pulses. It is imperative that only registered products are used at label rates. Exceeding maximum label rates will lead to the detection of chemical residues in excess of the allowable Maximum Residue Level (MRL) jeopardising market access and the future of the Australian grains industry.*

Herbicide	Example trade names	Operation	Crop	Rate	Withholding period
Diquat 200 g/L	Reglone®	Desiccation	Chickpea, faba bean, dry pea, lentil, lupin, mungbean	2 to 3 L/ha	Grazing/stockfeed (GSF): 1 day Harvest: 0 days (lupin, dry pea) 2 days (chickpea, lentil, faba bean)
Paraquat 250 g/L	Gramoxone®	Croptopping	Chickpea, faba bean, field pea, lentil, lupin, vetch	400 to 800 mL/ha	GSF: 1 day (7 days for horses) Stock must be removed from treated areas 3 days before slaughter Harvest: 7 days
Glyphosate 480 g/L	Ripper 480®	Croptopping	Faba bean, field pea	360 to 765 mL/ha	GSF: 7 days Harvest: 7 days
		Desiccation	Chickpea, faba bean, field pea, lentil, mungbean	765 mL to 2.025 L/ha	GSF: 7 days Harvest: 7 days
Glyphosate 500 g/L	Touchdown Hi Tech®	Croptopping	Faba bean, field pea	300 to 700 mL/ha	GSF: 7 days Harvest: 7 days
Glyphosate 540 g/L	Roundup PowerMAX®	Croptopping	Faba bean, field pea	320 to 680 mL/ha	GSF: 7 days Harvest: 7 days
		Desiccation	Chickpea, faba bean, field pea, lentil, mungbean	680 mL/ha to 1.8 L/ha	GSF:7 days Harvest: 7 days
Metsulfuron + Glyphosate 540 g/L	Ally® + Roundup PowerMAX®	Desiccation + knockdown weed control	Chickpea	5 g + 500 mL to 1.1 L/ha	GSF: 7 days Harvest: 7 days
Saflufenacil	Sharpen	Desiccation	Field pea, faba/ broad bean, chickpea, lentil, lupin	34 g/ha plus recommended label rate of glyphosate or paraquat herbicide plus 1 % Hasten or high quality MSO	GSF: 7 days Harvest: 7 days

GSF - Withholding period for grazing or cutting for stock food

Note: Observe the Harvest Withholding Period and GSF for each crop.

Glyphosate is not registered for seed crops and should not be used in pulses intended for seed production or sprouting.

Source: Pulse Australia

MORE INFORMATION

Paraquat for crop-topping pulses

Stay up to date with APVMA registered products.

Paraquat is registered for crop-topping; however, may not be effective on grass seed-set as chickpeas mature quite late.

The major differences between timing of desiccation and croptopping are:

- application timing is different and initiated by different criteria
- herbicides for croptopping and desiccation are not always the same
- herbicide rates for desiccation are higher than that required for croptopping
- croptopping will advance the harvest timing in some pulse crops
- neither desiccation nor croptopping can be used effectively in all pulses

- both will cause reduced grain quality and yield if applied at the wrong maturity stage of the crop [8]

NOTE: Desiccation can affect seed viability if applied incorrectly. To avoid damaging seed viability, it is advisable not to desiccate or croptop a pulse *seed* crop.

11.4 Croptopping

Croptopping is timed to prevent weed seed-set, not by the crop growth stage. Hence, croptopping is generally not possible in chickpea, as they are too late in maturing. Croptopping chickpeas can result in discoloured cotyledons (kernel) and seed coats, leading to rejection at delivery and/or severe downgrading. Even in other pulses, growers need to be aware of grain quality defects if crop-topping is done earlier than the crop desiccation or windrowing stage.

Genesis™ 079 is the earliest maturing chickpea variety, but in most cases, it will not mature early enough to enable efficient croptopping without grain quality impacts. Evidence of the lack of suitability of crop-topping in chickpea is provided in Table 3, from a South Australian Research and Development Institute crop-topping trial at Melton, South Australia, in 2009. Visual grain quality data are not presented, but in this trial:

- Many responses to crop-topping treatments may have been masked by rapid senescence from a rapid, early seasonal finish (e.g. ALMAZ and Genesis™ 114).
- When croptopped at the recommended stage, yields were 69–86% of the untreated control (31–14% yield loss). When croptopped 2 weeks after the optimum stage for ryegrass, yields were 92–114% of the untreated control. When croptopping was 3 weeks ahead of the recommended ryegrass stage, yields were 17–48% of the untreated control (83–52% yield loss). [9]

Table 3: *Impact of crop-topping timing on chickpea varieties of differing maturity compared with an untreated control at Melton, South Australia, 2009 Pink shading denotes significant difference from the control treatment.*

	Control yield (t/ha)	Yield (% of control) for each timing			Control grain weight (g/100 seeds)	Grain weight (% of control) for each timing		
		Minus 3 weeks (9 Oct.)	Recommended (30 Oct.)	Plus 2 weeks (12 Nov.)		Minus 3 weeks (9 Oct.)	Recommended (30 Oct.)	Plus 2 weeks (12 Nov.)
Almaz⍉	1.18	19	83	92	27.4	91	92	91
PBA Slasher⍉	1.96	30	70	99	15.5	87	84	100
PBA HatTrick⍉	1.37	36	69	85	18.1	77	81	93
Genesis™ 079	2.09	25	80	107	18.0	95	104	104
Genesis™ 090	1.43	25	84	97	22.1	79	93	93
Genesis™ 114	0.90	17	86	114	22.1	96	102	104
Genesis™ 509	1.96	32	71	96	13.6	129	101	94
Howzat⍉	1.70	21	72	94	16.6	87	87	117
Sonali	2.13	40	77	104	14.5	96	80	101
Mean (t/ha)	1.90	0.6	1.5	1.90	18.6	16.3	15.9	18.2
Mean (g/100)					18.6	16.3	15.9	18.2

Source: M Lines and L McMurray (SARDI), Southern Pulse Agronomy Research trials

8 Pulse Australia. Australian Pulse Bulletin: Desiccation and croptopping in pulses PA 2010 #14. http://www.pulseaus.com.au/growing-pulses/publications/desiccation-and-croptopping

9 Pulse Australia (2015) Desiccation and crop-topping in pulses. Pulse Australia, Australian Pulse Bulletin, http://www.pulseaus.com.au/growing-pulses/publications/desiccation-and-croptopping

Harvest

Key messages

- Greatly improved crop management and harvest timing has meant that chickpea can be harvested earlier with associated yield and marketing benefits. The tradition of delaying the harvest of chickpea until after wheat can result in considerable chickpea losses.
- If harvesting grain for seed, germination rates are improved if grain is harvested at 12–14% and then stored in aerated silos or immediately graded and bagged.
- Early, or timely, harvest of the chickpea crop has the potential to increase returns by up to 50% (Figure 1).
- Clean headers and sowing equipment to remove grain, soil and stubble before moving from property to property to avoid disease and weed spread. Spray rigs should also be cleaned to reduce the risk of disease transmission. [1]
- During harvest, chickpea can produce a dust that is quite flammable, so make sure headers are blown down frequently to avoid a fire risk.

Figure 1: *Chickpea harvest under way.*

Photo: R. Bowman, Seedbed Media

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

Paddock selection for a happy harvest

Planning before and during sowing can reduce many harvest difficulties. Paddock selection will determine the risk of disease, waterlogging, weeds and poor establishment, ultimately influencing crop maturity. Sowing method and row spacing will affect evenness, crop height and lodging potential. All of these factors can affect the ease and timeliness of harvest. [2]

Agronomist's view

12.1 Windrowing

Windrowing (or swathing) at early or late maturity stages has been found to decrease seed yield, weight per seed and harvest index compared to direct combine practices. Seeds from the windrow treatments have been found to have high percentages of green and shrivelled seeds with high levels of fungal colonisation. Both seed and straw from windrowing have been found to have poor feeding quality measured as neutral detergent fibre, acid detergent fibre, and organic matter content and digestibility. [3]

Windrowing of chickpeas is possible, but not widely used because there is little or no stubble for the windrow to sit on compared with, for example, canola. Losses at harvest may be greater, and more dirt may enter the grain sample. Light windrows can be blown away in strong winds.

Despite this, provided the windrows are large enough and compacted, windrowing is possible. It may also be possible to place two swathes into the one windrow and compact it with a cotton reel roller when windrowing. Harvesting time can therefore be improved.

In chickpeas, windrowing or desiccation can occur when less than 20% of pods are green and 90% of seed is changing from a green colour. The main advantages of windrowing are earlier harvest, reduced seed damage and less shattering or pod loss, particularly if harvest is delayed. Pod loss and shatter are reduced because windrowers allow unhindered passage onto the canvas due to the absence of platform augers. Lower harvesting heights may also be possible. Windrowing helps to dry out green broadleaf weeds, such as radish, which can cause major problems at harvest.

Windrowing also reduces damage to headers. Use of headers in rougher country can damage knife fingers and sections, retractable fingers and other components, because of sticks and stones. Pick-up fronts leave most of these on the ground. The cutting height for windrowing should be just below the bottom pods, with the reel following the top of the crop. The reel speed should be quite slow. The delivery opening in the windrower should be large enough to prevent blockages; otherwise, there will be lumps in the windrow. Windrows should be dense and tightly knit for best results.

Curing should take about 10 hot days. However, heavy infestations of radish and other weeds could delay drying. Pick-up fronts are the most common type used for harvesting windrows. However, crop lifters placed close together on open fronts have been used with some success. [4]

2 DAFF (2012) Chickpea—harvesting and storage. Department of Agriculture, Fisheries and Forestry Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/harvesting-and-storage

3 Y Gan, AD Iwaasa, MR Fernandez, R McVicar (2008) Optimizing harvest schemes to improve yield and feeding quality in chickpea. Canadian Journal of Plant Science, 88(2), 275-284.

4 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013.

12.2 Harvest timing

Chickpea harvest can often clash with wheat harvest, and traditionally wheat has been given priority due to potential quality premiums. However, this thinking needs to be balanced against the relatively higher value and potential losses that can result from a late chickpea harvest. Agronomists report that many growers consider losses in chickpeas will generally be less than in cereals. However, yield losses increase significantly the longer harvest is delayed.

Chickpeas should be harvested as soon as they mature (Figure 2), as pods will fall if harvest is delayed. [5] Crop desiccation enables even earlier harvest. [6]

Figure 2: *Mature chickpea plant.*

Source: The Land

Harvesting early also minimises infection of seed. Diseases can be transmitted in stubble and soil, and on machinery and boots. Soil and stubble can be moved by machinery, during windy or wet weather, and in floodwater. To reduce the transmission of diseases, clean headers, sowing equipment and spray rigs to remove grain, soil and stubble before moving from property to property. [7]

Harvest timing will depend on the moisture content that is acceptable for delivery or storage. This will depend on who is buying the grain, or whether aeration is available in the storage. Harvesters should be set up to operate efficiently at 14–15% grain MC. This effectively doubles the harvest period available on any one day compared to harvesting at 12%. Research has shown that average harvest losses increased as harvest was delayed (and seed moisture decreased). [8]

The maximum moisture for chickpeas is 14% for grower receivals. Harvesting grain at 13–15% moisture content will help to minimise cracking. Above 14% moisture, the crop should be either aerated or dried. Aeration is usually very effective in reducing chickpea moisture content by several percentage points. [9]

Harvesting at moisture levels below the receival standard of 14% can be costly. Moisture content decreases with late harvest (Table 1). [10] Delaying harvest from 14% MC to 8% MC for a 500 tonne crop equates to a 32 tonne weight reduction, and a

5 GRDC (2008) Harvesting. In Grain Legume Handbook. GRDC, http://www.grdc.com.au/uploads/documents/9%20Harvesting.pdf

6 GRDC (2013) Chickpea disease management (southern and northern regions). Fact sheet. GRDC, http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management

7 GRDC (2013) Chickpea disease management (southern and northern regions). Fact sheet. GRDC, http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management

8 B O'Mara, S Belfield, G Cumming (2007) Chickpea harvest and seed storage. Pulse Australia, http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

9 DAF Queensland (2012) Chickpea—harvesting and storage. Department of Agriculture and Fisheries Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/harvesting-and-storage

10 B O'Mara, S Belfield, G Cumming (2007) Chickpea harvest and seed storage. Pulse Australia, http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

loss of $17,500 (at $550/t). This is in addition to any harvest losses that occur due to low moisture at harvesting. Pulse Australia has calculated the economic losses caused by loss of moisture below the Grain Trade Australia (GTA) receival standard of 14% moisture content (MC) maximum.

- 500 t of chickpea at 14% grain moisture, at $450/t, is worth $225,000.
- The same grain harvested at 8% moisture delivers 470 t, at $450/t, and is worth $210,600.
- This is a loss to the grower of $14,400. [11]

Table 1: *Yield and moisture loss with delayed harvest.*

Harvest timing	Average moisture	Harvest loss
On time	12.7	10%
Late	10.3	23%

Source: Pulse Australia

Note: Crops intended for seed are best harvested at 14–16% MC and dried or aerated back to 12% to maximise both germination and vigour when held in storage. [12]

Yield losses of up to 30% have been recorded in the field, due to delayed harvest (Figure 3). Grain losses due to a 2–4 week delay in harvest were estimated at A$93–238/ha, depending on seasonal conditions. In this instance, most of these losses were due to pod loss at the header front, or unthreshed pods discarded out of the back of the machine.

In most years, chickpea yields can average ~70% of wheat yields when sown in an identical situation. The use of specialised headers and separate storage facilities for chickpeas may alleviate the competition with wheat for time, labour and equipment usage.

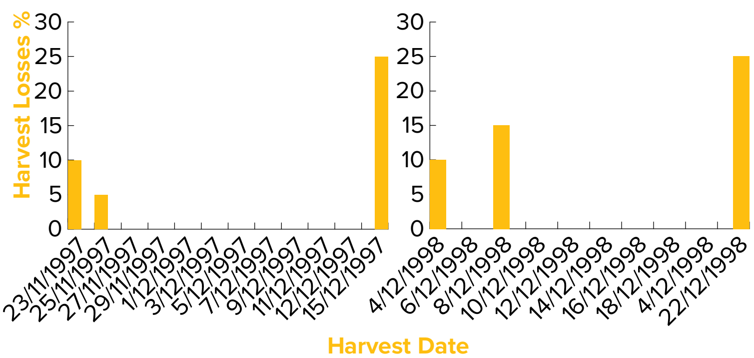

Figure 3: *Harvest yield losses in 1997 (left) and 1998 (right).*

Source: Pulse Australia

Although not normally prone to pod splitting and shelling-out in all but extreme wet-weather conditions, chickpeas are very prone to pod-drop as the plant dries down. Prolonged weathering in the field weakens the hinge attaching the pod to the stalk, thus increasing pod-drop both before and at harvest, and causing drops in yield.

Lodging is increasingly likely the longer chickpeas are left in the field. The risk is higher if the crop is high yielding and has been planted on wide rows of 70–100 cm.

11 Pulse Australia (2013) Northern Chickpea—Best Management Practices Training Course Manual 2013. Pulse Australia.

12 B O'Mara, S Belfield, G Cumming (2007) Chickpea harvest and seed storage. Pulse Australia, http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

Increased storage is helping farmers to manage losses, and in some instances, reduce freight and handling costs where direct transport of grain to the end-user is possible.

NOTE: Crops intended for seed are best harvested at 14-16% moisture and dried or aerated back to 12% moisture to maximise both germination and vigour when held in storage. [13]

12.2.1 Major losses from late harvest include:

Major losses incurred by harvesting chickpeas late include loss of yield, loss of quality, greater likelihood of disease and insect damage to pods and seeds, and loss of markets.

Loss of yield

- Losses due to pod drop can be severe as weathering weakens the hinge attaching the pod to the stem.
- Weathered pods become more difficult to thresh, resulting in grain loss from unthreshed pods passing out the back of the header, increased cracked grains and a slower harvest.
- Increased lodging, especially in higher yielding crops that are planted on wide rows.
- Harvesting at 8% moisture instead of 14% results in a harvest loss.
- Farmer experience has shown yield losses of up to 30% if harvest is delayed 2–4 weeks.

Loss of quality

- Weathered or very dry grain is more likely to crack when handled, increasing the amount of split grain in the sample. Levels of cracked and damaged grain can be as high as 50% in extreme cases of weathering and prolonged rainfall.
- The number of unthreshed pods in the sample will increase, as they become harder to thresh with weathering.
- NOTE: Both of the above can result in rejection or the need for grading to meet market requirements.
- The germination rate and vigour of planting seed will be reduced by weathering.
- Chickpea grain discolours and darkens with weathering, reducing its marketability, particularly in the container market. The following conditions play a major role in accelerating seed coat darkening (Figure 4):
    - » rainfall
    - » cool-mild temperatures
    - » high humidity
- Although there is usually no direct penalty or discount for a moderate degree of seed coat darkening, it does have a significant impact on the marketability of the product and the reputation of the Australian industry as a supplier of quality product. Quality is becoming increasingly important as Australian traders attempt to establish market share against other chickpea-exporting countries (Canada, Turkey, Mexico). We will likely see much greater segregation and premiums paid for lighter coloured, large-seeded Desi types as new varieties with these traits are developed and the Australian industry becomes more quality conscious.

13 Pulse Australia Ltd (2007) Chickpea harvest and seed storage. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

Figure 4: *Pistol chickpea showing grain discolouration due to weathering.*

Photo: Jenny Wood. Source: NSW DPI

NOTE: Chickpeas that do not meet the Export Receival Standard of 6% maximum 'defective' chickpeas will need to be graded. This incurs a grading cost to the grower of $15–25/t. Downgrading into the stockfeed market results in a value of $120–140/t.

Increased disease and insect risk to pods and seed

- Weathering of seed due to delays in harvest can greatly increase levels of mould infections. High levels of mould infection will also cause darkening of the seed coat.
- Humid (>70% relative humidity), wet conditions favour the development of a range of fungi in late-harvested chickpea crops. *Alternaria spp.* usually predominate, species of Asperguillus, Cladosporium and Penicillium may also be present.
- There is increased risk of late infection by the Ascochyta blight fungus on pods. Ascochyta can infect senescing pods under wet conditions, leading to infected and discoloured seed (and possible rejection). The current Export Receival Standard for visible Ascochyta blight lesions is a maximum of 1% on the seed cotyledon (kernel).
- Native budworm (*Helicoverpa punctigera*) can cause damage to mature seeds. Larvae can occasionally attack senescing chickpeas, particularly where rainfall has softened the pod. Insect-damaged seeds are classified as defective chickpeas, and they cannot exceed the tolerance level of 6%.

Lost marketing opportunities

- Chickpea prices can reach peaks during harvest to meet shipping schedules. Earlier harvesting may allow access to these opportunities.

- Early harvest gives the grower some control over how and when the crop is marketed, whereas late-harvested chickpeas can be 'price-takers' in a falling market.
- Darker, weathered seed may be discriminated against in the market.

Harvest delays in chickpeas cost growers and the pulse industry a lot of money. In any production area, a spread of up to 4–6 weeks can occur in the harvesting of chickpea crops planted on the same sowing rain. Many of the late-harvested crops often have moisture content down to ~8%, whereas the maximum moisture content for receival is 14% and the preference is for 12%. [14]

12.2.2 Planning for early harvest

Early, or timely, harvest of the chickpea crop has the potential to increase returns by up to 50%. Management to ensure even crop maturity and timely harvest consists of a combination of factors including:

- paddock selection and agronomy
- disease and insect control
- desiccation
- harvest timing and technique
- handling and storage [15]

A range of management components contributes to an early crop. They can all be important at different times and for different reasons. It is important to understand the potential and limitations of each management component. Optimal results in terms of yield, profit and earliness will be due to these components being applied in the most appropriate and balanced way, and as dictated by seasonal conditions. These components include:

1. Planting

- Sow at the earliest opportunity within the preferred planting window for your area. Moisture-seeking equipment and/or press wheels can significantly enhance seeding opportunities under marginal conditions.
- Select adapted varieties that meet your target for early harvesting.
- Using precision planters will often achieve more uniform plant establishment and crop development and, consequently, more even crop maturity. Precision planters are not widely used in the south and west but there is growing interest in them.

2. In-crop management

- Control Botrytis grey mould if present during flowering.
- Control native budworm during flowering to maximise early pod set.
- Avoid using herbicides that delay crop maturity, such as flumetsulam (e.g. Broadstrike®).

3. Harvest management

- Consider using Roundup UltraMAX® and Ally® (or equivalent registered products) to terminate the crop at 80–90% yellow–brown pod stage.
- Set the header up to operate efficiently at 14–15% grain moisture content.
- A major advantage of high-moisture harvesting is that harvest can commence earlier in the season and earlier each day.
- Harvesting at 14% moisture content, compared with 12%, can effectively double the harvest period available on any one day.
- Blend, aerate and/or dry the sample to the required receival standard of 14% moisture. [16]

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14 Pulse Australia Ltd (2013) Northern chickpea best management practices training course—2013.

15 Pulse Australia Ltd (2007) Chickpea harvest and seed storage, http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

16 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013.

12.3 Header modifications and settings

Early harvesting means that plants can be easier to gather because they stand more erect, allowing the harvester front to operate at a greater height which reduces the risk of soil, rock and sticks entering the harvester. Early harvesting also means there are fewer summer weeds to clog the harvester. Grain loss can be reduced by harvesting in high humidity—at night if necessary—to minimise pod shattering. Avoid reaping in extreme heat. [17] Chickpeas can be harvested with minor adjustments and modifications to equipment. Open-front or pick-up fronts are best suited to the job. Pulses are easily threshed, so concave clearances should be opened and the drum speed reduced. The crop varies in height from 15–80 cm, with pods held up in the canopy, so direct heading without crop lifters is possible with open-front and closed-front machines. Some fingers may have to be removed when using closed-front machines. Chickpeas thresh easily but are prone to cracking, particularly Kabuli types, so adjust thresher speed (400–600 rpm) and concave (10–30 mm) to suit (Table 2). Because chickpeas are destined for human consumption, a good sample off the header is usually required. [18]

Table 2: *Harvester settings for pulses.*

Reel speed	Spiral clearance	Thresher speed	Concave clearance	Fan speed	Top sieve	Bottom sieve	Rotor speed
Medium	High	400–600 rpm	10-30 mm	High	32 mm	16 mm	700–900 rpm

Source: Grain Legume Handbook

A straw chopper may be of value to chop up the stubble and spread it uniformly. Crop lifters are not usually required unless the crop is badly lodged. Set the finger-tine reel to force the chickpea material down onto the front. Moving the broad elevator auger forward can improve the feeding of light chickpea material. Vibration from cutter-bar action, plant-on-plant or reel-on-crop impact, and poor removal of cut material by the auger all cause shattering and grain loss. 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 (Figure 5). [19]

17 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013.

18 GRDC (2008) Grain Legume Handbook.

19 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013.

Figure 5: *Finger guard.*

Source: Grain Legume Handbook

Options to improve harvest:

- Vibra-mat. A vinyl mat that vibrates with the knife, stops bunching at the knife of open-front headers and helps the table auger to clear-cut materials. This device is very cheap. It is more effective in light crops. It is important to match ground speed to table auger capacity and crop density: too slow and the plants will not have enough momentum to carry to the front; too fast and the cut crop will not be cleared from behind the knife.
- Extension fingers. (Figure 6) Plastic extension fingers ~30 cm long that fit over existing fingers can save significant losses, for little financial outlay, at the knife. Pods that would have fallen in front of the knife are caught on the fingers and pushed into the comb by the incoming crop.
- Extended fronts. Now available for some headers. They reduce losses at the knife by increasing the distance between the knife and auger to a maximum of 760 mm. This helps to stop material bunching in front of the auger, where pods can fall over the knife and be lost.
- Platform sweeps. Used in conjunction with extended fronts. They consist of fingers that rake material towards the auger to help eliminate bunching. They can also be used on conventional fronts.

Note that cost benefits must be assessed; a small area of pulses may not justify the cost of some of the above modifications. [20]

20 Grain Legume Handbook Committee (2008) 'Grain legume handbook.' Supported by the Grains Research and Development Corporation (GRDC), https://grdc.com.au/uploads/documents/Index.pdf

Figure 6: *Plastic extension fingers fitted to a draper front.*

Photos: G. Cumming, Pulse Australia

12.3.1 Draper Fronts

Draper fronts (i.e. MacDon or Honeybee) have become increasingly popular. The centre feed draper platform provides uniform crop flow into the header, with minimal crop loss, and little damage to the seed. The cutter bar design allows for both vertical and end table flotation. While their contour following ability is not quite as good as a floating cutter bar, they have performed very well, provided the paddock is relatively level. Operators claim they can be operated at higher travel speeds than a conventional front in chickpea.

12.3.2 Preferred Air Front Setups

Air fronts help to reduce shattering losses, and minimise the amount of soil and other debris (stubble, sticks) in the final sample. Where soil contamination is likely to be a problem, fit perforated screens to replace the feeder-house floor and elevator doors, and clean the grain cross augers. Twin blowers may be necessary on fronts wider than 7.6 m. [21]

- Harvest-Aire or other air fronts are generally considered better than batt reels as they minimise the risk of pods detaching from the plant.
- They also improve feed in over the knife section, and reduce soil and stubble contamination and allow the operator a clearer view of the cutting platform, and any rocks or sticks in the paddock. Adjustment of the angle and height of the air nozzles is critical, and may need adjustment as crop conditions change.
- Fit a Vibra-Mat to improve the flow of material over the knife-section and along the platform. They are relatively cheap with a low maintenance cost.
- Fit cast, short crop fingers. If using a closed front the fingers will need to be spaced 19 mm or more apart.
- Fitting double density Kwik-cut knife guards will help reduce plant 'vibration' and the risk of pods detaching from the plant. This method may be unsuitable if there are a lot of green weeds in crops that are not desiccated causing blockages.
- Check that the header front is level, and not higher at one end than the other. Set the knife at the correct angle for short crops, and install a simple depth gauge.
- In crops with a short height to lowest pod, soil contamination is likely to be a problem, so it is advisable to fit perforated screens under the platform auger and/or broad elevator. Fit screens to repeat and clean-grain cross augers.

21 DAFF (2012) Chickpea—harvesting and storage. Department of Agriculture, Fisheries and Forestry Queensland, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/harvesting-and-storage

- Floating or flexible cutter bars can be useful in short crops.

12.3.3 Conventional Headers

- Aim to harvest at 300–500 rpm where possible to minimise cracking. Adjust upwards if 'jamming' occurs in crops that are not desiccated.
- Concave clearance 10–30 mm depending on seed size. Check the concave for uneven clearance. Standard concaves tend to bow in the centre when fully loaded, and may need strengthening or replacement (i.e. with a 'Loewen' concave). Removing alternate wires and the blank-off plates from the concave will also help reduce cracking. If possible cover the rasp bars with plate.
- Beater: Reduce speed to 100% of drum speed. Wheat is usually set at 150%.
- Set fan speed at 80–100% of maximum. The relatively heavy weight of individual chickpea grains allows the use of high air flow. [22]

12.3.4 Sieves

An alternative to the barley sieve is a mesh sieve made using 18 mm tubing for the frame and 1 cm by 1 cm, 14-gauge wire mesh. This screen increases capacity because the whole area is able to sieve. If there are summer weeds, the rake at the back of the sieves should be blanked-off to stop them entering the returns. Summer weeds may cause walkers and sieves to block completely, causing high grain loss. [23]

Set sieves to suit the grain size of the chickpea being harvested. This is more critical than for wheat:

- Top sieve 20–25 mm—a B & D Airfoil non-adjustable top sieve is reported to work well in chickpeas, and increases overall sieving capacity.
- Bottom sieve 12–16 mm—the bottom sieves can be altered so that the front 400 mm can be adjusted separately to the rear section. This allows the front section to be left open, and more air can be directed onto the top sieve if required.

12.3.5 Header Speeds

Relatively slow ground speeds are considered essential when harvesting chickpea to minimise excessive losses at the front of the header and the amount of dirt entering the machine.

- A maximum speed of 8 km per hour is recommended.
- If using a batt reel, it should be set at the same speed as the header. [24]

12.4 Getting a clean sample

Harvesting of chickpeas can be costly if stones, sticks or too much soil are picked up with the chickpeas. Machinery damage can be reduced by a variety of practices.

12.4.1 Perforated screens

Perforated screens fitted on the bottom of the broad elevator, cross augers, grain and seconds elevators all reduce the amount of soil in the sample. The perforated screen at the broad elevator is large and removes soil before it enters the main working mechanism of the harvester.

22 Pulse Australia Ltd (2007) Chickpea harvest and seed storage. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

23 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013.

24 Pulse Australia Ltd (2007) Chickpea harvest and seed storage. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

12.4.2 Harvester speed

Excessive harvester speeds will cause large losses of grain and force more soil into the harvester. Generally, speeds >8 km/h are not recommended, irrespective of the type of harvester front used.

12.4.3 Harvesting in high humidity

Harvesting in humid conditions, when pods are less prone to shatter, can reduce grain losses. However, more unthreshed pods may appear in the grain sample. It is unwise to harvest peas at night unless using a pick-up front or some positive height control, which will stop the front from digging into the soil. Some farmers have fitted wheels on the outer end of their fronts as a depth stop. Others have purchased ultrasonic automatic depth controls to control header height.

12.4.4 Pick-up fronts

Pick-up fronts that are the same as, or similar to, those used for picking up windrows can be used to harvest windrowed chickpeas. Pick-up fronts greatly reduce the amount of soil entering the harvester and make harvesting easier because harvesting height is not as critical as with a front fitted with lifters. This allows harvesting at night. The fingers on the pick-ups are closely spaced and they will gather the entire crop, so crop losses are reduced.

There are different types of pick-ups. Some have fingers attached to rotating belts (draper pick-ups) and others have fingers attached to rotating drums (peg-roller pick-ups). The pegroller types are similar and cheap but tend to shatter pods and cause slightly higher grain losses than the draper type. The draper types are more expensive but will reduce losses if harvesting late.

12.4.5 Flexible cutter-bar fronts (flexi-fronts)

The cutter-bars of these fronts are hinged in short sections, allowing the whole front to flex and closely follow the ground contour. They use skid plates and are particularly good for short crops such as lentils and peas, but can also be used on cereals by locking the hinged sections together. [25]

12.4.6 Lodged crops

If the crop has lodged, the best option is usually to harvest directly into, or at right angles to, the direction the crop has fallen. If on wide rows, use crop lifters and harvest up and back in the rows. The crop usually feeds in better over the knife section, and also provides the header operator with a better view of any rocks or sticks in the paddock. [26]

12.5 Fire prevention

Growers must take precautions during the harvest season, as operating machinery in extreme fire conditions is dangerous. They should take all possible measures to minimise the risk of fire. Fires are regularly experienced during harvest in stubble as well as standing crops. The main cause is hot machinery combining with combustible material. This is exacerbated on hot, dry, windy days. Seasonal conditions can also contribute to lower moisture content in grain and therefore a greater risk of fires.

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.

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25 Grain Legume Handbook Committee (2008) 'Grain legume handbook.' Supported by the Grains Research and Development Corporation (GRDC), https://grdc.com.au/uploads/documents/Index.pdf

26 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013.

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.
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. [27]

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.

27 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

Keep machinery clean and as free from fine debris as possible, as this can reduce on board ignitions. [28]

With research showing an average of 12 harvesters burnt to the ground every year in Australia (Figure 7), agricultural engineers encourage care in keeping headers clean to reduce the potential for crop and machinery losses.

Key findings:

- Most harvester fires start in the engine or engine bay.
- Other fires are caused by failed bearings, brakes and electricals, and rock strikes. [29]

Figure 7: *GRDC figures show that there are 1000 combine harvester fires in Australia each year.*

Source: Weekly Times

12.5.1 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 8).

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.

28 NSW Rural fire Service. Farm firewise. NSW Government, http://www.rfs.nsw.gov.au/dsp_content.cfm?cat_id=1161

29 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

PODCAST

GRDC Podcasts: Harvester Fires.

MORE INFORMATION

GRDC Reducing Harvester Fire Risk: The Back Pocket Guide

An investigation into harvester fires

Plan of attack needed for harvester fires

MORE INFORMATION

Standards and charts to check visual quality of desi chickpeas are available from Pulse Australia

Australian Pulse Standards 2016–2017

Desi chickpea sample chart of visual standards

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 8: *Grassland fire danger index guide.*

Source: CFS South Australia

12.6 Receival standards

National receival standards for chickpea are set by the pulse industry and maintained by Pulse Australia. Receival and export standards reflect the market requirements for a quality food product. Desi chickpeas should be sound, dry, fresh and light to medium brown in colour, although a greenish tinge is allowed (see Tables 3 and 4). Kabuli chickpeas should be sound, dry, fresh and cream to light brown in colour.

Failure to achieve these receival standards may mean price discounts, re-cleaning or, if severe, market rejection.

Table 3: *Example of visual charts designed to be used as a guide in conjunction with the current Australian Pulse Trading Standards.*

Defect	Visual examples of defective chickpeas
Frost damaged, shrivelled and wrinkled	
Broken, chipped, loose seed coat, and split.	
Insect damaged, and sprouted.	
Hail damaged	

Source: Pulse Australia

Definitions:

- *Defective grains:* includes max 2% field peas (in Desi), 2% poor coloured grains, broken, damaged and split, shrivelled, distorted, grub eaten, sprouted and affected by mould in the paddock.
- *Poor colour:* if cotyledon is distinctly blemished and/or off colour from the characteristic yellow colour of the predominate class, including the 1% visible Ascochyta.
- *Foreign material:* includes unmillable material and all foreign vegetable matter (includes cereals, wild oats, oilseeds, other legumes and weed seeds not otherwise specified).
- *Unmillable material:* includes soil, stones, metal and non-vegetable matter.

Table 4: *Receival standards for Desi and Kabuli chickpea.*

Chickpea type	Max. moisture content (%)	Min. purity (%)	Max. defective & poor colour	Screen size for defective seeds (mm)	Poor colour max. (%)	Foreign material max. in total (%)	Unmillable material max.	Snails max.	Insects max.
Desi	14	97	6	3.95 slotted	2% (but 1% Ascochyta)	3	0.5 (0.3% soil)	1 per 200 g	15 per 200 g
Kabuli	14	97	3	6 round	2% (but 1% Ascochyta)	3	0.5 (0.3% soil)	2 per 400 g	30 per 400 g

Source: Pulse Australia

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.

12.7 Harvest weed seed management

Targeting weed seed has been identified as a key strategy in controlling resistant annual weed populations. The control of these populations is a numbers game and weed seed removal is an excellent strategy that can be used to keep the numbers low. A number of techniques can be used to destroy/remove at least 50% of weed seeds of annual ryegrass and wild radish populations at harvest. Computer modelling suggests that 50% seed removal at harvest will not fix a weed control system that is not working. It will, however, have a significant impact where a weed seed bank is being maintained or increasing slowly.

Trials in both south-western and eastern Australian grain growing regions have found a 55-58% reduction, overall, in the emergence of annual ryegrass across the three main harvest weed-seed control (HWSC) systems being practised by growers. [30]

Research has demonstrated that for a continuous cropping system where only 90% ryegrass control is achieved each year the seed bank of the ryegrass increases slowly over a ten-year period (Figure 9). By adding a chaff cart or baler at harvest that removes 50% and 75% of the ryegrass seeds in the paddock each year respectively, the ryegrass seed bank is eroded over time. Our aim for managing resistant weeds should simply be to continually reduce weed seed banks. Removing weed seeds at harvest is probably the most important non-herbicide weed management tool to achieve this. [31]

30 Clarry S. (2015). Trials measure harvest weed-seed control. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

31 DAFWA (2014) Factsheet—Harvest weed seed management. Weed seeds at harvest—spread, catch, divert, burn or destroy?

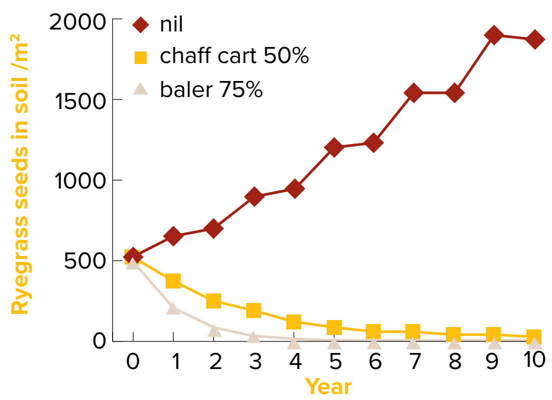


Figure 9: *Computer simulation using RIM program showing the predicted ryegrass seed bank (seeds/m^2) in a pulse-wheat rotation where 90% weed control is achieved each year for three harvest options; Nil (conventional harvest), Chaff cart removing 50% of weed seeds in each crop, or a baler towed behind the header removing 75% of the weed seeds in each crop.*

Source: DAFWA

Weed seed removal can be achieved in two ways:

- Harvesting provides an excellent opportunity to remove weed seeds from the system and prevent them from being spread across the paddock or farm. Collecting seed at harvest has the potential to be a useful component of an integrated weed management program.
- Grazing weed contaminated crop residue can be a cost-effective way of controlling weed growth. Animal digestion of weed seeds prevents a large proportion of seeds from entering the seedbank.

Weed seed collection at harvest will not increase grain yield, as the weeds have already caused damage to the crop. This tactic can only prevent increases to the seedbank, although it may give a subsequent yield advantage to the next season's crop through reduced weed numbers during the season.

12.7.1 Factors affecting weed seed removal

The weed species has a major influence on the proportion of weed seed removed from the paddock when collected at harvest. For example, annual ryegrass is much more available to collect than wild oats, which tend to shed seed before harvest. Successful collection and control depends on the weed:

- maturing at the same time, or later than, the crop being harvested;
- having seeds at a similar or greater height compared with the crop being harvested (this may be overcome by setting the header at a height so that weed seeds are captured);
- having seeds that do not shed or shatter before or during harvest; and
- having seeds that can be threshed and are of a size that end up in the chaff component of the harvested crop.

Timing of harvest will affect the amount of seed removed from the paddock when residue is collected. As harvest is delayed, a greater proportion of the weeds presented will shatter or lodge, reducing the total proportion of seed able to be collected. [32]

32 DAFWA. Crop weed: Weed management at harvest. https://www.agric.wa.gov.au/grains-research-development/crop-weeds-weed-management-harvest

12.7.2 Strategies for weed seed removal at harvest

Chaff carts/Harrington Destructor/Diversion onto tramlines should be able to remove 70–80% of the ryegrass and wild radish that enters the harvester. However, due to ryegrass shedding or lodging this represents approximately 50% of the total weed seeds in the paddock.

The baler and windrow burning should be able to remove 95% of ryegrass and wild radish that enters the front of the harvester. This represents approximately 70% of weed seeds in the paddock (Table 5). [33]

Table 5: *A comparison of the various methods for weed seed collection and management at harvest.*

Tool	Set up cost	Pros	Cons
Windrow burning	$100 to $500	Cheap to get into. No loss of harvest efficiency. Very effective.	Involves burning. Wind erosion risk. Difficult in some cereals. Time consuming in autumn. Nutrient banding.
Chaff cart	$30,000 to $50,000	Minimises area of paddock burnt. Can provide feed source for livestock.	Reduces harvest efficiency. Cost. Burning heaps in autumn is very time consuming.
Chaff diversion onto tramlines	$400 to $5,000	Cheap. No burning. No loss of harvest efficiency. Reduces dust during summer spraying.	Must have fully matched tramline system. Unproven. High weed density on tramlines.
Harrington Destructor	Approx. $100,000	No burning. Nothing to do after harvest. Very robust machine—can handle house bricks!	Cost. Extra piece of machinery.
Baling everything—Glenvar system	$150,000 to $200,000	No burning. Additional income from bales. Most effective tool on the market.	Cost. Extra nutritional drain on soil. Need a market for bales. Handling of lots of bales.

Source: DAFWA

Narrow windrow burning

During traditional whole paddock stubble burning, the very high temperatures needed for weed seed destruction are not sustained for long enough to kill most weed seeds. By concentrating harvest residues and weed seed into a narrow windrow, fuel load is increased and the period of high temperatures extends to several minutes, improving the kill of weed seeds.

Windrow burning for weed control

- Continued reliance on herbicides alone is not sustainable in our continuous cropping systems. Rotating herbicides alone will not prevent the development of resistance

33 DAFWA (2014) Factsheet—Harvest weed seed management. Weed seeds at harvest—spread, catch, divert, burn or destroy?

MORE INFORMATION

IWM manual section on narrow windrow burning

- Early implementation of windrow burning will prolong the usefulness of herbicides, not replace them
- Windrow burning is the cheapest non-chemical technique for managing weed seeds present at harvest
- Windrow burning is an effective weed management strategy, even in the absence of resistance. [34]

Narrow windrow burning is extremely effective—destroying up to 99% of annual ryegrass and wild radish seeds—but it must be done properly. For ryegrass, a temperature of 400°C for at least 10 second is needed to destroy the seeds' viability. For wild radish, the temperature needs to be 500°C for at least 10 seconds. [35]

Chaff Carts

Chaff carts are towed behind headers during harvest to collect the chaff fraction (Figure 10). Collected piles of chaff are then either burnt the following autumn or used as a source of stock feed.

Figure 10: *Chaff cart in action*

Photo: A. Storrie

MORE INFORMATION

IWM manual section on chaff carts

Chaff carts will collect and remove up to 85 per cent of annual ryegrass and wild radish seeds that pass through a header. Collected chaff must be managed to ensure the seeds are then removed from the cropping system. This can be done by burning in the following autumn or by removing the chaff from the paddock and using it as a livestock feed. [36]

MORE INFORMATION

IWM manual section on bale direct systems

Bale direct systems

The bale direct system uses a baler attached to the harvester to collect all chaff and straw material. 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 source. (See http://www.glenvar.com/ for the story and development of header-towed bailing systems).

34 Street M, Shepherd. (2013). Windrow burning for weed control—WA fad or a viable option for the east? 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

35 Clarry S. (2015). Trials measure harvest weed-seed control. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

36 Clarry S. (2015). Trials measure harvest weed-seed control. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

Integrated Harrington Seed Destructor

The iHSD is the invention of Ray Harrington, a progressive farmer from Darkan, WA (Figure 11). Developed as a trail behind unit, the iHSD system comprises a chaff processing cage mill, 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 when compared with windrow burning, chaff carts and baling. [37]

The iHSD, which renders seeds non-viable by collecting and impacting the chaff as it exits the harvester, can be 92-99% effective, depending on seed species. [38]

Figure 11: *Harrington seed destructor at work.*

Source: GRDC.

WATCH: Harvest weed seed control for the high rainfall zone.

MORE INFORMATION

Managing weeds at harvest

IWM manual section on Harrington seed destructor

37 GRDC Integrated weed management hub. Section 6: Managing weeds at harvest. https://grdc.com.au/Resources/IWMhub/Section-6-Managing-weeds-at-harvest

38 Clarry S. (2015). Trials measure harvest weed-seed control. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-115-MarApr-2015/Trials-measure-harvest-weed-seed-control

WATCH: Harvest – the time to get on top of resistant weeds.

WATCH: A beginner's guide to harvest weed seed control.

Storage

Key messages

- Unlike cereal grains, pulses cannot be treated with protectants to prevent insect infestations. Therefore, meticulous hygiene and aeration cooling to manage storage temperature and moisture are crucial to prevent insect damage and moulds from downgrading stored chickpeas.
- Pulses stored above 12% moisture content require aeration cooling to maintain quality.
- 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 make chickpeas less attractive to insect pests.
- It is important that growers minimise the number of handling operations wherever possible and use efficient handling techniques that minimise damage, such as belt conveyors rather than spiral augers.

Successful storage of pulses requires a balance between ideal harvest and storage conditions. Harvesting at 14% seed moisture content (MC) captures grain quality and reduces mechanical damage to the seed, but requires careful management in aerated silos to avoid deterioration during storage. [1]

Testa quality and physiological age are two principle components of pea, lentil, faba bean and chickpea seed quality. Both are influenced by harvest and storage practices. Both influence germination, as well as other measures of seed quality, which affect the ability of seeds to produce seedlings that can emerge and establish. [2]

Many of the quality characteristics of the grain from these crops are in the appearance, size and physical integrity of the seed. Mechanical seed damage, discolouration, disease, insect damage (Figure 1), split seeds or small seeds will lead to a downgrade in quality and market value. Buyers prefer large, consistently sized seed free of chemical residues for easy processing and marketing to consumers.

Figure 1: *Insect (cowpea weevil) damage on seeds of two 'kabuli' and three 'desi' chickpeas (from left to right).* [3]

1 DAFWA. Desi Chickpea Essentials. https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

2 RH Ellis, PK Agrawal, EE Roos (1988) Harvesting and storage factors that affect seed quality in pea, lentil, faba bean and chickpea. In World crops: Cool season food legumes (303–329). Springer Netherlands.

3 Erler, F., Ceylan, F., Erdemir, T., & Toker, C. (2009). Preliminary results on evaluation of chickpea, Cicer arietinum, genotypes for resistance to the pulse beetle, Callosobruchus maculatus. Journal of Insect Science, 9(1), 58.

Unlike cereal grains, pulses cannot be treated with protectants to prevent insect infestations. Therefore, meticulous hygiene and aeration cooling to manage storage temperature and moisture are crucial to prevent insect damage and moulds from downgrading stored chickpeas. The Australian Pulse Standards stipulate standards for heat-damaged, bin-burnt, mouldy, caked or insect-infested chickpeas, and breaching of any of these can result in the discounting or rejection of product. [4] Effective management of stored chickpeas can eliminate all of these risks to pulse quality. Growers contemplating medium-long-term storage (6–12 months) need to be aware that chickpeas continue to age, and that quality deteriorates over time. Desi chickpeas will darken considerably in storage, with the rate of seed coat darkening being accelerated by:

- high seed moisture content (MC)
- high temperatures
- high relative humidity

Condition of the seed at harvest

- Seed subject to field weathering prior to harvest will deteriorate a lot faster in storage, even when stored under 'acceptable' conditions of temperature and relative humidity.
- Conditions of high relative humidity and high temperatures will result in rapid deterioration in grain colour.
- To maintain yellow colour and minimise darkening of seed, any grain stored at over 12% MC will require cooling and/or drying.
- Growers should avoid even short–medium storage of weather-damaged grain. [5]

WATCH: GCTV Stored Grain: Storing pulses.

13.1 How to store chickpeas on-farm

Key points

- Combining good hygiene, well-managed aeration cooling and regular grain inspections provide the best foundation for successful grain storage.
- Findings of recent ecological research, which involved trapping flying storage pests across grain-growing regions, reinforced the value of cleaning up grain residues in storages and equipment.
- New, easy-to-use functions in automatic aeration controllers provide improved reliability of achieving good results from aeration cooling.

4 Grain Trade Australia (2011) Australian pulse standards, 2011-2012 season. GTA August 2011, http://www.graintrade.org.au/sites/default/files/file/Commodity Standards/Pulse Standards 201112.pdf

5 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013.

- Recirculation and ground-level applications have a role to play in effective, safe fumigation. [6]

13.1.1 Handling and storage of chickpea seed

Planting-seed selection

Special attention should be given to the harvest, handling and storage of planting seed retained on the farm. Seed should be:

- Sourced from the cleanest paddocks, where Ascochyta blight was not detected.
- Harvested at minimum of 13–14% MC to minimise mechanical damage to the seed.
- If heat dried, at temperatures below 40°C.
- Stored at approximately 13% MC.
- Kept at a grain temperature of below 30°C (see Table 2).
- Graded to remove split, damaged and small seeds.

Handling

Grain may have been handled (augured) up to six times by the time it is delivered to receival points or is planted. It is important that growers minimise the number of handling operations, and use efficient handling techniques to minimise damage; e.g. using belt conveyors rather than spiral augers.

If using augers:

- Operate slowly and full.
- Use large-diameter augers.
- Length of the auger should be no longer than is necessary.
- Keep auger incline low.
- Check flight casing clearance—optimal clearance is typically 50% of grain size to minimise the grain being wedged between the auger spiral and the casing.

Seed longevity in storage

Growers contemplating medium- to long-term storage (6–12 months) need to be aware that chickpea seed continues to age, and that quality deteriorates over time (Table 1). Desi chickpea will darken considerably, and seed germination capacity and vigour will decline in storage, with the rate being accelerated by:

- high seed-moisture content
- high temperatures
- high relative humidity
- condition (weathering) of the seed at harvest.

Seed that has been weathered before harvest will deteriorate quicker in storage, even when stored under acceptable conditions of temperature and relative humidity. To maintain colour and minimise darkening of seed, any grain stored above 12% moisture will require cooling. [7]

6 P Burrill (2013) Grain storage: future pest-control options and storage systems 2013–2014. GRDC Update Papers. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014

7 B O'Mara, S Belfield, G Cumming (n.d.) Chickpea harvest and seed storage. Pulse Australia, http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

Table 1: *Effect of moisture content and temperature on storage life of chickpea.*

Storage moisture (%)	Storage temperature (°C)	Longevity of seed (days)
12	20 30 40	>2000 500-650 110-130
15	20 30 40	700-850 180-210 30-50

Source: Pulse Australia

Note: Most planting seed will need to be stored for a period of 180 days or more.

Moisture and temperature

Research has shown that harvesting pulses at higher moisture content (up to 14%) reduces field mould, mechanical damage to the seed, and splitting, and preserves seed viability. The challenge is to maintain this quality during storage, when there is an increased risk of deterioration at these moisture levels. As a result, pulses stored above 12% MC require aeration cooling to maintain quality.

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%. [8] As a general rule of thumb, the higher the moisture content, the lower the temperature required to maintain seed quality (Table 2). [9]

Table 2: *Maximum recommended storage period.*

Moisture content (%)	Grain temperature (°C) 20	Grain temperature (°C) 30
14	3 months	N/A
13	9 months	3 months
12	>9 months	9 months

Source: GRDC

Green pods and grains increase the risk of mould developing during storage—even at a lower moisture content. Aeration cooling will help prevent mould and hot spots by creating uniform conditions throughout the grain bulk. [10]

Weathering damage hinders storage

Pulses exposed to weathering before harvest deteriorate more quickly in storage. Chickpeas stored for the medium to long term (6–12 months) continue to age and lose quality (see Table 1 above). Growers can minimise the effects of seed darkening, declining germination capacity and reduced seed vigour by:

- Lowering moisture content and temperature.
- Harvesting before weather damages the grain. [11]

8 Storing pulses. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/storing-pulses/

9 B O'Mara, S Belfield, G Cumming (n.d.) Chickpea harvest and seed storage. Pulse Australia, http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

10 Storing pulses. Stored Grain Information Hub. GRDC, https://grdc.com.au/Resources/Factsheets/2014/07/Grain-Storage-Fact-Sheet-Storing-Pulses

11 GRDC Stored Grain Hub. Storing pulses. http://storedgrain.com.au/storing-pulses/

WATCH: GCTV: Stored grain: Oilseeds and pulse storage

13.1.2 On-farm storage

Growers might only plan to store grain on-farm for a short time, but markets can change, so investing in gas-tight sealable structures means you can treat pests reliably and safely and leave your business open to a range of markets.

Growers should approach storage as they would purchasing machinery: Growers spend a lot of time researching a header purchase to make sure it is fit-for-purpose. Grain storage can also be a significant investment, and a permanent one, so it pays to have a plan that adds value to your enterprise into the future.

> *Decide what you want to achieve with storage, critique any existing infrastructure and be prepared for future changes: A good storage plan can remove a lot of stress at harvest – growers need a system that works so they capture a better return in their system.* [12]

Agronomist's view

The two most common of the serious threats to grain quality in Australia's storages are insect pest infestations and grain moisture problems causing the growth of mould or fungus. Key initial strategies include:

- Thorough hygiene maintained in storages and equipment.
- Keeping grain cool and dry grain in storage.

Attention paid to the three areas listed below will provide reliable grain quality:

- Good storage and equipment hygiene reduces early pest infestations and grain-contamination problems. Sieve and inspect grain in storages monthly.
- High-moisture grain in storage—have the right equipment and management strategies in place to deal promptly with any growth of mould or fungus. Monitor regularly.
- Cool grain temperature—use aeration to achieve cool, uniform temperature in storages in the first few weeks after harvest. Monitor to maintain these conditions. [13]

12 GRDC. (2015). Ground cover issue 119—Grain storage. Extension tailored for regional challenges. https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-119--Grain-storage/Extension-tailored-for-regional-challenges

13 P Burrill (2013) Grain storage: future pest-control options and storage systems 2013–2014. GRDC Update Papers. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014

In most cases, for on-farm storage to be economical it will need to deliver on more than one of these benefits (Table 3). Under very favourable circumstances grain storage facilities can pay for themselves within a few years but it is also possible for an investment in on-farm storage to be very unprofitable. The grain storage cost-benefit analysis template is very useful step in the decision-making process to test the viability of grain storage on your farm. [14]

Table 3: *Advantages and disadvantages of grain storage options.*

Storage type	Advantages	Disadvantages
Gas-tight sealable silo	Gas-tight sealable status allows phosphine and controlled atmosphere options to control insects Easily aerated with fans Fabricated on-site or off-site and transported Capacity from 15 tonnes up to 3,000 tonnes Up to 25 year plus service life Simple in-loading and out-loading Easily administered hygiene (cone base particularly) Can be used multiple times in-season	Requires foundation to be constructed Relatively high initial investment required Seals must be regularly maintained Access requires safety equipment and infrastructure Requires an annual test to check gas-tight sealing
Non-sealed silo	Easily aerated with fans 7–10% cheaper than sealed silos Capacity from 15 tonnes up to 3,000 tonnes Up to 25 year plus service life Can be used multiple times in-season	Requires foundation to be constructed Silo cannot be used for fumigation—see phosphine label Insect control options limited to protectants in eastern states and Dryacide™ in WA Access requires safety equipment and infrastructure

14 GRDC. (2015). Grain storage strategies in the northern region. https://grdc.com.au/Media-Centre/Hot-Topics/Grain-storage-strategies-in-the-northern-region

Storage type	Advantages	Disadvantages
Grain storage bags	Low initial cost Can be laid on a prepared pad in a paddock Provide harvest logistics support Can provide segregation options Are all ground operated Can accommodate high-yielding seasons Grain is untreated for wider market access.	Requires purchase or lease of loader and unloader Increased risk of damage beyond short-term storage (typically three months) Limited insect control options. Fumigation only possible under specific protocols Requires regular inspection and maintenance, which need to be budgeted for Aeration of grain in 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
Grain storage sheds	Can be used for dual purposes 30 year plus 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

Established strategies

There is an increasing number of growers who are reaping rewards by placing extra emphasis on the management of their grain-storage facilities. It is the combination of practices listed below that provides the real strength to successful storage.

Key strategies include:

- High standard of hygiene for storages and grain-handling equipment—minimising insect-pest breeding sites.
- Monthly checks of grain in storage, including those of planting seed—sieving for insects and checking quality.
- Aeration—aeration fans fitted to storages, and operated by an automatic controller.
- Grain temperatures—checked and maintaining 20–23°C in summer and less than 15°C in winter.
- Fumigations, when required, are carried out in sealable silos. The silos are pressure-tested at least once a year.
- Storage record keeping—a simple system is used to record details such as grain variety, moisture content, any treatments given, inspection dates, and information on insects found and grain temperature.

New products and equipment

Aeration using automatic controllers

Reliability good results with aeration cooling are significantly increased with the use of automatic controllers to turn on silo fans when the best ambient temperature and humidity conditions are available. There are new functions in automatic aeration controllers. Some of the options available include:

- The ability to have fans automatically step through the three important stages of aeration cooling—continuous, purge, and protected.
- The ability to exclude very humid air (more than 85% relative humidity) in all three of these stages.
- The ability to cater for fans with air-flow rates higher than the standard 2–3 litres per second per tonne (L/s/t).

These functions provide another good reason to stop using the less-reliable methods of trying to remember to manually switch fans on and off, or using power-point timers.

High–flow rotary grain cleaner

One of benefits of having storages on the farm is the ability to segregate different quality grades of grain at harvest time. For farmers who only just miss being given a premium grade due to a few extra percent screenings in wheat, or who face downgrades in pulses due to splits or weed seed contamination, grading is an option that can quickly add value.

Storage safety is also improved by grading out impurities and fines from oilseeds when filling silos.

The rotary grader has multiple screen tubes designed for flow rates that will keep up with most harvesting operations. A range of screen sizes and slot designs suit most grading requirements.

WATCH: Over the Fence: On-farm storage pays in wet harvest

MORE INFORMATION

Grain storage facilities: Planning for efficiency and quality.

13.1.3 Silos

Well-designed and properly operated on-farm storage provides the best insurance that a grower can have to maintain the quality of chickpeas to be out-turned. Storages must be used in conjunction with sound management practices, which include monthly sieving for insects, regular grain-quality inspections, and ensuring that aeration cooling equipment is operating as required. [15]

15 P Burrill, P Botta, C Newman, B White, C Warrick (2014) Storing pulses. Fact sheet. Updated July 2014, https://grdc.com.au/Resources/Factsheets/2014/07/Grain-Storage-Fact-Sheet-Storing-Pulses

Silos are the ideal storage option for pulses, especially if they are cone-based for easy out-loading with minimal seed damage (Figure 2). Because chickpeas are susceptible to splitting at the ideal storage moisture content of less than12%, cone-based rather than flat-based silos are recommended for easy out-loading with minimal seed damage. For anything more than short-term storage (three months) aeration cooling and gas-tight sealable storage suitable for fumigation are essential features for best-practice 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 may cause it to collapse. Avoid storing lentils in silos with horizontally corrugated walls, as the grain can run out from the bottom first and cause the collapse of the silo as, in bulk, the grain will slide down the silo walls rather than from the centre.

Figure 2: *On-farm grain storage silos in one of the first trials in Western Australia assessing seed quality in on-farm storage systems.*

Photo: Ben White. Source: GRDC

Paint the outside of the silo with white paint. This reduces storage temperature by as much as 4–5 °C and can double the safe storage life of grains. Aerate silos with dry, ambient air. In addition to reducing storage temperatures, aeration is also effective in reducing moisture of seed harvested at high moisture content if flow rates are sufficient. Growers should avoid even short–medium storage of weather-damaged grain. [16]

Sealed silos offer a more permanent grain storage option than grain storage bags. Depending on the amount of storage required, they will have a higher initial capital cost than grain storage bags and are depreciated over a longer time frame than the machinery required for the grain bags. In a silo grain storage system as stored tonnage increases the capital cost of storage increases.

16 DAF Queensland (2012) Chickpea: harvesting and storage. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/harvesting-and-storage

Potential advantages of using sealed grain silos as a method for grain storage include improved harvest management, reduced harvest stress, reduced harvest freight requirements, minimal insecticide exposure and the opportunity to segregate and blend grain.

Potential disadvantages of using sealed grain silos as a method for grain storage include the initial capital outlay, the outlay required to meet occupational health and safety requirements, the additional on farm handling required and the additional site maintenance requirements. [17]

Pressure testing

At industry level, it is within growers' best interests to house grain in aerated, sealable storages to help curtail the rise of insect resistance to phosphine. Resistance has come about because of the prevalence of silos that are poorly sealed, or even unsealed, during fumigation. [18]

- 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.

A silo is only truly sealed if it passes a five-minute half-life pressure test according to the Australian Standard AS2628. Often silos are sold as sealed but are not gas-tight — rendering them unsuitable for fumigation.

Even if a silo is sold as 'sealed' it is not sealed until it is proven gas-tight with a pressure test.

The term 'sealed' has been used loosely during the past and in fact some silos may not have been gas-tight from the day they were constructed.

However, even a silo that was gas-tight to the Australian Standard on construction will deteriorate over time so needs annual maintenance to remain 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.

MORE INFORMATION

GRDC Pressure testing sealable silos factsheet.

GRDC Silo buyer's guide

17 Francis J. (2006). An analysis of grain storage bags, sealed grain silos and warehousing for storing grain. https://grdc.com.au/uploads/documents/Final%20report%20Grain%20Storage%20Bags%2021%20Jul%20061.pdf

18 C Warrick (2012) Fumigating with phosphine, other fumigants and controlled atmospheres. Reprinted August 2012. GRDC, http://www.grdc.com.au/~/media/5EC5D830E7BF4976AD591D2C03797906.pdf

WATCH: Pressure testing sealed silos.

The importance of a gas-tight silo

Growers should pressure-test sealable silos once a year to check for damaged seals on openings. Storages must be able to be sealed properly to ensure high phosphine gas concentrations are held long enough to give an effective fumigation. At an industry level, it is in growers' best interests to only fumigate in gas-tight sealable storages to help stem the rise of insect resistance to phosphine. This resistance has come about because of the prevalence of storages that are poorly sealed or unsealed during fumigation. [19]

Research shows that fumigating in a storage that is not gas-tight does not achieve a sufficient concentration of fumigant for long enough to kill pests at all life cycle stages. For effective phosphine fumigation, a minimum gas concentration of 300 parts per million (ppm) for 7 days or 200 ppm for 10 days is required. Fumigation trials in silos with small leaks demonstrated that phosphine levels are as low as 3 ppm close to the leaks. The rest of the silo also suffers from reduced gas levels. [20]

It is recommended to pressure-test silos that are sealable once a year to check for damaged seals on openings. Storages must be able to be sealed properly to ensure effective fumigation.

There is no compulsory manufacturing standard for sealed silos in Australia. A voluntary industry standard was adopted in 2010. Watch this GRDC Ground Cover TV clip to find out more.

19 C Warrick (2011) Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once: A Grains Industry Guide. GRDC Stored Grain Project, January 2011 (reprinted June 2013), https://grdc.com.au/uploads/documents/GRDC-Fumigating-with-Phosphine-other-fumigants-and-controlled-atmospheres.pdf?shortcut=1

20 P Botta, P Burrill, C Newman (2010) Pressure testing sealable silos. GRDC Grain Storage Fact Sheet, September 2010 Revised July 2014, http://storedgrain.com.au/wp-content/uploads/2014/09/GSFS-3_PressureTest-July14.pdf

WATCH: Stored grain: Managing sealed and unsealed storage.

13.1.4 Grain bags

Grain storage bags are relatively new technology offering a low cost alternative for temporary storage of grain to permanent grain storage structures on farm such as silos. Grain storage bags are made of multilayer polyethylene material similar to that used in silage fodder systems. Bags typically store between 200 and 220 tonnes of grain and are filled and emptied using specialised machinery (Figure 3). The bags are sealed after filling producing a relatively airtight environment which, under favourable storage conditions, protects grain from insect damage without the use of insecticides.

Potential advantages of using grain storage bags as a method for grain storage include the low capital set up costs, improved harvest management, less harvest stress, reduced harvest freight requirements, minimal cost in occupational health and safety (OH&S) requirements, reduced grain insecticide requirements and the opportunity to segregate and blend grain.

Potential disadvantages of using grain storage bags as a method for grain storage include the requirement for disposal of used bags, the period of storage before bag deterioration and the management necessary to ensure bag integrity. Another potential disadvantage of this system, when compared to permanent structures, is that once the storage period is complete there is no asset value in the storage system other than the bagging machinery. [21]

21 Francis J. (2006). An analysis of grain storage bags, sealed grain silos and warehousing for storing grain. https://grdc.com.au/uploads/documents/Final%20report%20Grain%20Storage%20Bags%2021%20Jul%20061.pdf

Figure 3: *A 100 m bag can be filled in 30 minutes with a constant supply of grain.*

Source: StarTribune.

MORE INFORMATION

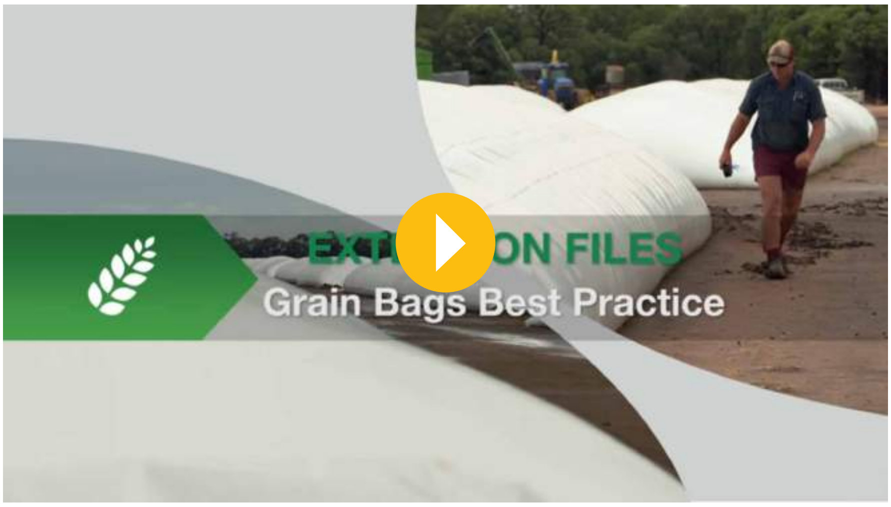
Fumigating in a silo bag with phosphine?

Risks with chickpeas

Chickpeas can be stored successfully in silo bags of up to three months, but it is a less desirable option than silo storage. Marketers have rejected pulse grain because of moulds, taints and odours from storage in grain bags. Such taints and odours are not acceptable in pulse markets. [22]

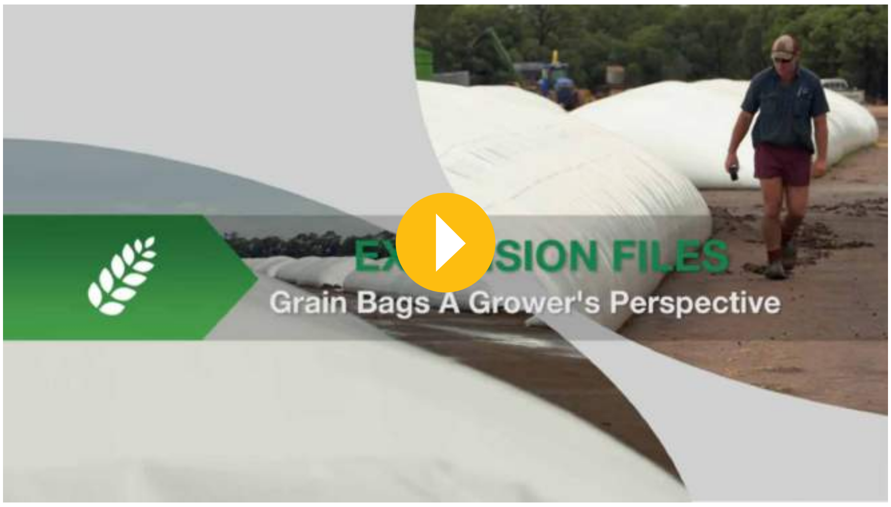
Black discoloration of chickpeas due to moisture ingress into the base of grain bags has also occurred, causing serious losses in storage.

WATCH: Grain bags best practice.



22 W Hawthorne, A Meldrum, G Cumming (2010) Grain bags for pulse storage—use care. Australian Pulse Bulletin 2010 No. 3, http://www.pulseaus.com.au/storage/app/media/crops/2010_APB-Pulse-grain-bag-storage.pdf

WATCH: Extension Files: Grain bags—a grower's perspective.



13.1.5 Grain storage—get the economics right

As growers continue to expand their on-farm grain storage, the question of economic viability gains significance. There are many examples of growers investing in on-farm grain storage and paying for it in one or two years because they struck the market at the right time, but are these examples enough to justify greater expansion of on-farm grain storage?

The grain storage extension team conduct approximately 100 grower workshops every year, Australia wide and it's evident that no two growers use on-farm storage in the exact same way. Like many economic comparisons in farming, the viability of grain storage is different for each grower. Depending on the business's operating style, the location, the resources and the most limiting factor to increase profit; grain storage may or may not be the next best investment. For this reason, everyone needs to do a simple cost benefit analysis for their own operation.

Comparing on-farm grain storage

To make a sound financial decision, we need to compare the expected returns from grain storage versus expected returns from other farm business investments, such as more land, a chaser bin, a wider boomspray, a second truck or paying off debt. The other comparison is to determine if we can store grain on-farm cheaper than paying a bulk handler to store it for us.

Calculating the costs and benefits of on-farm storage will enable a return-on investment (ROI) figure, which can be compared with other investment choices and a total cost of storage to compare to the bulk handlers.

Cheapest form of storage

The key to a useful cost–benefit analysis is identifying which financial benefits to plan for and costing an appropriate storage to suit that plan. People often ask, "what's the cheapest form of storage?" The answer is the storage that suits the planned benefits. Short term storage for harvest logistics or freight advantages can be suited to grain bags or bunkers. If flexibility is required for longer term storage, gas-tight, sealable silos with aeration cooling allow quality control and insect control.

Benefits

To compare the benefits and costs in the same form, work everything out on a basis of dollars per tonne. On the benefit side, the majority of growers will require multiple financial gains for storing grain to make money out of it. These might include harvest logistics or timeliness, market premiums, freight savings or cleaning, blending, or drying grain to add value.

Costs

The costs of grain storage can be broken down into fixed and variable. The fixed costs are those that don't change from year to year and have to be covered over the life of the storage. Examples are depreciation and the opportunity or interest cost on the capital. The variable costs are all those that vary with the amount of grain stored and the length of time it's stored for. Interestingly, the costs of good hygiene, aeration cooling and monitoring are relatively low compared to the potential impact they can have on maintaining grain quality. One of the most significant variable cost, and one that is often overlooked is the opportunity cost of the stored grain. That is the cost of having grain in storage rather than having the money in the bank paying off an overdraft or a term loan.

The result

While it's difficult to put an exact dollar value on each of the potential benefits and costs, a calculated estimate will determine if it's worth a more thorough investigation. If we compare the investment of on-farm grain storage to other investments and the result is similar, then we can revisit the numbers and work on increasing their accuracy. If the return is not even in the ball park, we've potentially avoided a costly mistake. On the contrary, if after checking our numbers the return is favourable, we can proceed with the investment confidently.

Summary

Unlike a machinery purchase, grain storage is a long-term investment that cannot be easily changed or sold. Based on what the grain storage extension team are seeing around Australia, the growers who are taking a planned approach to on-farm grain storage and doing it well are being rewarded for it. Grain buyers are seeking out growers who have a well-designed storage system that can deliver insect free, quality grain without delay.

Table 4 is a tool that can be used to figure out the likely economic result of on-farm grain storage for each individual business. Each column can be used to compare various storage options including type of storage, length of time held or paying a bulk handler. [23]

23 Warrick C. (2016). GRDC Update Papers: Grain storage—get the economics right. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/09/Grain-storage-get-the-economics-right

Table 4: *Cost-benefit template for grain storage.*

Financial gains from storage		Example $/t
Harvest logistics/ timeliness	Grain price x reduction in value after damage % x probability of damage %	$16
Marketing	Post harvest grain price - harvest grain price	
Freight	Peak rate $/t - post harvest rate $/t	$20
Cleaning to improve grade	Clean grain price - original grain price - cleaning costs - shrinkage	
Blending to lift average grade	Blended price - ((low grade price x %mix) + (high grade price x %mix))	
Total benefits	Sum of benefits	$36.20
Capital cost	Infrastructure cost / storage capacity	$155
Fixed costs		
Annualised depreciation cost	Capital cost $/t / expected life storage eg 25yrs	$6.20
Opportunity cost on capital	Capital cost $/t x opportunity or interest rate eg 8% / 2	$6.20
Total fixed costs	Sum of fixed costs	$12.40
Variable costs		
Storage hygiene	(Labour rate $/hr x time to clean hrs / storage capacity) + structural treatment	$0.23
Aeration cooling	Indicatively 23c for the first 8 days then 18c per month / t	$0.91
Repairs and maintenance	Estimate e.g. capital cost $/t x 1%	$1.51
Inload/outload time and fuel	Labour rate $/hr / 60 minutes / auger rate t/m x 3	$0.88
Time to monitor and manage	Labour rate $/hr x total time to manage hrs / storage capacity	$0.24
Opportunity cost of stored grain	Grain price x opportunity interest rate e.g. 8% / 12 x No. months stored	$7.20
Insect treatment cost	Treatment cost $/t x No. of treatments	$0.35
Cost of bags or bunker trap	Price of bag / bag capacity tonne	
Total variable costs	Sum of variable costs	$11.32
Total cost of storage	Total fixed costs + total variable costs	$23.72
Profit/Loss on storage	Total benefits - total costs of storage	$12.48
Return on investment	Profit or loss / capital cost x 100	8.1%

Source: GRDC.

MORE INFORMATION

GRDC Economics of on-farm grain storage, cost benefit analysis

Economics of on-farm grain storage: a grains industry guide

WATCH: Over the Fence: On-farm storage delivers harvest flexibility and profit.

WATCH: Stay safe around grain storage.

Insects are not considered to be a major problem in stored chickpea. The exceptions appear to be where chickpeas have higher levels of splits and damaged seed, or are loaded into storages containing residues of cereal grains that are already infested with pests, or both. Then chickpeas may harbour several insects, including:

- rust-red flour beetle (*Tribolium castaneum*)
- lesser grain borer (*Rhyzopertha dominica*)
- saw-toothed grain beetle (*Oryzaephilus surinamensis*)

Where a prior infestation exists in storage facilities, pests can spread and develop in chickpeas. The most common pulse pests are the cowpea weevil and pea weevil (Note that pea weevil is a pest of field peas and infection occurs in the field. It is not a stored grain pest as such although adults can emerge from peas in storage) which can also survive and breed at slower rates in chickpeas. The cowpea weevil has a short life span of 10–12 days while the pea weevil only breeds one generation per year. [24] Hygiene is the most cost-effective method of managing bruchid problems. Growers need to thoroughly clean all residues of other pulses from headers, planting equipment, shed floors, augers and empty trucks and storages after each harvest, and whenever pulse seeds are handled on the farm. [25]

24 Storing pulses. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/storing-pulses/

25 DAF Queensland (2012) Chickpea: harvesting and storage. DAF Qld, https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/chickpeas/harvesting-and-storage

If weather damage before harvest or header settings have led to chickpeas containing higher levels of split grain and trash, they are more prone to infestation by pests such as the rust-red flower beetle. Pre-storage grading to remove splits or extra storage monitoring is required.

Chickpea gradings are attractive to storage pests. Gradings can act as a breeding site, causing infestations to spread to the storage complex. Use or remove gradings from the area as soon as possible.

Good hygiene by ensuring that all handling equipment and storages are clean before handling chickpea should prevent infestations from developing. If insects are found in stored chickpeas, the only registered treatment option are controlled atmospheres (CO_2, N_2) or phosphine fumigation. [26]

The high numbers of storage pests that can fly away from on-farm sources of infested grain in spring and summer looking for newly harvested clean grain to infest (Figure 4) demonstrates the value of regularly maintaining hygiene and inspecting grain.

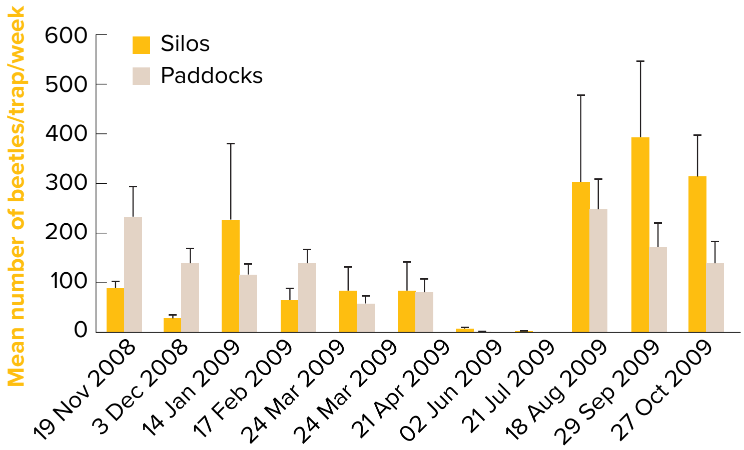


Figure 4: *Numbers of lesser grain borers trapped in warm and cooler months at farm silos and 1 km away in the paddocks.*

Source: GRDC

No insecticide sprays are currently registered for use on chickpeas. Markets are particularly sensitive to insecticide residues, so the detection of any residues on chickpeas could result in the loss of a market, not just the rejection of a contaminated delivery.

For structural treatments of silos, use an inert dust such as diatomaceous earth (DE) after a thorough cleaning of all old grain residues. Wash out the silo with a pressure hose, then leave it open to dry is also recommended, particularly if an insect infestation occurred in the last grain stored in it. [27]

The aeration of pulses stored in silos is the key non-chemical tool used to minimise the risk of insect infestations and spoiling through heat and/or moisture damage. Pulses stored above 12% moisture content (MC) require aeration cooling to maintain quality. Australian pulse trading standards are set at a maximum moisture limit of 14% for chickpeas, and most other pulses [28], 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.

26 Pulse Australia. Chickpea harvest and seed storage. http://www.pulseaus.com.au/storage/app/media/crops/2007_Chickpea-Harvest-Storage.pdf

27 Pulse Australia (2013) Northern Chickpea—Best Management Practices Training course Manual 2013. Pulse Australia.

28 Pulse Australia (2016) Australian Pulse Standards 2016–2017. Pulse Australia, http://www.pulseaus.com.au/storage/app/media/markets/20160801_Pulse-Standards.pdf

Aeration of chickpeas as soon as they go into the silo will provide uniform moisture conditions in the grain bulk, and quickly lower grain temperatures, which will minimise the effects of seed darkening, declining germination capacity and seed vigour.

13.1.6 Hygiene

Key points:

- Effective grain hygiene requires the complete removal of all waste grain from storages and equipment.
- Be meticulous with grain hygiene: pests only need a small amount of grain in order to survive and reproduce.
- Structural treatments, such as diatomaceous earth (DE), can be used on storages and equipment to protect against grain pests.
- Check delivery requirements before using chemical treatments, and avoid using with pulses and oil seeds.

The first line of defence against grain pests occurs before the pulses are put into storage—in meticulous grain hygiene. Because pest control options are limited, it's critical to remove pests from the storage site before harvest. The key to control is to ensure that all handling equipment and storages are cleaned of old grain residues before they are used to handle chickpeas. Effective hygiene plus aeration cooling can overcome 75% of pest problems in on-farm storage.

A bag of infested grain can produce more than one million insects during a year, and these can walk and fly to other grain storages where they will start new infestations.

Cleaning silos and storages thoroughly and removing spilt and leftover grain removes the feed source and harbour for insect pests.

WATCH: GCTV2: Grain silo hygiene

Where to clean

Removing an environment for pests to live and breed in is the basis of grain hygiene, which includes all grain handling equipment and storages (Figure 5). Grain pests live in dark, sheltered areas, and breed best in warm conditions.

Common places where pests are found include:

- Empty silos and grain storages.
- Aeration ducts, augers and conveyers.
- Harvesters, field bins and chaser bins.
- Left-over bags of grain trucks.
- Spilt grain around grain storages.

- Equipment and rubbish around storages.
- Seed grain.
- Stockfeed grain. [29]

Successful grain hygiene involves cleaning all areas where grain gets trapped in storages and equipment. Grain pests can survive in a tiny amount of grain, so any fresh parcel of grain passing through machinery, storage or equipment can easily become infested.

Figure 5: *Grain left in trucks is an ideal place for grain pests to breed. Keep trucks, field bins and chaser bins clean.*

Source: Stored Grain Information Hub

When to clean

Straight after harvest is the best time to clean grain handling equipment and storages, before they have time to become infested with pests. A trial carried out at the start of a harvest in Queensland revealed more than 1,000 lesser grain borers in the first 40 L of grain through a harvester, which had been considered reasonably clean at the end of the previous season. Discarding the first few bags of grain at the start of the harvest is a good idea.

Studies have revealed that insects are least mobile during the colder months of the year. Cleaning around silos from July–August can reduce insect numbers before they become mobile.

How to clean

The better the cleaning job, the less chance there is of pests being harboured. The best ways to get rid of all grain residues use a combination of:

- sweeping
- vacuuming
- compressed air
- blow guns or vacuum guns
- pressure washers
- fire-fighting hoses

Using a broom or jets of compressed air gets rid of most grain residues, and a follow-up wash-down removes grain and dust left in crevices and hard-to-reach spots (Figure 6). Choose a warm, dry day to wash storages and equipment so they dry out quickly and do not get rusty. When inspecting empty storages, look for ways to make

29 Hygiene and structural treatments for grain storage. Fact sheet. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/hygiene-structural-treatments/

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.

Figure 6: *Clean silos, including the silo wall, with air and/or water to provide a residue-free surface to apply structural treatments.*

Source: Stored Grain Information Hub

The process of cleaning on-farm storages and handling equipment should start with the physical removal, blowing and/or hosing out of all residues. Once the structure is clean and dry, consider the application of DE as a structural treatment. (See Section 1.2.2 Structural treatments for chickpea storage for more information.)

A concrete slab underneath silos makes cleaning much easier (Figure 7).

Agronomist's view

Figure 7: *Concrete slab under silo makes cleaning up spilled grain much easier.*

Source: Stored Grain Information Hub

13.1.7 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 the relative humidity of the ambient air exceeds 85%.
- Automatic grain-aeration controllers that select optimum fan running times provide the most reliable results.

Not all growers are convinced that the aeration of grain is worthwhile, or a valuable asset for their storage system in this region, and have been reluctant to install aeration fans in their storages. However, a well-managed aeration system typically reduces grain temperatures by at least 10°C (Figure 8). This has a significant impact on reducing insect-pest problems and in maintaining grain quality.

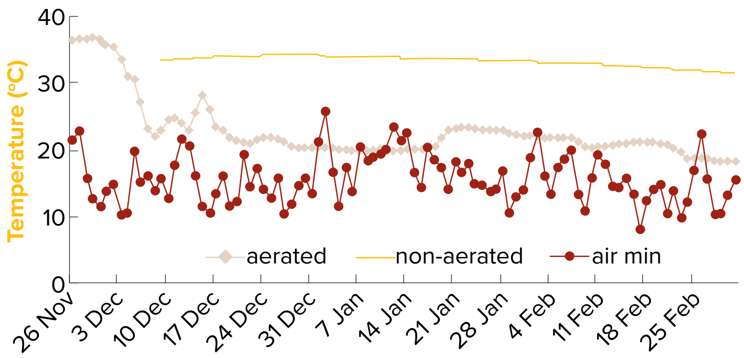


Figure 8: *Comparison of grain temperatures in aerated and non-aerated silos.*

Source: GRDC

Using aeration cooling for stored grain in Western Australia

Western Australian growers are encouraged to use aeration cooling systems and regularly check the pest, quality and temperature status of grain being held in on-farm storage from the 2015 harvest. Storing grain on-farm is becoming an increasingly popular practice in some parts of the state to take advantage of marketing opportunities, provide flexibility at harvesting time and improve grain quality control.

Industry experts recommend close monitoring of stored grain—at least once every month, including during winter—to avoid any nasty surprises when it comes time to sell or plant (in subsequent years). In warmer months, it is advisable to check grain in storage every two weeks. Aeration cooling to reduce grain temperature in storage is key to maintaining the quality of the grain and slowing—or stopping—insect pest breeding. If harvest conditions are wet or moist, aeration drying might also be needed at that time of year to ensure grain meets specifications for sale and to slow mould and insect development. [30]

Aeration cooling:

- Creates uniform conditions throughout the grain bulk.
- Prevents moisture migration.
- Maintains seed viability (germination and vigour).

30 GRDC (2016) Using aeration cooling for stored grain in Western Australia, https://grdc.com.au/Media-Centre/Hot-Topics/Using-aeration-cooling-for-stored-grain-in-Western-Australia

- Reduces mould growth.
- Lengthens (and in some instances stops) insect reproduction cycles.
- Slows seed-coat darkening and quality loss.

Grain temperatures below 15°C stop the breeding cycle for all common storage pests. During summer, achieving grain temperature close to 20°C is also valuable, as it either stops or significantly slows insect population increases.

Fungal growth in grain in storage is kept in check with appropriate grain-moisture. Keeping grain at lower temperatures also assists to some extent in reducing fungal growth.

While adult insects can still survive at low temperatures, most of the young of storage pests stop developing at temperatures below 18–20°C (Table 5). At cool temperatures (20–23°C) 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. [31]

Table 5: *The effect of grain temperature on insects and mould.*

Grain temp (°C)	Insect and mould development	Grain moisture content (%)
40–55	Seed damage occurs, reducing viability	
30–40	Mould and insects are prolific	>18
25–30	Mould and insects are active	13–18
20–25	Mould development is limited	10–13
18–20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Source: Kondinin Group

With the support of an aeration controller, aeration can rapidly reduce stored grain temperatures to a level that helps maintain grain quality and inhibit insect development.

The recommended airflow rate for cooling grain is 2–3 litres of air per second per tonne (L/s/t) of grain in the storage.

Grain is an effective insulator because, like housing insulation, it holds many tiny pockets of air within a stack. Without aeration it will maintain its warm harvest temperature for a long time. 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 (L/s/t) of grain, from fans driven by a 0.37 kilowatt (0.5 horsepower) electric motor for silos of around 100 t capacity.

High-moisture grain can also be safely held for a short time with aeration cooling before it is blended or dried. Run fans continuously to prevent self-heating and quality damage. [32]

During trials where grain was harvested at 30°C and 15.5% MC, 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 from November to March.

Before replicating these results on the farm, growers need to:

- Know the capacity of their existing aeration system.
- Determine whether grain requires drying before cooling can be carried out.

31 Aeration cooling for pest control. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/aeration-cooling/; Keeping aeration under control (2010) Farming Ahead. No. 208, March 2010. Kondinin Group, http://storedgrain.com.au/wp-content/uploads/2013/06/Kondinin-Group-Report-Aeration-Controllers-Reduced.pdf

32 P Burrill, P Botta, C Newman, B White, C Warrick (2014) Storing pulses. Fact sheet. Updated July 2014, https://grdc.com.au/Resources/Factsheets/2014/07/Grain-Storage-Fact-Sheet-Storing-Pulses.

MORE INFORMATION

Aeration cooling for pest control.

- Understand the effects of relative humidity and temperature when aerating stored grain.
- Determine the target conditions for the stored grain.

Air movement within the stack

The grain at the top of the stack is the hottest, as heat rises through the grain and the top grain is exposed to the head space in the silo (Figure 9).

As the air in the head space heats and cools each day, it creates ideal conditions for condensation to form. If this happens, the grain on the top of the stack will get wet.

Be aware that aeration drying requires specifically designed equipment and the process is much slower than aeration cooling or hot-air drying.

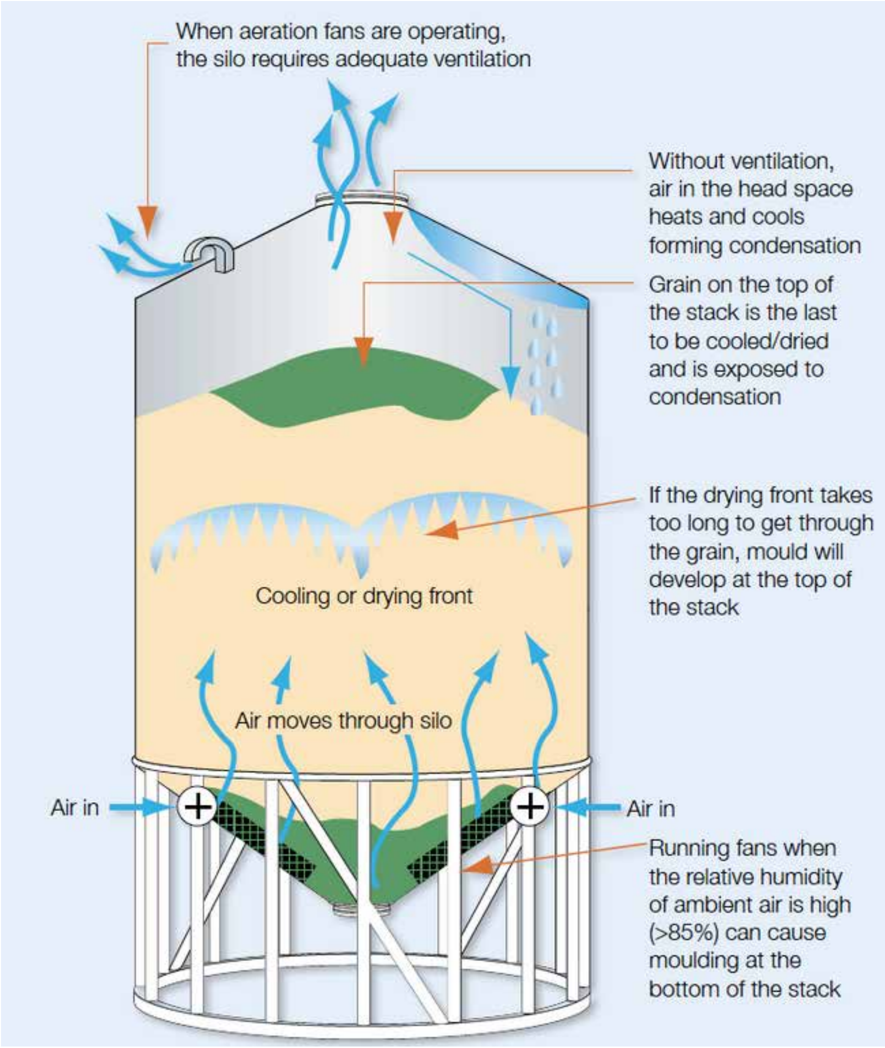


Figure 9: *Air movement within an aerated silo.*

Source: Stored Grain Information Hub

The cooling process

Operating an aeration fan for cooling requires a planned control program, which is best done with an automatic aeration controller. But even without a controller, growers need to aim for the same run time, following the same process.

The initial aim is to get maximum airflow 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 and 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 per cent 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 the running time to 9–12 hours per day during the coolest part of the day, 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, for an average of 100 hours per month.

Grain temperature is gradually reduced as low as possible and then maintained throughout the storage period.

Achieving reliable results with aeration cooling

Tips for producing the best results using aeration:

- Fan operations—replace manual switching or timers with automatic controllers to provide reliable, consistent cool grain temperatures. Buy them from a trustworthy supplier.
- Maintenance—manually test individual silo fans to check there are no electrical faults. For auto-controllers, check that the temperature and humidity sensor is clean. Also compare its readings with a reliable hand-held thermometer and RH (relative humidity) reader.
- Fan operations—ensure fans are stepped through the three important stages of aeration cooling. The most recent auto-controller models (e.g. Grainsafe-5000) automate this procedure over the first two weeks of storage.
- Fan performance—during 2011–2012 an Australian research group developed a simple, accurate method for testing the air-flow performance of aeration fans while they are operating. The recommended air-flow rate for cooling grain is 2–3 L/s/t of grain in the storage. Field tests on farm storages have shown that some fans do not deliver these rates. [33]

MORE INFORMATION

GRDC Performance testing aeration systems Fact sheet.

The risks of getting it wrong

Once in maintenance mode, running aeration fans on timers that are preset to run at the same time each day will not ensure the selection of the most appropriate air to maintain grain quality. The biggest risk with running aeration fans without a controller is forgetting to turn them off, or not being available to, if the relative humidity exceeds 85%.

Operating fans for extended periods of a few hours or days during 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. [34]

Weevil development ceases at temperatures below 20°C. This is a strong incentive for aeration cooling, especially if gas-tight storage is not available. [35]

MORE INFORMATION

Aeration cooling for pest control.

33 P Burrill (2013) Grain storage: future pest-control options and storage systems 2013–2014. GRDC Update Papers. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014

34 Aeration cooling for pest control. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/aeration-cooling/

35 Storing pulses. Stored Grain Information Hub. GRDC, https://grdc.com.au/Resources/Factsheets/2014/07/Grain-Storage-Fact-Sheet-Storing-Pulses

WATCH: GCTV2: Grain storage cooling aeration.

Installation and management tips

When retrofitting an aeration system, avoid splitting airflow from one fan to more than one storage. Each storage will provide a different amount of back-pressure on the fan, resulting in uneven airflow 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 weather. To avoid the chance of a dust explosion, do not install aeration controllers in a confined space.

Ensure your electrician installs wiring that is properly insulated and protected from potentially damaging equipment, such as augers.

Monitoring is a must

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 (Figure 10).

Figure 10: *Temperature check: monitor the effectiveness of the cooling process by checking grain temperature with a probe or a thermometer taped to a rod.*

Source: Stored Grain Information Hub

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 of whether the system is working. The exhaust 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. [36]

13.1.8 Aeration drying

Ambient air can also be used to dry grain. Here, air is pumped through the grain bulk at high flow rates and at a temperature and humidity that will remove water from the grain (see Table 5). [37]

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 occurs more readily with hot-air dryers.

36 Aeration cooling for pest control. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/aeration-cooling/

37 GRDC (2004) How aeration works. Grains Research Update Advice. GRDC, https://grdc.com.au/uploads/documents/Grains-Research-Update-Advice-How-Aeration-Works.pdf

Unlike aeration cooling, drying requires high airflow rates of at least 15–25 L/s/t and careful management.

Aeration drying relies on a high air volume and is usually done in a purpose-built drying silo or a partly filled silo with high-capacity aeration fans. Aeration drying is a slow process and relies on four keys:

- High airflow rates.
- Well-designed ducting for even airflow through the grain.
- Exhaust vents in the silo roof.
- Warm, dry weather conditions.

It is important to seek reliable advice on equipment requirements and correct management of fan run times, otherwise there is a high risk of damaging grain quality.

Management strategies

If ambient air conditions are such that grain will dry, fans should be turned on and left on. When conditions are such that grain is no longer drying, turn the fans off, and only turn them back on when air conditions will again allow grain to dry. The moisture content that grain will dry to is determined by the average condition of the air used. If the average condition of air used is too dry, grain below the drying front will be over-dried. To calculate if air of a certain quality will dry grain, training in calculating the equilibrium moisture content is needed. The data presented in Table 6 provides a rough guide. It should be noted that different types of grain have slightly different equilibrium grain moistures.

Table 6: *Approximate moisture content of grain resulting from aeration with air at various temperatures and humidity (equilibrium grain moisture content).*

Temp °C	Relative humidity (%)				
	30	40	50	60	70
15	9.8	11	12.1	13.4	15
25	9	10.3	11.4	12.8	14
35	8.5	9.7	10.7	12.0	13.5

Source: GRDC.

Automated controllers simplify the process of selecting air that is suitable for drying. If air conditions are such that drying will not occur, supplemental heating can be used to raise the air inlet temperature a few degrees. This greatly increases the potential of that air for drying, but care should be taken not to over dry. If supplementary heating is unavailable and the available air will not dry the grain, a short-term holding measure may be to change strategy and cool the grain, with the intent of maintaining its quality, until better quality air for drying is available. The grain is placed at risk of mould development if air conditions do not improve in the short term; and this risk is far greater if air of suitable quality to cool grain is also unavailable.

The best air for drying is often from midday to dusk, but this varies from region to region. There are 50 locations around Australia where the drying potential of air has been monitored and recorded over many years. This data can provide information on the frequency of air suitable to dry grain from varying moisture contents and will assist in determining if supplemental heating is likely to be needed. It also gives insight as to the time of the day when the best air quality for cooling or drying is likely to occur. [38]

High airflow for drying

Unlike aeration cooling, aeration drying requires high airflow, in excess of 15 L/s/t, to move drying fronts quickly through the whole grain profile and depth and carry moisture out of the grain bulk. As air passes through the grain, it collects moisture

38 GRDC (2004) How aeration works. Grains Research Update Advice. GRDC, https://grdc.com.au/uploads/documents/Grains-Research-Update-Advice-How-Aeration-Works.pdf

and forms a drying front. If airflow is too low, the drying front will take too long to reach the top of the grain stack – often referred to as a 'stalled drying front.' Providing the storage has sufficient aeration ducting, a drying front can pass through a shallow stack of grain much faster than a deep stack of grain. As air will take the path of least resistance, make sure the grain is spread out to an even depth.

Ducting for drying

The way to avoid hot spots is with adequate ducting to deliver an evenly distributed flow of air through the entire grain stack (Figure 11). A flat-bottom silo with a full floor aeration plenum is ideal providing it can deliver at least 15 L/s/t of airflow. The silo may only be able to be part filled, which in many cases is better than trying to dry grain in a cone-bottom silo with insufficient ducting.

Figure 11: *Aeration drying requires careful management, high airflow rates, well designed ducting, exhaust vents and warm, dry weather conditions.*

Source: GRDC.

Venting for drying

Adequate ventilation maximises airflow and allows moisture to escape rather than forming condensation on the underside of the roof and wetting the grain on the top of the stack. The amount of moisture that has to escape with the exhaust air is 10 L for every one per cent moisture content removed per tonne of grain.

Weather conditions for drying

For moisture transfer to occur and drying to happen, air with a lower relative humidity than the grain's equilibrium moisture content must be used. For example, Table 8 shows that grain at 25°C and 14% moisture content has an equilibrium point of the air around it at 70% relative humidity. In order to dry this grain from its current state, the aeration drying fans would need to be turned on when the ambient air was below 70% relative humidity.

Phase one of drying

Aeration drying fans can be turned on as soon as the aeration ducting is covered with grain and left running continuously until the air coming out of the top of the storage has a clean fresh smell. The only time drying fans are to be turned off during this initial, continuous phase is if ambient air exceeds 85% relative humidity for more than a few hours.

Phase two of drying

By monitoring the temperature and moisture content of the grain in storage and referring to an equilibrium moisture table, such as Table 7, a suitable relative humidity trigger point can be set. As the grain is dried down the equilibrium point will also fall, so the relative humidity trigger point will need to be reduced to dry down the grain further. Reducing the relative humidity trigger point slowly during phase two of the drying process will help keep the difference in grain moisture from the bottom to the top of the stack to a minimum, by ensuring the fans get adequate run time to push each drying front right through the grain stack.

Table 7: *Equilibrium moisture content for wheat. NOTE: values may be different for other grains.*

Relative humidity (%)	Temperature 15	Temperature 25	Temperature 35
	Grain moisture content %		
30	9.8	9.0	8.5
40	11.0	10.3	9.7
50	12.1	11.4	10.7
60	13.4	12.8	12.0
70	15.0	14.0	13.5

Source: GRDC.

Supplementary heating

Heat can be added to aeration drying in proportion to the airflow rate. Higher airflow rates allow more heat to be added as it will push each drying front through the storage quick enough to avoid over heating the grain close to the aeration ducting. As a general guide, inlet air shouldn't exceed 35°C to avoid over heating grain closest to the aeration ducting.

Cooling after drying

Regardless of whether supplementary heat is added to the aeration drying process or not, the grain should be cooled immediately after it has been dried to the desired level. [39]

MORE INFORMATION

Dealing with high moisture grain.

39 GRDC Stored Grain Information Hub: Dealing with high moisture grain. http://storedgrain.com.au/dealing-with-high-moisture-grain/

WATCH: Aeration drying – getting it right.

MORE INFORMATION

Aerating stored grain: cooling or drying for quality control.

13.1.9 Cooling or drying: making a choice

It can be difficult to know whether grain needs to be dried or cooled, but there are some simple rules of thumb to help you decide. For longer-term storage grain must be lowered to the correct moisture content. Grain that is dry enough to meet the 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 (for example, 16% or more for wheat) will require immediate moisture reduction before cooling for maintenance. [40]

13.1.10 Aeration controllers

Aeration controllers manage both aeration drying, cooling and maintenance functions in up to ten separate storages (Figure 12). The unit it takes into account the moisture content and temperature of grain at loading, the desired grain condition after time in storage and selects air accordingly to achieve safe storage levels.

A single controller has had the ability to control the diverse functions of aeration: cooling, drying and maintenance. The controller can not only combine the ability to control all three functions, but automatically selects the correct type of aeration strategy to obtain the desired grain moisture and temperature. [41]

Research has shown 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.

40 Aeration cooling for pest control. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/aeration-cooling/

41 GRDC. (2007). Ground Cover Issue 57 – New Generation in aeration controller. https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-57-Grain-Storage-Supplement/New-generation-aeration-controller

- Determine the target conditions for the stored grain.

Figure 12: *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.

WATCH: Aeration controllers with Philip Burrill.

MORE INFORMATION

Performance testing aeration systems.

13.1.11 Structural treatments for chickpea storage

Chemical sprays are not registered for pulses in any state in Australia. While there is a maximum residue limit (MRL) for dichlorvos on lentils, the product is only registered for use on cereal grains.

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.

One possibility of a structural treatment is using diatomaceous earth (DE), an amorphous silica that is sold commercially as Dryacide®. It acts by absorbing the insect's cuticle or protective waxy exterior, causing death by desiccation. Before applying DE for use with pulses, wash and dry the storage and all equipment to be used in the application to remove any residues left from previous years. This will ensure the DE doesn't discolour the grain surface. If applied correctly, with complete coverage in a dry environment, DE can provide up to 12 months of protection for storages and equipment. [42]

If unsure, check with the grain buyer before using any product that will come into contact with the stored grain.

Application

Inert dust requires a moving airstream to direct it onto the surface being treated; alternatively, it can be mixed into a slurry with water and sprayed onto surface. Follow the label directions. Throwing dust into silos by hand will not achieve an even coverage, and so will not be effective. For very small grain silos and bins, a hand-operated duster, such as a bellows duster, is suitable. Larger silos and storages require a powered duster operated by compressed air or a fan. If compressed air is available, it is the most economical and suitable option for use on the farm; connect it to a Venturi duster (e.g. Blovac BV-22 gun) (Figure 13).

Figure 13: *A blower/vacuum or Venturi gun are the best applicators for inert dusts. Aim for an event coat of diatomaceous earth across the roof, walls and base.*

Photo: C. Warrick, Proadvice

The application rate is calculated at 2 g/m^2 of the surface area treated. Although DE is inert, breathing in excessive amounts of it is not ideal, so use a disposable dust mask and goggles during application (see Table 8).

Silo application

Apply inert dust in silos, starting at the top (if safe), by coating the inside of the roof then working your way down the silo walls, finishing by pointing the stream at the bottom of the silo. If silos are fitted with aeration systems, distribute the inert dust into the ducting without getting it into the motor, where it could cause damage. [43]

42 Storing pulses. Stored Grain Information Hub. GRDC, http://storedgrain.com.au/storing-pulses/

43 Pulse Australia (2013) Northern Chickpea—Best Management Practices Training Course Manual 2013. Pulse Australia.

MORE INFORMATION

Hygiene and structural treatments for grain storages Fact sheet.

Table 8: *Diatomaceous earth application guide.*

Storage capacity (t)	Dust quantity (kg)
20	0.12
56	0.25
112	0.42
224	0.60
450	1.00
900	1.70
1,800	2.60

WATCH: GCTV7: Applying diatomaceous earth demonstration

13.1.12 Fumigation

The only control options against stored pests are phosphine, an alternative fumigant, or a controlled atmosphere.

Protectant insecticide sprays, as commonly used to protect cereal grains against insect infestations, cannot be used with pulses. Phosphine is the only fumigant currently registered for use in pulses (Figure 14), and successful fumigation requires a storage that can be sealed gas-tight.

Figure 14: *Phosphine is widely accepted as having no residue issues.*

Photo: DAF Qld

There is some resistance to phosphine, the grain industry has adopted a voluntary strategy to manage the build-up of phosphine resistance in pests. Its core recommendations are to limit the number of conventional phosphine fumigations on undisturbed grain to three per year, and to employ a break strategy. Phosphine is widely accepted as causing no residue problems. [44]

Maximum residue limits

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.

Measures growers need to take to avoid MRL violations are detailed in a new *Grain Marketing and Pesticide Residues* Fact Sheet, produced by the Grains Research and Development Corporation (GRDC). The Fact Sheet states 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. [45]

MORE INFORMATION

Managing MRLs factsheet

44 P Collins (2009) Strategy to manage resistance to phosphine in the Australian grain industry. Cooperative Research Centre for National Plant Biosecurity, http://www.graintrade.org.au/sites/default/files/file/NWGP/Phosphine%20Resistance%20Strategy.pdf

45 S Watt. (2014). Know your maximum residue limits. https://grdc.com.au/Media-Centre/Media-News/South/2014/07/Know-your-maximum-residue-limits

Phosphine application

You achieve effective fumigation by placing phosphine tablets at the rate directed on the label onto a tray and hanging the tray in the top of a pressure-tested, sealed silo, or into a ground-level application system if the silo is fitted with recirculation. Keep the silo sealed for 7–10 days: seven days if the grain temperature is above 25°C, and 10 days if it is 15–25°C. Do not fumigate if the temperature inside the silo is less than 15°C as insects will not be active and the phosphine will therefore be ineffective. After the waiting period, open the top lid of the silo and ventilate grain for a minimum of one day with aeration fans running, or five days if no fans are fitted. A minimum withholding period of two days is required after ventilation before grain can be used for human consumption or stock feed. The total time required for fumigating ranges from 10–17 days. Read label directions.

When using phosphine, it is important that gas concentrations are held at high levels for the full fumigation exposure time. Immature stages of the insects and resistant strains that are being found more frequently will be controlled by phosphine only in a sealed, gas-tight storage. Phosphine is toxic to people as well as insects, so do not handle treated grain before the completion of the 7–10-day exposure period and the required airing period.

Fumigating in silo bags

In some situations, growers may find it difficult to gain access to a sealable, gas-tight silo in which to carry out effective fumigation of infested grain. Trials have shown that a silo bag can be used successfully for fumigation with phosphine when using the correct procedure.

Key steps:

- A gas-tight seal—inspect the silo bag and repair any minor holes.
- Correct phosphine tablet dose—apply in multiple grain spears evenly placed 7 m apart
- Allow a 14-day fumigation period.
- Vent the gas safely using a standard F650 aeration fan.

High concentrations of phosphine can be maintained for the required length of time to fumigate grain successfully in a silo bag. Fumigation trials on a standard 75-m-long bag containing ~230 t of grain were successful in controlling all life stages of the lesser grain borer.

When using phosphine in silo bags, remember that it is illegal to mix phosphine tablets with grain because of residue issues. Separate them by using perforated conduit to contain tablets and spent dust. The 1-m tubes can be speared horizontally into the silo bag and removed at the end of the fumigation. Trial results suggest that the spears should be no more than 7 m apart and fumigation should occur over 12–14 days. In previous trials when spears were spaced 12 m apart, the phosphine diffused through the grain too slowly. [46]

Fumigating in silos

The standard recommended practice for phosphine application has been to place tablets in trays in the sealed silo headspace. For small- and medium-sized silos (i.e. less than 150 t capacity) this is an effective method. The phosphine gas only takes approximately 24 hours to diffuse from the top to the bottom, through the 5–7 m depth of grain to the base of the silo.

For larger, taller silos (over 150 tonnes), however, it can take two or more days for phosphine gas to reach the grain in the base of the silo. This can be a problem for a standard 7 or 10-day fumigation period, because any infested grain at the bottom does not get enough exposure to high gas concentrations to kill all stages of the insects.

46 Silo bag fumigation (2012) Northern Update, Issue 66, Spring 2012. GRDC, http://www.icanrural.com.au/newsletters/NL66.pdf

The answer is recirculation. This is simply a system of adding plumbing to the silo to connect the silo base with the top of the silo to speed up the movement of gas through all grain in it. Recirculation should provide faster, more uniform gas distribution.

A number of silo manufactures now offer silos fitted with PVC tubes that run down the outside of silos from top to bottom. The complete system, including the silo itself, still needs to be well sealed so that it is gas-tight. Otherwise gas will leak out and the fumigation will fail to kill all the pests.

The two main systems are:

- Recirculation—has silo roof-to-base plumbing, with the addition of a small aeration fan that is used to force the phosphine gas around the silo. The critical time to have this operating is during the first 3–4 days, while tablets are liberating gas.
- Thermosiphon—has the same plumbing arrangement as the recirculation system, without the use of an electric fan. The heating and cooling of the silo head space and the black piping down side of the silo (passive heat exchange) is used to help generate air currents which distribute the phosphine gas.

A useful piece of equipment is a ground-level application box. To assist with safety and reduce the amount of time climbing silos to place tablets, phosphine tablets or bag chains can be placed in appropriate structures or containers on the ground at the base of the silo. These are often part of a recirculation system and connect to the internal aeration ducting.

Whatever system is used, it is very important to ensure it is designed so that it has ample space for tablets with free gas flow, to prevent the phosphine gas concentrations building up above the flammable limit, above 17,000 ppm, when it becomes explosive. Do not restrict gas movement with small containers for tablets or small-diameter pipe while gas is liberated in the first 3–4 days. Seek advice to ensure only safe designs are used. [47]

Non-chemical treatment options

Non-chemical treatments include:

- Carbon dioxide—treatment with CO_2 involves displacing the oxygen inside a gas-tight silo with CO_2, which creates a toxic atmosphere to grain pests. 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.
- Nitrogen—grain stored under N_2 also provides insect control and quality preservation without chemicals. It is safe to use, and environmentally acceptable, and the main operating cost is the capital cost of equipment and electricity. It also leaves no residues, so grains can be traded at any time, unlike with chemical fumigants, which have withholding periods. Insect control with N_2 involves using pressure-swing adsorption (PSA) technology, and works by modifying the atmosphere inside the grain storage to remove everything except N_2, thereby starving the pests of oxygen. [48]

The carbon dioxide and nitrogen methods are sometimes referred to as a controlled atmosphere, because the composition of air in the silo is changed. They are more expensive than using phosphine, but they offer an alternative for resistant pest species.

MORE INFORMATION

Fumigating with phosphine, other fumigants and controlled atmospheres.

47 P Burrill (2013) Grain storage: future pest-control options and storage systems 2013–2014. GRDC Update Papers. GRDC, https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014

48 C Warrick (2011) Fumigating with phosphine, other fumigants and controlled atmospheres. GRDC, http://www.grdc.com.au/~/media/FC440FBD7AE14140A08DAA3F2962E501.pdf

MORE INFORMATION

GRDC's Stored grain pest identification: The back pocket guide

13.2 Monitoring stored chickpeas

Like cereal grains, chickpeas need to be delivered with nil live storage insects. [49] It is essential that any insect pests present in the on-farm storage are identified so that the best use of both chemical and non-chemical control measures can be exploited to control them.

Growers are advised to monitor all grain storages every two weeks during warmer periods of the year and at least monthly during cool periods (Figure 15). Use sieving and quality inspections to monitor stored pulses, and keep records of what you find. Use one of the GRDC publications on stored pest identification to help. Also, record any fumigation action taken. If safe, visually check, smell and sample grain at the bottom and top of the stack regularly. [50] Having sample ports fitted in the side of the silos also enables temperature probe checks and grain sampling.

Figure 15: *Keep records of findings from monitoring insects in stored grain.*

Source: DAF Qld

Here are some basic points to follow when monitoring for insect pests in your pulses:

- Sample and sieve grain from the top and bottom of grain storages for early pest detection. Probe or pitfall traps placed into the top of the grain will often detect storage-pest insects before you can see them in your sieve, as the traps remain in the grain all the time.
- Holding an insect sieve in the sunlight will encourage insect movement, making pests easier to see. Sieve samples onto a white tray, again to make small insects easier to see. Sieves should be of 2 mm mesh and need to hold at least 0.5 L of grain.
- One way to help identify live grain pests is to place them into a glass container and hold them in sunlight to warm the grain and insects. This will encourage activity without overheating or killing them. Rice weevils, cowpea bruchids and saw-toothed grain beetles can walk up the walls of the glass easily, but flour beetles and lesser grain borers cannot. Look closely at the insects walking up

49 Pulse Australia (2013) Northern Chickpea—Best Management Practices Training Course Manual 2013. Pulse Australia.

50 P Burrill, P Botta, C Newman (2010) Aeration cooling for pest control. Fact sheet. GRDC, http://www.grdc.com.au/~/media/AB8938CFDCCC4811AD218B45C308BEBD.pdf

MORE INFORMATION

Stored grain Pests Fact Sheet Western Region

the glass. Rice weevils have a curved snout, saw-toothed grain beetles do not; and cowpea bruchids have a globular, tear-shaped body. [51]

13.3 Grain protectants for storage

Grain protectants can be applied to grain for protection against insect infestation, however, they are not allowed to be used in Western Australia.

51 GRDC (2011) Stored grain pests identification: The back pocket guide. GRDC, http://www.grdc.com.au/~/media/8253D697BA6F4BF3AA5B5CBDFA7F4D2D.pdf

Environmental issues

Key messages

- Environmental stresses during seed development have a negative effect on the quality of chickpea seeds.
- Freezing temperatures at the late vegetative stage in chickpea development can cause considerable damage and yield losses.
- Chickpea is prone to waterlogging, and as there are no in-crop control measures to deal with waterlogging, a critical management tool is avoidance of high-risk paddocks (based on previous experience and paddock history). [1]
- Both low and high temperatures can limit the growth and grain yield of chickpea at all phenological stages. Temperature is a major environmental factor regulating the timing of flowering thus influencing grain yield.
- After disease, the major constraint to greater chickpea production is its sensitivity to the end-of-season drought that occurs in both the Mediterranean-type climates and when grown on stored soil moisture in the summer- rainfall region of Australia. Unlike many other crops, chickpea is unable to escape this terminal drought through rapid development because low temperatures (less than 15°C) often cause flower and pod abortion.
- Chickpea is sensitive to salinity, and can have difficulty accessing water and nutrients from saline layers in the soil.
- Chickpea is classified among the most sensitive of all field crops to sodic soil conditions.

14.1 Frost issues for chickpeas

Radiant can be frost is a major stress to crops, and one of the principal limiting factors for agricultural production worldwide, including Australia. Radiant frosts occur when plants and soil absorb sunlight during the day and radiate heat during the night when the sky is clear and the air is still. Dense, chilled air settles into the lowest areas of the canopy, where the most serious frost damage occurs. The cold air causes the plasma membrane in plant tissues to rupture. [2]

The historical incidence of frost greatly varies across the agricultural regions of WA, with greatest occurrence in the central, eastern and southern regions. Northern and coastal regions in general have a lower risk.

In 2016 parts of WA felt the effect of very damaging frost, with some growers around Kondinin facing crop losses of up to ~70%. [3]

Legumes, including chickpeas, field peas, faba beans and lentils, are very sensitive to chilling and freezing temperatures, particularly at the stages of flowering, early pod formation and seed filling, although damage may occur at any stage of development.

Frosts (or isolated freezing events) are a problem for chickpeas (Figure 1) in south-western Australia, especially when they occur in the late vegetative and reproductive phenological (climate-induced developmental) stages, and the air temperature drops to 2°C or less on clear nights in early spring. They occur most frequently after the

1 W Parker. Desi Chickpea Essentials. DAFWA, https://www.agric.wa.gov.au/chickpeas/desi-chickpea-essentials

2 A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops: a review. Euphytica 172 (1), 1–12.

3 B Varischetti. (2016). Frost wipes out 70 per cent of WA farmer's wheat crop. ABC Rural. http://www.abc.net.au/news/2016-10-05/frost-devastation-in-konindin/7906428

passing of a cold front, when the moisture and wind dissipates, leaving cold and still conditions with clear skies.

Figure 1: *Frost damage to a chickpea crop.*

Source: ABC Rural 2013

The occurrence and extent of frost damage tends to be affected by the microclimate, with great variability occurring within paddocks and even on the same plant. Frost conditions can be amplified by climatic conditions such as clear sky, dry atmosphere, and windless conditions.

Soil type, soil moisture, position in the landscape, and crop density can also have a bearing on the damage caused by a frost event. In some species, crop nutrition has been shown to mitigate the effect of freezing range temperatures on the plant. It is thought that fertilisation of the plant, and consequent fast growth rates, can exacerbate the effect of freezing, particularly on the part of the plant undergoing elongation. [4]

WATCH: GCTV20: Extreme temperature analysis to better understand Frost events.

MORE INFORMATION

The science of frost

4 A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops—a review. Euphytica, 172(1), 1–12.

14.1.1 Impacts on chickpea

Chickpeas are rated as one of the least tolerant pulses to frost events (Table 1).

Table 1: *Order of frost tolerance in pulses.*

Crop in order of tolerance (highest to lowest)	Notes
Faba beans	Faba beans have a medium tolerance to frost due to thick pod walls, which provide insulation to the developing seed.
Lupins	Lupins have a low frost tolerance and are generally unable to compensate after flowering.
Field peas	Field peas have a low tolerance due to thin pods walls and exposure of the pods to the atmosphere.
Chickpeas	Chickpeas have a low tolerance to frost due to the exposed nature of the flowers.

Source: DAFWA

Though chickpea seedlings are tolerant of frost, the plants have low tolerance to frost during the flowering stage due to the exposed nature of flowers.

Isolated frost events during the reproductive stage commonly result in flower or pod abortion, and this can be detrimental to yield in environments that experience terminal drought.

During frost events, the temperature decreases to levels cold enough to cause nucleation of the intracellular fluid and the subsequent rupturing of the plasma membrane. Damage can also be caused via dehydration of cells as a result of the freezing of the extracellular spaces. [5]

Symptoms of frost in chickpeas:

- Leaf margins are bleached.
- Flowers are killed.
- Growing points are sometimes distorted (bent) during early vegetative and flowering stages.
- Pods may develop, but seeds abort.
- Even after a frost, chickpeas will continue to flower and set pods well into spring. [6]

Damage to vegetative growth

Damage is more likely to occur where the crop has grown rapidly during a period of warm weather, and is then subjected to freezing temperatures. In chickpea, the elongation regions are often the first affected by freezing, and this can show up in a frost-damaged plant by sigmoidal curves around the elongation point—commonly referred to as 'hockey stick' symptom. Depending on the minimum temperature and the duration of the frost, plants may be partially damaged or killed, resulting in lower yield and quality at harvest or even complete crop failure.

Sub-zero temperatures in winter and spring can damage leaves and stems of the plant. Frosts can cause bleaching of leaves, especially on the margins, and a 'hockey-stick' bend (Figure 2). However, chickpea has an excellent ability to recover from this superficial damage and is able to regenerate new branches in severe cases. Late frosts also cause flower, pod and seed abortion.

5 A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops—a review. Euphytica, 172(1), 1–12.

6 B Biddulph. (2016). Frost: diagnosing the problem. DAFWA. https://www.agric.wa.gov.au/frost/frost-diagnosing-problem?page=0%2C1

Figure 2: *Frost can cause bends like a hockey stick in chickpea stems.*

Photo S Loss. Source: DAFWA

Visible effect may occur as patches in the field, or on individual plants or branches of plants. Damage is usually more severe where stubble has been retained. Regrowth will generally occur provided soil moisture levels are adequate.

Chickpea may be able to recover to flower and set pods following an isolated frost event during the reproductive growth stage, provided soil moisture conditions are favourable during the subsequent periods.

In the field, frost tolerance decreases from the vegetative stage to reproductive stage. [7]

Damage to flowers and pods

Freezing temperatures damage leaves and destroy flowers and young developing seed (Figures 3 and 4). The time and duration of flowering affects tolerance and the ability to compensate after the frost has occurred. Early flowers are often aborted in chickpea, but if soil moisture is available long-duration cultivars compensate for the loss. Frosts that occur toward the end of the reproductive period following pod-set are more damaging, resulting in the abortion of pods and large yield reduction. [8]

Frost will normally affect the earliest formed pods low on the primary and secondary branches. By contrast, pod abortion induced by moisture stress is normally noted on the last-formed pods at the tips of the branches. Pods at a later stage of development are generally more resistant to frost than flowers and small pods, but may suffer some mottled darkening of the seed coat. Varieties with an extended podding period can compensate for damage better than varieties that tend to pod up over a shorter period provided soil moisture levels are adequate.

Minimum temperatures below 5°C during the reproductive stage will kill the crop, but new regrowth can occur from the base of the killed plants if moisture conditions are favourable. [9]

Frost is most damaging to yield:

- when it occurs during later flowering–early pod fill; and

7 A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops—a review. Euphytica, 172(1), 1–12.

8 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

9 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013.

- under dry conditions where moisture limits the plant's ability to re-flower and compensate for frost damage.

Figure 3: *Frost damage to leaves.*

Photo: G: Cumming, Source: Pulse Australia

Figure 4: *Frosted chickpea at flowering.*

Source: Pulse Australia

14.1.2 Industry costs

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 management 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 such as barley and oats; and
- avoiding cropping on the valley floors, which also contain some of the most productive parts of the landscape.

MORE INFORMATION

Pulse and canola – Frost identification, Back pocket guide.

WATCH: GCTV20: Frost's emotional impact, is it greater than its economic impact?

14.1.3 Managing to lower frost risk

The different conditions under which the frost occurs will influence what management practices will be more effective. Management practices include:

- Delay flowering.
- Avoid high inputs.
- Sow more frost tolerant crops and pastures.
- Grow hay.
- Avoid sowing susceptible crops in frost prone areas, such as low-lying areas.
- Sow and graze dual-purpose crops.
- Encourage cold air drainage. Consult a specialist.
- Clay sandy-surfaced paddocks.

Frost risk is difficult to manage in pulses, however some management strategies may reduce the risk or the extent of damage. These include:

- Knowing 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 to reduce exposure or impact at vulnerable growth stages.
- Carefully assessing the soil type, condition, and soil-moisture levels, and managing stubble and the crop canopy.
- Correcting crop nutrition and minimising stressors of the crop to influence the degree of frost damage.

Ensure crops have an adequate supply of trace elements and macronutrients. 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. [10]

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 occurs is also important for crop management.

10 Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November, http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

Crop and sowing time

The main strategy used to minimise frost risk in broadacre cropping has been to sow crops later. Risks exist with delayed sowing, even though this practice can reduce the probability of crops flowering in a frost-risk period. Crops sown later can still be affected by frost.

Strategies to minimise frost damage in pulses work in combinations of:

- 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
- ensuring that most grain is sufficiently filled to avoid damage when frost occurs (Table 1).

Targeting flowering and early podding to periods of the lowest probability of frost is achieved through combinations of sowing date and variety choice based on flowering time and flowering duration. Local experience will indicate the best choices.

By planting for late flowering, farmers target the avoidance of early frosts, but in the absence of frost, late flowering may reduce yields if moisture is deficient or there are 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.

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 use for the pulse in paddocks with a high frost risk provides flexibility.

Mixing two pulse varieties (e.g. long and short season, tall and short) balances the risks of frost and of end-of-season (terminal) drought, and reduces the risk of losses from any one-frost event. Multiple frost events can damage both varieties. If grain from both varieties is not of the same delivery grade, then only the lowest grade is achieved. The only realistic, practical options are in peas, narrow-leafed lupins, kabuli chickpeas; perhaps desi chickpeas are an option. Differences in flowering times are minimal in lentils and beans.

Sowing a mixture of pulse species is feasible, but not common. Complications in crop choice include achieving contrasting grain sizes, herbicide requirements, harvest timing and grain cleaning. Multiple frosts may damage both crops. Pulses grown in a mix will be suitable for feed markets only unless they can be cleaned to enable purity in segregation. If these difficulties can be overcome there is an opportunity for alternate-row sowing of different pulses.

Reduce frost damage

Managing inputs

To minimise financial risk in frost-prone paddocks when growing susceptible crops, growers can:

- Apply conservative rates of fertilisers to frost-prone parts of the landscape.
- Avoid using high sowing rates.

Advantages of avoiding high inputs are:

- Less financial loss if the crop is badly frosted.

- Lower-input crops, though potentially lower yielding during favourable seasons, are less like to suffer severe frost damage than higher-input crops with a denser canopy.
- Input costs saved on the higher frost-risk paddocks may be invested in other areas where frost risk is lower.

Lower sowing rates may result in a less dense canopy and may allow more heating of the ground during the day, and transfer of this heat to the canopy at night. However, there is no hard evidence that lower sowing rates will reduce frost damage.

The main disadvantage of this practice is that in the absence of frost, lower grain yield and/or protein may be the result during favourable seasons, contributing to the hidden cost of frost. (This is a particular disadvantage in barley and wheat delivery grades.) Less-vigorous crops can also result in the crop being less competitive with weeds.

Managing nodulation and nutrition.

Ensure pulse crops are adequately nodulated and fixing nitrogen. Ensure pulses have an adequate supply of trace elements and macronutrients, although 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.

Use soil tests to calculate conservative fertiliser rates. The Department of Agriculture and Food, Western Australia (DAFWA) has made available decision tools for nutrient management.

Managing the canopy

A bulky crop canopy and exposure of the upper pods may increase frost damage to pulses. Semi-leafless, erect peas may be more vulnerable than conventional, lodging types because their pods are more exposed. A mix of two varieties of differing height, maturity and erectness may also assist in reducing frost damage.

Sow in wider rows

Sowing wider rows may mean 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, however this may not always be effective. This strategy may allow more airflow through crops, allowing soil heat to rise up to canopy height during frosts. Previous trial work has shown that wide-row sowing can have some effectiveness on both sandy and heavy-texture soil. However, there is a 1% yield loss per inch increase in row spacing and compromised weed control.

Channel cold air flow away from the susceptible crop by using wide rows aligned up and down the hill or slope. Where cold air settles, a sacrifice area may be required.

Stubble management

The presence of cereal stubble makes the soil cooler in the 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 types. [11]

Sow a mixture of long season and short season varieties

This practice expands the period of flowering and different canopy heights may create a more undulating crop that could assist the emission of warm air from the soil to buffer cold temperatures around the crop heads on frost nights. Blending

11 Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November, http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

varieties is not usually recommended due to higher cost of seed, extra time required for sowing and the potential contamination of non-frosted grain from one variety with frosted grain from the other resulting in quality downgrading at delivery. To achieve the highest grade, grain from both varieties must be suitable for delivery to the same grade.

Lower sowing rates

A low sowing rate may allow a more open canopy. It also allows any heat in the soil to transfer to canopy height, reducing frost damage. This practice is not usually recommended but as the thinner crop is less competitive with weeds and crop yield potential is limited if a major frost event does not occur.

Cross sowing

Crops are sown twice with half the seed sown in each run producing an even plant density and generating a complete crop canopy that still allows air flow. Two trials across two seasons have been carried out in WA. In one trial a conventionally-sown wheat crop was compared with a cross-sown wheat crop at varying sowing rates. The conventionally sown crop experienced more frost damage and lower yields at all sowing rates compared with cross-sown crops. Cross sowing is not usually recommended due to the additional cost and time taken to sow the paddock twice and the minimum trial work that has been done to look at the impact of cross sowing. [12]

Roll sandy and loamy clay soil after seeding

This practice consolidates moist soil providing a reduced surface areas. This enables more radiant heat to be trapped and stored during the day compared with dry, loose soil. Moist and firm soil is a better conductor of heat and will cool slowly because heat removed at the surface by radiation is replaced in part by heat conducted upwards from the warmer soil below. A roller is usually towed behind the seeder machinery or it can be done post-emergent. Rolling is not usually recommended due to the extra expense, extra time required, inconsistent effectiveness, inter-row weed germination and increased wind erosion risk on susceptible soil types.

Rolling can help keep soils warm by slowing soil-moisture loss, but not necessarily on self-mulching or cracking soils. Note that press wheels roll only in the seed row, and 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 increases the ability of the soil to absorb and hold heat by making the soil colour darker, and retaining moisture nearer the surface.

Increase carbohydrate levels

Higher carbohydrate levels in the plant during frost leads to less leakage during thawing. 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 plants to increase plant carbohydrates is unknown. [13]

A five-year research project funded by GRDC examined the effects of agronomic practices on frost risk in broadacre agriculture in southern Australia. The researchers manipulate the soil heat bank to store heat during the day and release heat into the canopy of the crop at night. The research examined how the crop canopy could be manipulated to allow for warm air from the soil to rise and increase the temperature at crop head height (Figure 5). [14]

12 B Biddulph. (2017). Frost and cropping. DAFWA. https://www.agric.wa.gov.au/frost/frost-and-cropping?nopaging=1

13 Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November, http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

14 M Rebbeck, G Knell (2007) Managing frost risk: a guide for southern Australian growers. SARDI, GRDC.

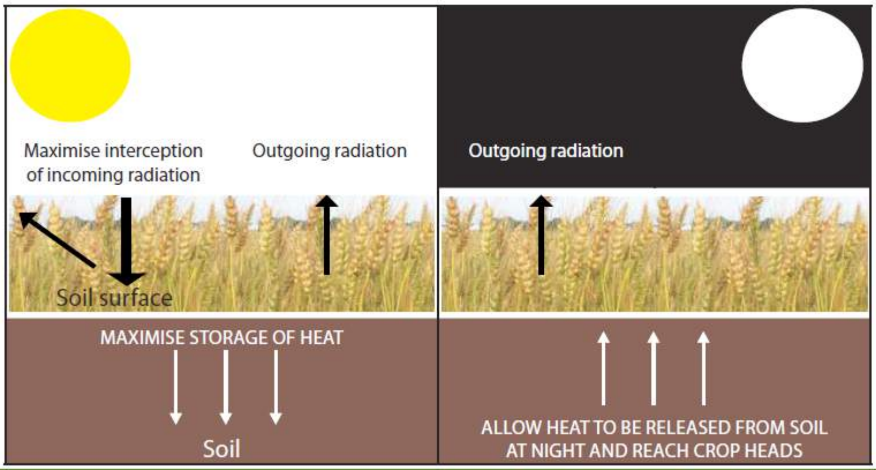


Figure 5: *Temperature dynamics in a crop canopy and canopy interactions.*

Source: Rebbeck and Knell 2007

Importance of soil moisture

Soil moisture is the most important factor for storing soil heat that will be released to and through the crop canopy at night. Because water has a high specific heat, radiation cooling overnight will be reduced when moisture is present in the soil. On a daily basis, heat is transferred into and out of approximately the top 300 mm of soil. When the soil is wet, heat transfer and storage in the upper soil layer is higher, so more heat is stored during daytime for release during the night.

There is also some evidence that moist soils can retain their warming properties for more than 24 hours, allowing some scope for an accumulation of heat from sunlight for more than one day. Heavier textured soils hold more moisture (and therefore heat) than lighter textured soils. Denser soil can hold more moisture within the soil surface for heat absorption and subsequent release. Darker soils also absorb more light energy than lighter soils. Water-repellent sandy soils are usually drier at the surface than normal soils, and are therefore more frost prone. Frost studies in SA have found that crops were likely to be more damaged on lighter soil types because the soil temperature is lower as a result of lower soil moisture and the more reflective nature of these soils. On such soils, clay spreading or delving may be an option for reducing frost risk. [15]

Breeding frost tolerance

Through Pulse Breeding Australia, the GRDC is investing in germ plasm enhancement and variety breeding to increase frost tolerance in pulses. The focus is on 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. [16]

15 M Rebbeck, G Knell (2007) Managing frost risk: a guide for southern Australian growers. SARDI, GRDC.

16 Pulse Australia (2015) Minimising frost damage in pulses. Australian Pulse Bulletin. Updated 20 November, http://pulseaus.com.au/growing-pulses/publications/minimise-frost-damage

MORE INFORMATION

Managing frost risk – Eastern WA

Growing oaten hay for frost prone paddocks

WATCH: Managing the effects of Frost.

14.1.4 Managing frost affected crops

There are a number of options available for managing crops that have been frosted (e.g. Figure 6). Table 2 highlights these options and the pros and cons of each. The suitability of each option will be dependent on the severity of the frost and analysis costs versus returns. [17]

Table 2: *Options to manage frosted crops.*

Option	Advantages	Disadvantages
Harvest	No damage estimates required. Salvage remaining grain. Condition stubble for seeding	Costs may be greater than returns. Need to implement weed control. Threshing problems. Need to remove organic matter.
Hay/Silage	Stubble removed. Weed control.	Cost per hectare. Quality may be poor (especially wheat).
Chain/Rake	Retains some stubble and reduces erosion risk. Allows better stubble handling.	Cost per hectare. Time taken.
Graze	Feed value (Figure 6). Weed control.	Inadequate stock to utilise feed. Remaining grain may cause acidosis. Stubble may be difficult to sow into.
Spray	Stops weed seed set. Preserves feed quality for grazing. Gives time for decisions. Retains feed. Retains organic matter.	Difficulty getting chemicals onto all of the weeds with a thick crop. May not be as effective as burning. Boom height limitation. Cost per hectare. Some grain still in crop.

17 DAFWA (2016) Frost and cropping. https://www.agric.wa.gov.au/frost/frost-and-cropping

Option	Advantages	Disadvantages
Plough	Recycles nutrients and retains organic matter. Stops weed seed set. Green manure effect.	Requires offset discs to cut straw. Soil moisture needed for breakdown and incorporation of stubble.
Windrow	Stops weed seed set. 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 swath. Cost per hectare.
Burn	Recycles some nutrients. Controls surface weed seeds. Permits recropping with disease control. Can be done after rain.	Potential soil and nutrient losses. Fire hazard. Organic matter loss.

Source: DAFWA

Figure 6: *Frosted pulses make excellent quality forage.*

Source: Pulse Australia

MORE INFORMATION

What to do with a frosted crop

14.2 Temperature

Both low and high temperatures can limit the growth and grain yield of chickpea at all phenological stages. Temperature is a major environmental factor regulating the timing of flowering thus influencing grain yield. The production of the cool season chickpea is constrained by low temperatures across much of its geographical range, including southern WA. Cold stress generally occurs in the late vegetative and reproductive stages across the geographical areas of chickpea production. Cold and freezing temperatures (-1.5°C–15°C) are considered a major problem during the seedling stage of winter-sown chickpea in Mediterranean-climate areas and autumn-sown crops in temperate regions. Southern Australia is most affected by chilling temperatures at flowering. On the other hand, high day and night temperatures (above 30/16°C) may cause damage during the reproductive stage on winter-sown chickpea in Mediterranean-climate areas or in season rainfall areas. [18]

Chilling and freezing range temperatures are one of the three most important abiotic stresses (frost, heat stress and drought) causing flower sterility and pod abortion. [19]

18 V Devasirvatham, DK Tan, PM Gaur, RM Trethowan (2014) Chickpea and temperature stress: An overview. Legumes under Environmental Stress: Yield, Improvement and Adaptations, 81.

19 A Maqbool, S Shafiq, L Lake (2010) Radiant frost tolerance in pulse crops—a review. Euphytica, 172(1), 1–12.

14.2.1 Impact of freezing range (below -1.5°C)

Freezing-sensitive plants are damaged or killed by temperatures below -1.5°C. Damage from freezing commonly occurs due to ice forming within the intercellular spaces. The rigid ice lattice structure extends with decreasing temperature and may penetrate cellular walls and membranes to an extent that is irreparable by normal cell processes.

The freezing tolerance of a plant varies greatly between different tissues—that is, upper and lower leaves of the plant canopy, stems, meristems, or roots. Tolerance to freezing range temperatures has been shown to decrease as the plant progresses from the seedling stage (most tolerant) to flowering (least tolerant).

Freezing stress predominantly occurs during the seedling and early vegetative stages of crop growth.

Prolonged periods of freezing range temperatures can prevent germination, reduce the vigour and vegetative biomass of the developing plant, and can be fatal to plants, especially those at the late vegetative and reproductive phenological growth stages.

The main effects of freezing temperatures on the developing seedling are related to membrane injury and include reduced respiration and photosynthesis and loss of turgor, resulting in wilting and temperature-induced drought stress. Some observations have indicated that freezing can reduce seed size and cause seed coat discolouration, probably due to stress conditions affecting the mobilisation of plant resources. [20]

14.2.2 Impact of chilling range (-1.5°C–15°C)

In chickpea, the upper limits of the chilling range are quite acceptable and even optimum for early growth in some genotypes, but the reproductive processes can become susceptible to damage from temperatures of ca. 15°C and lower.

In the Mediterranean-type environment of south-west Australia, chickpea yields are limited by chilling range temperatures during flowering, causing extensive flower and pod abortion. This is especially a problem for early sown crops aiming for high yield potential (high biomass) and for early flowering genotypes due to the abortion of flowers and pods in late winter and early spring, which in turn leads to low harvest index.

Desi chickpea seed can germinate in soil as cold as 5°C, but seedling vigour is greater if soil temperatures are at least 7°C. Kabuli chickpea seed is more sensitive to cold soils and should not be seeded into excessively wet soil or into soil with temperatures below 12°C at the placement depth.

In chickpea, sensitivity to freezing and chilling range temperatures increases as the plant progresses from germination to flowering. Temperatures within the chilling range can limit the growth and vigour of chickpea at all phenological stages, but are considered most damaging to yield at the reproductive stages. Southern Australia is most affected by chilling range temperatures at flowering.

A prolonged period of chilling range temperatures at any phenological stage of development in chickpea has detrimental effects on final seed yield. During germination, chilling range temperatures result in poor crop establishment, increased susceptibility to soil-borne pathogens, and reduced seedling vigour. At the seedling stage, long periods of chilling range temperatures can retard the growth of the plant and, in severe cases, cause plant death. Visual symptoms of chilling injury at the seedling stage can include the inhibition of seedling growth, accumulation of anthocyanin pigments, waterlogged appearance with browning of mesocotyls, and the browning and desiccation of coleoptiles and undeveloped leaves. At the vegetative stage, chilling range temperatures have a pronounced negative effect on plant growth and dry matter production. Less dry matter production

20 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

reduces the reproductive sink that the plant can support, which, in turn, reduces potential yield. Flower, pod, or seed abortion are further symptoms of chilling range temperatures (Figure 7).

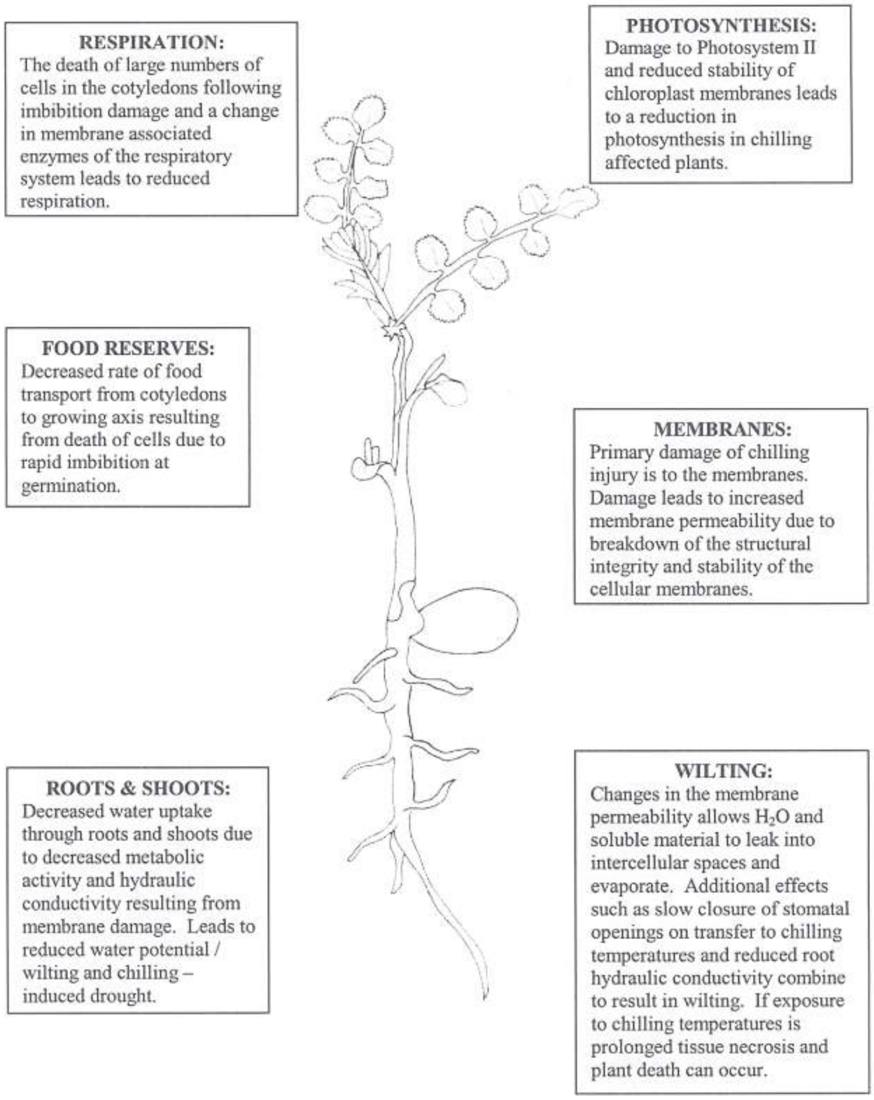


Figure 7: *Effect of chilling injury on chickpea at the seedling to vegetative phenological stage.*

Source: Croser et al. 2003

Chilling range temperatures at the mid to late vegetative stage retard growth rate and reduce plant vigour (Tables 3 and 4). These effects are due to the same mechanisms that affect post-emergent seedling growth—that is, reduced respiration and photosynthesis, and in severe cases a loss of turgor and subsequent water stress.

Air temperature and photoperiod have a major influence on the timing of reproductive events in chickpea, with the rate of progress to flowering being a linear function of mean temperature. Pollen germination and vigour is affected by chilling range temperatures. [21]

21 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

Table 3: *Effect of chilling range temperatures on Chickpea reproduction.*

Effect	Description
Flower shedding/floral abortion Pod shedding/drop	Sudden low temperatures (0° to 10°C) during flowering induces flower shedding, which causes partitioning of assimilates to vegetative growth, resulting in lowered Harvest Index. Major cause of low pod and seed set in subtropical South Asia and Australia.
Interrupted pollen tube growth	Temperatures up to 25°C shown to interrupt pollen tube growth. Failure of fertilisation results from poor germination and slow growth of pollen tubes in susceptible genotypes at low temperatures (Figure 4).
Lowered pollen viability	Pollen in tolerant genotypes more viable (90%) compared to susceptible genotypes (60%). Two stages of pollen sensitivity at 5 and 9 days before anthesis have been identified.
Reduced ovule size	Ovules in flowers opening on cool days were 9–45% smaller than warm day ovules – more pronounced in chilling susceptible than tolerant genotypes.
Reduced pistil size	Heterostyly – the distance between the anther and stigma at the time of flower opening is greater in sensitive than in tolerant genotypes.
Reduced stigmatic esterase activity	Reduced esterase activity was identified in susceptible genotypes suggesting the stigmas were less receptive to pollen tube growth.
Delayed anther dehiscence	Anther dehiscence is delayed by chilling temperatures, reducing fertilisation events.
Reduced pollen germinability	Possibly due to smaller amount of storage material in pollen from sensitive genotypes.
Reduced pollen turgor	Turgidity is an absolute requirement for germination. Pollen cells with leaking membranes cannot become turgid and germinate.

Source: Croser et al. 2003

Table 4: *Effect of chilling range temperatures at flowering on chickpea productivity at Merridin, Western Australia.* [22]

Date of planting	Date of 50% flowering	Mean daily temperature (°C) at 50% flowering	Number of aborted flowers (m^2)	Biological yield (t/ha^{-1})	Seed yield (t/ha^{-1})	Harvest Index
17 May	19 August	12.5	800	6.76	1.25	0.18
31 May	1 September	13.6	500	5.34	1.13	0.21
14 June	14 September	14.7	200	4.84	1.12	0.23
30 June	29 September	16.8	0	3.98	1.11	0.28
20 July	6 October	17.7	0	3.23	0.94	0.29

Source: Modified from Siddique and Sedgley (1983)

Exposure to prolonged periods of temperatures at the lower end of the chilling range can cause poor germination, slow growth, flower shedding and pod abortion, and in severe cases cell necrosis and plant death. The resulting yield penalty or reduction in harvest index varies dramatically in the field, but in some cases can be substantial (Figure 8).

22 KHM Siddique, C Marshall, RH Sedgley (1983) Temperature and leaf appearance in chickpea. Int. Chickpea Newsl. 8, 14–15

Figure 8: *Chilling damage in chickpea- sown paddock.*

Source: Pulse Breeding Australia

In Australia, flower shed and pod abortion due to chilling range temperatures at flowering is a major cause of poor yield. It should be noted that it is the combination of chilling range temperatures at flowering with terminal drought that is the cause of reduced seed yields in chickpea. Early sowing (winter) is essential in these environments in order to achieve high yield potential and avoid terminal soil moisture stress.

Desi types generally suffer less damage from low temperatures at germination than Kabuli types.

The development of cultivars with a higher degree of cold tolerance would facilitate the spread of chickpea growing regions to both higher altitudes and colder latitudes and therefore are worthy of considerable agronomic and breeding attention. [23]

Tolerance to low temperature

Low temperature at flowering is a major constraint to improving yields of chickpeas in many regions of the world. In particular, cool dryland environments such as that of south-western Australia would benefit from cultivars with the ability to flower and set pods early in the growing season before soil moisture becomes a limiting factor.

Desi types generally suffer less damage from low temperatures at germination than kabuli types. Research overseas and within Australia has demonstrated a range of cold tolerance among chickpea varieties. In parts of the world where chickpeas are grown as a spring crop because of the very cold winter, varieties have been developed that tolerate freezing conditions during vegetative growth. These varieties can be sown in autumn, survive over winter, and are ready to flower and set pods when temperatures rise in summer.

However, chickpea varieties resistant to low temperatures during flowering have not yet been found. Some genotypes from India are less sensitive than those currently grown in Australia, and these are being utilised in chickpea breeding programs at Department of Agriculture and Food, Western Australia (DAFWA) and the University of Western Australia (UWA).

Controlled environment studies at UWA have identified two stages of sensitivity to low temperature in chickpea. The first occurs during pollen development in the flower bud, resulting in infertile pollen even in open flowers. The second stage of sensitivity occurs at pollination when pollen sticks to the female style, and produces a tube that grows from the pollen down the style to the egg (Figure 9).

23 JS Croser, HJ Clarke, KHM Siddique, TN Khan (2003) Low-temperature stress: implications for chickpea (Cicer arietinum L.) improvement. Critical Reviews in Plant Sciences, 22(2), 185–219.

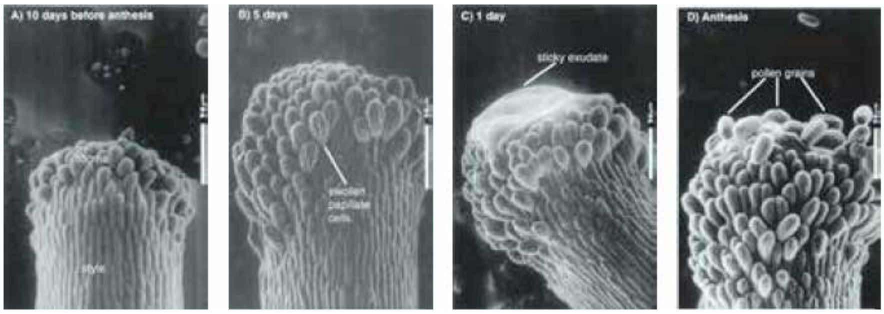


Figure 9: *Development of the style and stigma of chickpea flowers taken with an electron microscope.*

Photo: H Clarke. Source: UWA

At low temperatures pollen tubes grow slowly, fertilisation is less likely and the flower often aborts. The rate of pollen tube growth at low temperature is closely related to the cold tolerance of the whole plant. This trait can therefore be used to select more tolerant varieties (Figures 10).

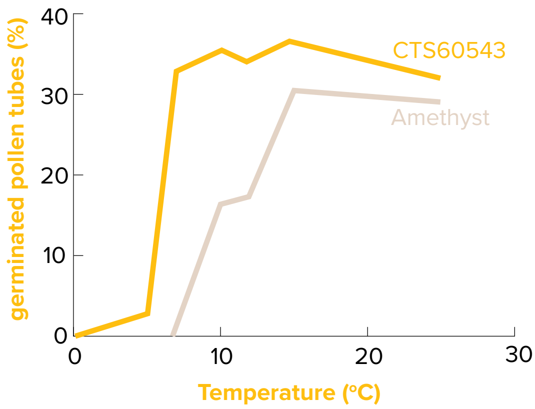


Figure 10: *Proportion of pollen germination at various temperatures in cold-sensitive (Amethyst) and cold-tolerant (CTS60543) varieties.* [24]

The critical average daily temperature for abortion of flowers in most varieties currently grown in Australia is about 15°C. New hybrids that set pods at ~13°C are being developed.

In the field, cold-tolerant varieties set pods about 1–2 weeks earlier than most current varieties. As well as conventional methods for plant improvement, DNA-based techniques are also being investigated. [25]

24 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

25 SC Sethi (1998) Improvement of cold tolerance and seed yield in chickpea. GRDC, DAFWA, UWA.

IN FOCUS

Response of chickpea genotypes to low-temperature stress during reproductive development

Clarke and Siddique (2004) demonstrated that temperatures of less than 15°C affect both the development and the function of reproductive structures in the chickpea flower. They studied aspects of the development of male and the female gametes and compared chilling-sensitive genotypes to identify the likely causes of flower abortion. They learned that, of all the aspects of reproduction, the function of pollen derived from chilling-sensitive plants is the most affected by low-temperature stress, and particularly the growth of the pollen tubes down the style before fertilisation occurs. In contrast, pollen tubes derived from chilling-tolerant plants continue to grow down the style under low-temperature stress. Although other stages of development and function, including the production of spores, pollen germination, and the stigma, were affected by low temperatures, none were correlated to the phenotype of the mother plant.

Having tested plants, the researchers then tested pollen.

Two periods of sensitivity to low temperature were identified during pollen development (sporogenesis) in both Amethyst (cold tolerant) and CTS60543 (cold sensitive), each of which resulted in chilling-stressed plants having flowers with only 50% viable pollen (Figure 11a). The chilling treatment of 3°C was assumed to be below the base temperature for growth in chickpeas. As a result, those flowers that flowered 'n' days after the end of chilling would have been stressed 'n' days before anthesis. On this basis, they estimated that the first stage of sensitivity occurred nine days before anthesis. The significant decrease in pollen viability coincided with lower podset (approximately 70%) in both genotypes. This was followed by a recovery in pollen viability and podset.

The second period of sensitivity occurred 4–6 days before anthesis. In Amethyst a dramatic drop to 40% podset correlated with the decrease in pollen viability (Figure 11b), while normal pods formed at other nodes before and after this chilling-sensitive stage. Despite lower pollen viability in CTS60543, podset was not affected at this time, and all of the flowers gave rise to full pods in this genotype.

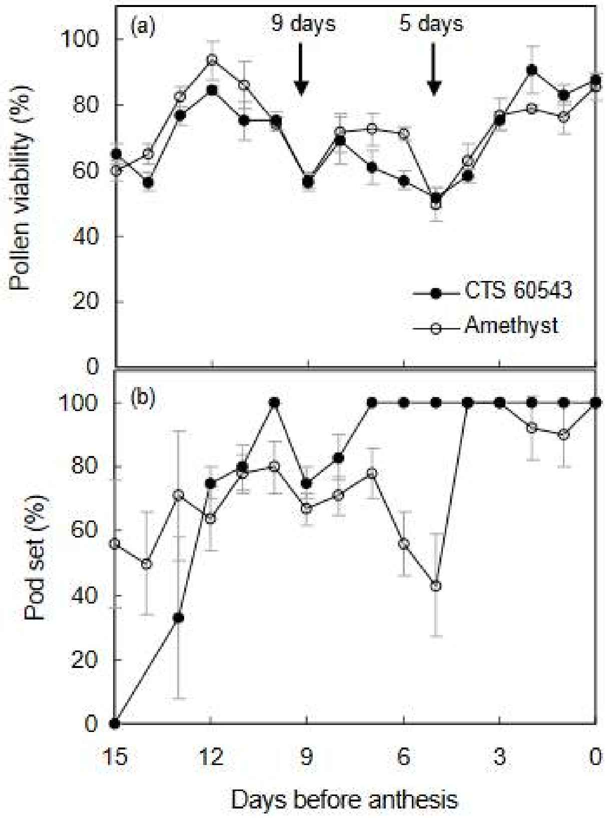


Figure 11: *The effects of stressing plants with a temperature of 3°C during flower development in tolerant (CTS60543) and sensitive (Amethyst) genotypes. (A) Pollen viability. (B) Podset. Arrows indicate susceptible periods at 9 days and 5–6 days before anthesis.*

Temperatures from 7–25°C did not affect the proportion of pollen grains which germinated after four-hour incubation in vitro, and 80–90% germination occurred in all of the genotypes examined (Figure 12). The percentage that germinated was significantly lower at 3°C than at other temperatures, but no significant difference was measured between genotypes at this temperature when samples were examined at four hours.

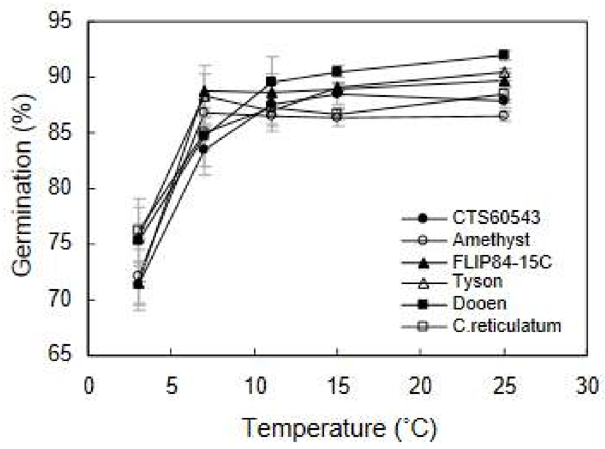


Figure 12: *The effect of temperature on pollen germination in chickpea genotypes after four-hour culture in lab conditions.*

A second experiment was therefore designed to examine the rate of germination with selected genotypes at 3°C in the period up to four hours in vitro. The researchers found that low temperature delayed the onset of germination by 20–40 minutes compared to the control at 25°C, and it decreased the rate at which the pollen germinated (Figure 13). No significant difference was measured in germination between genotypes in the first 40 minutes in culture. After this time the percentage that germinated was significantly different between genotypes.

However, no link was observed between the rate of pollen germination in vitro at 3°C and the chilling tolerance of the whole plant. In fact, pollen from CTS60543 was slightly slower to begin germination.

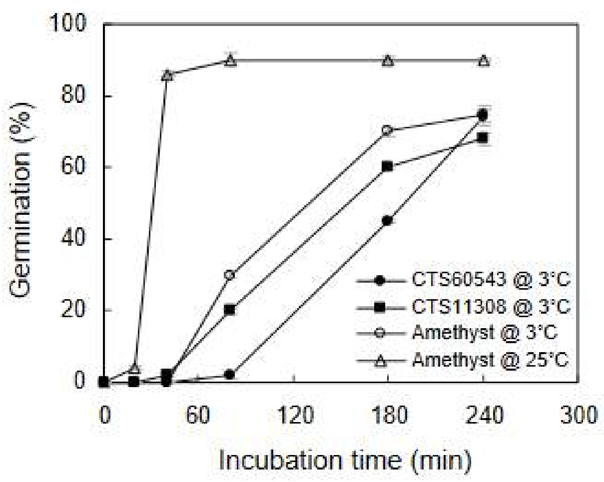


Figure 13: *Rate of pollen germination during 4 hour culture in lab conditions at low temperature (3°C) in sensitive and tolerant genotypes.*

Figure 14 illustrates a greater number of pollen tubes in the style in CTS60543 compared to Amethyst when hand-pollinated plants are stressed at 7°C for 24 h after pollination. [26]

26 HJ Clarke, KHM Siddique (2004) Response of chickpea genotypes to low temperature stress during reproductive development. Field Crops Research 90 (2), 323–334.

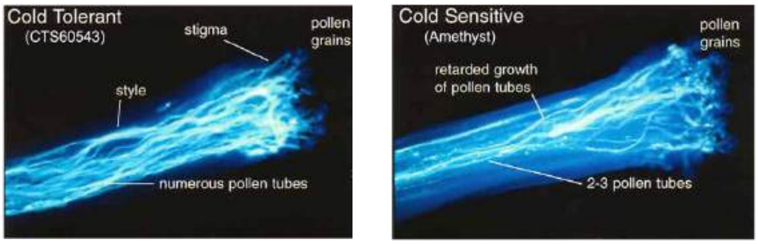


Figure 14: *More pollen tubes of CTS60543 grow down the style to the ovary at low temperature stress (7°C) compared to Amethyst. Styles were fixed 24 h after pollination and stained with aniline blue.* [27]

14.2.3 Heat stress

High temperature stress in chickpea causes substantial loss in crop yield due to damage to reproductive organs, increased rate of plant development, and reduced length of the reproductive period (Figure 15). [28]

Figure 15: *Chickpea varieties planted under hot conditions: heat sensitive plant with no pods (left) and heat tolerant plant with healthy pods (right).*

Photo: Daniel Tan. Source: Foodmag

In its reproductive stage chickpea is sensitive to heat stress (20°C or higher as day/night temperatures) with consequent substantial loss of potential yields at high temperatures. The anthers of heat sensitive genotypes have been found to have reduced synthesis of sugars due to inhibition of the appropriate enzymes. Consequently, effected plant pollen can have considerably lower sucrose levels resulting in reduced pollen function, impaired fertilisation and poor pod set in the heat sensitive genotypes.

27 HJ Clarke, KHM Siddique (2004) Response of chickpea genotypes to low temperature stress during reproductive development. Field Crops Research 90 (2), 323–334.

28 Y Gan, J Wang, SV Angadi, CL McDonald (2004) Response of chickpea to short periods of high temperature and water stress at different developmental stages. In Proceedings of the 4th International Crop Science Congress, Brisbane, 26–08..

IN FOCUS

Heat-stress-induced reproductive failures in chickpea are associated with impaired sucrose metabolism in leaves and anthers.

The physiological mechanisms associated with reproductive failures caused by heat stress have not been established. Researchers screened a large core-collection of chickpea against heat stress and identified two heat-tolerant (ICC15614, ICCV. 92944) and two heat-sensitive (ICC10685, ICC5912) genotypes. These four genotypes were sown during the normal time of sowing and also late, to expose them to heat stress (above 32/20°C) during reproductive stage. In the heat-stressed plants, phenology accelerated as days to flowering and podding, and biomass decreased significantly. The significant reduction in pod set (%) was associated with reduced pollen viability, pollen load, pollen germination and stigma receptivity in all four genotypes. Heat stress inhibited pollen function more in the sensitive genotypes than in the tolerant ones, and consequently showed significantly less pod set. Heat stress significantly reduced stomatal conductance, leaf water content, chlorophyll, membrane integrity and photochemical efficiency with a larger effect on heat-sensitive genotypes. The inhibition of important enzymes was significantly greater in the heat-sensitive genotypes. Concurrently, the anthers of these genotypes had significantly less enzymatic activity and therefore sucrose content. As a result, pollen had considerably lower sucrose levels, resulting in reduced pollen function, impaired fertilisation and poor pod set in heat-sensitive genotypes. [29]

Chickpea pollen grains are more sensitive to heat stress than the stigma. High temperatures have been found to reduce pollen production per flower, amount of pollen germination, pod set and seed number (Figure 16). [30]

Figure 16: *Comparison of seed size under heat stress. Larger seeds (left side) from non-stressed and smaller seeds (right side) from heat-stressed conditions.*

Photo: V Devasirvatham. Source: Devasirvatham et al. (2014)

Heat stress during the reproductive stage can cause significant yield loss. Very little of the germplasm will set pods when temperatures exceed 36°C. During the

29 N Kaushal, R Awasthi, K Gupta, P Gaur, KH Siddique, H Nayyar (2013) Heat-stress-induced reproductive failures in chickpea (Cicer arietinum) are associated with impaired sucrose metabolism in leaves and anthers. Functional Plant Biology, 40(12), 1,334–1,349.

30 V Devasirvatham, PM Gaur, N Mallikarjuna, RN Tokachichu, RM Trethowan, DK Tan (2012) Effect of high temperature on the reproductive development of chickpea genotypes under controlled environments. Functional Plant Biology, 39(12), 1,009–1,018.

reproductive stage, heat stress can cause male and female floral organ development to be timed differently and impair formation, resulting in lower yields. [31]

14.2.4 Heat and water stress

The combination of environmental stresses can also impact chickpea yield.

IN FOCUS

Response of chickpea to short periods of high temperature and water stress at different developmental stages.

A study was conducted to determine the effect of short periods of high temperature and water stress on pod production, seed set and yield of chickpea (see Figure 17 for results). Desi and Kabuli chickpea were grown in growth chambers under 20/16°C day/night temperatures, as a control treatment. High (35/16°C) and low (28/16°C) temperature stress was imposed for 10 days during flower and pod development. Simultaneously, high (plants remained at 50% available water) and low (at 90% available water) water stress was also imposed. Plants stressed at 35/16°C during flowering produced 53% fewer fertile pods on the mainstem and 22% fewer pods on the branches than those kept at 20/16°C. Nearly 90% of the pods formed during stress were infertile. Due to high temperature stress, kabuli crop filled 58% of the pods formed and decreased seeds pod by 26% from the check. Consequently, desi chickpea seed yield decreased by 54% when stressed during pod development and 33% when stressed during flowering. Kabuli chickpea seed yield decreased by 50% when stressed during pod formation and 44% when stressed during flowering. Shortening the stress period during reproductive development may increase the yield potential of chickpea. [32]

31 V Devasirvatham, DKY Tan, PM Gaur, TN Raju, RM Trethowan (2012) High temperature tolerance in chickpea and its implications for plant improvement. Crop and Pasture Science, 63(5), 419–428.

32 Y Gan, J Wang, SV Angadi, CL McDonald (2004) Response of chickpea to short periods of high temperature and water stress at different developmental stages. In Proceedings of the 4th International Crop Science Congress, Brisbane, 26–08.

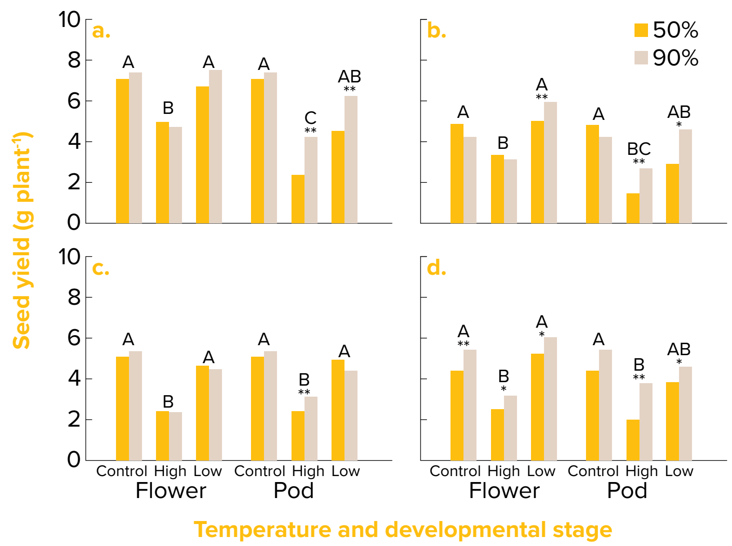


Figure 17: *Seed yield per plant produced by a) desi, b) large-seeded kabuli, c) small-seeded kabuli (small seed from previous year), and d) small-seeded (small seed from a small-seeded crop in the previous four years) chickpea stressed at high (35/16 °C) and low (26/16 °C) temperature during flower and pod developmental stages in comparison with no-stress control (20/16 °C). *, ** represent significant at P<0.05 and P<0.01, respectively, between low (90% available water) and high (50% available water) water stress treatments. Bars with the same capital letters did not differ among the temperature stress treatments at a given crop developmental stage.* [33]

14.3 Waterlogging/flooding issues for chickpeas

Chickpeas are particularly sensitive to waterlogging during flowering and podding.

Waterlogging occurs when there is too much water in the plant's root zone, which results in the roots not being able to access enough oxygen for respiration. Waterlogging, when it occurs, is a major constraint to production. Plant growth is affected, and under certain conditions will even lead to premature plant death.

Landholders may not realise a site is waterlogged until water appears on the soil surface (inundation).

Almost two-thirds of the agricultural land in the south west region of Western Australia has a duplex soil profile with sandy loam surface soils overlying sandy clay subsoils. These soils are susceptible to waterlogging when the amount of rainfall exceeds the ability of the soil to drain away excess moisture. This is exacerbated by the strong texture-contrast between the top and the subsoil, which allows more infiltration to the topsoil than can be transmitted by the subsoil.

33 Y Gan, J Wang, SV Angadi, CL McDonald (2004) Response of chickpea to short periods of high temperature and water stress at different developmental stages. In Proceedings of the 4th International Crop Science Congress, Brisbane, 26–08.

As there are no in-crop control measures to deal with waterlogging, a critical management tool is avoidance of high-risk paddocks (based on previous experience and paddock history) (Figure 18). [34]

Figure 18: *Water logging in chickpeas.*

Source: Australian UAV

14.3.1 Symptoms

Key points:

- plants most susceptible to waterlogging at flowering and early pod fill
- symptoms develop within 2 days of flooding
- roots not rotted and are not easy to pull out
- plants turn yellow/brown to reddish colour (Figure 19)
- leaflets are held upright and leaf edges turn yellow
- lower leaves defoliate
- plants die very fast (Figure 20) [35]

Figure 19: *Lower leaves on plants show marginal yellowing of leaflets (left). Mild waterlogging event with yellowing of leaves and roots intact with little discolouration (right).*

Source: QDAF in CropIT.

34 K Moore, M Ryley, M Sharman, J van Leur, L Jenkins, R Brill (2013) Developing a plan for chickpeas in 2013. GRDC Update Papers February 2013, http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02/Developing-a-plan-for-chickpeas-2013

35 CropIT. Chickpea – Waterlogging. http://www.cropit.net/?q=content/environment/waterlogging-0

Figure 20: *Severely waterlogged plants die rapidly when waterlogged during and after pod fill.*

Source: QDAF in CropIT.

Chlorosis has been observed after four days of waterlogging, firstly on the upper leaves. Reddish-brown anthocyanin pigmentation also develops on midribs, stems and some leaflets. Leaflets fold upward, a symptom typical of moisture stress. Unexpanded leaves have necrotic margins. Abscission of chlorotic leaflets can begin six days after waterlogging and progress until most of the plant is defoliated. [36]

Effect of waterlogging on stomatal conductance and photosynthesis

Stomatal conductance is the measure of the rate of passage of carbon dioxide (CO_2) entering or water vapor exiting through the stomata of a leaf, and photosynthesis is a process that converts light energy into chemical energy that can fuel growth. Within 24 hours, stomatal conductance of waterlogged chickpea can decline, and can completely stop within three days. One day after waterlogging, photosynthesis and stomatal conductance has been recorded at 87% and 36%, respectively, of unaffected plants. Rapid decline in stomatal conductance over 24 hours, followed by a sharp decrease in photosynthesis between two and four days, suggests that waterlogging decreases photosynthesis through stomatal closure. Stomatal closure may be caused by a decrease in potassium uptake, or production of abscisic acid or ethylene by the plant. Reduction in photosynthesis may result from the effects of waterlogging on carboxylation enzymes and the loss of chlorophyll, in addition to the effect of stomatal closure. [37]

36 AL Cowie, RS Jessop,DA MacLeod (1989) Effect of waterlogging on photosynthesis and stomatal conductance of chickpea leaves. 5th Aust. Agron. Conf.©, University of New England.

37 AL Cowie, RS Jessop,DA MacLeod (1989) Effect of waterlogging on photosynthesis and stomatal conductance of chickpea leaves. 5th Aust. Agron. Conf.©, University of New England.

IN FOCUS

Effects of waterlogging on chickpeas: influence of timing of waterlogging.

The effect of the timing of waterlogging on chickpeas was examined in two pot trials. Plants were waterlogged for ten days from 21 days after sowing (DAS), at flowering or at mid-pod fill, plus combinations of these times. Waterlogging at any stage reduced seed yield; waterlogging at 21 DAS had the least effect, reducing yield relative to the non-waterlogged control by 35%. Ability of the plant to survive and regrow following waterlogging decreased with increasing physiological age: mortality rate averaged 0, 30 and 100% after waterlogging at 21 DAS, flowering and pod fill, respectively (Table 5). Tolerance to waterlogging was not enhanced by previous exposure to waterlogging. In the second experiment, waterlogging was imposed at six different times shortly before or after flowering began. Ability to survive waterlogging declined sharply as flowering commenced: mortality rate increased from 13% when waterlogging was imposed six days before flowering to 65% one day after flowering, and 100% when waterlogging began 7.5 days after flowering (Table 5). The researchers suggest that survival and recovery after waterlogging may have been inhibited in flowering plants by an inadequate supply of nitrogen or carbohydrates. [38]

Table 5: *Mortality rate and regrowth following waterlogging imposed at five stages of floral development. Means followed by the same letter are not significantly different.*

Planting times	1	2	3	4	5
Time of waterlogging (days after sowing)	66	61	56	51	46
Time of flowering (days after waterlogging)	-7.5	-6	-1	+2	+6
Mortality rate (%)	100a	94a	63b	38c	13d
Total regrowth per pot (mg dry weight)	0a	0.4ab	18.1bc	32.6c	50.6d

Source: Cowie et al. (1996)

14.3.2 Management options for waterlogging

Key points:

- There is no in-crop treatment for waterlogging
- Avoid poorly drained paddocks and those prone to waterlogging.
- Use raised beds
- Use short duration flows under irrigation
- Do not flood-irrigate after podding has commenced, especially if the crop has been stressed.

38 AL Cowie, RS Jessop,DA MacLeod (1989) Effect of waterlogging on photosynthesis and stomatal conductance of chickpea leaves. 5th Aust. Agron. Conf.©, University of New England.

A rule of thumb is that if the crop has started podding and the soil has cracked, do not irrigate. Overhead irrigation is less likely to result in waterlogging, but consult your agronomist. [39]

Drainage can be improved on many sites and is the first thing to consider once a waterlogging problem has been identified. Options might vary from shallow surface drains (i.e. Spoon- and 'W'-drains) to more intensive drainage using wide-spaced furrows, to the intensive drainage form of raised beds.

Identifying problem areas

The best way to identify problem areas is to dig holes about 40 cm deep in winter and see if water flows into them (Figure 21). If it does, the soil is waterlogged. Digging holes for fence posts often reveals waterlogging.
Some farmers put slotted PVC pipe into augered holes. They can then monitor the water levels in their paddocks.
Symptoms in the crop of waterlogging include:

- Yellowing of crops and pastures.
- Presence of weeds such as toad rush, cotula, dock and Yorkshire fog grass. [40]

Figure 21: *Water fills hole while digging in waterlogged soil.*

Source: Soilquality.org

Raised bed scan overcome waterlogging

In most cases, drainage with or without raised beds are the best way to overcome waterlogging and inundation in most areas. A network of shallow drains in cropped areas pay for themselves within a few years. Where drains can only partially overcome the problem, changes to crop species, varieties and management may be necessary. [41]

39 K Moore, M Ryley, M Schwinghamer, G Cumming, L Jenkins (2011) Chickpea: Phytophthora root rot management. Northern Pulse Bulletin. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

40 D Bakker. Soilquality.org. Waterlogging Factsheet. http://soilquality.org.au/factsheets/waterlogging

41 D Bakker. (2014). Overcoming waterlogging. DAFWA. https://www.agric.wa.gov.au/soil-management/overcoming-waterlogging

14.4 Drought stress

Chickpea is an important winter pulse crop for the neutral-to-alkaline heavy textured soils in both the Mediterranean climatic region and summer-rainfall region of Australia, including WA. Chickpea growing regions of WA generally experience cool wet winters, whereas in spring, increasing temperatures and reduced rainfall result in a terminal drought situation for most crops. Unlike many other crops, chickpea is unable to escape this terminal drought through rapid development because low temperatures (<15°C) often cause flower and pod abortion, especially in cool southern areas. [42]

Yield losses can be the result of intermittent drought during the vegetative phase, due to drought during reproductive development or due to terminal drought at the end of the crop cycle. [43]

After disease, the major constraint to greater chickpea production is its sensitivity to the end-of-season drought that occurs in both the Mediterranean-type climates and when grown on stored soil moisture in the summer-rainfall region of Australia. Terminal drought occurs in the Mediterranean-type climates because they are dependent on rainfall and in spring, rainfall decreases and evaporation increases when chickpea enters its reproductive stage. The summer-rainfall regions are more dependent on the stored soil moisture and terminal drought occurs because the soil moisture is exhausted during the seed-filling stage.

Terminal drought reduces leaf photosynthesis in chickpea before seed growth commences so that seed filling is, in part, dependent on carbon and nitrogen accumulated prior to podding. For example, under terminal drought, more than 90% of the seed nitrogen in chickpea comes from pre-podding sources, particularly leaves. [44]

IN FOCUS

Response of chickpea to terminal drought: leaf stomatal conductance, pod abscisic acid concentration, and seed set, in WA.

Flower and pod production and seed set of chickpea are sensitive to drought stress. A two-fold range in seed yield was found among a large number of chickpea genotypes grown at three dryland field sites in south-western Australia. Leaf water potential, photosynthetic characteristics, and reproductive development of two chickpea genotypes with contrasting yields in the field were compared when subjected to terminal drought in 106 kg containers of soil in a glasshouse. The terminal drought imposed from early podding reduced biomass, reproductive growth, harvest index, and seed yield of both genotypes. Terminal drought at least doubled the percentage of flower abortion, pod abscission, and number of empty pods. Pollen viability and germination decreased when the fraction of transpirable soil water (FTSW) decreased below 0.18 (82% of the plant-available soil water had been transpired); however, at least one pollen tube in each flower reached the ovary. The young pods that developed from flowers produced when the FTSW was 0.50 had viable embryos, but contained higher abscisic acid (ABA) concentrations than those of the well-watered plants; all pods ultimately aborted in the drought treatment. Cessation of

42 RJ Jettner, SP Loss, KHM Siddique, RJ French (1999) Optimum plant density of desi chickpea (Cicer arietinum L.) increases with increasing yield potential in south-western Australia. Crop and Pasture Science, 50(6), 1,017–1,026.

43 A Mafakheri, A Siosemardeh, B Bahramnejad, PC Struik, Y Sohrabi (2010) Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Australian journal of crop science, 4(8), 580.

44 JA Palta, AS Nandwal, S Kumari, NC Turner (2005) Foliar nitrogen applications increase the seed yield and protein content in chickpea (Cicer arietinum L.) subject to terminal drought. Crop and Pasture Science, 56(2), 105–112.

seed set at the same soil water content at which stomata began to close and ABA increased strongly suggested a role for ABA signalling in the failure to set seed either directly through abscission of developing pods or seeds or indirectly through the reduction of photosynthesis and assimilate supply to the seeds. [45]

Drought after podding is a common feature of chickpea production in south-western Australia. One study investigated the effect of water stress, imposed after podding, on yield and on the accumulation of amino acids and soluble sugars in seeds. Although terminal water stress decreased the total plant dry mass and seed yield by 23% and 30% respectively, it had no effect on the mass of individual pods and seeds, which remained on the plant after the imposition of stress treatment. The deleterious effect of water stress on yield was due to increased pod abortion and a decrease in pod formation. Water stress improved the seed's nutritive value in terms of higher accumulation of soluble sugars, amino acids and proteins. [46]

Plants grown under drought condition have a lower stomatal conductance in order to conserve water. Consequently, CO_2 fixation is reduced and photosynthetic rate decreases, resulting in less assimilate production for growth and yield of plants. Drought stress during vegetative growth or anthesis significantly decreases chlorophyll and therefore photosynthesis. Drought stress at anthesis phase can reduce seed yield more severely than during vegetative stage. [47]

Water stress can impact light interception and light use efficiency by affecting chickpea development during leaf expansion. Therefore, the timing of water stress conditions during chickpea canopy development will determine whether the plant experiences poor light interception or light use efficiency. [48]

IN FOCUS

Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment, WA.

Two field experiments were carried out to investigate the effects of terminal drought on chickpea grown under water-limited conditions in the Mediterranean-climatic region of Western Australia. In the first experiment, five sesi chickpeas and one kabuli chickpea were grown in the field with and without irrigation after flowering. In the second experiment, two desi and two kabuli cultivars were grown in the field with either irrigation or under a rainout shelter during pod filling. Leaf water potential (ψl), dry matter partitioning after pod set and yield components were measured in both experiments while growth before pod set, photosynthesis, pod water potential and leaf osmotic adjustment were measured in the first experiment only. In the first experiment, total dry matter accumulation, water use, both in the pre- and post-podding phases, ψl and photosynthesis did not vary among genotypes. In the rainfed plants, ψl decreased below −3 MPa while photosynthesis decreased to about a tenth of its maximum at the start of seed filling. Osmotic adjustment varied significantly among genotypes. Although flowering commenced from about 100 days after

45 J Pang, NC Turner, T Khan, YL Du, JL Xiong, TD Colmer, KH Siddique (2016) Response of chickpea (Cicer arietinum L.) to terminal drought: leaf stomatal conductance, pod abscisic acid concentration, and seed set. Journal of experimental botany, erw153.

46 MH Behboudian, Q Ma, NC Turner, JA Palta, (2001) Reactions of chickpea to water stress: yield and seed composition. Journal of the Science of Food and Agriculture, 81(13), 1,288–1,291.

47 A Mafakheri, A Siosemardeh, B Bahramnejad, PC Struik, Y Sohrabi (2010) Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Australian journal of crop science, 4(8), 580.

48 S Fukai, GL Hammer (1995) Growth and yield response of barley and chickpea to water stress under three environments in southeast Queensland. II. Root growth and soil water extraction pattern. Crop and Pasture Science, 46(1), 35–48.

sowing (DAS) in both experiments, pod set was delayed until 130–135 DAS in the first experiment, but started at 107 DAS in the second experiment. Water shortage reduced seed yield by 50-80%, due to a reduction in seed number and seed size. Apparent redistribution of stem and leaf dry matter during pod filling varied from 0-60% among genotypes, and suggests that this characteristic may be important for a high harvest index and seed yield in chickpea. [49]

14.4.1 Managing for drought

Long-term historical records indicate that our climate is becoming progressively warmer and dryer. This trend is expected to continue due to increased levels of greenhouse gas in the atmosphere, with dry seasons likely to become more frequent over southern Western Australia. DAFWA has developed a Climate Change Response Strategy to focus its work in climate change on those areas of highest importance. The strategy identifies a range of actions including mitigation, sequestration, adaptation and governance, and rates them according to when the actions should be completed and the priority of the action. DAFWA provides data and information on current seasonal climate through its network of automatic weather stations and seasonal climate forecasts through the Statistical Climate Information system. In dry years, DAFWA provides a set of actions and information to assist growers and agribusiness in the management of seasonal conditions and their consequences. [50]

For crops exposed to terminal drought, the application of nitrogen fertiliser to the soil during pod set and seed filling is unlikely to assist in delaying the withdrawal of nitrogen from the leaves and maintaining leaf photosynthesis because nitrogen is not taken up from dry soil. However, foliar applications of urea have been effective in increasing the nitrogen availability for seed filling. [51]

IN FOCUS

Foliar nitrogen applications increase the seed yield and protein content in chickpea subject to terminal drought

In this study, it was hypothesised that foliar application of urea may increase nitrogen availability for seed filling in chickpea grown under terminal drought. The effect of foliar application of isotopically labelled nitrogen (15N-urea) at four stages during flowering and podding on the uptake and utilisation of nitrogen by chickpea (*Cicer arietinum* L.) under conditions of terminal drought was investigated in a glasshouse study. Five treatments were used to investigate the effect of timing of foliar application of urea, equivalent to 30 kg N/ha, on the uptake and utilisation of nitrogen for biomass, yield, seed protein content, and seed size: foliar application at (*i*) first flower, (*ii*) 50% flowering, (*iii*) 50% pod set, and (*iv*) the end of podding, and (*v*) an unsprayed control treatment. Terminal drought was induced from pod set onward, resulting in a rapid development of plant water deficits (–0.14 MPa/day) and a decrease in leaf photosynthesis irrespective of the timing of foliar urea application. Foliar applications of urea at first flower and at 50% flowering, before terminal drought was induced, increased yield and seed protein content. The increase in yield

49 L Leport, NC Turner, RJ French, MD Barr, R Duda, SL Davies, KHM Siddique (1999) Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment. European Journal of Agronomy, 11(3), 279–291.

50 DAFWA. Drought. https://www.agric.wa.gov.au/climate-land-water/climate-weather/drought

51 JA Palta, AS Nandwal, S Kumari, NC Turner (2005) Foliar nitrogen applications increase the seed yield and protein content in chickpea (Cicer arietinum L.) subject to terminal drought. Crop and Pasture Science, 56(2), 105–112.

resulted from an increase in the number of pods with more than one seed rather than from increased pod number per plant or increased seed size, indicating greater seed survival under terminal drought. Also, the increase in the seed protein content resulted from increased nitrogen availability for seed filling. Foliar application of urea during flowering, before terminal drought was induced, resulted in 20% more biomass at maturity, suggesting that growth prior to the development of water shortage increased the carbon resources for sustained seed filling under conditions of terminal drought. Foliar applications of urea at 50% pod set and at the end of podding did not affect the yield or seed protein content, primarily because the uptake of nitrogen was limited by the leaf senescence that occurred with the development of terminal drought. The results indicate the potential to increase yields of chickpea by application of foliar nitrogen near flowering in environments in which terminal droughts reduce yield. [52]

WATCH: Over the Fence west: Cost focus keeps profits up in drying climate.

14.4.2 Adaptation to drought stress

There are three strategies of crop adaptation to drought-stressed environments, all of which are useful in the Mediterranean climate of WA:

1. Drought escape, where the crop completes its life cycle before the onset of terminal drought.
2. Drought avoidance, where the crop maximises its water uptake and minimises is water loss.
3. Drought tolerance, where the crop continues to grow and function at reduced water contents. [53]

In all environments except in northern WA, chickpea is grown through the winter and spring as a rainfed crop and suffers from water shortage during seed development in spring. Despite a wide environmental range, many of the same cultivars are used across the country. The basis of the wide adaptation in chickpea is important as new cultivars are developed.

Chickpea may adapt to drought stress by maximising its water uptake through continuous root growth up to seed filling and by maintaining substantial water uptake

52 JA Palta, AS Nandwal, S Kumari, NC Turner (2005) Foliar nitrogen applications increase the seed yield and protein content in chickpea (Cicer arietinum L.) subject to terminal drought. Crop and Pasture Science, 56(2), 105–112.

53 Ludlow, M. M. (1989). Strategies of response to water stress. Structural and functional responses to environmental stresses, 269–281.

until the fraction of extractable moisture in the root profile falls to 0.4. [54] In addition to these strategies, early sowing of chickpeas in south-western Australia develops a large green area and rapid ground cover, absorbs a significant proportion of photosynthetic-active radiation early in the season when vapour pressure deficits are low, and uses more water in the post-flowering period. [55] Consequently, such crops produce large biomass and grain yield. Application of supplemental irrigation at flowering and early pod-filling can relieve drought stress and substantially increase seed yield. [56]

Plants can partly protect themselves against mild drought stress by accumulating osmolytes. Proline is one of the most common compatible osmolytes in drought-stressed plants. Proline does not interfere with normal biochemical reactions but allows the plants to survive under stress. More drought tolerant varieties have a greater capacity to accumulate proline and buffer the effects of drought than sensitive varieties. [57]

One study found that a strain of symbiotic rhizobia (nitrogen-fixing bacteria) was effective in root-nodule symbiosis, partially alleviated decreased growth and yield, and increasing root biomass of chickpeas under drought stress. [58]

IN FOCUS

The role of phenology in adaptation of chickpea to drought

Chickpea is grown from autumn to early summer in both Mediterranean-type climates with winter dominant rainfall and on stored soil moisture in sub-tropical climates with summer-dominant rainfall. In both types of environment, water shortages can occur at any time during the growing season, but terminal drought predominates. A study conducted over a two-year period with a common set of 73 genotypes showed that high-yielding genotypes flowered early, podded early and had a relatively long flowering period at most, but not all, low-yielding sites. Thus drought escape was an important phenological characteristic at sites with terminal drought. However, these characteristics did not predominate at a site in which the drought was severe throughout the growth period. Studies under rainfed conditions at a dry site in Western Australia have shown that a high degree of biomass redistribution from leaves to stems to the pod is associated with high yield, suggesting that physiological mechanisms in addition to rapid phenological development play a role in the adaptation of chickpea to water-limited environments. [59]

54 KHM Siddique, RH Sedgley (1987) Canopy development modifies the water economy of chickpea (Cicer arietinum L.) in south-western Australia. Crop and Pasture Science, 37(6), 599–610.

55 (Keatinge and Cooper 1983; Loss et al. 1997; Singh et al. 1997; Thomson and Siddique 1997; Siddique et al. 1997) as cited in H Zhang, M Pala, T Oweis, H Harris (2000) Water use and Water Use Efficiency of chickpea and lentil in a Mediterranean environment. Crop and Pasture Science, 51(2), 295–304.

56 H Zhang, M Pala, T Oweis, H Harris (2000) Water use and Water Use Efficiency of chickpea and lentil in a Mediterranean environment. Crop and Pasture Science, 51(2), 295–304.

57 A Mafakheri, A Siosemardeh, B Bahramnejad, PC Struik, Y Sohrabi (2010) Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Australian journal of crop science, 4(8), 580.

58 A Bano, R Batool, F Dazzo (2010) Adaptation of chickpea to desiccation stress is enhanced by symbiotic rhizobia. Symbiosis, 50(3), 129–133.

59 J Berger, NC Turner, RJ French (2003) The role of phenology in adaptation of chickpea to drought. In Solution for a better environment. Proceedings of the 11th Australian Agronomy Conference, Geelong, Victoria, Australia, 2–6.

GRDC Project ICA00008—Breeding chickpea for drought tolerance and disease resistance

This project aimed to enhance production, productivity and yield stability of chickpea under Mediterranean and similar Australian environments through genetic improvement and agronomic options. Most chickpea cultivars grown by farmers in Mediterranean and Australian environments are susceptible to Ascochyta blight, affected by terminal drought, and are susceptible cold stress during the vegetative and flowering stage.

To overcome these constraints, GRDC has funded a project aimed at developing methodologies, screening tools, and improved germplasm for Ascochyta blight resistance and drought related traits. The newly developed materials and methodologies will be shared with National Agricultural Research Systems (NARS) in West Asia and North Africa (WANA) and pulse breeding programs in Australia.

Identification of new sources of resistance/tolerance for Ascochyta blight, drought and Fusarium wilt is a continuous process, as the pressure from these stresses is continuously evolving. This project delivers improved germplasm for these stresses and other desirable traits, including good plant type suitable for mechanical harvesting, to Pulse Breeding Australia for the benefits of Australian farmers. Resistances to Ascochyta blight, drought, and Fusarium wilt were bred into adapted Australian cultivars and the new derived progenies have been advanced at International Center for Agricultural Research in Dry Areas (ICARDA). These materials will be shared with Australian partners at the advanced stage to screen under Australian conditions for relevant stresses. Selected lines will be either used in crossing programs or for testing in yield trials for direct release as cultivars. Pathway to market is through the release and adoption of improved chickpea varieties.

All these efforts are contributing to widen the genetic base of Australian chickpea, which will bring more plasticity to face any future threats to production. The adoption by farmers of new varieties developed from these materials, with improved drought tolerance and disease resistance, will lead to increased and sustainable chickpea production and thereby contribute significantly to raising the level of the chickpea industry in Australia. [60]

14.5 Other environmental issues

14.5.1 Salinity

Salinity is the presence of dissolved salts in soil or water. It causes iron toxicity in plants and impedes their ability to absorb water (see Figures 22 and 23 for typical salt effects). Salinity, a major abiotic stress, is a major environmental production constraint in many parts of the world. Chickpeas are extremely sensitive to salinity and can have difficulty accessing water and nutrients from saline layers in the soil. This effectively limits water extraction from the subsoil and consequently yields. Salinity impairs vegetative growth in chickpea, but reproductive growth is particularly salt sensitive.

60 GRDC. Project ICA00006. Breeding chickpea for drought tolerance and disease resistance, http://finalreports.grdc.com.au/ICA00006

Figure 22: *Salt effects as seen on a soil of EC 11 ds/m.* [61]

Figure 23: *Pod setting under salinity of a salinity tolerant and salinity sensitive genotype (left). The photograph shows that biomass can be very similar even though pod set can be differentially affected by salinity.* [62] *Typical salt effects on chickpea leaves (right).* [63]

More than one million hectares of broadacre farmland in WA is estimated to be currently affected by dryland salinity (Report Card for the south-west of Western Australia 2013, DAFWA). DAFWA is able to provide the technical information needed to assist landholders and the community to reduce the extent and effect of salinity. Through activities such as groundwater and soil analysis, landholders can confidently assess salinity risks and implement appropriate management responses. [64]

Nut grass (Figure 24) is often a good indicator of increased salt levels.

61 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

62 V Vadez, L Krishnamurthy, PM Gaur, HD Upadhyaya, DA Hoisington, RK Varshney, KH Siddique (2006) Tapping the large genetic variability for salinity tolerance in chickpea. In Proceeding of the Australian Society of Agronomy meeting (10–14 September) http://www.agronomy.org.au

63 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

64 DAFWA. Soil salinity. https://www.agric.wa.gov.au/climate-land-water/soils/soil-constraints/soil-salinity

Figure 24: *Nut grass growing in saline soil.* [65]

All current varieties of chickpea are considered highly sensitive to salinity. Levels of EC >1.5 dS/m will cause a yield reduction in chickpea (Table 6). The growth of chickpea is very sensitive to salinity, with the most susceptible genotypes dying in just 25 mm NaCl and resistant genotypes unlikely to survive 100 mm NaCl in hydroponics; germination is more tolerant with some genotypes tolerating 320 mm NaCl. When growing in a saline medium, Cl-, which is secreted from glandular hairs on leaves, stems and pods, is present in higher concentrations in shoots than Na+. Salinity reduces the amount of water extractable from soil by a chickpea crop and induces osmotic adjustment, which is greater in nodules than in leaves or roots. Chickpea rhizobia show a higher 'free-living' salt resistance than chickpea plants, and salinity can cause large reductions in nodulation, nodule size and N_2-fixation capacity. [66]

Table 6: *Crop tolerances to salinity (EC, mmhos/cm = dS/m = mS/cm).*

Crop	Expected yield reduction (%).				
	0	10	25	50	100
Chickpea	1.3	2.0	3.1	4.9	8.0
Barley	8.0	10.0	13.0	18.0	56.0

Source: adapted from Mass and Hoffman (1977) and Abrol (1973)

A 2016 study concluded that salt sensitivity in chickpeas is determined by Na(+) toxicity. [67] Another study suggested that Na+ accumulation in leaves is associated with delayed flowering, and that it is this plays a role in the lower reproductive success of the sensitive lines. The delay is longer in sensitive genotypes than in tolerant ones. Filled pod and seed numbers, but not seed size, have been associated with reduced seed yield in saline conditions. [68]

65 Pulse Australia (2013) Northern chickpea best management practices training course manual—2013. Pulse Australia Limited.

66 TJ Flowers, PM Gaur, CL Gowda, L Krishnamurthy, S Samineni, KH Siddique, TD Colmer (2010) Salt sensitivity in chickpea. Plant, cell & environment, 33(4), 490–509.

67 HA Khan, KHM Siddique, TD Colmer (2016) Salt sensitivity in chickpea is determined by sodium toxicity. Planta, 244 (3), 1–15, https://www.ncbi.nlm.nih.gov/pubmed/27114264

68 R Pushpavalli, J Quealy, TD Colmer, NC Turner, KHM Siddique, MV Rao, V Vadez (2016) Salt stress delayed flowering and reduced reproductive success of chickpea (*Cicer arietinum* L.), a response associated with Na+ accumulation in leaves. Journal of Agronomy and Crop Science, 202 (2), 125–138, http://onlinelibrary.wiley.com/doi/10.1111/jac.12128/abstract

It has also been found that salt stress reduces photosynthesis, decreases tissue sugars by 22–47%, and severely impairs vegetative and reproductive growth. [69]

Salt stress is thought to reduce germination either by making less water available for imbibition or by altering enzymatic activity, growth-regulator balance or protein metabolism in germinating seeds. One study has found that pre-soaking seeds for 24 hours in normal ground or tap water (0.8 dS m-1) increased germination by 27% compared to direct sowing. Sowing at depth of 4 cm also increased seedling growth under saline soils compared with sowing at 2 cm and 6 cm.

Altered growth-hormone balance during germination is another factor resulting in poor germination and seedling growth under salt stress. The application of growth regulators such as gibberellic acid and kinetin have been found to increase germination (32%), root (32%) and shoot (153%) dry mass of seedlings stressed by salt. [70]

IN FOCUS

Effects of salt stress on growth, nodulation, and nitrogen and carbon fixation of ten genetically diverse lines of chickpea

Over two dry seasons, 10 genetically diverse chickpea lines were compared for salt tolerance in terms of growth, nodulation, moisture content, and nodule nitrogen and carbon fixation. Chickpea lines were raised in an open-air chamber in soil supplied with 0, 50, 75, and 100 mM NaCl. The shoot, root, and the single-plant weight declined with increasing level of salt. An almost identical pattern of salt response was observed for nodule number, weight per nodule, nitrogen, and carbon fixation among the chickpea lines. No distinct relationship was found among root/shoot ratio, plant moisture content, and salt tolerance response of the chickpea. However, nodulation capacity (number and mass) under salt stress was related to salt tolerance response of chickpea lines. This trait could be used for improvement of salt tolerance of this legume species in order to increase its productivity and stability in saline soils. The research demonstrates that nodule number and not nodule mass is the trait that can be used as a useful marker in studying salt stress in chickpea. [71]

MORE INFORMATION

DAFWA, Dryland salinity in WA – an introduction.

14.5.2 Soil chloride levels

Soil chloride levels >600 mg/kg have been found to reduce root growth in crops such as chickpea, lentil and linseed. Soil analysis should be conducted to identify levels ofchloride and at what depth it changes. Thresholds for chloride concentration in soil and yield reductions differ between crops (Tables 7 and 8).

69 HA Khan, KHM Siddique, TD Colmer (2016) Vegetative and reproductive growth of salt-stressed chickpea are carbon-limited: sucrose infusion at the reproductive stage improves salt tolerance. Journal of Experimental Botany. Published online May 2016. DOI 10.1093/jxb/erw177, http://jxb.oxfordjournals.org/content/early/2016/04/29/jxb.erw177.full

70 S Samineni (2010) Physiology, Genetics and QTL Mapping of Salt Tolerance in Chickpea. Thesis. University of Western Australia.

71 B Singh, BK Singh, J Kumar, SS Yadav, K Usha (2005) Effects of salt stress on growth, nodulation, and nitrogen and carbon fixation of ten genetically diverse lines of chickpea (Cicer arietinum L.). Crop and Pasture Science, 56(5), 491–495.

Table 7: *Thresholds for chloride concentration in soil (mg/kg).*

Crop	10% Yield reduction	50% Yield reduction
Chickpeas	600	1,000
Bread wheat	700	1,500
Durum wheat	600	1,200
Barley	800	1,500
Canola	1200	1,800

Source: QLD Natural Resources and Water Bulletin

Table 8: *Soil constraint ratings for concentration of chloride (Cl) and Sodium (Na).*

Low	Medium	High
Surface soil (top 10 cm)		
<300 mg Cl/kg	300–600 mg Cl/kg	>600 mg Cl/kg
<200 mg Na/kg	200–500 mg Na/kg	>500 mg Na/kg
Subsoil (10 cm to 1m)		
<600 mg Cl/kg	600–1,200 mg Cl/kg	>1200 mg Cl/kg
<500 mg Na/kg	500–1,000 mg Na/kg	>1000 mg Na/kg

Source: QLD Natural Resources and Water Bulletin

Agronomic practices and crop choice

Agronomic practices and crop choices may have to vary for differing levels of soil salinity or sodicity constraints. Pulses such as chickpeas can be grown only where there are low salinity constraints.

Low constraints of Na and Cl (<600 mg Cl/kg, <500 mg Na/kg in top 1 m soil depth):

- Cereal–legume rotations are possible.
- Canola can be grown.
- Opportunity cropping to utilise available soil water can be tried.

Medium constraints of Na and Cl (600–1,200 mg Cl/kg, 500–1,000 mg Na/kg in top 1 m soil depth): tolerant crops should be grown (wheat, barley, canola):

- Consider tolerant crop varieties.
- The more tolerant of the pulses (vetch, faba bean, possibly lupin and field pea) will likely suffer yield penalties if grown.
- Match inputs to realistic yields.
- Cereal diseases must be managed.
- Avoid growing salt-susceptible pulses (including chickpea and lentil), or durum wheat.
- Opportunity cropping to utilise available soil water can be tried, but options may be more limited.

High constraints of Na and Cl (>1,200 mg Cl/kg, >1,000 mg Na/kg in top 1 m soil depth):

- Avoid growing crops or grow tolerant cereals.
- Match inputs to realistic yields.
- Consider alternative land use to cropping (e.g. saline-tolerant forages, pastures).

14.5.3 Soil pH

Chickpea crops are best suited to well-drained loam and clay loam soils that are neutral to alkaline (pH 6.0 to 9.0). [72]

Acidic soils

Acid soils can significantly reduce production and profitability before paddock symptoms are noticed. Danger levels for crops are when soil pH is less than 5.5 (in $CaCl_2$) or 6.3 (in water). Monitor changes in soil pH by regular soil testing. If severe acidity is allowed to develop, then irreversible soil damage can occur. Prevention is better than cure, so apply lime regularly in vulnerable soils. The most effective liming sources have a high neutralising value and have a high proportion of material with particle size smaller than 0.25 mm. More lime is required to raise pH in clays than in sands. Liming can induce manganese deficiency where soil manganese levels are marginal. Low soil pH often leads to poor or ineffective nodulation in pulses because acid soil conditions affect rhizobial initial numbers and multiplication. Field peas, faba beans, lentil and chickpea are vulnerable, as are vetches. Lupins are an exception because their rhizobia (Group G) are acid-tolerant. Granular inoculums seem to provide greater protection to rhizobia in acid soil conditions.

Between pH Ca 5.5 and pHCa8 is the ideal pH range for plants. Soil pH targets, as set by DAFWA and industry, are 5.5 in the topsoil, 0–10 cm, and over 4.8 in the subsurface soil, 10 cm and below. At pH ca of 4.8, or lower, levels of aluminium in the soil increase to toxic levels. Free aluminium has a large impact on crop yield. It reduces root growth in turn reducing the depth of soil the plant has access to.

In terms of lime movement through the soil, a pH level of 5.5 is required in the top 0–10 cm of soil before lime can influence any soil below this level. Lime applied to the surface will be worked in with the traffic of the seeding implement. This creates a layer where the pH is ameliorated to the depth of the seeding point but no further. Lime must be in contact with the soil of low pH in order to react. This layering effect has an impact on yield potential of rotation crops and pastures. An ameliorated surface, above pHca5.5, and subsurface with pH ca below 4.8 reduces the yield potential of rotation crops and the efficacy of N fixation. In spite of a lime application the subsurface pH remains unchanged until the lime is able to leach through the profile.

There is potential for incorrect decisions to be made without full knowledge of the soil pH to depth. This is particularly true when the crop is susceptible to low pH or aluminium toxicity, as are break crops like chickpea. Poor yields of these rotation crops may be the result of low pH at depth, in spite of good pH at the surface. A surface soil pH ca of 5.5, suitable for pulse crops, may conceal low pH in the subsurface unsuitable for pulse crops.

Soil pH in WA

A high proportion of paddocks (39%) sampled in the Profitable Crop and Pasture Sequences project (AKA Focus Paddocks) have subsurface pH below minimum target of pH Ca 4.8. The project also found 37% of sampled paddocks have pH Ca in the surface greater than 5.5 (Figure 25). Of these paddocks, 40% have pH ca of less than 4.8 at 10–30 cm. This has negative implications for legume break crops field pea and chickpea, and also legume pastures sown into these paddocks. [73]

72 Agriculture Victoria.(2016). Growing Chickpea. http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/growing-chickpea

73 W Parker DAFWA (2014) Crop Updates—Break crops being sown onto unsuitable soils, unsuspectingly.

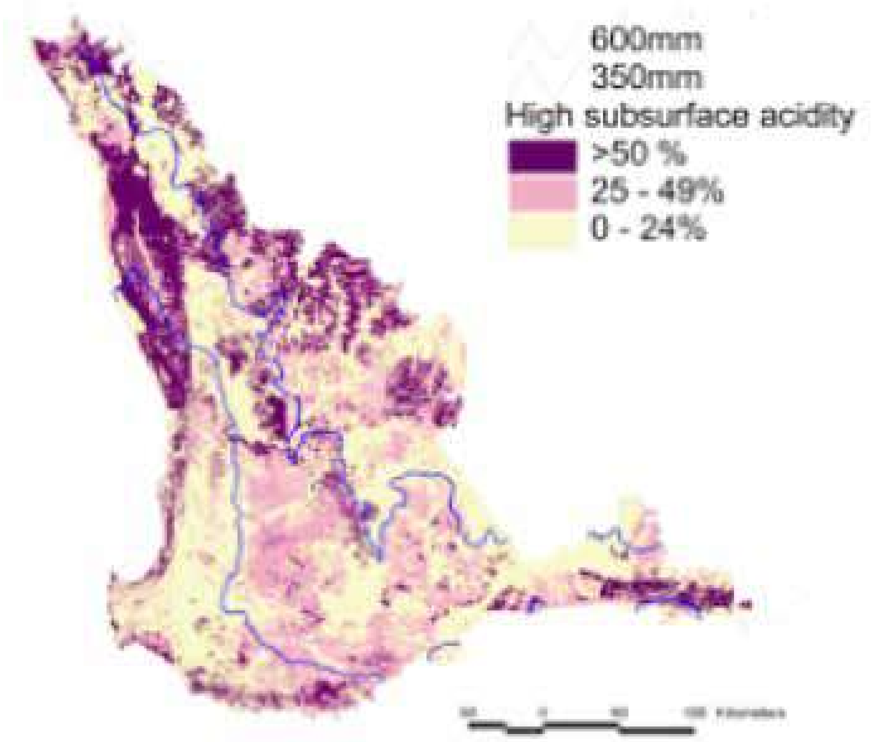


Figure 25: *The distribution of soils that are currently acid (pH<4.5 at 20 cm) or at high risk of subsurface acidity (within 10 years) determined using DAFWA's map unit database, accessed in May 2006.* [74]

Source: Davies et al. (2006)

Alkaline soils

In alkaline soils (Figure 26), the abundance of carbonates and bicarbonates can reduce crop growth and induce nutrient deficiencies. Presence of free lime has a major impact on lupin growth, inducing iron and manganese deficiency, which cannot be corrected by foliar sprays of those nutrients.

74 S Davies, C Gazey, B Bowden, D Van Gool, D Gartner, T Liaghati, B Gilkes (2006) Acidification of Western Australia's agricultural soils and their management. In Groundbreaking Stuff. Proceedings of the 13th Australian Agronomy Conference. Perth, Western Australia (N Turner & T Acuna, Eds.) p.[on line]. The Regional Institute Ltd, http://www.regional.org.au/au/asa/2006/concurrent/soil/4555_daviess.htm.

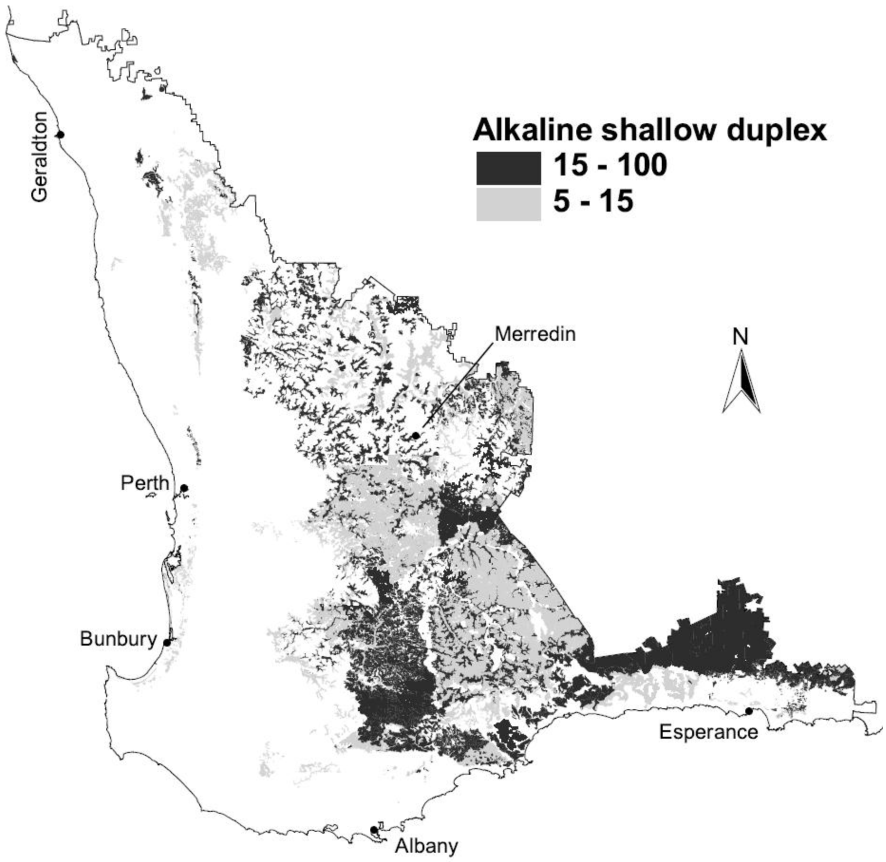


Figure 26: *Distribution of Alkaline shallow duplex soils in WA.*

Source: DAFWA

Managing soil acidity

Key points:

- Soil acidity across the south-west agricultural region of Western Australia is a major production constraint and is getting worse.
- Growers are applying more lime per hectare than in the past but, in many cases, much more lime is needed to recover the soil profile.
- Liming to remove soil acidity as a production constraint can also bring the benefits of increasing yields, maximising crop and pasture choice, and helping to protect the soil resource.

Soil acidification is an ongoing issue

Soil acidification is an ongoing and unavoidable result of productive agriculture. The main practices that cause soil acidification include removing harvested products and leaching of nitrate from soil. Because soil acidification is an ongoing result of farming, management also needs to be ongoing.

Lime use is increasing

Farmers in WA are increasing their use of lime and appropriate soil sampling to identify and prioritise lime application. For example, a survey was conducted of nearly 400 grain growers from across the WA wheat belt who indicated that the most common rates of application of lime would increase from 1–1.5 t/ha to 1.5–2 t/ha. Farmers also indicated that they intended to increase their testing of soil acidity in the subsurface layers.

Farmers in WA are also using more targeted applications of lime. Over 2010 to 2012, 75% of farmers applied lime at a single rate across paddocks. This method results in most soils receiving either too little or too much lime and not enough lime use overall. In the future, 50% of farmers intend to lime according to management areas or 'patch out' lime based on soil sampling results.

Soil acidification is still increasing

Despite higher applications of lime, the evidence clearly shows that soil pH in many areas of the south-west agricultural region is continuing to decline (Figure 27). Currently, more than 70% of soil samples from the 0–10 cm layer have pH in $CaCl_2$ below the minimum appropriate level of 5.5. In the 10–20 cm and 20–30 cm layers of soil, almost 50% of soil samples have pHCa below the minimum appropriate level of 4.8.

Soil acidity continues to be a major constraint to yield in Western Australia. Soil acidity costs WA agriculture about $500 million per annum in lost productivity. Without appropriate management, soil acidity will continue to prevent farmers from achieving their rain limited yield potential.

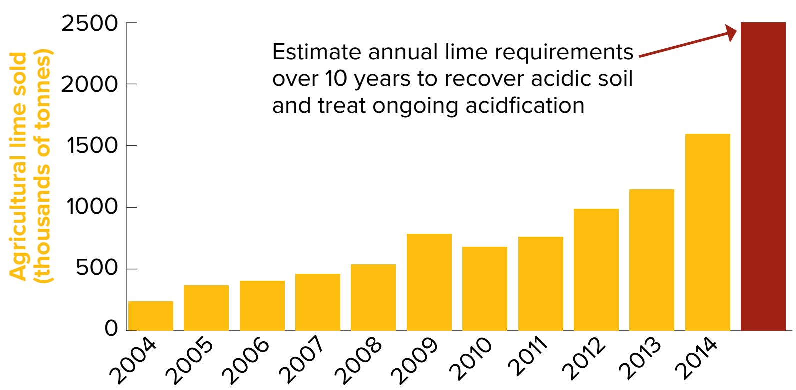


Figure 27: *Agricultural lime sales show that although lime use is increasing, it is only 60% of the estimated annual requirement for the next 10 years*

Source: Lime WA Inc.

More lime is needed

To manage soil acidification in WA, more lime must be applied to agricultural soils. The most effective method is to apply the right rate of lime in the right place at the right time. This will use resources most effectively and provide the best returns on investment.

The importance of soil testing

Soil testing has a vital role in the management of soil acidity. It is important that decisions on where and when to apply lime and how much lime to apply are based on objective measures of soil acidity. While it is possible to estimate maintenance liming rates based on farm inputs and outputs, the most direct method—and the only way to measure existing acidity—is to regularly test the surface and subsurface soil layers.

Yield increases from liming

Liming can increase grain yield when soil pH is below recommended targets and when soil pH is one of the factors constraining yield. DAFWA and the CSIRO investigated how liming affected yield in 69 lime trials from across the WA wheat belt. On average, applying lime increased yield by 0.2 t/ha, or 10%. This result is similar to findings in most other trials around Australia. However, the yield increases from liming may be even higher than this. When trials have included ripping or tillage,

MORE INFORMATION

Soil acidity and liming.

increases in yield were even greater. Also, it takes a few years for lime to react with the soil and increase the soil pH. If yield was calculated starting from the third harvest after lime was applied, the average yield increase was 0.25 t/ha, or 16%. Yield and yield gains from liming will depend on the relationship between paddock yield and yield potential. If the paddock yield is low relative to the yield potential, there is likely to be additional constraints present and there may be little gain from liming. Also, if the paddock yield is already close to potential pH is not likely to be a constraint and there may also be little immediate gain from liming. However, maintenance liming will be required to counter ongoing acidification and maintain the productivity of the paddock. [75]

14.5.4 Sodicity

Chickpea is classified among the most sensitive of all field crops to sodic soil conditions.

Soils high in sodium are structurally unstable, with clay particles dispersing when wet. This subsequently blocks soil pores, reduces water infiltration and aeration, and retards root growth. On drying, a sodic soil becomes dense and forms a hard surface crust up to 10 mm thick. This can also restrict seedling emergence. Sodic soils occupy almost one-third of the land area of Australia.

Some indicators of surface sodicity include:

- soils prone to crusting and sealing up
- ongoing problems with poor plant establishment
- presence of scalded areas in adjoining pasture

Exchangeable sodium percentage is the measure for sodicity:

- ESP less than 3: non-sodic soils
- ESP 3–14: sodic soil
- ESP greater than 15: strongly sodic

Sodicity has serious impacts on farm production, as well as significant off-site consequences such as:

- surface crusting
- reduced seedling emergence
- reduced soil aeration
- increased risk of run-off and erosion
- less groundcover and organic matter
- less microbial activity

Sodic soils are known as dispersive clays and reduce seedling emergence (Figure 28).

Sodic soils are can lead to tunnel erosion—they turn to slurry when wet, and channels are easily created through them by moving water. [76]

75 C Gazey, J Carson. Managing soil acidity–Western Australia Fact Sheet. The National Soil Quality Monitoring Program, http://www.soilquality.org.au/factsheets/managing-soil-acidity-western-australia

76 Corangamite CMA (2013) How do I manage the impact of sodic soils? Corangamite CMA, http://www.ccmaknowledgebase.vic.gov.au/brown_book/04_Sodic.htm

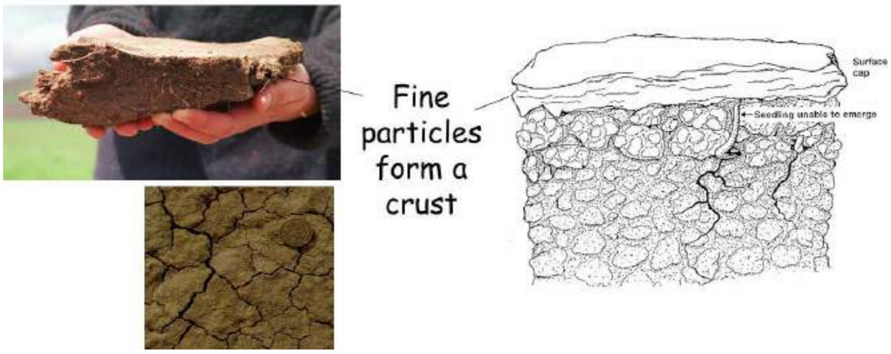


Figure 28: *The impact of sodic soils on seedling emergence: surface crusting and dispersive clay limit emergence.*

Source: Corangamite CMA

Soils that are sodic in the topsoil have the greatest impact on crop performance (see Figure 29 for effect of ESP on chickpea yield). Sodic layers deeper in the soil profile are not as great a concern but can still affect yields by restricting root development and water extraction from depth. The net effect of severely restricted root growth in chickpeas is usually the early onset of drought stress.

It is unlikely that soil sodic layers deeper than 90 cm will have significant impact on chickpea yields.

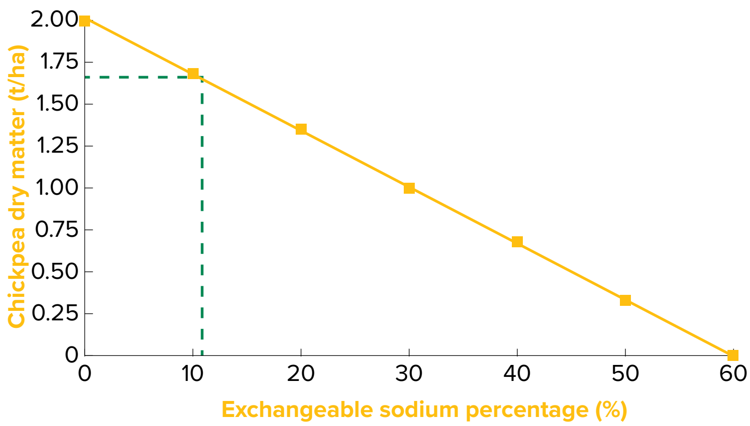


Figure 29: *Impact of sodicity on chickpea dry matter production.* [77]

Source: Pulse Australia Ltd

Sodic soils in WA

Sodic soils are common throughout WA, particularly in the south-west agricultural area where they occur mainly as duplex or gradational profiles. Soils with sodic properties are dominant in 26% of the state; saline-sodic sediments and soils in intermittent streams, lakes and estuarine plains occupy a further 5%. Sodic soils are moderately common throughout the southern and western portion of the rangeland areas (38% of the state). The south-west coastal sands and the desert and rangeland soils to the north and east of the state are rarely sodic. Efficient management of sodic soils in these areas must rely on the prevention of degradation and the use of biological and physical means to maintain adequate soil physical properties. Effective restoration of degraded sodic soils, however, often does require application of inorganic amendments in combination with tillage to initiate structural recovery. Sodicity is currently not considered to be a problem at any of the three main irrigation

77 Pulse Australia Ltd (2013) Northern chickpea best management practices training course manual–2013.

areas in WA, but all have sodic soil within their potentially irrigable lands, which may limit their future expansion. [78]

Managing sodic soils

- Growers need to correctly identify the problem first and ensure that the soils are in fact sodic.
- Sodic soils can be directly treated through the application of gypsum (particularly on the surface), which serves to replace the excess sodium in the soil with calcium.
- In southern Victoria, typical application rates of gypsum are around 2.5 t/ha and applied every 3–5 years.
- The application of lime to sodic soils acts in a similar manner to gypsum, but is much slower acting and less effective.
- Although the application of gypsum can effectively counter sodicity in the short run, longer-term management strategies need to be in place to increase, and then maintain, organic matter in soils. Increased organic matter can improve hard-setting soils, and it can also enhance the effect of gypsum.
- Sodicity can also be reduced by maintaining adequate vegetation cover, leaf litter or stubble on the soil surface.
- Trials in the high-rainfall zone of southern Victoria have shown that the amelioration of dense sodic subsoil using organic amendments can increase wheat yield more than using gypsum. [79]

78 HR Cochrane, G Scholz, AME Vanvreswyk (1994) Sodic soils in western Australia. Soil Research, 32(3), 359–388.

79 P Sale, J Gill, R Peries, C Tang (2008) Amelioration of dense sodic subsoil using organic amendments increases wheat yield more than using gypsum in a high rainfall zone of southern Australia. La Trobe University, Bundoora, Victoria.

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.

Figure 1 shows a grain selling flow chart that summarises:

- The decisions to be made.
- The drivers behind the decisions.
- The guiding principles for each decision point.

The reference column refers to the section of the GrowNote where you will find the details to help in making decisions.

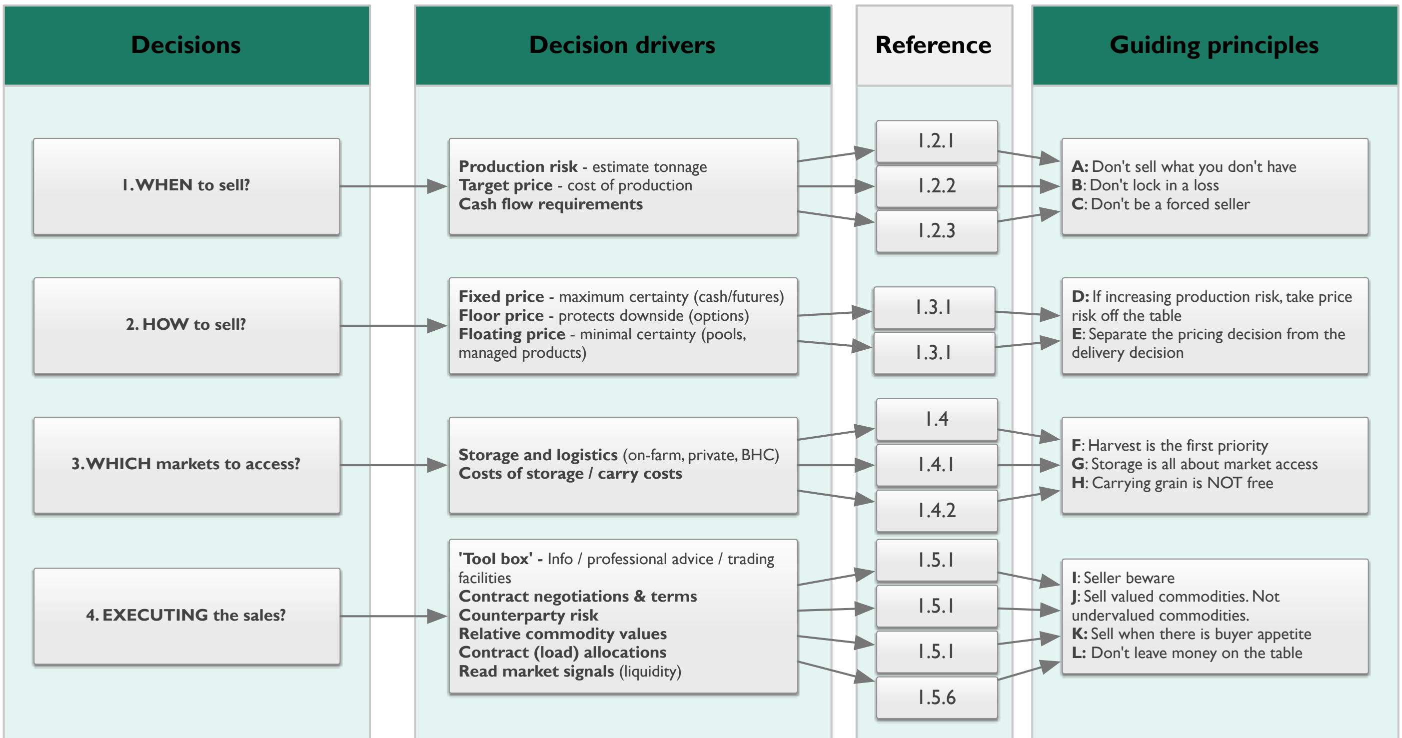
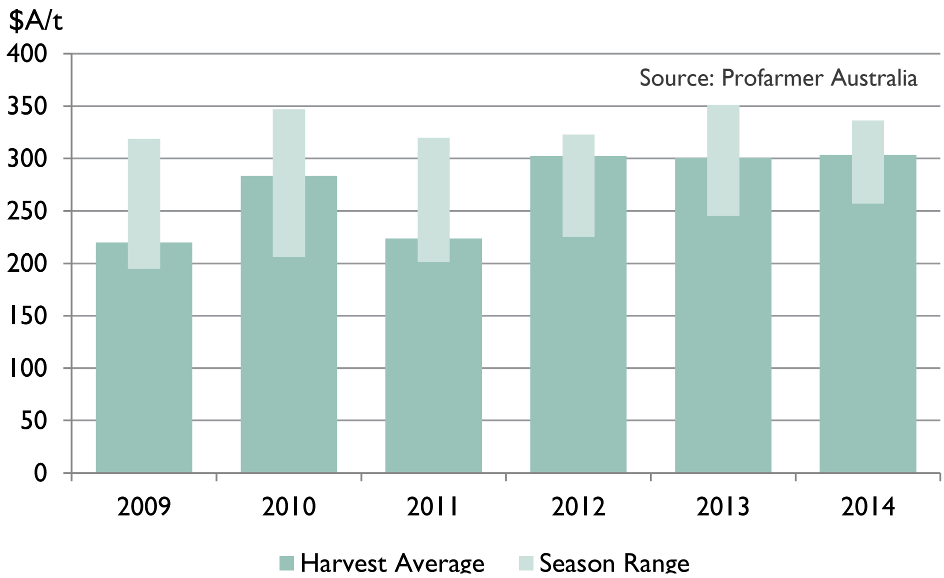


Figure 1: *Grain-selling flowchart.*

The grower will run through a decision-making process each season, because growing and harvesting conditions, and prices for grains, change all the time. For example, in the six years to and including 2014, Newcastle APWI wheat prices varied A$70–$150/t, a variability of 25–60% (Figure 2). For a property producing 1,000 tonnes of wheat this means $70,000–$150,000 difference income, depending on timing of sales.



Note to figure:
Newcastle APW1 wheat prices have varied A$70-$150/t over the past 6 years (25-60% variability). For a property producing 1,000 tonne of wheat this means $70,000-$150,000 difference in income depending on price management skill.

Figure 2: *Newcastle APWI price variation, 2009–2014.*

Source: Profarmer Australia

15.1 Selling principles

The aim of a selling program is to achieve a profitable average price (the target price) across the entire business. This requires managing several unknowns to establish a target price and then work towards achieving the target price.

Unknowns include the amount of grain available to sell (production variability), the final cost of producing the grain, and the future prices that may result. Australian farm-gate prices are subject to volatility caused by a range of global factors that are beyond our control and are difficult to predict.

The skills growers have developed to manage production unknowns can also be used to manage pricing unknowns. This guide will help growers manage and overcome price uncertainty.

15.1.1 Be prepared

Being prepared by having a selling plan is essential for managing uncertainty. The steps involved are forming a selling strategy, and forming a plan for effectively executing sales. The selling strategy consists of when and how to sell.

When to sell

Knowing when to sell requires an understanding of the farm's internal business factors, including:

- production risk
- a target price based on the cost of production and the desired profit margin
- business cashflow requirements

How to sell

Working out how to sell your grain is more dependent on external market factors, including:

- the time of year, which determines the pricing method
- market access, which determines where to sell
- relative value, which determines what to sell

The following diagram (Figure 3) lists the key principles to employ when considering sales during the growing season. Exactly when each principle comes into play is indicated in the discussion below of the steps involved in marketing and selling.

Figure 3: *Timeline of grower commodity selling principles.*

Source: Profarmer Australia

15.1.2 Establish the business risk profile

Establishing your business risk profile helps you determine when to sell: it allows you to develop target price ranges for each commodity, and provides confidence to sell when the opportunity arises. Typical business circumstances and how to quantify the risks during the production cycle are described below (Figure 4).

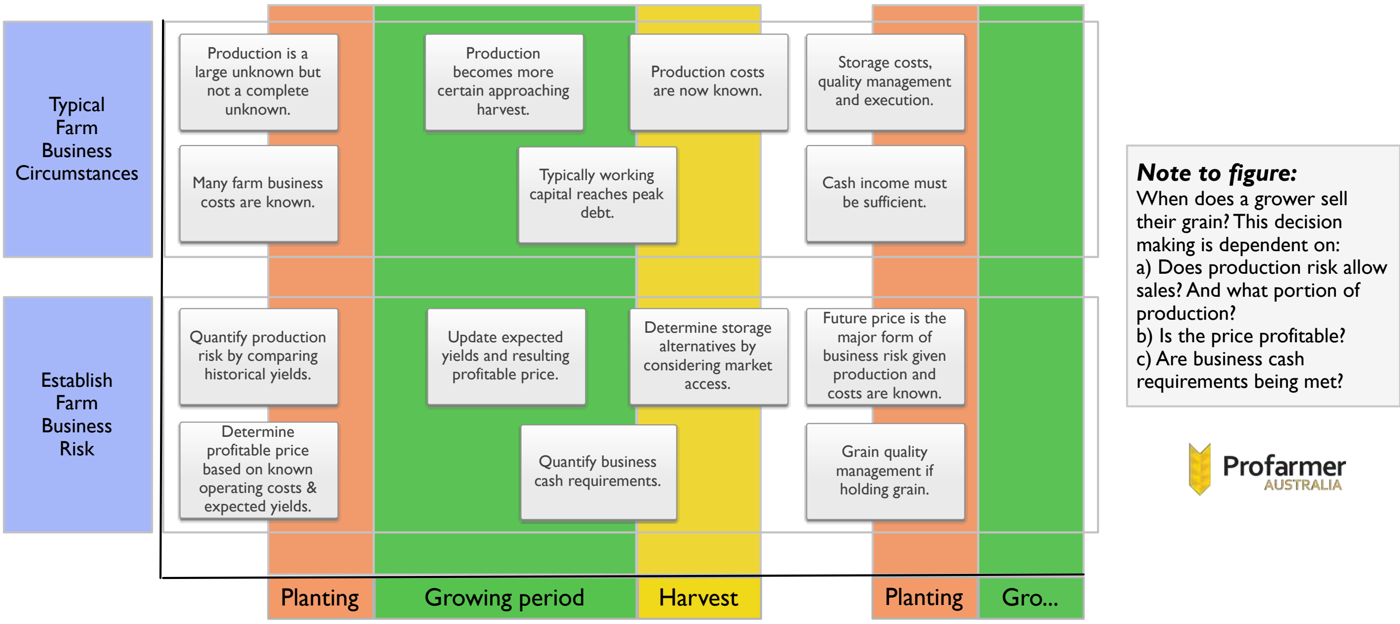


Figure 4: *Typical farm business circumstances and risk.*

Source: Profarmer Australia

Production risk profile of the farm

Production risk is the level of certainty around producing a crop and is influenced by location (climate, season and soil type), crop type, crop management, and the time of the year.

Principle: You can't sell what you don't have.

Therefore, don't increase business risk by over committing production. Establish a production risk profile (see Figure 5) by:

1. Collating historical average yields for each crop type and a below-average and above-average range.
2. Assessing the likelihood of achieving the average, based on recent seasonal conditions and the seasonal outlook.
3. Revising production outlooks as the season progresses.

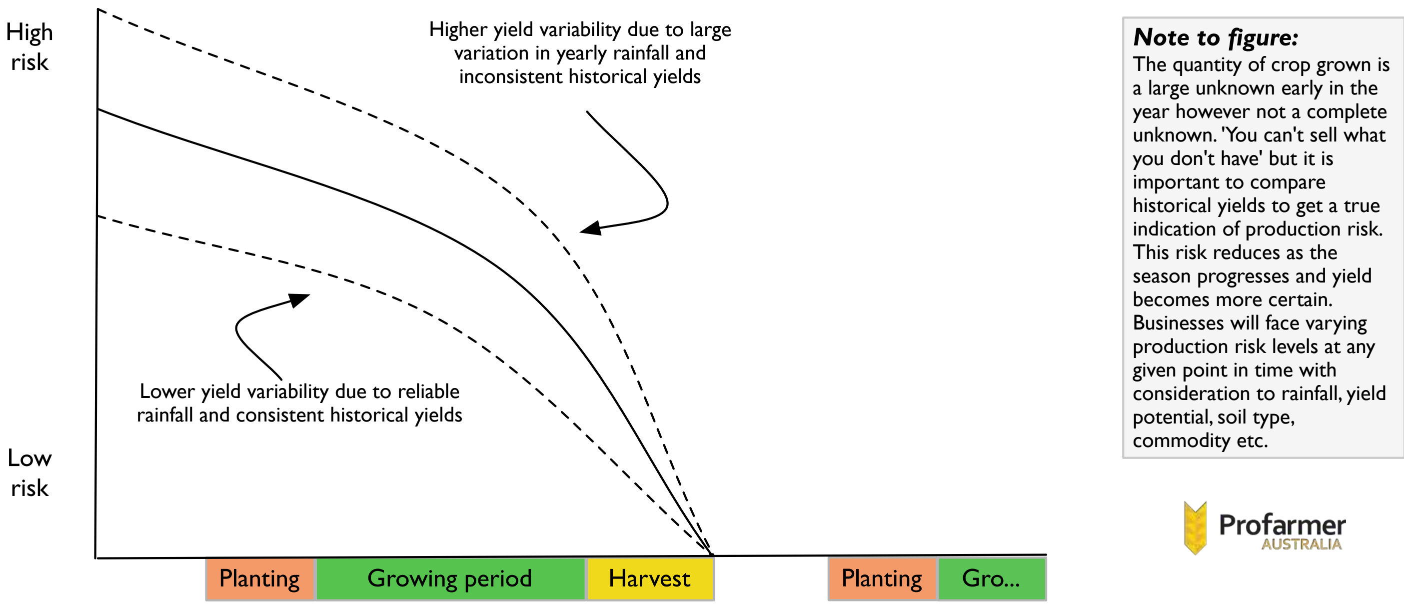


Figure 5: *Typical risk profile of a farm operation.*

Source: Profarmer Australia

Establishing a target price

A profitable commodity target price is the cost of production per tonne plus a desired profit margin. It is essential to know the cost of production per tonne for the farm business, which means knowing all farming costs, both variable and fixed.

Principle: Don't lock in a loss.

If committing production ahead of harvest, ensure the price will be profitable. The steps needed to calculate an estimated profitable price is based on the total cost of production and a range of yield scenarios, as provided below (Figure 6).

Estimating cost of production - Wheat	
Planted Area	1,200 ha
Estimate Yield	2.85 t/ha
Estimated Production	3,420 t
Fixed costs	
Insurance and General Expenses	$100,000
Finance	$80,000
Depreciation/Capital Replacement	$70,000
Drawings	$60,000
Other	$30,000
Variable costs	
Seed and sowing	$48,000
Fertiliser and application	$156,000
Herbicide and application	$78,000
Insect/fungicide and application	$36,000
Harvest costs	$48,000
Crop insurance	$18,000
Total fixed and variable costs	$724,000
Per Tonne Equivalent (Total costs + Estimated production)	$212 /t
Per tonne costs	
Levies	$3 /t
Cartage	$12 /t
Receival fees	$11 /t
Freight to Port	$22 /t
Total per tonne costs	$48 /t
Cost of production Port FIS equiv	$259.20
Target profit (ie 20%)	$52.00
Target price (port equiv)	**$311.20**

Step 1: Estimate your production potential. The more uncertain your production is, the more conservative the yield estimate should be. As yield falls, your cost of production per tonne will rise.

Step 2: Attribute your fixed farm business costs. In this instance if 1,200 ha reflects 1/3 of the farm enterprise, we have attributed 1/3 fixed costs. There are a number of methods for doing this (see M Krause “Farming your Business”) but the most important thing is that in the end all costs are accounted for.

Step 3: Calculate all the variable costs attributed to producing that crop. This can also be expressed as $ per ha x planted area.

Step 4: Add together fixed and variable costs and divide by estimated production

Step 5: Add on the “per tonne” costs like levies and freight.

Step 6: Add the “per tonne” costs to the fixed and variable per tonne costs calculated at step 4.

Step 7: Add a desired profit margin to arrive at the port equivalent target profitable price.

Figure 6: *An example of how to estimate the costs of production.*

Source: Profarmer Australia

Income requirements

Understanding farm business cash-flow requirements and peak cash debt enables growers to time grain sales so that cash is available when required. This prevents having to sell grain below the target price to satisfy a need for cash.

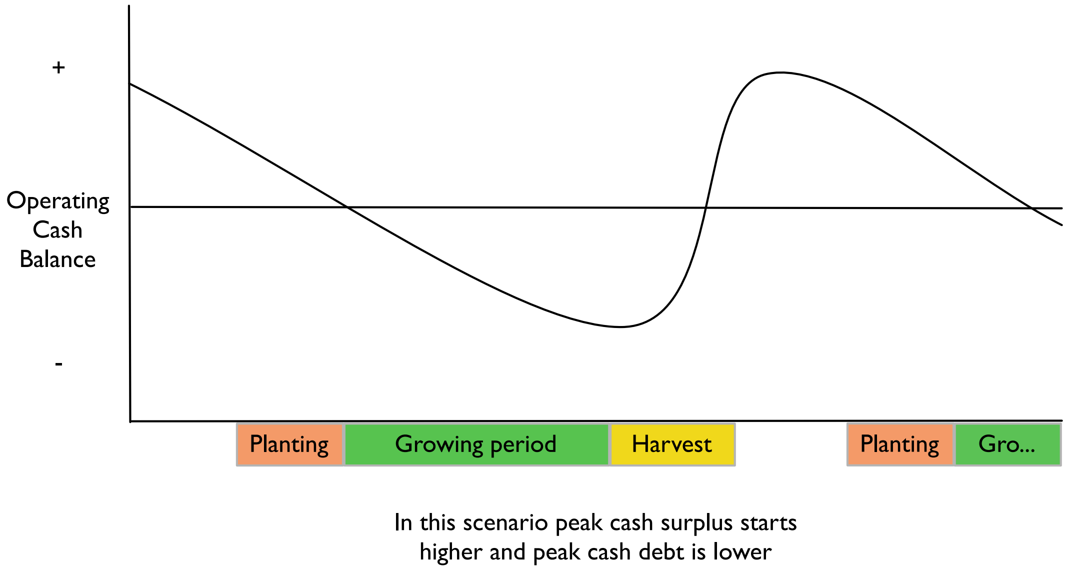
Principle: Don’t be a forced seller.

Be ahead of cash requirements to avoid selling in unfavourable markets.

Typical cash-flow to grow a crop are illustrated below (Figures 7 and 8). Costs are incurred up front and during the growing season, with peak working capital debt incurred at or before harvest. Patterns will vary depending on circumstance and enterprise mix. The second figure demonstrates how managing sales can change the farm’s cash balance.

MORE INFORMATION

GRDC’s manual Farming the Business also provides a cost-of-production template and tips on grain selling *v.* grain marketing.

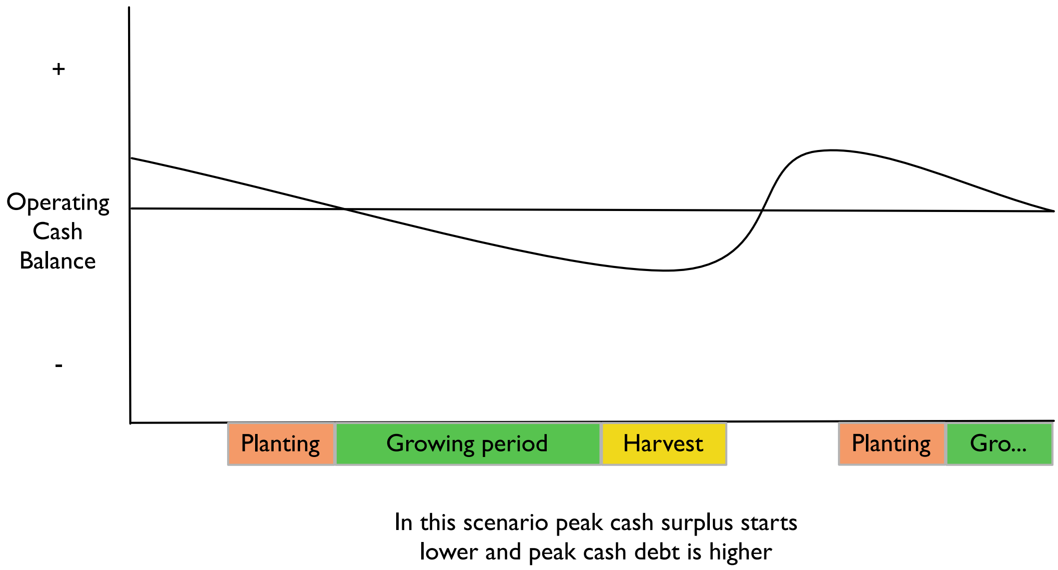


Note to figure:
The chart illustrates the operating cash flow of a typical farm assuming a heavy reliance on cash sales at harvest. Costs are incurred during the season to grow the crop, resulting in peak operating debt levels at or near harvest. Hence at harvest there is often a cash injection required for the business. An effective marketing plan will ensure a grower is 'not a forced seller' in order to generate cash flow.

Profarmer AUSTRALIA

Figure 7: *A typical operating cash balance when relying on cash sales at harvest.*

Source: Profarmer Australia



Note to figure:
By spreading sales throughout the year a grower may not be as reliant on executing sales at harvest time in order to generate required cash flow for the business. This provides a greater ability to capture pricing opportunities in contrast to executing sales in order to fulfil cash requirements.

Profarmer AUSTRALIA

Figure 8: *Typical operating cash balance when crop sales are spread over the year.*

Source: Profarmer Australia

The when-to-sell steps above result in an estimated production tonnage and the risk associated with producing that tonnage, a target price range for each commodity, and the time of year when cash is most needed.

15.1.3 Managing your price

The first part of the selling strategy answers the question about when to sell and establishes comfort around selling a portion of the harvest.

The second part of the strategy, managing your price, addresses how to sell your crop.

Methods of price management

Pricing products provide varying levels of price risk coverage, but not all products are available for all crops (Table 1).

Table 1: *Pricing methods and how they are used for different crops.*

	Description	Wheat	Barley	Canola	Oats	Lupins	Field Peas	Chick Peas
Fixed price products	Provides the most price certainty	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash, futures, bank swaps	Cash	Cash	Cash	Cash
Floor price products	Limits price downside but provides exposure to future price upside	Options on futures, floor price pools	Options on futures	Options on futures	none	none	none	none
Floating price products	Subject to both price upside and downside	Pools	Pools	Pools	Pools	Pools	Pools	Pools

Figure 9 summarises how the different methods of price management are suited to the majority of farm businesses.

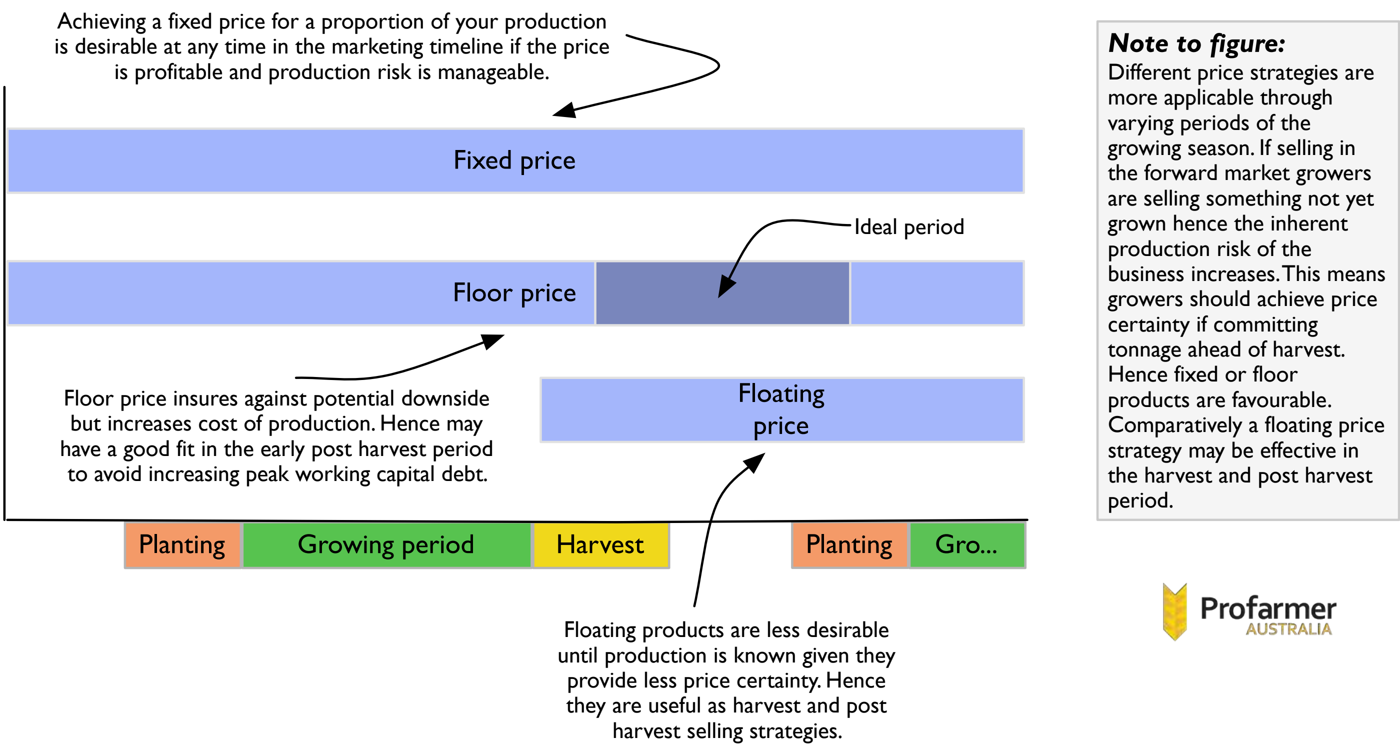


Figure 9: *Price strategy timeline, summarising the suitability for most farm businesses of different methods of price management for different phases of production.*

Source: Profarmer Australia

Principle: If increasing production risk, take price risk off the table.

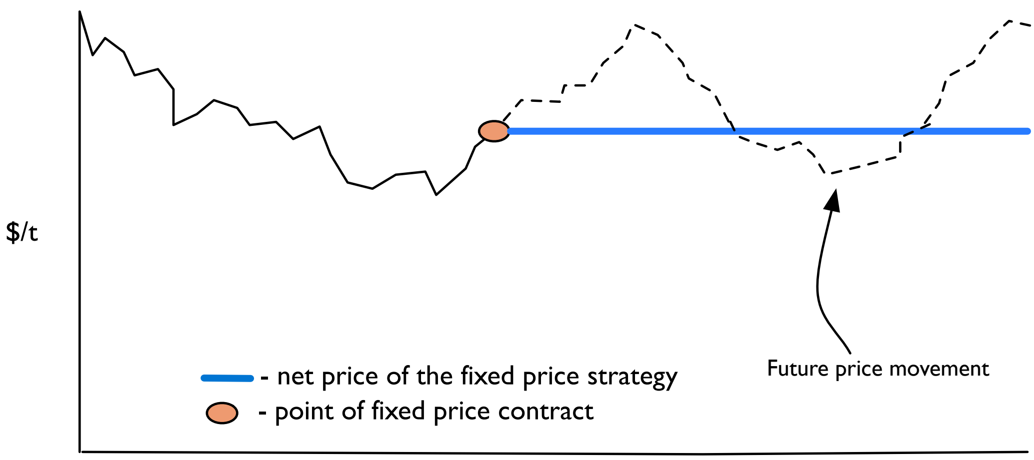
When committing to unknown production, price certainty should be achieved to avoid increasing overall business risk.

Principle: Separate the pricing decision from the delivery decision.

Most commodities can be sold at any time with delivery timeframes being negotiable, hence price management is not determined by delivery.

Fixed price

A fixed price is achieved via cash sales and/or selling a futures position (swaps) (Figure 10). It provides some certainty around expected revenue from a sale as the price is largely a known factor, except when there is a floating component in the price, e.g. a multi-grade cash contract with floating spreads or a floating-basis component on futures positions.



Note to figure:
Fixed price product locks in price and provides certainty over what revenue will be generated regardless of future price movement.

Profarmer AUSTRALIA

Figure 10: *Fixed price strategy.*

Source: Profarmer Australia

Floor price

Floor-price strategies (Figure 11) can be achieved by utilising options on a relevant futures exchange (if one exists), or via a managed-sales program (i.e. a pool with a defined floor-price strategy) offered by a third party. This pricing method protects against potential future downside while capturing any upside. The disadvantage is that this kind of price 'insurance' has a cost, which adds to the farm's cost of production.

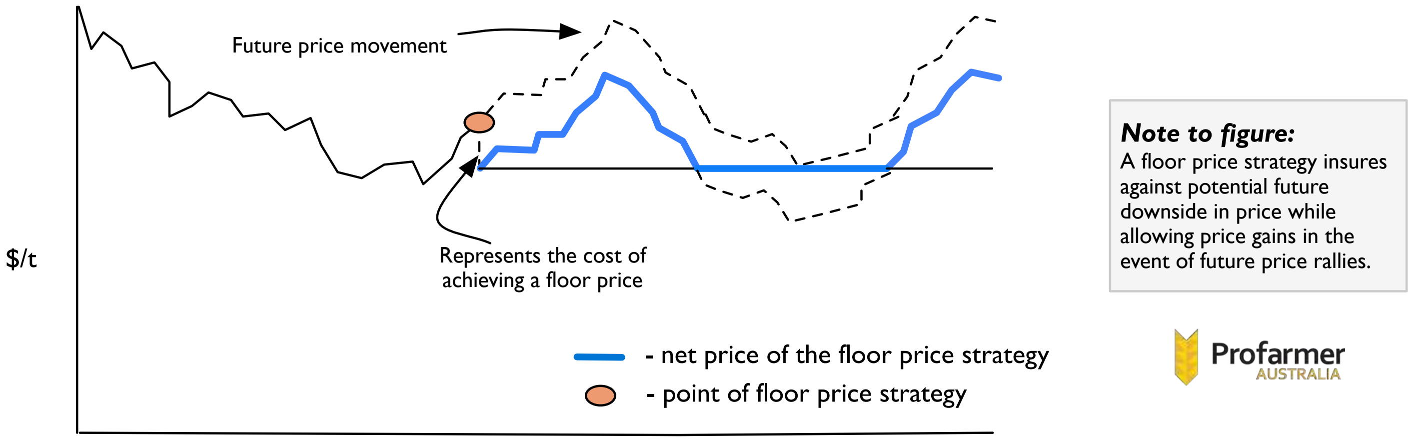


Figure 11: *Floor price strategy.*

Source: Profarmer Australia

3. Floating price

Many of the pools or managed-sales programs are a floating price, where the net price received will move up and down with the future movement in price (Figure 12). Floating-price products provide the least price certainty and are best suited for use at or after harvest rather than before harvest.

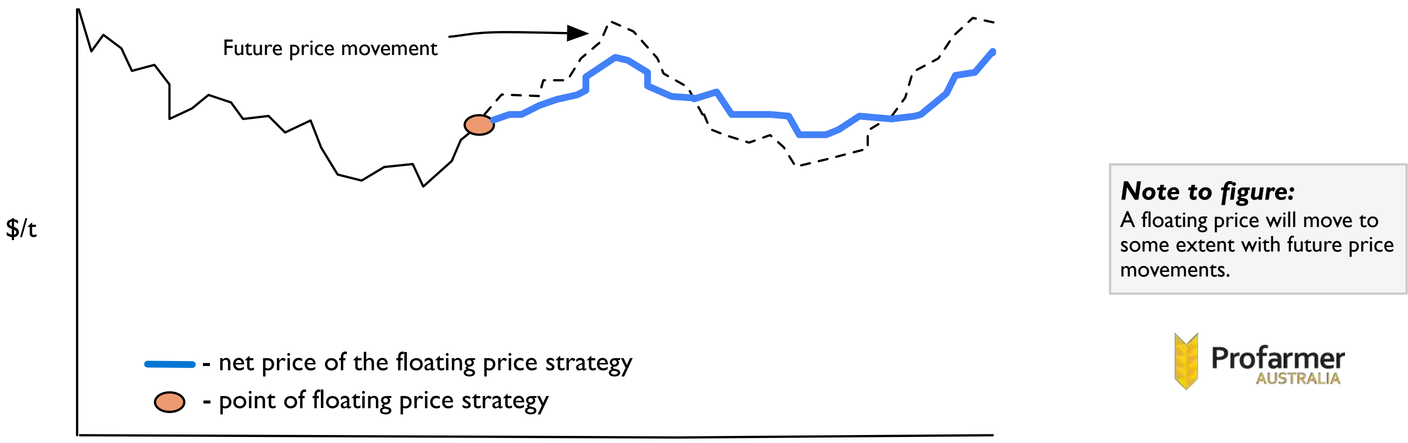


Figure 12: *Floating price strategy.*

Source: Profarmer Australia

Having considered the variables of production for the crop to be sold, and how these fit against the different pricing mechanisms, the farmer may revise their selling strategy, taking the risks associated with each mechanism into account.

Fixed-price strategies include physical cash sales or futures products, and provide the most price certainty, but production risk must be considered.

Floor-price strategies include options or floor-price pools. They provide a minimum price with upside potential and rely less on production certainty, but cost more.

Floating-price strategies provide minimal price certainty, and so are best used after harvest.

15.1.4 Ensuring access to markets

Once the questions of when and how to sell are sorted out, planning moves to the storage and delivery of commodities to ensure timely access to markets and execution of sales. Planning where to store the commodity is an important component of ensuring the type of access to the market that is likely to yield the highest return (Figure 13).

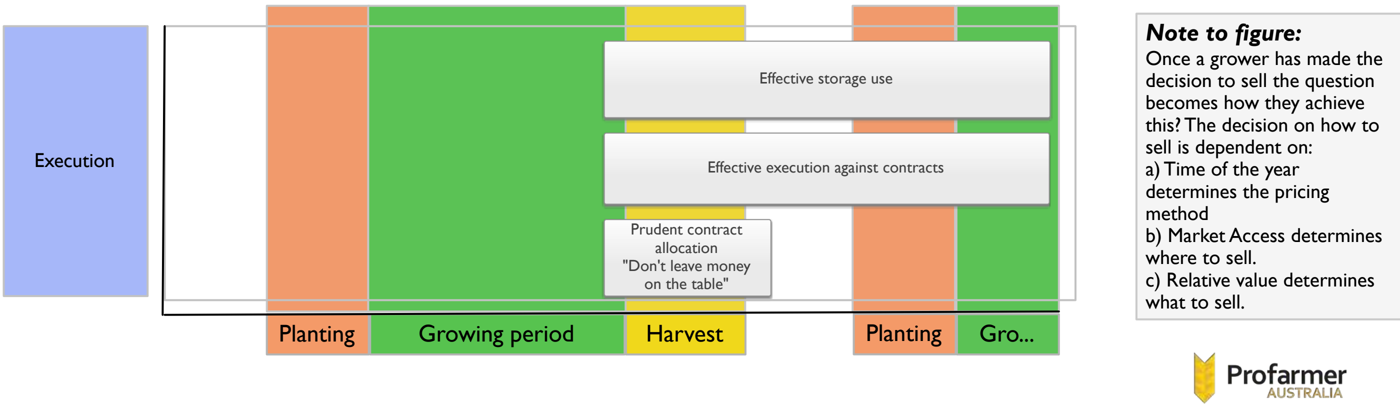


Figure 13: *Storage decisions are influenced by selling decisions and the timing of all farming activities.*

Source: Profarmer Australia

Storage and logistics

The return on investment from grain handling and storage expenses is optimised when storage is considered in light of market access so as to maximise returns as well as harvest logistics.

Storage alternatives include variations of bulk handling, private off-farm storage, and on-farm storage. Delivery and quality management are key considerations in deciding where to store your commodity (Figure 14).

Principle: Harvest is the first priority.

During harvest, getting the crop into the bin is the most critical aspect of business success; hence storage, sale and delivery of grain should be planned well ahead of harvest to allow the grower to focus on the harvest itself.

Bulk export commodities requiring significant quality management are best suited to the bulk-handling system. Commodities destined for the domestic end-user market, (e.g. feedlot, processor, or container packer), may be more suited to on-farm or private storage to increase delivery flexibility.

Storing commodities on the farm requires prudent quality management to ensure that the grain is delivered to the agreed specifications. If not well planned and carried out, it can expose the business to high risk. Penalties for out-of-specification grain arriving at a buyer's weighbridge can be expensive, as the buyer has no obligation to accept it. This means the grower may have to incur the cost of taking the load elsewhere, and may also have to find a new buyer.

On-farm storage also requires that delivery is managed to ensure that the buyer receives the commodities on time and with appropriate weighbridge and sampling tickets.

Principle: Storage is all about market access.

Storage decisions depend on quality management and expected markets.

MORE INFORMATION

For more information on on-farm storage alternatives and economics refer to Section 13: Grain Storage.

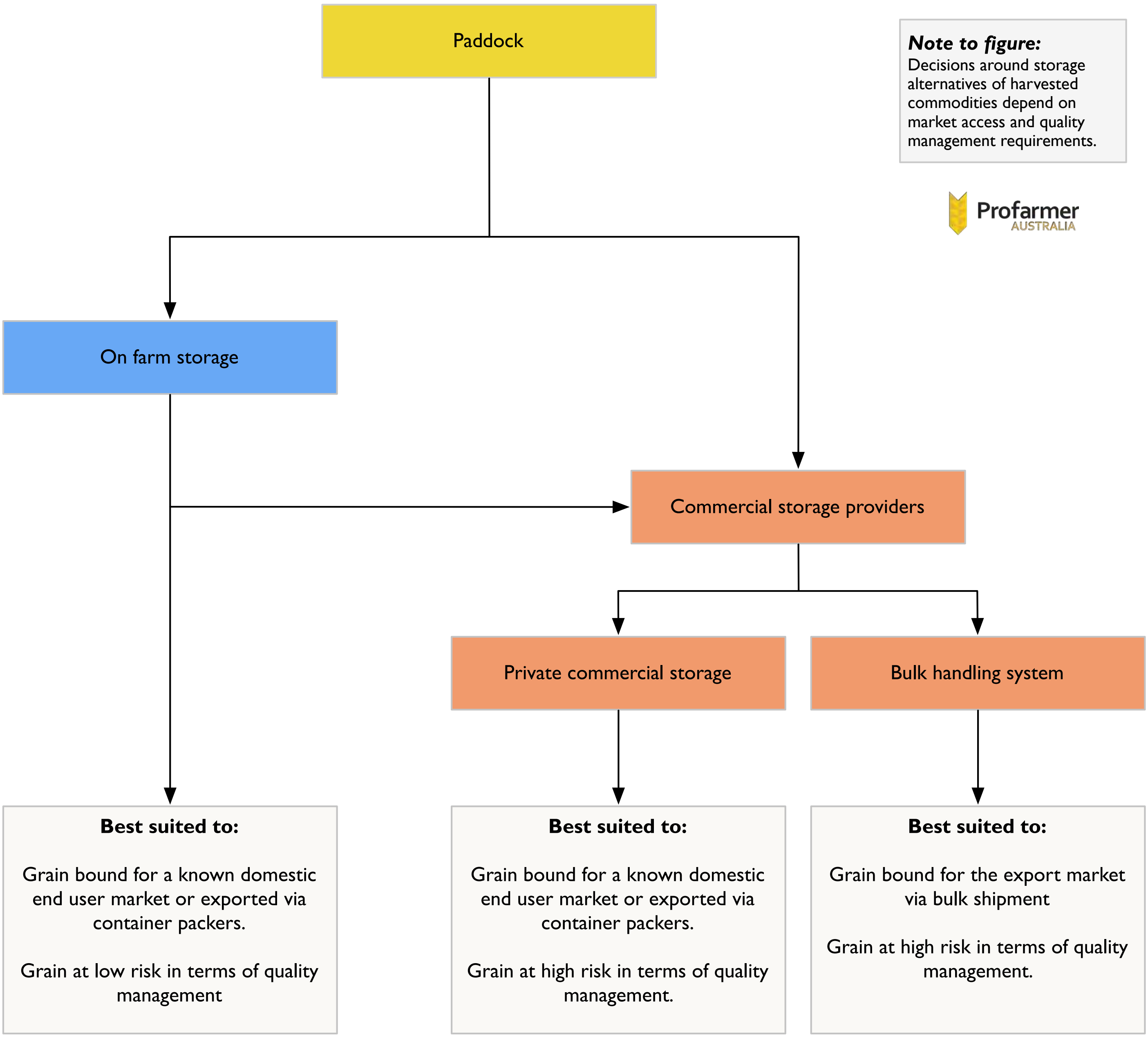


Figure 14: *Grain storage decision-making.*

Source: Profarmer Australia

Cost of carrying grain

Storing grain to access sales opportunities post-harvest invokes a cost to 'carry', or hold, the grain. Price targets for carried grain need to account for the cost of carrying it. Carrying costs are typically $3–4/t per month and consist of:

- Monthly storage fee charged by a commercial provider (typically ~$1.50–2.00/t).
- Monthly interest associated with having wealth tied up in grain rather than available as cash or for paying off debt (~$1.50–$2.00/t, depending on the price of the commodity and interest rates).

The price of carried grain therefore needs to be $3–4/t per month higher than the price offered at harvest (Figure 15).

The cost of carrying also applies to grain stored on the farm, as there is the cost of the capital invested in the farm storage plus the interest component. A reasonable assumption is a cost of $3–4/t per month for on-farm storage.

Principle: Carrying grain is not free.

The cost of carrying grain needs to be accounted for if holding it for sale after harvest is part of the selling strategy. if selling a cash contract with deferred delivery, a carry charge can be negotiated into the contract. For example, a crop sold in March for delivery in March–June on the buyer's call at $700/t + $5/t per month carrying would generate an income of $715/t if delivered in June (Figure 15).

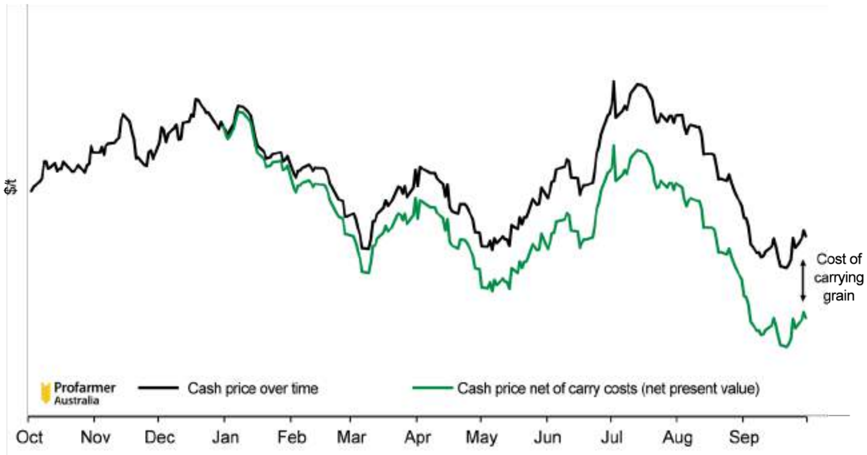


Figure 15: *Cash values compared with cash values adjusted for the cost of carrying.*

Source: Profarmer Australia

Optimising farm-gate returns involves planning the appropriate storage strategy for each commodity so as to improve market access and ensure that carrying costs are covered in the price received.

15.1.5 Converting tonnes into cash

This section provides guidelines for converting the selling and storage strategy into cash by effective execution of sales.

Set up the toolbox

Selling opportunities can be captured when they arise by assembling the necessary tools in advance. The toolbox for converting tonnes of grain into cash includes the following.

1. Timely information—this is critical for awareness of selling opportunities and includes:

- Market information provided by independent parties.
- Effective price discovery including indicative bids, firm bids and trade prices.
- Other market information pertinent to the particular commodity.

2. Professional services—grain-selling professional services and cost structures vary considerably. An effective grain-selling professional will put their clients' best interests first by not having conflicts of interest and by investing time in the relationship. A better return on investment for the farm business is achieved through higher farm-gate prices, which are obtained by accessing timely information, and being able to exploit the seller's greater market knowledge and greater market access.
3. Futures account and a bank-swap facility—these accounts provide access to global futures markets. Hedging futures markets is not for everyone; however,

MORE INFORMATION

Access to buyers, brokers, agents, products and banks through Grain Trade Australia

Commodity futures brokers

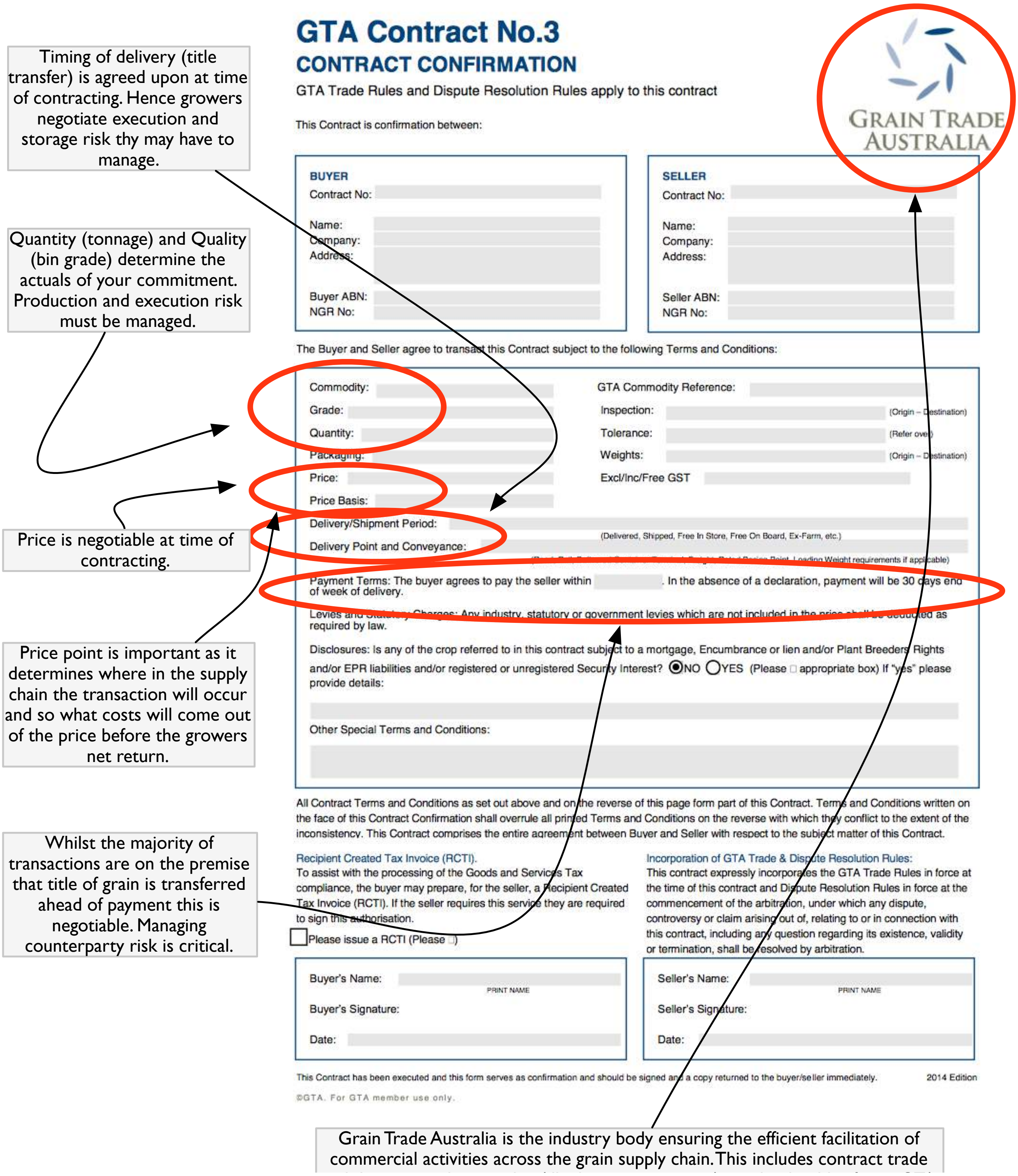
ASX, Find a futures broker

strategies which utilise exchanges such as the Chicago Board of Trade (CBOT) can add significant value.

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 (Figure 16):

- Price—future price is largely unpredictable, so devising a selling plan to put current prices into the context of the farm business is critical to managing price risk.
- Quantity and quality—when entering a cash contract, you are committing to deliver the nominated amount of grain at the quality specified, so production and quality risks must be managed.
- Delivery terms—the timing of the 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 on the grain to be transferred ahead of payment, so counterparty risk must be managed.



GTA Contract No.3
CONTRACT CONFIRMATION
GTA Trade Rules and Dispute Resolution Rules apply to this contract

This Contract is confirmation between:

BUYER
Contract No:
Name:
Company:
Address:
Buyer ABN:
NGR No:

SELLER
Contract No:
Name:
Company:
Address:
Seller ABN:
NGR No:

The Buyer and Seller agree to transact this Contract subject to the following Terms and Conditions:

Commodity:
Grade:
Quantity:
Packaging:
Price:
Price Basis:
GTA Commodity Reference:
Inspection: (Origin – Destination)
Tolerance: (Refer over)
Weights: (Origin – Destination)
Excl/Inc/Free GST
Delivery/Shipment Period:
(Delivered, Shipped, Free In Store, Free On Board, Ex-Farm, etc.)
Delivery Point and Conveyance:
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
Buyer's Signature:
Date:

Seller's Name: PRINT NAME
Seller's Signature:
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
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Figure 16: *Typical terms of a cash contract.*

Source: Grain Trade Australia

The price point within a cash contract will depend on where the transfer of grain title will occur along the supply chain. Figure 17 depicts the terminology used to describe these points and the associated costs to come out of each price before growers receive their net return.

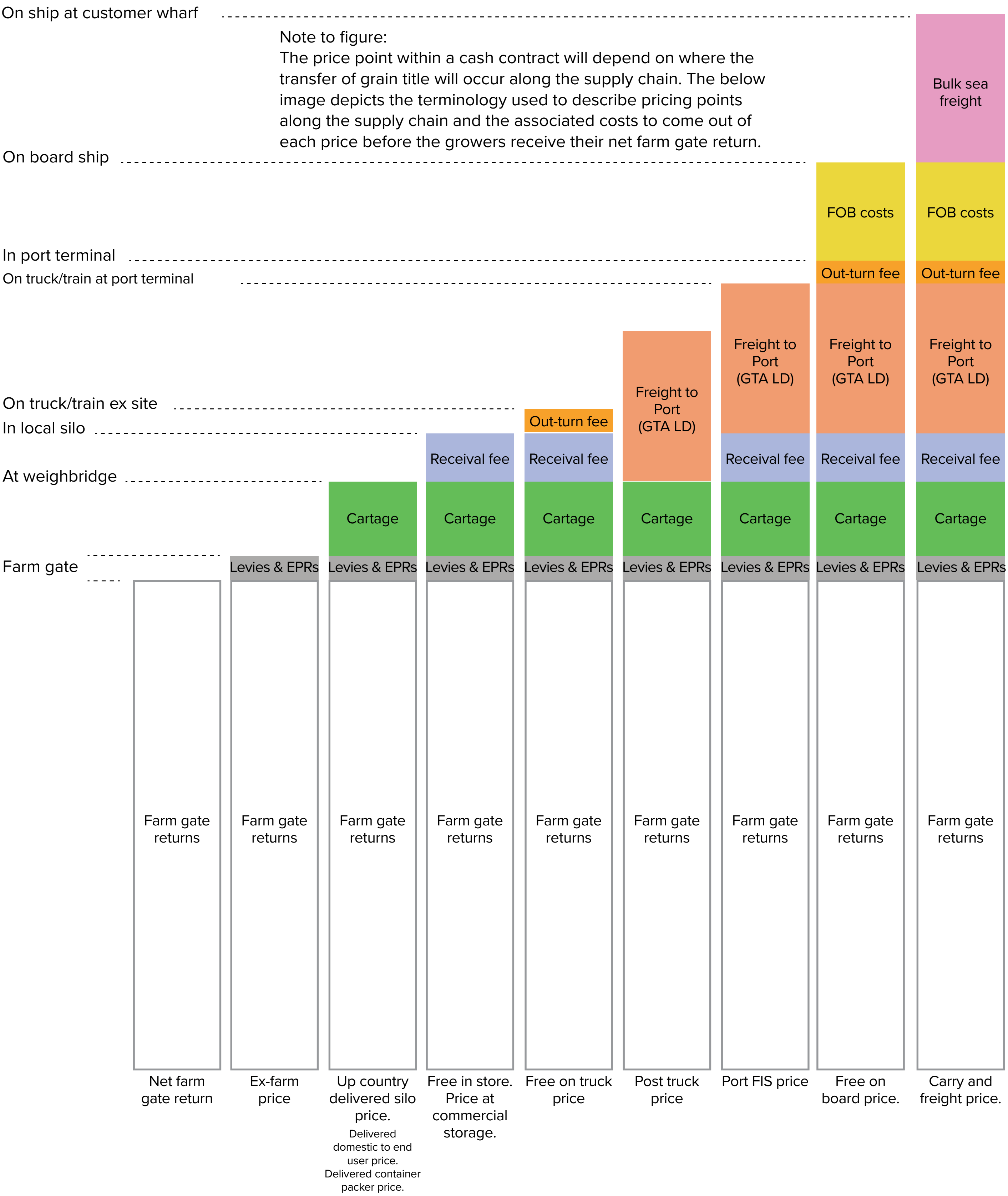


Figure 17: *Cost and pricing points throughout the supply chains.*

Source: Profarmer Australia

MORE INFORMATION

Grain Trade Australia, A guide to taking out grain contracts

Grain Trade Australia, Trading standards

GrainTransact Resource Centre

GrainFlow

Emerald Grain

Clear Grain Exchange, Getting started

Clear Grain Exchange, Terms and conditions

MORE INFORMATION

GTA, Managing counterparty risk

Clear Grain Exchange's title transfer model

GrainGrowers, Managing risk in grain contracts

Leo Delahunty, Counterparty risk: A producer's perspective

Cash sales generally occur through three methods:

- Negotiation via personal contact—traditionally prices are posted as a public indicative bid. The bid is then accepted or negotiated by a grower with the merchant or via an intermediary. This method is the most common and is available for all commodities.
- Accepting a public firm bid—cash prices in the form of public firm bids are posted during harvest and for warehoused grain by merchants on a site basis. Growers can sell their parcel of grain immediately by accepting the price on offer via an online facility and then transfer the grain online to the buyer. The availability of this option depends on location and commodity.
- Placing an anonymous firm offer—growers can place a firm offer price on a parcel of grain anonymously and expose it to the entire market of buyers, who then bid on it anonymously using the Clear Grain Exchange, which is an independent online exchange. If the offer and bid match, the particulars of the transaction are sent to a secure settlement facility, although the title on the grain does not transfer from the grower until they receive funds from the buyer. The availability of this option depends on location and commodity. Anonymous firm offers can also be placed to buyers by an intermediary acting on behalf of the grower. If the grain sells, the buyer and seller are disclosed to each counterparty.

Counterparty risk

Most sales involve transferring the title on the 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:

- Dealing only with known and trusted counterparties.
- Conducting a credit check (banks will do this) before dealing with a buyer they are unsure of.
- Selling only a small amount of grain to unknown counterparties.
- Considering credit insurance or a letter of credit from the buyer.
- Never delivering a second load of grain if payment has not been received for the first.
- Not parting with the title before payment, or requesting and receiving a cash deposit of part of the value ahead of delivery. Payment terms are negotiated at time of contracting. Alternatively, the Clear Grain Exchange provides secure settlement whereby the grower maintains title on the grain until they receive payment, and then title and payment are settled simultaneously.

Above all, act commercially to ensure the time invested in implementing a selling strategy is not wasted by poor management of counterparty risk. Achieving $5/t more on paper and not getting paid is a disastrous outcome.

Relative values

Grain-sales revenue is optimised when selling decisions are made in the context of the whole farming business. The aim is to sell each commodity when it is priced well, and to hold commodities that are not well priced at any given time. That is, give preference to the commodities with the highest relative value. This achieves price protection for the overall revenue of the farm business and enables more flexibility to a grower's selling program while achieving the business goal of reducing overall risk.

Principle: Sell valued commodities, not undervalued commodities.

If one commodity is priced strongly relative to another, focus sales there. Don't sell the cheaper commodity for a discount.

For example, a farmer with wheat and barley to sell would sell the one that is getting good prices relative to the other, and hold the other for the meantime (Figure 18).

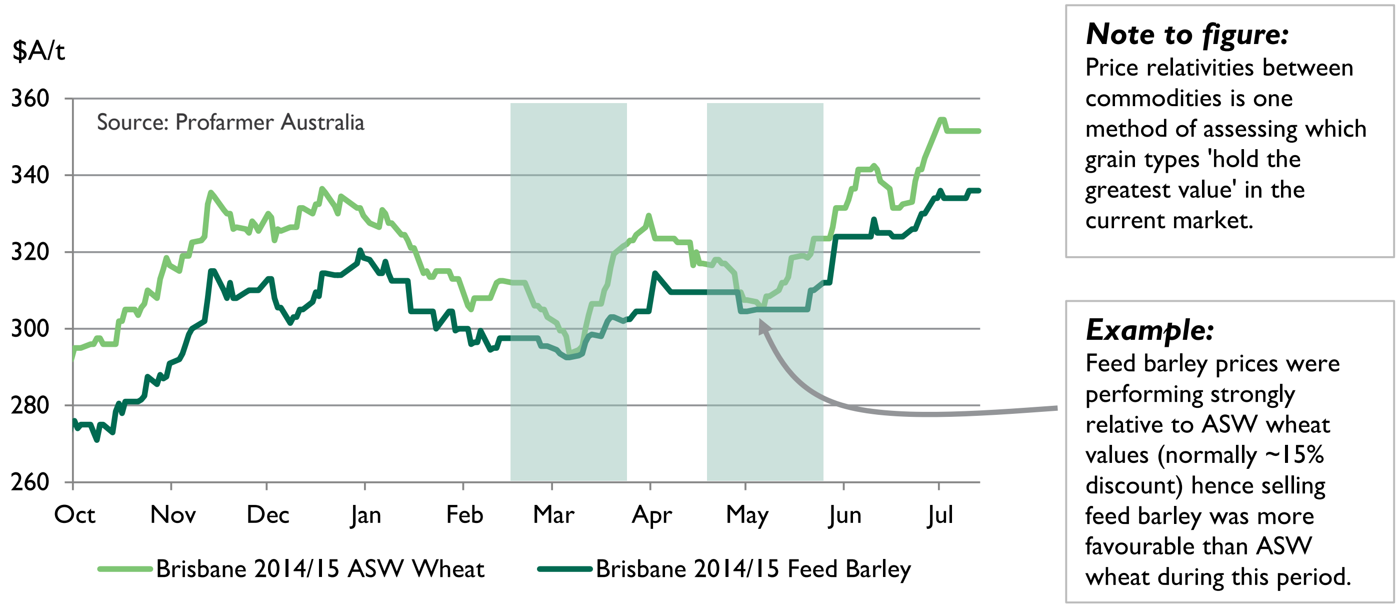


Figure 18: *Prices for Brisbane ASW wheat and feed barley are compared, and the barley held until it is favourable to sell it.*

Source: Profarmer Australia

If the decision has been made to sell wheat, CBOT wheat may be the better alternative if the futures market is showing better value than the cash market (Figure 19).

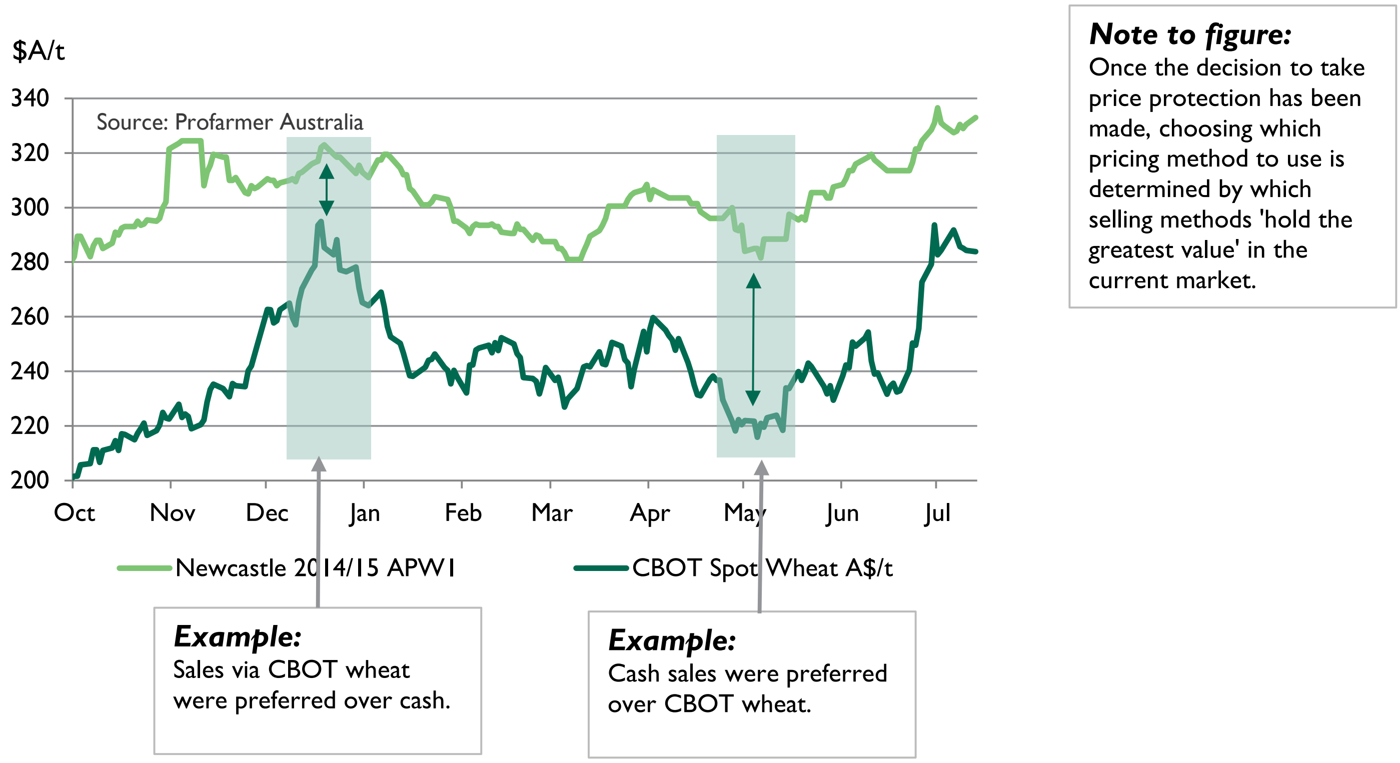


Figure 19: *Newcastle APWI and CBOT wheat prices (A$/t), showing when it is best to sell into each market.*

Source: Profarmer Australia

Contract allocation

Contract allocation means choosing which contracts to allocate your grain against come delivery time. Different contracts will have different characteristics (e.g. price, premiums-discounts, oil bonuses), and optimising your allocation reflects immediately on your bottom line.

Principle: Don't leave money on the table.

Contract allocation decisions don't take long, and can be worth thousands of dollars to your bottom line.

To achieve the best average price for their crop growers should:

- Allocate lower grades of grain to contracts with the lowest discounts.
- Allocate higher grades of grain to contracts with the highest premiums (Figure 20).

The grower may have several options. For example, Figure 20 shows that the only difference between achieving an average price of $290/t and $295/t is which contract each parcel is allocated to. Over an amount of 400 t, the difference in average price equates to nearly $2,000, which could be lost just in how parcels are allocated to contracts.

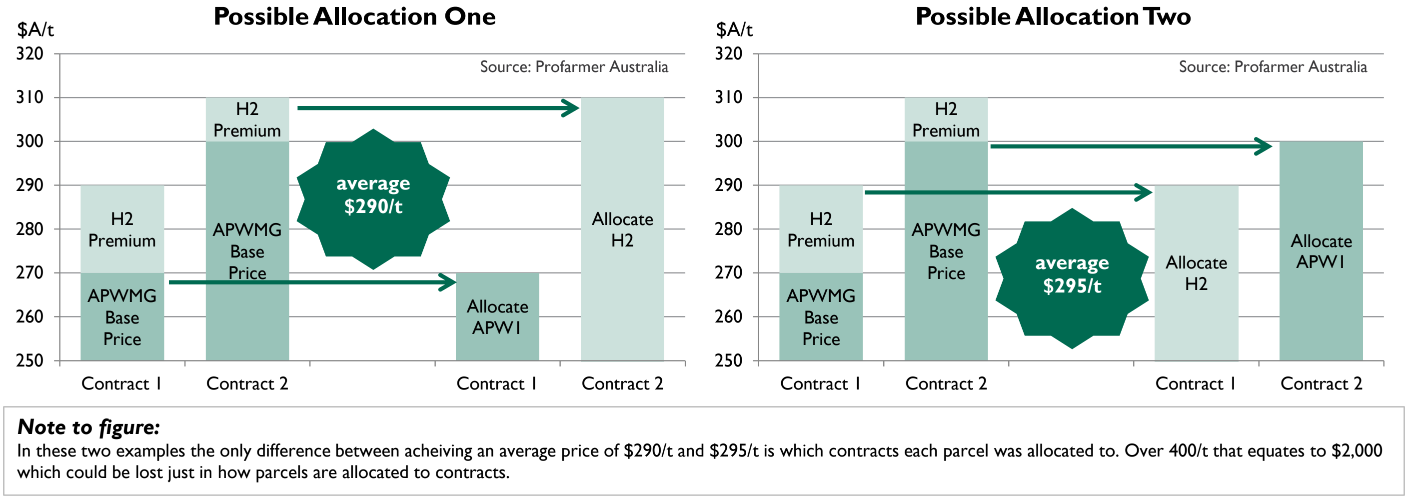


Figure 20: *How parcels of the crop are allocated across contracts can make a substantial difference in income.*

Source: Profarmer Australia

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 very interested.

Principle: Sell when there is buyer appetite.

When buyers are chasing grain, growers have more market power to demand the price they want.

Buyer appetite can be monitored by:

- The number of buyers at or near the best bid in a public bid line-up. If there are many buyers, it could indicate that buyer appetite is strong. However, if one buyer is offering $5/t above the next best bid, it may mean that cash prices are susceptible to falling $5/t as soon as that buyer satisfies their appetite.

- 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. The chart below plots actual trade prices on the Clear Grain Exchange against the best public indicative bid on the day.

The selling strategy is converted to maximum business revenue by:

- Ensuring timely access to information, advice and trading facilities.
- Using different cash-market mechanisms when appropriate.
- Minimising counterparty risk by conducting effective due diligence.
- Understanding relative value and selling commodities when they are priced well.
- Thoughtful contract allocation.
- Reading market signals to extract value from the market or to prevent selling at a discount.

15.2 Western chickpeas: market dynamics and execution

15.2.1 Price determinants for western chickpeas

Australia is a relatively small player in terms of world pulse production, producing 1–2 million tonnes of pulses in any given year, compared to a global production of approximately 60 million tonnes. Chickpeas are the largest global pulse crop, with 11–12 million tonnes produced annually; field peas come in second with approximately 10 million tonnes. Australia's combined production of these crops is 1–1.3 million tonnes, or approximately 5% of global production.

Of the two major types of chickpeas grown in Australia, the desi chickpea is the predominant variety grown in NSW and Queensland, and the kabuli is more prominent in South Australia and Victoria. In WA, chickpea production is still only a very small part of the state's crop.

Most of the desi chickpea crop is exported, and in terms of world trade, Australia is a major player. The major export markets for chickpeas are India and Pakistan, which between them import on average 1–1.5 million tonnes of chickpeas each year. In these markets, field peas can be used as a substitute to chickpeas. India imports 1.5–2.0 million tonnes of field peas each year.

Given this dynamic, Australian farm-gate prices are heavily influenced by global production volatility, international trade values into each of the major destinations, and price relativities between substitute products. For example, when India has a poor monsoon, Australian chickpea values tend to increase, as demand for imported product increases providing flow-on support to the Australian market. However, in years when Indian production is in surplus and import requirements are small, Australian product can become discounted, and Australia must seek other export destinations for local production. Because of Australia's involvement in international trade, it is important for growers to understand the timing of chickpea production world wide (Figure 21) and the quantity of chickpea production in competitor nations (Figure 22).

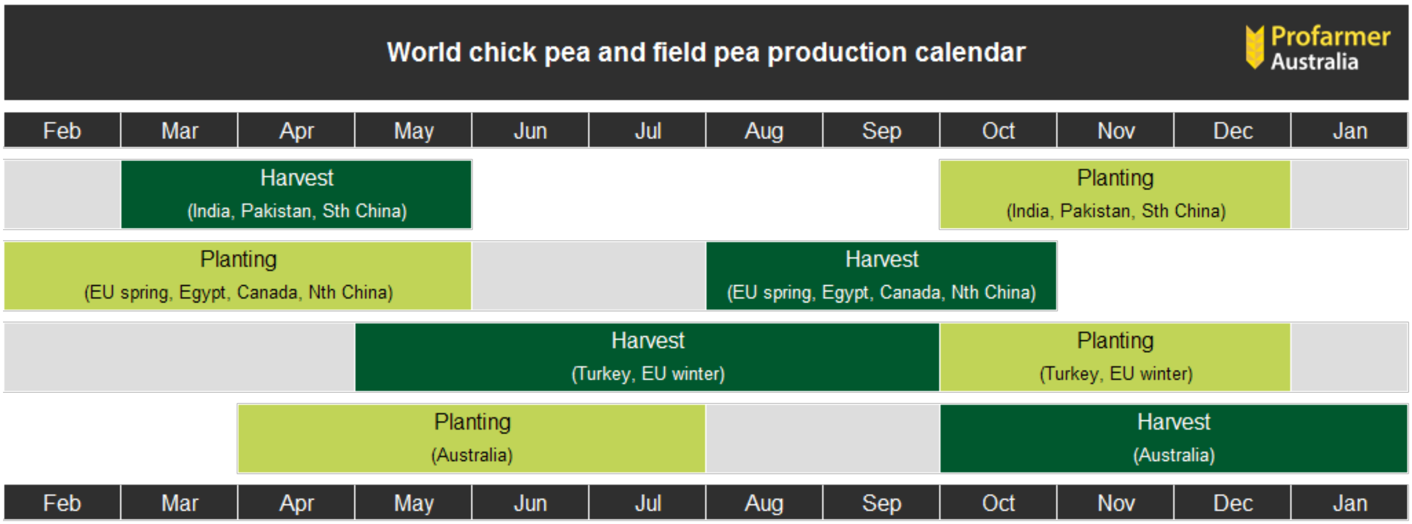


Figure 21: *Global chickpea production calendar.*

Some of the global influences on Australian chick pea pricing are:

- Pulse production from the Indian domestic *rabi* cropping season (where harvest is April–May)—any negative influences will increase the need for imports of either chickpeas or field peas.
- The world price of field peas—field peas are purchased as a substitute pulse when the chickpea price is high.
- The timing of festivals in importing countries—Ramadan is the most important festival. It occurs in the ninth month of the Islamic calendar and goes for 29 days. Ramadan occurs around June then May for the next few years then will get closer to the end of the Australian harvest. This is favourable for supplying the Ramadan market post-harvest.

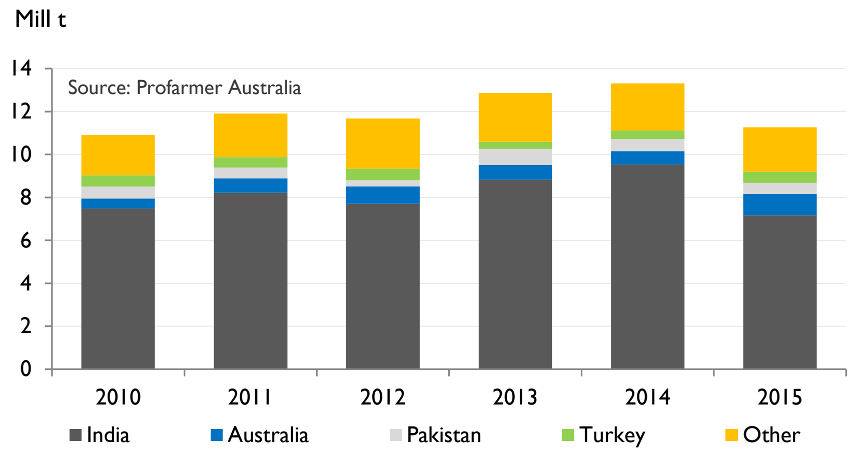


Figure 22: *Global chickpea production.*

The pace of Australian chickpea exports is typically strongest shortly after our harvest, as buyers seek to move crop ahead of the Indian harvest (Figure 23).

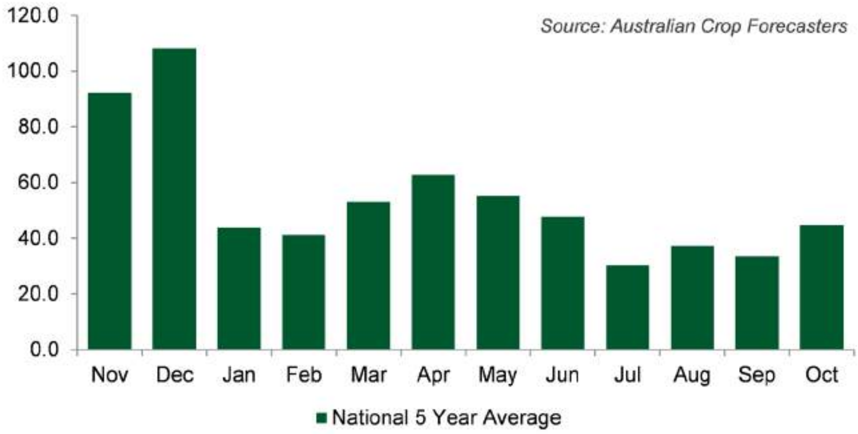


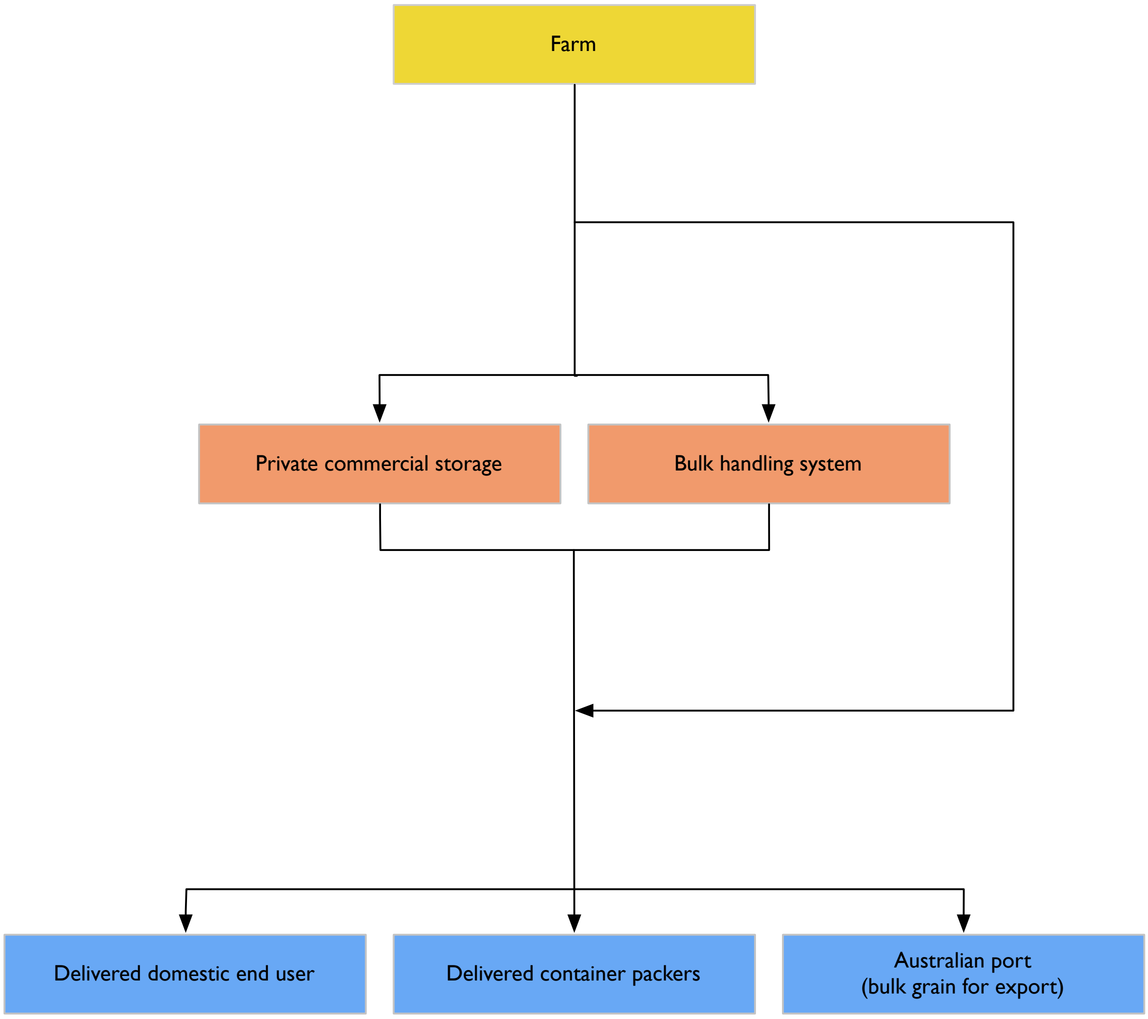
Figure 23: *Monthly export pace for chickpeas ('000 t) averaged over five years.*

Source: Australian Crop Forecasters

15.2.2 Ensuring market access for western chickpeas

The primary market for the Australia chickpea crop is exports for human consumption. A proportion of the north-eastern crop is exported in bulk, and the majority is exported in containers.

Chickpeas can also find homes as a source of protein in local stockfeed rations. By and large, whether finding homes in export (generally via container) or domestic markets, private commercial storage and on-farm storage both provide efficient paths to market.



Note to figure:
Storage decisions should be determined by assessing market access. The large majority of northern canola is exported in bulk. Hence the bulk handling system should provide efficiencies to market. NSW also services a relatively large domestic market and private commercial and on-farm storage should provide a reasonable method to access these markets.

Profarmer AUSTRALIA

Figure 24: *Australian supply chain.*

15.2.3 Converting tonnes into cash for western chickpeas

Given the volatile nature of chickpea pricing, setting a target price using the principles outlined in section 15.2.2 minimises the risk of taking an unprofitable price or holding out for an unrealistically high price that may not eventuate.

The selling options for chickpeas are:

1. Store on farm then sell—this is the most common option. Chickpeas are relatively safe to store and require less maintenance than cereal grains. It is still important to monitor and maintain quality, as chick peas must meet strict quality specifications for export in order to avoid being discounted at the time of delivery. The grower must take into account cost of storage when setting target prices.
2. Cash sale at harvest—this is the least preferred option as buyer demand does not always coincide with harvest. Values can come under pressure at harvest time if a sudden increase in grower selling occurs in a small window, providing buyers with the confidence that they can meet their short- and medium-term commitments.
3. Warehouse then sell—this option provides flexibility for sales if on-farm storage is not available. The grower must take into account warehousing costs as part

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AEGIC, Australian pulses

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of the cost of production when setting target prices. Warehousing is unlikely to be available to western growers, as the major bulk handlers do not provide this option due to the low volume of production. The availability of this option from packers within the 'delivered' market will vary depending on the individual buyer.

As with all sales, a thorough understanding of counterparty risk and the terms of the contract of sale is essential. Counterparty risk considerations are especially important for pulse marketing, as there is a higher risk of contract default in international pulse markets than for canola or cereals. This is due to the markets they are traded into; the lack of appropriate price-risk tools (such as futures); and, often, the visual and subjective nature of quality determination. This can place extra risk on Australian-based traders endeavouring to find buyers for their product.

With the majority of Western Australia's container packing facilities located in or around Perth, WA growers looking to market chickpeas should consider their access to these facilities as part of their overall marketing plan. Pulse Australia provides information about pulse exporters in Australia.

If targeting buyers in domestic stockfeed markets, it is important to explore how strong and where the appetite is before planting a chickpea crop for the first time.

Price discovery for chickpeas in the west can be difficult, given the small size of the market, particularly relative to other grains produced. Hence, South Australian markets, which have much greater market depth, can be an important source of price discovery, especially for those looking to understand export values.

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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