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GRDC GROWNOTES™

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GRAINS RESEARCH & DEVELOPMENT CORPORATION

LENTIL

SECTION 4

PLANTING

KEY POINTS | TIME OF SOWING | SOWING RATE / TARGET POPULATION | SOWING DEPTH | ROW SPACING | DRY SOWING | HERBICIDE RESIDUES | SAFE RATES OF FERTILISER SOWN WITH THE SEED | MACHINERY FOR SOWING | INOCULATION | IRRIGATION

Planting

Key points

- Choice of sowing date should take into consideration the location (district) and the variety.
- Ideal sowing time is a compromise between early sowing (to increase yield) and delayed sowing (to reduce yield-loss factors such as heat and frost at flowering).
- Plant densities of 120 plants/m^2 are recommended for lentil.
- Lentil should be sown at a depth of 2–6 cm.
- Sowing into standing stubble ensures taller, more erect plants with pods higher above the ground and reduces lodging before harvest.
- Dry sowing can be successful in lentil, provided weeds like medic and vetch are not a problem.
- Lentil varieties differ in their sensitivity to residual herbicides.
- Lentil is very sensitive to fertiliser toxicity when fertiliser is sown with the seed.
- Lentil can 'fix' its own nitrogen.
- Inoculation of lentil may not be required on some alkaline soils if inoculated and well-nodulated field peas, faba beans or lentils have recently been grown in the paddock.

4.1 Time of sowing

Time of sowing of lentil is critical for several reasons:

- to maximise yield;
- to control disease;
- to avoid frost during flowering; and
- to prevent heat damage during flowering.

The ideal sowing time largely depends on location and includes:

- rainfall;
- soil type and fertility;
- dates of risk periods, such as frost and heat stress; and
- soil moisture at sowing time.

In some areas, the ideal sowing date will be a compromise between optimum yields achieved by early sowing, and delaying sowing until risk factors (heat and frost at flowering) have been reduced to an acceptable level.

4.1.1 Ideal sowing time

The ideal time of sowing will ensure that the lentil crop:

- has finished flowering before being subject to periods of heat stress. This is, generally, when maximum day temperatures over a week average 25°C or more (refer to Section 6: Plant growth and physiology); and
- will produce sufficient growth to flower over an extended period, and encourage a better pod-set and filling of the pods.

In other words, there can be a significant difference between the optimum sowing time (for maximum potential yields) and the ideal sowing time (reducing yield- loss factors).

4.1.2 Time of sowing for southern region

- Rainfall <400 mm ➔ mid-May to early June.
- Rainfall 400–450 mm ➔ late May to late June.
- Rainfall 450–500mm ➔ late May to early July.
- Rainfall 500–600mm ➔ early June to mid-July.
- Rainfall >600mm ➔ early August to mid-September.[1]

Sowing date of lentil needs to take into account the location (district) and the variety.

1 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia.

FEEDBACK

Table 1: Optimum time of sowing for lentil in southern Australia.

Region (annual rainfall)	Month	May				June				July			
	Week	1	2	3	4	1	2	3	4	1	2	3	4
350–375 mm		Marginal	Preferred	Preferred	High risk								
375–400 mm			Marginal	Marginal	Preferred	Preferred	High risk						
400–450 mm					Marginal	Preferred	Preferred	Preferred	High risk	High risk			
450–500 mm						Marginal	Preferred	Preferred	Preferred	High risk	High risk	High risk	
500–600 mm						Marginal	Marginal	Preferred	Preferred	Preferred	Preferred	High risk	High risk

Marginal area or low disease risk area; Preferred sowing time; High disease risk areas or more susceptible varieties

NOTE: 1. Sowing time may need to vary with flowering and maturity time of the variety. 2. Preferred sowing time for spring-sown lentils is August-September 3. Sow later to reduce the disease risk if: a more susceptible variety (e.g. PBA Flash⁽ᴰ⁾, Northfield); or in districts with milder winter temperatures where Botrytis grey mould (BGM) is a regular problem (e.g. Yorke Peninsula, Lower Eyre Peninsula, Upper SE of SA).

Source: Pulse Australia

MORE INFORMATION

The interaction between sowing date and different stubble handling methods on lentil grain yield at Mallala (South Australia) in 2010. (M. Lines & L. McMurray, Southern Pulse Agronomy Project)

The interaction between sowing date and lentil genotype on grain yield at Curyo (Victorian Mallee region) in 2012. (J. Brand, Southern Pulse Agronomy Project)

The interaction between sowing date and lentil genotype on grain yield at Rupanyup (Vic Wimmera) 2012. (J. Brand, Southern Pulse Agronomy Project)

The interaction between sowing date and lentil genotype on grain yield at Wagga Wagga (NSW) 2011. (L. Gaynor, NSW DPI, Southern Pulse Agronomy Project)

The interaction between sowing date and lentil genotype on grain yield at Wagga Wagga (NSW) in 2012. (L. Gaynor, NSW DPI, Southern Pulse Agronomy Project)

The interaction between sowing date and lentil genotype on grain yield at Yenda (NSW) in 2012. (L. Gaynor, NSW DPI, Southern Pulse Agronomy Project)

4.1.3 Yield

Lentil sown 'on time' has an excellent chance of producing very high yields. However, lentil sown earlier or later than recommended will often suffer from reduced yield.

A number of lentil trials examining the relationship between time of sowing and yield have been conducted in recent years.

4.1.4 Disease

Most lentil varieties are either susceptible or moderately susceptible to Botrytis grey mould (BGM), caused by Botrytis cinerea. This means that sowing times in southern Australia may need to be delayed in some circumstances to reduce the risk of BGM infection.[2]

Most new lentil varieties are either resistant or moderately resistant to Ascochyta blight. This means time of sowing no longer needs to be delayed to reduce the risk of Ascochyta blight infection with these varieties. However, under intensive lentil rotations, this resistance can change as the organism adapts. Therefore, complacency is not an option due to the changing nature of the disease.

If the variety is more susceptible to Botrytis grey mould, or in districts with milder winter temperatures where BGM is a regular problem (coastal areas), then sowing needs be delayed to reduce disease risk.

2 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia.

MORE INFORMATION

For further information on frost go to Section 14: Environmental issues

MORE INFORMATION

For further information on heat stress go to Section 14: Environmental issues

4.1.5 Frost

Planning time of sowing to avoid frost or cold conditions during flowering is an important consideration. This is especially true in areas with long growing seasons where sowing time may need to be delayed to avoid Botrytis grey mould.

Lentil seed can germinate in soil as cold as 5°C; however, emergence will be slow. Seedling vigour will be greater if soil temperatures are at least 7°C.

Lentil seedlings are tolerant of frost.

In lentil, selection of sowing date is a trade-off between:

- sowing early with high yield potential – important in those years where moisture stress occurs early, or excessive frosts or high temperatures are to be avoided; and
- lower yield potentials with delayed sowing to ensure flowering occurs in warmer temperature and sunlight conditions but before temperatures become excessive or moisture stress sets in.

4.1.6 Heat

Significant reductions occur in yield and seed quality of lentil when heat stress occurs during flowering and pod-filling. Time of sowing needs to minimise this factor as much as possible.

4.1.7 Water-use efficiency

Water-use efficiency for lentil is commonly in the range of 8–12 kg grain per hectare per millimetre of water for sowing during the preferred sowing window. Very late or very early sowing will result in reduced water use efficiency of 4–6 kg grain/ha/mm. of water-use[33]

4.1.8 Sowing too early

Early sowing, even dry sowing, is a priority in some drier areas or where sowing is completed early to optimise operations and enable optimum sowing times for cereals. Actual time of sowing may depend on:

- the maturity of the variety being sown;
- the disease susceptibility of the variety;
- expected plant height;
- row spacing; and
- overall attitude towards risk from disease.

Sowing prior to the recommended sowing window results in a more vegetative lentil plant.[4] The plant can suffer from:

- poor early podset because of low light or low temperatures (10°C) at the start of flowering;
- a higher risk of Botrytis grey mould, after canopy closure, coinciding with flowering and podding;
- increased likelihood of lodging;
- increased frost risk at flowering and early podding;
- higher water use prior to effective flowering;
- earlier moisture stress during flowering and podding; and
- increased risk of Ascochyta blight in susceptible varieties.

3 H Cutforth, B McConkey, D Ulrich, P Miller, S Angadi (2002) Yield and water use efficiency of pulses seeded directly into standing stubble in the semiarid Canadian prairie. Can. J. Plant Sci. 82: 681-686

4 Pulse Australia (2015) Best Management Guide – Lentil Production: Southern Region. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

Early sowing can often produce the highest potential yields in lentil, but requires greater attention to disease control, particularly for Botrytis grey mould (BGM).

Some lentil varieties with best resistance to BGM and shorter height (PBA Hurricane XT⁽ᵇ⁾) enable earlier sowing in many areas. Wider row spacing (skip row or wider) delays canopy closure and so lessens disease risk associated with early sowing.

Other varieties (PBA Bolt⁽ᵇ⁾, PBA Flash⁽ᵇ⁾, PBA Blitz⁽ᵇ⁾) can respond less to early sowing because they have to set early pods under cold, frosty or more shaded conditions.

The higher risk of fungal disease is particularly pertinent to medium and high rainfall areas.

Weed control

Weed control can be an issue with sowing early. Sowing too early can result in conditions not suitable for controlling broadleaf weeds. This is because there are limited or risky post-emergence broadleaf weed control options available in lentil. This might result in lentil crops with a high weed burden.

4.1.9 Sowing too late

Late sowing produces short, low-yielding crops with less disease.

Lentil sown too late is more likely to suffer from:

- high temperatures and moisture stress during flowering and podding;
- greater native budworm pressure;
- less branching and flowering sites; and
- shorter plants and lower podset, which makes harvest more difficult.

Late-sown crops run the risk of being too short to harvest satisfactorily in many areas, along with the risk of high temperatures and dry conditions during flowering and pod- fill reducing yields. Spring sowing is desirable in some higher rainfall areas, or areas with a longer growing season.

Pulse Australia states that yield losses of up to 200 kg/ha of lentil can be expected for every week sowing is delayed.

Lentil sowing dates are often a compromise between delaying sowing to reduce disease without severely reducing yield potential with delays.

IN FOCUS

4.1.10 Low-rainfall areas

In low-rainfall areas lentil must be sown relatively early. Hot winds in spring cause lentil to stop flowering and prompt premature ripening. Compacted soils or those with a boron/salt subsoil that do not allow root penetration will exaggerate this effect.

4.1.11 High-rainfall areas

In the higher-rainfall districts (>600 millimetres' annual rainfall), some pulses like field pea, lentil and chickpeas can be sown in August or September (spring sowing) to avoid waterlogging and to reduce foliar diseases. Lentil can therefore be sown as spring-sown option in these areas, despite the long, cool growing season.

Having a deep, fertile soil profile that retains moisture is important. Crop height and onset of hot conditions become yield-limiting factors.[5]

5 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia.

4.2 Sowing rate / target population

Plant densities of approximately 100 to 120 plants per square metre are recommended for lentil.[6]

Sowing rate (kilograms per hectare) is calculated for individual varieties based on their germination percentage and seed weight.

The number of seeds that actually emerge is often less than the viable seed number sown. This can be due to non-vigorous seedlings, disease, herbicide damage or poor soil structure. Sowing rate may need to be increased to take into account these factors.[7]

4.3 Sowing depth

Lentil should be sown at a depth of 2–6 cm (Table 2)[8] to help minimise herbicide damage.

Lentil emerges faster than most other pulses, despite its seed size, but plant growth is slow during winter. If germination coincides with soil temperatures below 5°C, complete emergence may take up to 30 days.

Lentil emerges fast, despite its seed size, but plant growth is slow during winter.

Sowing depth of lentil must take into account:

- soil type;
- herbicide used;
- diseases likely to be present; and
- soil temperature at sowing time, i.e. how long the crop will take to emerge.

Table 2: Sowing depth for pulses.

Crop	General recommended sowing depth range*
Chickpeas	3–5 cm
Faba beans	5–8 cm
Lentils	2–6 cm
Lupins	1–3 cm
Peas	3–5 cm
Vetch	3–5 cm

* Note if applying a pre-emergent herbicide, a deeper depth should be used.
Source: Pulse Australia

6 Grains Research and Development Corporation (2016) Lentils: The Ute Guide. Grains Research and Development Corporation, https://grdc.com.au/resources-and-publications/all-publications/publications/2008/11/lentils-the-ute-guide

7 Pulse Australia (2015) Best Management Guide – Lentil Production: Southern Region. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

8 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

Photo 1: *Lentil is capable of emerging through thick cereal stubble.*

Photo: W. Hawthorne, formerly Pulse Australia

Photo 2: *Lentil sown too shallow is vulnerable to herbicide damage, especially if left in a deep furrow enabling herbicide 'wash' into the seed row.*

Photo: W. Hawthorne, formerly Pulse Australia

There is a maximum depth at which lentil can be safely sown to avoid poor establishment and lower seedling vigour. Sowing seed outside the suggested range (Table 7) will delay emergence and slow seedling growth.

The deepest sowings tend to be in sandy soil with warm soil temperatures, or dry sowing. The shallowest sowings tend to be in heavy soils with cold soil temperatures, or late sowing.[9]

9 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

4.3.1 Sowing depth and herbicide interaction

Pulses can be more tolerant of some herbicides if shallow sowing is avoided.

For example, **lentil is less affected by metribuzin applied post-sowing pre-emergent (PSPE) if it is sown deeper**.[10,11] Simazine* and metribuzin can result in 'crop 'effect' in lentil if wet conditions prevail after sowing. This means sowing up to 10 centimetres' depth may be required to avoid herbicide damage. (*Simazine not registered for use in lentil but commonly used.)

Lighter textured soils can be more prone to herbicide leaching in wet winters. Hence, deeper sowing in sandier soils is often recommended if applying a pre-emergent herbicide.

Leaving the soil ridged (instead of rolling), increases the risk of post-sowing pre-emergent herbicide washing into the furrow (Image 9), especially on sandy soil. As pre-sowing applications of herbicide may be less effective in the furrows, The Grain Legume Handbook (2008) suggests a split herbicide application to ensure effective weed control while avoiding the risk of herbicide damage.

MORE INFORMATION

For information on deep seeding strategies, please refer to: http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/deep-seeding

4.3.2 Deep sowing

Deep sowing of faba bean and chickpea is used in northern Australia to sow into dry surfaces with wet sub-surface moisture.[11]

Deep sowing may be of use in southern Australia to ensure timely sowing of lentil into moisture when the soil surface is dry. Otherwise dry sowing is required while awaiting a germinating rain.

Deep sowing also allows more time to apply a knockdown herbicide prior to crop emergence.

10 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

11 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

4.4 Row spacing

Lentil crops in southern Australia are increasingly being sown at wider than 'standard' (18–25 cm) row spacing. This is when sown into standing stubble as part of a whole farming system. If used, wider row and 'skip' row lentil crops (30–50 cm) must be part of an overall system.[12]

Standing stubble is essential when sowing on wider rows to avoid moisture loss and prevent weed infestation inter-row. **Standing stubble ensures taller, more erect plants with pods higher above the ground, and reduces lodging before harvest.**

When sowing wider rows, any non-sowing tynes should be lifted so inter-row soil disturbance is minimised.[13] This reduces the risk of weeds germinating where there is no crop competition.

Reasons for choosing wider rows with lentil vary depending on location, farming system and grower preference, and include:

- better yields and yield consistency;
- availability of equipment with better stubble clearance and other sowing practicalities;
- improved water-use efficiency (drought tolerance);
- delay of canopy closure to minimise disease risk and for easier management;
- option to sow early and minimise foliar disease risks with a bigger crop canopy;
- better weed control through minimised soil disturbance;
- option of shielded sprayers for weed control inter-row; and
- improved harvesting speeds and efficiency.[14]

If row spacing is doubled, the sowing rate per row must also be doubled to achieve the same plant density.[15] This is significant for seeders with one seed meter per row, but relatively unimportant in air seeders where one meter supplies all or part of the machine. Sowing rate calibrations must be carefully managed.

The same considerations apply for fertiliser rates. However, the risk of toxicity to seed is increased when fertiliser is more concentrated in the seeding furrow. Sowing pulses into wider rows may require deep placement or side banding of the fertiliser. (See section 4.7 Safe rates of fertiliser sown with the seed.)

Trials have been conducted on the effects of row spacing on lentil.

MORE INFORMATION

Refer to the following trials for more information:

The interaction between sowing date, row spacing and lentil genotype on lentil yields (t/ha) at Minyip (Vic Wimmera) in 2009. J. Brand, Southern Pulse Agronomy Project

The interaction between sowing date*, row spacing and lentil genotype on lentil yields (t/ha) at Curyo (Vic Mallee) in 2009. J. Brand, Southern Pulse Agronomy Project

The effect of the interaction between sowing date and row space treatment on grain yield (t/ha) at Curyo in 2009. J. Brand, Southern Pulse Agronomy Project

12 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

13 Pulse Australia (2015) Best Management Guide – Lentil Production: Southern Region. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

14 Pulse Australia (2015) Best Management Guide – Lentil Production: Southern Region. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

15 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

4.5 Dry sowing

Dry sowing is a means of getting crops sown on time in seasons with a delayed autumn break. The autumn break is the "*first significant rainfall of the winter growing season … the time for successful grain sowing.*"[16]

Dry sowing can be successful in lentil, provided weeds like medic and vetch are not a problem. Rather than waiting for the correct moisture status, lentil can be sown according to date to ensure that sowing is completed on time, and/or to avoid interfering with other cropping operations.

Paddock selection is particularly important for dry sowing lentil. The following should be considered:

- paddock history of weed seeds, herbicide resistance and available weed control options;
- a seed inoculation method that is suited to dry soil conditions, such as granular inoculants;[17]
- soil type and ability to sow at required depth;
- ease of sowing into dry soil, soil tilth and uniformity of sowing depth;
- ability to physically access paddock after rain and before emergence (for harrowing, rolling or spraying pre-emergent herbicides);
- 'cloddiness' of soil after dry sowing for herbicide application and harvesting;
- whether additional levelling is required to flatten the ridges, cover press-wheel furrows or flatten clods; and
- whether time is available to apply herbicides before crop emergence.

4.5.1 Herbicide options with dry sowing

Herbicides react differently when applied to dry soil compared to moist soil.

The following factors are important with regard to herbicide use with dry sowing:

- pre-sowing application is often less effective because of herbicide breakdown over time and untreated soil remaining in the inter-row;
- when spraying post-sowing pre-emergence (PSPE) the soil surface may need levelling. This is especially so when sowing with press wheels in order to prevent herbicide from being washed into seed furrows by rain;[18]
- PSPE herbicides may not always be effective with dry sowing. Post-emergent herbicides might need to be considered;
- alternative options for weed control and harvesting need to be considered. This is especially so when it becomes too wet to spray or roll after the germinating rains and pre-emergent treatments are unable to be undertaken;
- crop emergence times may differ with dry sowing (bean and chickpea are slow, pea is intermediate, lentil, lupin and vetch are quickest to emerge);
- there may be an increased disease risk due to emergence soon after opening rains; and
- a longer growing season will lengthen the time the plant is exposed to diseases and, hence, the period it may need to be protected with foliar fungicides. Varieties with superior disease resistances should be chosen or, alternatively, paddocks with low disease risk should be selected.[19]

Lentil is one of the quickest pulses to emerge with dry sowing.

16 M Pook, S Lisson, J Risbey, C Ummenhoffer, P McIntosh, M Rebbeck (2008) The autumn break for cropping in southeast Australia: trends, synoptic influences and impacts on wheat yield. International Journal of Climatology DOI 10.1002/joc

17 Pulse Australia (2015) Best Management Guide – Lentil Production: Southern Region. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

18 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

19 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

FEEDBACK

MORE INFORMATION

See more on herbicide residues in Section 8.7 "Herbicide residues"

4.6 Herbicide residues

When growing pulses it is important to be aware of:

- possible herbicide residues impacting on crop-rotation choices when rainfall has been minimal;
- herbicide residues that could influence crop rotations more than disease considerations.
- weed burdens in the new crop (based on seed-set from last year); and
- herbicide efficacy and crop safety of the new crop and how it can suffer if the soil is dry at time of application.[20]

Pulses differ in their sensitivity to residual herbicides.[21] It is important to check each herbicide prior to use for sensitivity to residues.

Group B

- **Standard lentil varieties are extremely sensitive to the imidazolinones (IMIs)[22];**
- 'XT' varieties are tolerant to IMIs. For example, PBA Hurricane XT⊕ and PBA Herald XT⊕.
- Lentil cannot immediately follow after bean or field pea if IMIs or sulfonamides were used.
- Lentil and chickpea are most vulnerable to sulfonylurea residues, with field pea, faba and broad bean the least. Residues persist longer in high pH soil.
- Lentil, faba and broad bean, and lupin are more sensitive to sulfonamide residues, particularly on shallow duplex soils where breakdown is slower.
- At low pH (<6.5) faba and broad bean are more sensitive to Monza® residues (sulfonylurea) than lentil, chickpea, lupin and field pea. All are sensitive at higher pH (>6.5).

Group I

- All pulses are vulnerable to pyridine residues (Lontrel®). Lontrel® is more likely to persist in stubble-retention systems.
- Spikes (dicamba) added to knockdown sprays may persist under dry conditions and can reduce pulse crop establishment. Dicamba plant-backs require 15 mm of rain. **Lentil and faba bean are not listed on label**.
- Picloram and aminopyralid applied to previous summer fallows are more likely to persist and damage crops under dry conditions.

Group C

- Triazine herbicides applied in-crop can potentially cause crop damage in some circumstances.

Group F

- Lentil cannot follow straight after chickpea if Balance® has been used in the chickpea.

20 Pulse Australia (2015) Best Management Guide – Lentil Production: Southern Region. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

21 P Matthews, D McCaffery, L Jenkins (2016) Winter crop variety sowing guide 2016, NSW DPI Management Guide. NSW Department of Primary Industries, http://www.dpi.nsw.gov.au/agriculture/broadacre/guides/winter-crop-variety-sowing-guide

22 GRDC (2014) Imidazolinone residues, https://grdc.com.au/Media-Centre/Media-News/South/2014/04/Imidazolinone-residues

FEEDBACK

Table 3: Minimum re-cropping intervals and guidelines.

Group and type	Product	pH (H_2O) or product rate (ml/ha) as applicable	Minimum re-cropping interval (months after application), and conditions Pulses
I, pyridine	clopyralid e.g. Lontrel®	Rate <300 ml	Chickpea, faba bean, pea, lentil, lupin, vetch = 9 >150 mm rainfall, with >25 mm summer–autumn
		Rate of 300–500 ml	Chickpea, faba bean, pea, lentil, lupin, vetch = 12
		Rate 500 ml	>150 mm rainfall, with >25 mm summer-autumn
I, pyridine	aminopyralid +fluroxypyr Hotshot®	Rate 500 ml southern/western areas	Chickpea, faba bean, pea, lentil, lupin = 20 (southern) >150 mm rainfall, with >25 mm summer–autumn
		Rate 750 ml northern Australia	Chickpea, faba bean = 9 >100 mm on black cracking clays
F, isoxazoles	isoxaflutole e.g. Balance®	> 7.0 < 7.0	Chickpea = 0 Faba bean, pea = 9 (>250 mm rainfall) Lentil = 21 (>500 mm rainfall) Prolonged dry or cold periods may extend re-cropping intervals May result in extended re-cropping intervals
B, sulfonylurea (SU)	chlorsulfurons e.g. Glean®, Seige®, Tackle®	< 6.5	Faba bean, pea, lupin = 12 Others >>18 (rainfall not specified)
		6.6–7.5	Faba bean, pea = 22 (all states) minimum 700 mm Lupin = 22 (Victoria, NSW), but >> 22 (other states) minimum 700 mm Others >> 22
		7.6–8.5	24 + (if test strip grown to maturity year before)
		> 8.6	NR
B, sulfonamide	flumetsulam e.g. Broadstrike®	NA	Pea, chickpea =3 Faba bean, lupin = 9, but = 24 on shallow duplex soils (sand over clay) with low organic matter (rainfall not specified)
B, sulfonyl urea (SU)	triasulfuron, e.g. Logran®, Nugrain®	< 6.5	Faba bean, pea, lupin, chickpea = 12 (> 300 mm rainfall spraying to sowing) Lentil, others >> 18
		6.6–7.5	Faba bean, pea, lupin = 22 chickpea = 12 (NSW/Queensland) or 22 (rest) (> 500 mm rainfall spraying to sowing) Lentil, others >> 22
		7.6–8.5	Chickpea (NSW/Queensland) = 12 (500 mm spraying to sowing rainfall). Chickpea (rest), lupin, faba bean, pea =24 (> 700 mm rainfall spraying to sowing) Lentil, others >> 22
		> 8.6	Chickpea, lupin, faba bean, pea =24 (> 700 mm rainfall spraying to sowing) Lentil, others >> 24
B, sulfonamide	metosulam, e.g. Eclipse®	NA	Not specified = 9? (rainfall not specified)
B, sulfonylurea (SU)	metsulfuron e.g. Ally®, Associate®	5.6–8.5	= 9 (rainfall not specified)
		> 8.5	Tolerance of crops grown through to maturity should be determined (small scale) previous season before sowing larger area

Source: W Hawthorne (2007) Residual Herbicides and Weed Control. Pulse Australia Southern Pulse Bulletin, PA 2007 #03, http://www.pulseaus.com.au/growing-pulses/publications/residual-herbicides
Note that herbicide-tolerant (XT)[Φ] lentil varieties have the same plant-back periods on label as conventional lentil varieties.
There is however greater safety with these XT[Φ] varieties to residual herbicides in Group B (SUs, iMIs).

FEEDBACK

MORE INFORMATION

Nitrogen fixation of crop legume: basic principles and practical management Fact Sheet. https://grdc.com.au/resources-and-publications/all-publications/factsheets/2014/07/grdc-fs-nfixation-legumes

Rhizobial inoculants Fact Sheet. https://grdc.com.au/Resources/Factsheets/2013/01/Rhizobial-Inoculants

The GRDC has produced a reference manual and videos on pre-emergent herbicides. Please see *Soil behaviour of pre-emergent herbicides in Australian farming systems: a reference manual for agronomic advisers*: www.grdc.com.au/SoilBehaviourPreEmergentHerbicides

4.6.1 Herbicides in previous crops

Herbicides applied to paddocks in previous years may not have broken down adequately due to insufficient rainfall. This is because **herbicides require moist soil to break down.** For example, Lentil cannot follow straight after Lontrel® (Group I) has been used in the previous crop (e.g. canola).[23]

Where dry conditions (minimal summer–autumn rain and delayed opening rain) persist between herbicide application and sowing there is a higher risk of residual herbicide damage. This means a pulse following a cereal rotation might be a higher risk than a pulse following a pulse.[24]

The herbicide residual effect becomes far more critical for rotation choice when there has been minimal summer–autumn rain and delayed opening rain.

Furthermore, summer rainfall is not necessarily as effective as growing season rainfall in breaking down herbicide residues. Rainfall needs to be substantial and has to keep the soil wet for a specified time.[25]

Herbicides applied two years ago could still have an impact too, as could the presence of cereal stubble with herbicides like Lontrel®.[26]

It is extremely important to know the chemical used, as well as plant-back periods, soil pH, rainfall and other requirements for herbicide breakdown.

Photo 3: *Imazethapyr (e.g. Spinnaker®) injury in conventional lentil*.

Photo: W. Hawthorne, formerly Pulse Australia

23 http://www.pulseaus.com.au/growing-pulses/publications/residual-herbicides

24 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

25 Pulse Australia (2015) Best Management Guide – Lentil Production: Southern Region. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

26 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

Photo 4: *Imazethapyr (e.g. Spinnaker®) injury in conventional lentil plants (page 13) compared to an 'IMI'-tolerant (XT) lentil variety (above).*

Photo: W. Hawthorne, formerly Pulse Australia

4.6.2 Herbicides for current crop

Pre-sowing herbicide applications are often considered safer and more reliable than post-sowing applications, particularly under dry conditions. To ensure weed control, in the sowing furrow and to minimise crop damage, a combination of pre and post-sowing applications may be required.[27]

Under adverse seasonal or soil conditions, most post-sowing pre-emergent herbicides can damage lentil.

To reduce the risk of herbicide damage when using metribuzin or other soluble products post-sowing pre-emergent (PSPE) on lentil:

- sow at a depth of 5 cm or deeper;
- apply the herbicides to a level soil surface (after prickle chaining or rolling);
- recognise that rolling after press wheels may not be enough to level out the furrow;
- avoid applying these herbicides post-sowing to dry soils;
- choose the correct herbicide rate for the soil type (lighter soils require lower rates than heavier soils);
- check susceptibilities of varieties; and
- consider splitting the applications between pre-sowing and PSPE.[28]

Post-emergent applications can cause crop damage in some circumstances. In most cases damage can be attributed to the product solubility and agronomic or environmental factors.[29]

To reduce the risk of herbicide damage when using broadleaf control herbicides post-emergent on lentil:

- sow at a depth of 5 cm or deeper;
- ensure soil conditions are similar as for spraying PSPE; and
- apply post-emergent herbicides under warmer (>5°C) conditions during a period where some rain has fallen and there are no frosts (see Table 3 Minimum re-cropping intervals and guidelines on page 12).

27 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

28 Grains Research and Development Corporation (2016) Lentils: The Ute Guide. Grains Research and Development Corporation, https://grdc.com.au/resources-and-publications/all-publications/publications/2008/11/lentils-the-ute-guide

29 Pulse Australia (2015) Best Management Guide – Lentil Production: Southern Region. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

4.7 Safe rates of fertiliser sown with the seed

Germinating seeds can be damaged by fertiliser placed too close or applied at too high rates.

Increased row spacing and zero-till sowing can result in more fertiliser being placed in the sowing row, causing damage to emerging seedlings. This risk can be reduced by increasing the spread of seed and fertiliser in the row, reducing in-furrow fertiliser rates, or separating seed and fertiliser bands.

There are several factors that contribute to the safe amount of fertiliser that can be placed with the seed:

- crop type;
- fertiliser type;
- soil type and environment; and
- machinery configuration.[30]

4.7.1 Crop type

Overall canola and lentil are particularly sensitive to fertiliser toxicity, while wheat and barley are relatively tolerant. The order of sensitivity for crop species can vary based on fertiliser type. In general, the order from most to least sensitive in major grain crops is:

canola > lentil > peas > oats > wheat > barley.[31]

Lentil is very sensitive to fertiliser toxicity when fertiliser is sown closely with the seed.

4.7.2 Fertiliser type

Fertilisers can affect delicate germinating seeds in at least three ways:

Salt index: Most fertilisers are salts. Salts can affect the ability of the seedling to absorb water. Too much fertiliser salt can 'burn' the seedling. Most common nitrogen and potassium fertilisers have higher salt index than phosphorus fertilisers. Sulfate fertilisers tend to have lower salt indexes.

Ammonia in fertiliser: Free ammonia (a form of nitrogen) can be toxic to seed. **Placement in-furrow of urea (nitrogen-based fertiliser) is usually not advisable.**

Polymer coatings or urease inhibitors slow the rate of ammonia production. Utilising these products can reduce the risk of seed damage caused by ammonia-based fertilisers.

4.7.3 Soil type and environment

The risk of fertiliser damage increases with lighter soil texture (sands) and in drier soil conditions. Environmental conditions that induce stress or slow germination (cold temperature) prolong fertiliser and seed contact, thus increasing the likelihood of damage.

30 R Norton, G Sandral (2016) Give seeds the best chance by avoiding fertiliser damage. Extension Hub, https://extensionhub.com.au/web/crop-nutrition/-/give-seeds-the-best-chance-by-avoiding-fertiliser-damage?inheritRedirect=true

31 R Norton, G Sandral (2016) Give seeds the best chance by avoiding fertiliser damage. Extension Hub, https://extensionhub.com.au/web/crop-nutrition/-/give-seeds-the-best-chance-by-avoiding-fertiliser-damage?inheritRedirect=true

FEEDBACK

MORE INFORMATION

Information on seed bed utillisation and fertiliser crop combination thresholds can be found at International Plant Nutrition Institute: http://anz.ipni.net/article/ANZ-3074

MORE INFORMATION

For further information on fertiliser placement with seed go to:

Give seeds the best chance by avoiding fertiliser damage https://extensionhub.com.au/web/crop-nutrition/-/give-seeds-the-best-chance-by-avoiding-fertiliser-damage?inheritRedirect=true

Care with fertiliser and seed placement https://grdc.com.au/Resources/Factsheets/2011/05/Fertiliser-Toxicity

4.7.4 Machinery configuration

The type of point used in sowing equipment and the spacing between rows affect the concentration of fertiliser placed near seed and, therefore, the likelihood of damage.

Row spacing: The safe rate of fertiliser per hectare increases as row spaces narrow. Narrower row spacings have the effect of diluting fertiliser over the length of row.

Twin-chuting systems: Separate seed and fertiliser delivery chutes, either to different tynes or to different parts of the same tyne, provide separation of seed and fertiliser. Fertiliser is placed in bands either to the side or below the seed band. A separation distance of 3–5 cm is considered adequate to prevent seed damage.[32]

Seed bed utilisation: The more scatter there is between seed and fertiliser in the seed band the less risk of fertiliser damage to the seed.

The concept of seed bed utilisation (SBU) is used to address this factor.

SBU is the seed row width divided by the tyne spacing or row width; in other words, it is the proportion of row width occupied by seed row.

The wider the seed row for a specific row width the greater the SBU. As SBU increases so does the safe rate of in-furrow fertilisation.[33]

Liquid fertilisers

There are few guidelines for in-furrow liquid fertiliser application. As a general rule, the same rules for granulated (solid) products should be applied for in-furrow liquid fertiliser application.

32 R Norton, G Sandral (2016) Give seeds the best chance by avoiding fertiliser damage. Extension Hub, https://extensionhub.com.au/web/crop-nutrition/-/give-seeds-the-best-chance-by-avoiding-fertiliser-damage?inheritRedirect=true

33 R Norton, G Sandral (2016) Give seeds the best chance by avoiding fertiliser damage. Extension Hub, https://extensionhub.com.au/web/crop-nutrition/-/give-seeds-the-best-chance-by-avoiding-fertiliser-damage?inheritRedirect=true

4.8 Machinery for sowing

Lentil can be sown with a standard air seeder or conventional combine. Due to its small seed size, sowing lentil does not have the same issues that some of the other pulses encounter, due to their larger grain size.

Care must be taken when sowing lentil as seeds can 'bridge' (or accumulate) over the outlets causing uneven sowing. This can be eliminated by fitting an agitator. Adequate airflow is also critical: too much air pressure can cause seed damage and too little results reduced seed movement within the tubes.

4.8.1 Parameters for sowing equipment

Key elements required in sowing equipment include:

- adequate sowing mechanism to handle seed without damaging it or causing bridging or blocking;
- adequate sizes of seed and fertiliser tubes and boots to prevent blockages and bridging;
- can sow into stubble and residue, without blockages;
- sufficient down pressure to penetrate the soil, sow at the desirable depth, and place all seeds at a uniform depth;
- cover the seeds so that good seed-to-soil contact or moisture vapour ensures rapid germination;
- compact the soil with press-wheels or closers (if not a prickle chain or roller may be required later);
- disturbs the soil to the required level. This means no disturbance in zero-till with disc sowing; and
- having sufficient soil throw to incorporate herbicides (trifluralin). This can be by using either aggressive discs or narrow point set-ups in no-till, or full disturbance in more conventional or direct-drill systems.

4.8.2 Comparison of tynes

Successful plant establishment is critical. There are several options available to achieve this.

Narrow points are widely used in minimum or no-till sowing systems. There are also several other points available to achieve even plant establishment.

There are many variations within disc seeders. They differ in terms of soil disturbance and soil throw, as well as the ability to handle trash (stubble and residue) and 'sticky' conditions.

Table 4 highlights a range of functions required in tillage equipment and compares a range of no-till openers. In interpreting this table Pulse Australia[34] (2016) emphasises the following:

- With tynes, the slot created is different with 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. These tynes perform differently in some functions.
- Residues need to be handled in all conditions, not just when dry.
- 'Hairpins' (stubble is pressed into the slot by the disc ahead of the seed) needs to be avoided with seed placement away from the hairpin.
- Vertical slots tend to not self-close, especially in wet, clay soils.
- Ability of openers to follow ground surface variation is critical for uniform depth of sowing.

34 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia

FEEDBACK

- Springs do not always apply consistent down force on openers throughout a range of soil conditions.
- Banding of fertiliser away from the seed is important for crop establishment. This is especially so when high rates or high analysis products are applied and the seed is in a narrow opening slot.
- Tines can manage stones, but can raise them to the soil surface. This means rolling is required after sowing to press stones back into the soil profile.
- Table 4 does not list 'deep working' as an opener. Deep working assists in the control of rhizoctonia. Deep working needs to be considered in situations where rhizoctonia may be an issue.

Table 4 is a basic guide to comparing openers for tillage. Consultation should be made with both an experienced agronomist and machinery dealer to assess the most appropriate system to suit paddock conditions and circumstances, and the overall cropping program.

Photo 5: *A Primary Precision Seeder fitted with hydraulic breakout for consistent penetration. It is also fitted with narrow points that form an 'inverted T' slot. It is capable of deep or side placement of fertiliser.*

Photo: W. Hawthorne, formerly Pulse Australia

Photo 6: *The DBS system parallelogram for uniform seeding depth and deep placement of seed or fertiliser.*

Photo: W. Hawthorne, formerly Pulse Australia

Photo 7: *A Case IH SDX-40 single disc drill.*

Photo: W. Hawthorne, formerly Pulse Australia

Photo 8: *One of several seeding mechanisms for uniform sowing depth using the press-wheel for depth control.*

Photo: W. Hawthorne, formerly Pulse Australia

FEEDBACK

Photo 9: *A Bio Blade or Cross slot™ disc opener with opening disc and seeding tyne, 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 bean are being sown.*

Photo: W. Hawthorne, formerly Pulse Australia

FEEDBACK

Table 4: Comparison scores of no-till openers by function.

Rating basis: (1 = poor, 5 = excellent)	Narrow point	Wide point	Sweep	Double disc	Single disc	Slanted disc	Combined winged tyne & disc**
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*	3	4	3	1	3	3	5
Avoid in-slot soil compaction or smearing in wet soils*	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*	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*	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	5	1	1	2	5
Be able to handle sticky soils*	5	5	4	1	3	3	2
Be able to handle stony soils*	4	3	1	4	4	2	4
Avoid bringing stones to the surface*	1	1	1	5	5	3	5
Functionality unaffected by hillsides*	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
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**

* Functions that may be deleted in some circumstances, but all other functions are more universal. ** Combination is otherwise known as the Cross Slot™ or Bio Blade
NOTE that this is a broad GUIDE ONLY. Scores given in this table are subjective and may vary with individual openers etc. Source: C.J Baker 2010, SANTFA 12th Annual Conference pp 7-13, in Pulse Australia 2016

4.9 Inoculation

How nodulation works

Symbiotic nitrogen fixation is the result of the mutually beneficial relationship between the pulse host and Rhizobium bacteria. These bacteria colonise legume roots soon after seed germination then form root nodules. Rhizobia live in the soil, on plant roots and in legume nodules, but only fix nitrogen when inside a legume nodule. Rhizobia in the nodules are dependent on the host plant for water, nutrients and energy, but in return supply the plant with available nitrogen for growth. This 'fixed' nitrogen is derived from the gaseous nitrogen in the air.

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

A well-nodulated and productive crop of lentil will fix about 120 kg of nitrogen per hectare. After grain harvest, fixed N can remain in the stubble and roots which, when mineralised, becomes available to the following crop: "on average, concentrations of soil mineral N after legumes [including lentil] can be expected to be 25–35 kg N/ha higher than following cereals".[35]

4.9.1 Inoculant groups

Lentil, in common with bean, field pea and vetch, is nodulated by *Rhizobium leguminosarum* bv. *viciae*. This species of rhizobia is produced and sold commercially as inoculant groups E and F (Table 5).

Table 5: Inoculation groups E and F.

Field pea and vetch	**Strain: SU303 (group E)**
Pisum sativum, Vicia species	*Rhizobium leguminosarum* bv. *viciae*
Faba bean, broad bean and lentil	**Strain: WSM1455 (group F)**
Vicia faba, Lens culinaris	*Rhizobium leguminosarum* bv. *viciae*

Source: Drew *et al.* (2014).

Inoculant strain WSM1455 is provided for lentil and bean to optimise nitrogen fixation potential of these legume hosts. Lentil can also be nodulated by strain SU303 (e.g. from a background population of rhizobia in a soil where pea or vetch have been grown) but inoculation with this strain is not recommended.

Lentil is not nodulated by the rhizobia which nodulate chickpea (Group N), lupin (Group G) or pasture legumes.

4.9.2 When to inoculate

Lentil will be responsive to inoculation if it (or bean, field pea and vetch) has not previously been grown in the paddock. Lentil is also likely to be responsive to inoculation on acidic soils because the rhizobia of these legumes are moderately sensitive to soil acidity (Photo 10). Lentil rhizobia may be absent or their number may be sub-optimal where soil pH ($CaCl_2$) is less than 6.0, even where there has been recent history of legumes that support lentil rhizobia. See Table 6 for likelihood of response to inoculation.

MORE INFORMATION

Nitrogen fixation of crop legume: basic principles and practical management Fact Sheet. www.grdc.com.au/GRDC-FS-NFixation-Legumes

Rhizobial inoculants Fact Sheet. https://grdc.com.au/Resources/Factsheets/2013/01/Rhizobial-Inoculants

35 M Peoples *et al.* (2015) Legume effects on soil N dynamics - comparisons of crop response to legume and fertiliser N. GRDC Research Updates 2015

Photo 10: *Lentils on acid soil can fail to nodulate if they are not well inoculated. Poorly nodulated plants may appear yellow, with less biomass, but above-ground symptoms are not always obvious.*

Photo: W. Hawthorne, formerly Pulse Australia

Table 6: Likelihood of response to inoculation for lentil.

Likelihood	Conditions
HIGH	• Soils with pH ($CaCl_2$) below 6.0 and high summer soil temperatures (>35°C for 40 days); OR • Legume host (pea, faba bean, lentil, vetch) not previously grown.
MODERATE	• No legume host (pea, faba bean, lentil, vetch) in previous four years (recommended pulse rotation); OR • Prior host crop not inoculated or lacked good nodulation.
LOW	• Loam or clay soils with neutral or alkaline pH and a recent history of host crop with good nodulation.

Source: Drew *et al.* (2014).

Inoculation of lentil is generally not necessary where well-nodulated lentil (or bean, field pea, vetch) has been grown in the preceding five years and soil conditions are favourable to the survival of the rhizobia. Loam or clay soils with neutral or alkaline pH are favourable to the survival of lentil rhizobia.

If paddock conditions and legume history indicate a likelihood of a response to inoculation (Table 6) then the following guidelines should be followed:

- Inoculate with AIRG-approved* inoculants ('green tick' logo).
- Use Group F inoculant for lentil; Group E may be used in place of F.
- Do not expose inoculants to direct sunlight, high temperatures (>30°C), chemicals or freezing temperatures (they contain live bacteria).
- Always use inoculants before their expiry date has passed.
- Keep inoculants dry and cool. Reseal opened bags of inoculant and refrigerate; use resealed bags within a short time (days).
- Follow instructions on recommended rates of inoculation.
- Consider doubling the inoculation rate in very acidic soils or where lentil, vetch, bean or field pea have not been grown previously. Start with a small batch of seed to establish that it can be satisfactorily dried in order to avoid auger and seeder blockages.

FEEDBACK

- Always sow freshly inoculated seed as soon as possible, within 24 hours.
- When applying liquid or slurry inoculants, use clean, potable non-chlorinated water and ensure the mixing tanks are free of toxic chemical residues.
- Do not mix zinc or sodium molybdate with liquid or slurry inoculants.
- Check the product label or contact the manufacturer for compatibility of inoculants with fertilisers and seed dressings.
- Ensure inoculants remain cool in transport and do not leave inoculants or inoculated seed in the sun.

* AIRG is the Australian Inoculants Research Group, part of the NSW Department of Primary Industries.

4.9.3 Inoculant types

A range of different inoculant formulations are available to Australian legume growers (Table 7). Inoculant for lentil can be obtained as peat, freeze-dried or granular formulations.

Table 7: Inoculant formulations available to Australian growers of lentil.

Inoculant formulation	Composition
Peat	High organic matter soil, milled and irradiated, with rhizobia added and a nutrient suspension.
Freeze-dried	Concentrated pure cells of rhizobia following extraction of water under vacuum.
Granular	Clay or peat granules impregnated with rhizobia.
Liquid	Suspension of rhizobia in a protective nutrient solution.
Pre-inoculated seed	Seed coated with polymers and peat inoculant.

Source: Drew *et al.* (2014).

The different formulations vary in the number of rhizobia they contain and so it is important that recommended application rates are followed.

Peat is the most commonly used formulation and provides reliable nodulation across a range of sowing conditions. Peat inoculants also provide some protection to the rhizobia where they are applied to seed treated with pesticides.

Freeze-dried inoculants should only be used where legumes are sown into moist soils. They provide a good option where liquid injection systems are used to deliver inoculant in-furrow.

Granular inoculants can be used where separation between the rhizobia and pesticides or fertilisers is needed.

4.9.4 Inoculum survival

Moist peat formulation provides protection while unopened inoculum is stored.

Rhizobia will lose viability as they dry out after being applied to seed, prior to sowing into moist soil.

Seed coated with peat slurry mixes should be sown as soon as possible and definitely within 24 hours.

With non-peat-based inoculants, such as freeze-dried rhizobia, it is recommended that treated seed should be sown within five hours of inoculation.

Dry-dusting the peat inoculant into the seed box is not an effective means of either getting or keeping rhizobia uniformly on seed. Under some conditions, rhizobial death is so rapid where dry dusting is used that no rhizobia are alive by the time the seed reaches the soil.[36]

Dry sowing

Where lentil (or a crop using Group F or E inoculant) has not been grown in a paddock before, dry sowing is not recommended.

Inoculum viability rapidly diminishes over time in warm, dry soils. There are no guidelines to survival times, and it is best to sow as close as possible to predicted rain or as deep as is practical, where there is a likelihood of higher soil moisture content.

Rhizobia may survive for longer in granules than when applied to seed if granules are drilled into soil below the seed. Hence, **when dry sowing pulses, granular inoculant is preferred over peat and liquid injection methods.**[37]

Nodulation failure after dry sowing of inoculated seed is more likely if the soil has no suitable rhizobia present from previous crops.

4.9.5 Storing inoculants

For maximum survival, peat and freeze-dried inoculants should be stored in a refrigerator until used. Both types of inoculant can be kept for many months if stored correctly (4–10°C), but pay attention to the date of expiry and do not freeze inoculant. If refrigeration is not possible, store in a cool dry place away from direct sunlight. Granules also need to be stored in a cool place out of direct sunlight. Opened peat inoculum packets are best discarded, but if resealed and kept cool can be used within a few days.

Discard the inoculant after the expiry date shown because the population of rhizobia may have dropped to an unacceptable level.

4.9.6 Seed treatment compatability

The survival of rhizobia may be compromised when mixed with pesticides, fertilisers or other amendments. Guidelines are provided by inoculant manufacturers on the compatibility of their specific products with commonly used pesticides and fertilisers. The guidelines should be strictly followed.

More generally, consideration of the following principles will help reduce the likelihood of killing inoculant rhizobia.

- Direct mixing of rhizobia with amendments in tank mixes or during preparation of the peat slurry is most likely to kill rhizobia.
- Most rhizobia are sensitive to pH below 5 or above 8. Avoid mixing rhizobia with very acidic or alkaline products. Fertilisers and trace elements are often outside this pH range; product MSDSs usually contain information on pH of the products.
- Metals such as zinc, mercury, copper and manganese may be harmful. Sodium molybdate is toxic to rhizobia.
- When applying fungicides and insecticides to seed, minimise the time the rhizobia are exposed to the pesticide by applying the rhizobia last to the dried seed and sow as soon as possible. Where possible, sow within 6 hours of rhizobia application.
- Peat inoculant formulations may assist the survival of the rhizobia that come into contact with toxic chemicals.

36 E Drew, D Herridge, R Ballard, G O'Hara, R Deaker, M Denton, R Yates, G Gemell, E Hartley, L Phillips, N Seymour, J Howieson, N Ballard (2014) Inoculating legumes: A practical guide. Grains Research & Development Corporation, https://grdc.com.au/GRDC-Booklet-InoculatingLegumes

37 E Drew, D Herridge, R Ballard, G O'Hara, R Deaker, M Denton, R Yates, G Gemell, E Hartley, L Phillips, N Seymour, J Howieson, N Ballard (2014) Inoculating legumes: A practical guide. Grains Research & Development Corporation, https://grdc.com.au/GRDC-Booklet-InoculatingLegumes

4.9.7 Inoculant quality assurance

Most pulse inoculants sold in Australia must pass a rigorous quality assurance (QA) program.[38]

Cultures of inoculant are tested by the Australian Inoculants Research Group (AIRG) to establish that the correct rhizobial strain is present and the viable cell number exceeds a minimum value (Table 8).

Products which pass QA tests by AIRG bear the 'green tick' logo, either on the bag, the packet or on the box of packets.

Table 8: AIRG Quality Assurance rhizobia minimum numbers.[39]

Product	Viable rhizobia/g	Rate/ha	Rhizobia/ha	Expiry (months)
Peat	1×10^{9}	250 g	3×10^{11}	12–18
Liquid	5×10^{9}	300 ml	2×10^{12}	6
Granular	1×10^{7}	10 kg	1×10^{11}	6
Freeze-dried	1×10^{12}	0.15 g	2×10^{11}	24

4.9.8 Inoculation methods

Inoculation with rhizobia is a numbers game: we aim is to get as many rhizobia as possible onto the seed or near the seed, to maximise the potential for nodulation. There will always be a loss of rhizobia, but by using appropriate methods these losses can be minimised to obtain prompt and abundant nodulation. It is advisable to use high quality inoculants, such as AIRG-approved ('green tick') products.

Lentil has historically been inoculated with a slurry of peat inoculant onto the seed. But now rhizobia can also be purchased in a freeze-dried form suitable for application to seed or water injection into the soil, or granules that are sown at same time as the seed from a separate box.

Peat inoculants

Most peat inoculants for lentil now contain a pre-mixed sticker, and only require the addition of water to make the slurry. When preparing the slurry **DO NOT** use hot or chlorinated or saline water.

How to apply slurry to the seed:

- Through an auger: make sure the auger is turning as slowly as possible, to achieve effective mixing. Reduce the height of the auger to minimise the height of seed fall.
- Meter the peat slurry in, according to the flow rate of the auger (remember 250 g packet per 50 kg of seed).
- Through a tubulator: similar to applying through an auger, except that the tubulator reduces the risk of damaging the seed. Its mixing ability is not as effective as an auger.

Peat inoculant can also be injected as dilute filtered slurry directly into the sowing furrow, with or below the seed. Agitators and in-line filters may be necessary to avoid blockages to nozzles and capillary tubes. Typically, the peat inoculant is filtered and applied at low pressure in a water volume of 50–100L/ha.

Sprinkling moist peat inoculant into the seed box is **not recommended**. This is not an effective means of getting good contact between rhizobia and seed. Attachment of the rhizobia to the seed can be very poor, and under some conditions rhizobial death is so rapid that no inoculant is alive by the time the seed reaches the soil.

38 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

39 J Lamb, A Poddar (2008) Grain Legume Handbook for the Pulse Industry. Grain Legume Hand Book Committee, https://grdc.com.au/grainlegumehandbook

Freeze-dried inoculants

Freeze-dried inoculants can be applied to seed or delivered as a liquid into the furrow. Freeze-dried inoculants are not suitable for application to dry soils.

The rhizobia become active when the inoculant is reconstituted with liquid. The product comes with a protective polymer in a separate packet, which assists survival of the rhizobia. A standard vial of inoculant will treat up to 250 kg of lentil seed.

Treated seeds need to be sown into moist soil within five hours of application. Contact with seed applied pesticides and fungicides must be avoided.

For liquid injection into the seeding furrow, add the inoculant suspension to 2 L of cool water containing the protective polymer. Add this solution to the clean spray tank and deliver at 50–100 L per hectare into the furrow.

Granular inoculants

Granular inoculants are applied as a solid product directly into the seed furrow, near the seed or below the seed. They avoid many of the compatibility problems that rhizobia have with fertilisers and fungicides. They also eliminate the need to inoculate seed before sowing. Granular inoculants are reported to be effective where dry sowing is practiced.

If granules are mixed with the seed, rather than applied separately, then distribution of both seed and inoculum may be uneven, causing either poor and uneven establishment and/or patchy nodulation. Granules should not be stored in seeding boxes overnight because they can settle or solidify and cause blockages.

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 among products. Depending on product or row spacing sown, rates can vary from 2 to 10 kg/ha to deliver adequate levels of rhizobia into the seeding row.

4.9.9 Check for nodulation

It is important to determine how effective inoculant application has been and if the nodules are actively fixing nitrogen. The amount of nitrogen fixed by the crop is related to the amount of nodulation. By checking the number of nodules and their distribution on the roots, you can assess the effectiveness of the inoculum product used and the application method.

If you have not inoculated, it can still be helpful to assess nodulation of your lentil crop, to assess whether inoculation may be needed in the future.

For lentil, 20 to 50 pink nodules per plant after approximately 10 weeks' plant growth is an adequate level of nodulation Photo 11). A strong pink colour inside the nodule indicates the rhizobia are actively fixing nitrogen for use by the plant (Photo 12).

Sampling and processing

At least 30 plants should be sampled, 10 at each of three locations, spaced 40 m apart in the crop. Plants should be gently dug from the soil and the root system carefully rinsed in several changes of water before estimating nodule number. It is helpful to float the root systems in water on a white background (a cut down, clean chemical drum is easy to use).

Nodule number and distribution

Score each plant for nodulation. At least 20 pink nodules per plant is considered adequate (Photo 12). Separate plants into adequate and inadequate groups. If the adequate group contains more than 70% of the plants then inoculation has been successful.

Photo 11: *Well-nodulated roots of lentil showing nodules clustered on the main taproot.*

Photo: Maarten Ryder; University of Adelaide

Observe the pattern of nodules on the root system. Following inoculation, nodules on the main taproot clustered near the seed are a clear indication that nodulation occurred early. These are referred to as 'crown nodules'. If there are no crown nodules, but nodules on the lateral roots, then it is more likely nodulation has been delayed, indicating that there may have been issues with the inoculation process.

Nodules on both the crown and lateral roots indicate that inoculation was successful, and that bacteria have spread in the soil. This is the ideal situation, with the crown nodules providing good levels of N fixation early in the plant's growth, supported by the lateral root nodules which may extend N fixation activity later into the season because they are less affected by drying of the surface soil.

Nodule appearance

If necessary, cut or break open a few root nodules to check the colour: nodules that are actively fixing nitrogen are pink inside. Very young nodules (after a couple weeks' plant growth) are usually white because they still need to develop. However, in older plants (at 10–12 weeks' growth when assessment is recommended) an abundance of white nodules may indicate the rhizobia in the soil that formed the nodules were poorly effective and they will not fix nitrogen. This is rare for lentil, but indicates that the crop should be inoculated next time it is grown. White nodules can also result from trace element deficiencies such as molybdenum.

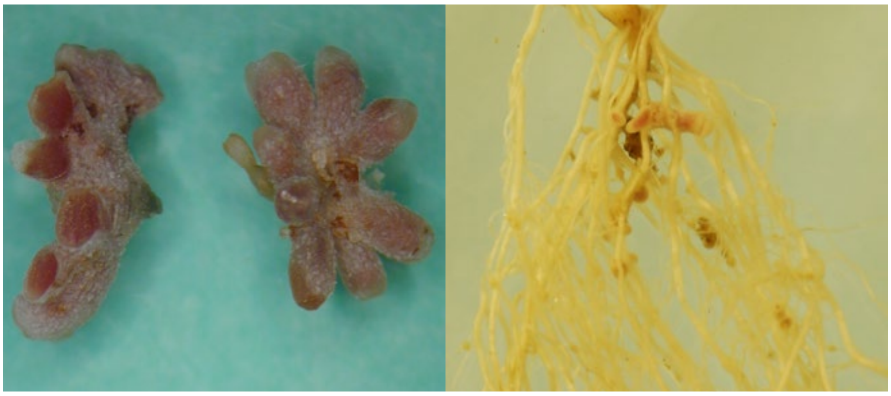

Photo 12: *Roots with large pink nodules. Young, active nodules are an intense pink colour inside.*

Photos: Liz Farquharson, SARDI; Ross Ballard, SARDI

Sometimes nodules may appear green or grey inside. At the 10-week growth stage, this would likely indicate herbicide damage or that the plant has suffered water stress. These nodules are unlikely to recover N fixation activity. However, later in the season, as plants approach flowering, the development of green pigmentation in the nodules occurs as a normal part of nodule maturation. Lentil nodules are indeterminate. This means they continue to grow and form elongated or lobed structures with distinctly different zones visible inside the nodule. With maturity, the section of nodule closest the plant root loses its pink coloration, turning grey or green. As long as the section of the nodule furthest from the root retains some pink tissue, the nodule remains actively fixing nitrogen.

If you have spent time and resources on inoculation, it is worthwhile to carry out this nodulation check, to determine whether your inoculation has been successful and is likely to provide N benefits. It may also indicate whether troubleshooting is required, or whether inoculation is needed in future.

4.10 Irrigation

Irrigating lentil, as either fully irrigated or supplementary, is not widely practised in Australia due to the high risk of yield loss with waterlogging.[40]

Nevertheless, irrigating lentil may be economical if:

- the irrigation system allows adequate drainage;
- the water quality is high; and
- the rotation with other winter and summer crops is managed to reduce disease pressure.

4.10.1 Principles

There are a number of factors to consider when irrigating lentil:

- avoid soils and irrigation layouts that do not drain freely and are subject to waterlogging;
- avoid heavy clay or dense soil types (bulk density > 1.5);
- select paddocks with good irrigation layout, such as beds or hills, and relatively good grades;
- assess layouts steeper than 1:800 grade for suitability. Runs must be short with free draining soils that can be irrigated quickly and do not remain saturated;
- rolling may also be required to flatten the ridges left by press-wheel furrows or to flatten clods; and
- irrigation can be used in activating and incorporating a number of pre-emergent herbicides.[41]

4.10.2 Management

Management requirements for irrigated lentil are the same as for dryland crops, with a greater emphasis on disease control as irrigated crops are more prone to the spread of foliar diseases. This is due to the dense canopy and potentially prolonged leaf wetness after irrigation.[42]

The amount of water to apply is dependent on rainfall and rate of evaporation.

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40 Pulse Australia (2015) Best Management Guide – Lentil Production: Southern Region. Pulse Australia, http://www.pulseaus.com.au/growing-pulses/bmp/lentil/southern-guide

41 E Drew, D Herridge, R Ballard, G O'Hara, R Deaker, M Denton, R Yates, G Gemell, E Hartley, L Phillips, N Seymour, J Howieson, N Ballard (2014) Inoculating legumes: A practical guide. Grains Research & Development Corporation, https://grdc.com.au/GRDC-Booklet-InoculatingLegumes

42 E Drew, D Herridge, R Ballard, G O'Hara, R Deaker, M Denton, R Yates, G Gemell, E Hartley, L Phillips, N Seymour, J Howieson, N Ballard (2014) Inoculating legumes: A practical guide. Grains Research & Development Corporation, https://grdc.com.au/GRDC-Booklet-InoculatingLegumes

As a shallow-rooted plant, lentil requires significant moisture to produce an optimum yield. However, lentil dies quickly when flooded. **Good drainage is essential to prevent water accumulation on the soil surface and waterlogging of the soil, particularly during planting and early flowering.** Even short periods of waterlogging can result in severe losses, particularly if the crop is stressed (from herbicides, disease, moisture, etc.).

- Pre-irrigate to fill the moisture profile prior to planting unless this has already been achieved by rainfall.
- Do not dry sow and then irrigate unless under sprinkler irrigation.
- As a general rule, in-crop irrigation should start early when there is a deficit of between 30–40 mm and around 60–70% of field capacity. Irrigating according to moisture is more important than irrigating for growth stage.
- Irrigations should commence prior to flowering to prevent moisture stress and high temperatures impacting on yield, quality and grain size.
- For furrow irrigation, every second row should be irrigated to avoid waterlogging. Doubling up siphons can increase water flow and reduce irrigation time.
- Irrigating should be completed in less than 8 hours. This includes good tail water drainage to avoid waterlogging.
- Supplemental irrigation with 1.2 cm of water may be required prior to canopy closure. This encourages pod formation and filling and carry the crops water needs to maturity.
- Avoid irrigating if there is likelihood of rain soon after.

Sprinkler irrigation is more suited to lentil as there is very little risk of waterlogging even during flowering and pod-fill. However, water quality is important, and there may be a need for greater disease control against Botrytis grey mould (BGM) or Ascochyta blight. This is due to more frequent wet leaf and soil conditions.

Salinity levels in irrigation water or the soil must be low. **Lentil is one of the more sensitive crops to salinity.** A 10% reduction in yield is expected if irrigation water measures 1.0 deciSiemens per metre (dS/m).[43]

MORE INFORMATION

For further information, go to: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/157729/faba-bean-pt1.pdf

4.10.3 Irrigation findings from NSW DPI

Taking into account the differences between lentil and faba bean, lessons learnt from 'Faba Check' can be utilised to assist with tips for irrigated lentil production.

New South Wales (NSW) Department of Primary Industries (DPI) conducted 'Faba Check' monitoring of irrigated bean crops in southern NSW from 2000 to 2004. Key factors for success of irrigated faba bean crops were identified. When utilising this information for growing lentil, the greater sensitivity of lentil to waterlogging, compared to faba bean, must always be considered.

43 Pulse Australia (2016) Southern Lentil: Best Management Practices Training Course. Pulse Australia