Producing lupins

Peter White
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Producing lupins

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Foreword

*Producing Lupins in Western Australia* was first published during a remarkable period of expansion in the lupin industry. In 1990 when the lupin industry was barely 20 years old, lupin had become the most widely grown grain legume in Australia. Research and development were key elements in this success. Innovative researchers, extension officers and farmers, working together to overcome the constraints to cropping on acid sandy soils, developed the wheat:lupin rotation into a highly productive and profitable cropping system.

Farming technology has continued to evolve rapidly since the first edition of this book was published. Farming practices unknown in the early 1990s are commonplace in today’s farming enterprises. Precision seeding, stubble handling, tramline farming and shielded spraying are just a few of the recent developments.

New challenges also confront the modern lupin farmer with the onset of herbicide resistance in weeds, anthracnose disease, a changing climate and the relentless cost–price squeeze.

This second edition of *Producing Lupins in Western Australia* (now renamed *Producing Lupins*) has been revised and updated to help the new generation of lupin farmers overcome these challenges. The book contains detailed information on lupin establishment, weed control, disease management and harvesting. It also provides an excellent background to the history of lupins in Western Australia, the development of the plant and its adaptation to the Western Australian environment. Once again it has been innovative researchers working with innovative farmers who have contributed these major advances in our knowledge. Congratulations to the editors of this excellent publication which maintains the high standards of the first edition. The researchers, farmers and funding agencies whose work it is, are to be commended.

Rob Delane, Director of Biosecurity and Research
Department of Agriculture and Food, Western Australia
Acknowledgments

The first edition of *Producing lupins in Western Australia* was compiled by Peter Nelson and Rob Delane and published by the Department of Agriculture, Western Australia in March 1990. A revised edition was subsequently published as Bulletin 4179 in August 1991. We acknowledge the valuable contribution made by the authors of the first and revised editions to this second edition of *Producing lupins*.

All chapters in this second edition have been completely revised and re-written. Chapters 12 (End uses for lupin) and 13 (Lupinosis), however, still contain significant proportions of text from the 1991 revised edition which has been reviewed and updated by Marion Seymour. Chapter 12 includes substantial new information added by Sofia Sipsas.

Most of the information contained in this book is based on work conducted by research scientists, extension officers and plant breeders working at the Department of Agriculture and Food, Western Australia (DAFWA), the University of Western Australia, Murdoch University, Curtin University and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Valuable contributions have also been made by our research partners, principally the Grains Research and Development Corporation (GRDC), the Grain Pool CBH Group, farmers and farmer groups (particularly the Mingenew-Irwin Group and the Liebe Group). Special thanks also go to Rod Birch, Steve Brindal, Piers Blake, Nils Blumann, Will Carrington-Jones, Ray Fulwood, Clancy Michael and the Obst family who provided information for their case studies.

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1 Introduction and history

Bob French, Greg Shea and Bevan Buirchell
Lupin in Western Australian farming

Lupin species are perhaps best known to most people as garden flowers or green manure plants. They are also a critical component of a uniquely Western Australian farming system, the wheat-lupin rotation, which is barely 40 years old. Yet in this time Western Australia has become the world’s leading producer, currently responsible for about 80 per cent of world production, and the only significant exporter of lupin grain. In 2005 the state produced 920,000 t of lupin on 650,000 ha (Figure 1.1).

Lupin species provide an excellent example of how farming in Australia has evolved in response to changes in technology and economics. The modern wheat-lupin rotation became possible through the research of Dr John Gladstones, the University of Western Australia and Department of Agriculture, Western Australia (now DAFWA). Dr Gladstones released the first fully domesticated narrow-leafed lupin (*Lupinus angustifolius*) cultivars adapted to Western Australian conditions in the late 1960s and early 1970s. This was a major technological breakthrough that marked the beginning of grain lupin cropping in Australia.

Lupin is unusual among broadacre crops in that domestication has played a crucial role in its modern development. Other familiar broadacre crops have a much longer history of cultivation, and the varieties we grow today are not very different from those available to farmers one hundred years ago. On the other hand, the lupin

---

**Figure 1.1** Lupin production in Western Australia since 1970

Source: Australian Bureau of Statistics
Lupin species of one hundred years ago were at best semi-domesticated according to modern criteria. This had to be rectified before the usual plant breeding objectives of better adaptation, yield and disease resistance could be pursued.

After the release of the first domesticated varieties, new farming systems utilising lupin emerged slowly through the 1970s. During this time improved methods of managing lupin crops were being developed by Peter Nelson and Dr John Hamblin, from DAFWA, and other scientists. These methods were based in part on early sowing and the correct use of herbicides for weed control. The management guidelines in this book owe a great debt to the pioneering work of these scientists.

Once sound management packages were available, the lupin industry grew rapidly in the 1980s and 1990s, reaching peak production in 1999. The decline in production and the area sown to lupin since then reflects a decrease in the price of lupin grain relative to other commodities, difficulties in controlling weeds that have become resistant to herbicides, and the availability to Western Australian farmers of a greater range of alternative land uses such as canola, new pasture species and field pea.

Lupin is uniquely well suited to the deep, acid sandy soils that occur over large areas of the Western Australian wheatbelt. This unique adaptation, together with further improvements in the techniques for producing lupin and the development of premium paying markets, will ensure that lupin remains a vital component of profitable and sustainable farming systems in Western Australia.

**Early history**
Lupin species were present in Western Australia as early as the 1850s. They initially spread on uncultivated land and were thought to have little value. People soon noticed their ability to grow vigorously on poor sandy soils, and how much better other crops grew on land that had previously grown lupin.

The newly established *Journal of Agriculture* in the early 1900s published several articles advocating the use of lupin as green manure. Trials evaluating lupin as green manure crops were set up at the Narrogin, Chapman and Nangeenan State Farms in the first decade of the 20th century, but the results seem to have been lost and there is little evidence that the practice became widespread.

At about the same time, the value of the sandplain lupin as a sheep feed was recognised at Geraldton and it was extensively planted there after 1910, and at Gingin and Dandaragan from about 1920. Lupin was incorporated in rotation trials at the new light land research station at Wongan Hills in the 1920s. Interest in sandplain lupin waned in the 1930s and 1940s when increasing emphasis was given to subterranean clover as a basis for Western Australian farming systems.

Dr John Gladstones began his long association with lupin research at the University of Western Australia in 1954. The Deputy Director of the Institute of Agriculture at the time, Andrew Stewart, was convinced that lupin had great potential in Western Australia, and persuaded Dr Gladstones to make them the subject of his BScAgric honours thesis. This work expanded into a PhD project and later into the lupin breeding program that made possible modern lupin-based cropping systems in Western Australia.

While this work at the University of Western Australia (which eventually concentrated mainly on narrow-leafed lupin) was in its early stages, sandplain lupin was playing an important role in the post-war agricultural expansion of Western Australia. Eric (later Sir Eric) Smart developed a large tract of land at Mingenew in the 1950s using a system which relied on sandplain lupin as summer feed for sheep and to build up soil fertility for cereal cropping. This demonstrated the capacity to transform otherwise unproductive soils with lupin and was widely copied by other farmers, thanks in no small part to the large field days Sir Eric hosted on his farm and research trials conducted there by scientists from the University of Western Australia and the Department of Agriculture. This system was the forerunner of the modern wheat:lupin cropping system.

**Lupin species used in agriculture**
Lupin species belong to the genus *Lupinus*, which is large and diverse. The genus is divided into two main groups: the New World species which occur naturally in the Americas, and the Old World species which occur naturally in the countries bordering the Mediterranean Sea and in eastern Africa.
There are more than 100 New World lupin species. However, only one of these, pearl lupin (*Lupinus mutabilis*), currently has potential as a crop species in Western Australia. Traditional farmers in Andean regions have grown pearl lupin for many centuries.

There are 12 Old World lupin species. All modern lupin cultivars used in crop production have been developed from this group. Old World lupin species have been used in traditional agriculture in the Mediterranean region for thousands of years. These traditional lupin species, however, are at best semi-domesticated.

There are three main differences between wild and domesticated lupin. All wild lupin have bitter alkaloids in the seeds which make them unpalatable and sometimes toxic to livestock. Their hard seed does not readily imbibe water, so that some seed survives in the soil for several seasons before germinating; and their shattering pods scatter seed on the ground at maturity. Domesticated lupin species have sweet (low alkaloid) seed that can be fed to livestock or eaten by people; soft seed that will germinate as soon as it is sown into moist soil; and non-shattering pods that retain seed on the plant until it is harvested. Fully domesticated lupin crops were not developed in Europe or Australia until the 20th century.

Four lupin species have been grown commercially in Western Australia: narrow-leafed lupin, albus lupin, yellow lupin and sandplain lupin.

**Narrow-leafed lupin (*Lupinus angustifolius*)**

Also known as Australian sweet lupin, narrow-leafed lupin (*Lupinus angustifolius*) is by far the most important lupin species in Western Australia, comprising over 95 per cent of all lupin grain production (Figures 1.2 and 1.3).

The first fully domesticated cultivar of narrow-leafed lupin, Unilwhite, was released in Western Australia in 1967 (Table 1.1). It was named for its white flower which Dr Gladstones incorporated to distinguish it from the blue-flowered, bitter narrow-leafed lupin then used for green manuring. It matured too late to perform well in most wheatbelt areas, so lupin cropping did not begin to expand in the areas we now associate with lupin until the release of the early flowering Unicrop in 1973.

Initial cultivar development concentrated on earlier flowering and resistance to grey leaf spot disease which threatened the industry in the 1970s. Subsequent breeding in DAFWA has aimed at improving adaptation, yield potential and resistance to other diseases. Cultivars with resistance to phomopsis, which causes lupinosis in grazing animals, and anthracnose (first released respectively in 1988 and 1996), were important breeding milestones. DAFWA has recently increased the emphasis on breeding for better herbicide tolerance and grain quality.
# Table 1.1 Narrow-leafed lupin varieties in Western Australia

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Release date</th>
<th>Maturity</th>
<th>Status in 2007</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniwhite</td>
<td>1967</td>
<td>Late</td>
<td>Obsolete</td>
<td>First fully domesticated cultivar</td>
</tr>
<tr>
<td>Uniharvest</td>
<td>1971</td>
<td>Late</td>
<td>Obsolete</td>
<td>Better shattering resistance than Uniwhite</td>
</tr>
<tr>
<td>Unicrop</td>
<td>1973</td>
<td>Early</td>
<td>Obsolete</td>
<td>First early flowering cultivar</td>
</tr>
<tr>
<td>Marri</td>
<td>1976</td>
<td>Mid</td>
<td>Obsolete</td>
<td>Grey leaf spot resistance</td>
</tr>
<tr>
<td>Illyarrie</td>
<td>1979</td>
<td>Early</td>
<td>Obsolete</td>
<td>Grey leaf spot resistance and early flowering</td>
</tr>
<tr>
<td>Yandee</td>
<td>1980</td>
<td>Early</td>
<td>Obsolete</td>
<td>Very similar to Illyarrie</td>
</tr>
<tr>
<td>Chittick</td>
<td>1982</td>
<td>Mid</td>
<td>Obsolete</td>
<td>High yielding midseason type</td>
</tr>
<tr>
<td>Danja</td>
<td>1986</td>
<td>Early</td>
<td>Obsolete</td>
<td>Improved pod set</td>
</tr>
<tr>
<td>Gungurru</td>
<td>1988</td>
<td>Early</td>
<td>Obsolete</td>
<td>First phomopsis resistant cultivar</td>
</tr>
<tr>
<td>Yorrel</td>
<td>1989</td>
<td>Very Early</td>
<td>Obsolete</td>
<td>Phomopsis resistant</td>
</tr>
<tr>
<td>Merrit</td>
<td>1991</td>
<td>Early</td>
<td>Obsolete</td>
<td>Selection from Gungurru</td>
</tr>
<tr>
<td>Myallie</td>
<td>1995</td>
<td>Early</td>
<td>Obsolete</td>
<td>Improved brown spot tolerance</td>
</tr>
<tr>
<td>Kalya</td>
<td>1996</td>
<td>Early</td>
<td>Replaced by Mandelup</td>
<td>Resistant to aphid colonisation</td>
</tr>
<tr>
<td>Wonga</td>
<td>1996</td>
<td>Early</td>
<td>Suggested in Zone 1 only</td>
<td>Highly tolerant of anthracnose</td>
</tr>
<tr>
<td>Belara</td>
<td>1997</td>
<td>Very Early</td>
<td>Replaced by Mandelup</td>
<td>High yield potential</td>
</tr>
<tr>
<td>Tailerack</td>
<td>1997</td>
<td>Very Early</td>
<td>Obsolete</td>
<td>First restricted-branching cultivar</td>
</tr>
<tr>
<td>Tanjil</td>
<td>1998</td>
<td>Early</td>
<td>Suggested in Zone 1</td>
<td>Selection from Wonga; high anthracnose tolerance but sensitive to metribuzin</td>
</tr>
<tr>
<td>Moonah</td>
<td>1998</td>
<td>Early</td>
<td>Not recommended in Western Australia</td>
<td>Released for eastern Australia</td>
</tr>
<tr>
<td>Quilinock</td>
<td>1999</td>
<td>Early</td>
<td>Suggested for Zones 6, 7, 8</td>
<td>High yield potential but susceptible to anthracnose</td>
</tr>
<tr>
<td>Jindalee</td>
<td>2000</td>
<td>Late</td>
<td>Not recommended in Western Australia</td>
<td>Released for eastern Australia</td>
</tr>
<tr>
<td>Mandelup</td>
<td>2004</td>
<td>Very Early</td>
<td>Suggested in all zones except Zone 1</td>
<td>High yield potential; improved metribuzin tolerance</td>
</tr>
<tr>
<td>Coromup</td>
<td>2006</td>
<td>Early</td>
<td>Suggested for Zones 2, 3, 5 and 7</td>
<td>High grain protein, but lower yield potential than Mandelup or Quilinock</td>
</tr>
<tr>
<td>Jenabillup</td>
<td>2007</td>
<td>Mid</td>
<td>Suggested for Zones 4, 8</td>
<td>Best resistance for “black pod” syndrome</td>
</tr>
</tbody>
</table>

(©) = Plant Breeder’s Rights  
Note: For Zones see Figure 1.13
Introduction and history

Albus lupin (Lupinus albus)

Also known as the European white lupin, albus lupin (Lupinus albus) is the major lupin species grown in Europe (Figures 1.4 and 1.5). Fully domesticated cultivars of albus lupin were first developed in Germany in the 1930s.

Albus lupin is only a minor crop in Western Australia. Almost 40,000 ha of the Russian cultivar Kiev Mutant were grown annually in the northern wheatbelt during the 1990s, but this disappeared when lupin anthracnose was identified in Western Australia in 1996. Andromeda is the first anthracnose-resistant albus lupin cultivar and was released in 2005 by DAFWA. It has only moderate anthracnose resistance and flowers later than Kiev Mutant, so further cultivar development will be necessary before the local albus lupin industry can be completely restored.

Yellow lupin (Lupinus luteus)

Yellow lupin (Lupinus luteus) was the first lupin species to be fully domesticated (Figures 1.6 and 1.7). The first cultivars were released in Germany in the 1930s. It has been extensively grown in northern and eastern Europe. The German variety Weiko III was released in Western Australia in 1959, but it never became firmly established.

Local interest in yellow lupin was renewed in the 1990s when DAFWA researchers noticed its high level of resistance to brown spot, pleiochaeta root rot and Eradu patch and its tolerance of very acid soils. In 1997 DAFWA released the cultivar Wodjil, which had been selected from a Polish cultivar. Wodjil was very susceptible to anthracnose and to aphid feeding damage, and further work led to DAFWA releasing Pootallong in 2005. Yellow lupin is also the most frost susceptible grain lupin species. Plant breeders are still striving for better yield potential and aphid tolerance in yellow lupin.
Yellow lupin grain has a higher protein content and better amino acid balance than narrow-leafed lupin grain and is therefore more valuable as poultry, pig and aquaculture feed. Nevertheless, yellow lupin remains a minor crop in Western Australia.

Sandplain lupin (Lupinus cosentinii)

The Department of Agriculture released the cultivar Erregulla in 1976. This had white flowers and sweet seed and did not shatter but it was not widely adopted. Another line of sandplain lupin was developed which also had soft seed, but this was not released.

There are 400,000 to 750,000 ha of self-regenerating sandplain lupin in Western Australia. Some farmers still value sandplain lupin but many others now regard it as a weed. There are two reasons for this. First, sandplain lupin emerges as a weed in grain lupin crops because the hard seeds can persist in the soil over several cropping cycles. As well as competing with grain lupin, sandplain lupin seeds are an undesirable contaminant in narrow-leaved lupin grain. There are no herbicides that will selectively control sandplain lupin in crops of other lupin species. Second, sandplain lupin is very susceptible to anthracnose which it harbours and spreads to other lupin species growing nearby.

Other lupin species

Three other lupin species have potential to contribute to Western Australian agriculture. Atlas lupin (L. atlanticus) and hairy lupin (L. pilosus) (Figure 1.10) belong to the same rough-seeded group as sandplain lupin and both are adapted to fine-textured alkaline soils. Plant breeders in DAFWA have fully domesticated both species but no further breeding is being done at present, and they are not yet grown commercially.
Pearl lupin (L. mutabilis) is of great interest because it has higher protein and oil content in its grain than any of the domesticated lupin species (Figures 1.11 and 1.12). Sweet lines of pearl lupin have been developed recently and they are currently being tested for their adaptation and agricultural potential in Western Australia.

Lupin cropping zones

The importance of lupin in farming systems varies throughout Western Australia as do the major constraints to lupin production, so appropriate management in one part of the state may not be so appropriate in another. The agricultural areas of Western Australia have been divided into eight lupin production zones (Figure 1.13) and the regionally specific management recommendations in this book are made in reference to these zones.

The lupin production zones were chosen to distinguish areas with broadly similar farming systems and yield potential, similar constraints to production and similar management requirements. For example, Zones 3 and 7 are drier and therefore have lower yield potential than the others; but Zone 7 has colder winters and a higher risk of brown spot than Zone 3 so wider rotations may be better in Zone 7. Similarly, naturalised sandplain lupin is more common in Zone 1, so anthracnose risk is higher than in Zone 2 and different cultivars are recommended. In the south, abortion of pods on the main stem is more common in Zone 8 than elsewhere, so different cultivars are recommended here. The fringes of the agricultural areas are not included in any zone because we do not recommend lupin cultivation there.
2 Lupin growth and development

Miles Dracup
Lupin growth and development

The life cycle of lupin, from germination through to seed ripeness, can be divided into definable stages:
- germination and seedling emergence
- initiation and growth of leaves
- stem elongation and branching
- root growth
- inflorescence and flower development
- pod and seed development.

These stages overlap and are closely linked. Figure 2.1 illustrates the life cycle for narrow-leafed lupin with approximate timing for each stage. Actual timing of stages for growing plants will depend on species, cultivar, time of sowing and weather. The critical stages for managing a lupin crop are slightly differently from the natural development of the plant that is explained here. Stages for crop management are described in the table at the end of the book.

The seed
The lupin seed consists of a seed coat (also called testa) and embryo. The embryo is already a well developed plant consisting of two cotyledons, five or six leaf primordia on a tiny seedling axis and the radicle (embryonic root) (Figure 2.2). Cotyledons account for about 75 per cent of the weight of the seed. The seed coat accounts for almost 25 per cent of the weight.

If too dry, lupin seeds can be brittle and vulnerable to damage during harvesting, handling and sowing. Cracks can occur in the embryo that may reduce seedling establishment and vigour.

Figure 2.1 Development of the narrow-leafed lupin plant
Source: M Dracup
Lupin growth and development

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The point of attachment of the cotyledons to the seedling axis is particularly susceptible to damage. Loss of a cotyledon will reduce seedling vigour because cotyledons are the food store for the growing seedling. Cracks elsewhere in the seed embryo can lead to seedling abnormalities such as a missing taproot or upside down growth.

Germination and seedling emergence

After sowing into moist ground, lupin seeds imbibe water readily. The water content increases from about 10 per cent for dry seed to about 60 per cent at germination. During this time, the embryo swells and the radicle ruptures the seed coat and pushes through it. When the radicle is 5 mm long, the seed is considered to have germinated.

After germination, the radicle continues to grow downwards and firmly anchors the plant in the soil, while the remainder of the seedling pushes upwards through the soil. The radicle becomes the plant’s taproot. The seedling stem between the radicle and cotyledons is called the hypocotyl. The hypocotyl forms a downward hook to protect the growing apex of the seedling and cotyledons as they are pushed upwards towards the soil surface. A seedling is considered to have emerged when any part of it protrudes above the soil surface. When soil is moist and the temperature averages 15°C, emergence occurs about six to seven days after sowing seeds 4 cm deep.

Lupin emergence is called hypogeal emergence because the hypocotyl expands to push the cotyledons and growing apex above the soil surface. This differs from the epigeal emergence of faba bean and field pea in which the cotyledons remain where the seed was placed in the soil and only the stem above them (epicotyl) lengthens to protrude from the soil. The size of lupin cotyledons and the force needed to push them towards the surface makes lupin comparatively sensitive to soil crusting compared with species that have epigeal emergence.

After germination, the hypocotyl hook straightens and the cotyledons turn green and expand further as the shoot apex continues to develop (Figure 2.3). The hypocotyl above the soil surface also turns green. Depth of sowing can be determined on seedlings by measuring the length of the white portion of hypocotyl above the root junction. Because the cotyledons and shoot apex are above the soil, lupin is particularly susceptible to sandblasting, grazing and insect damage, compared to cereals, in which the shoot apex remains underground during vegetative growth.

Figure 2.2 Structure of lupin seed
Source: Dracup & Kirby 1996

Figure 2.3 Lupin seedling
Source: Dracup & Kirby 1996
**Initiation and growth of leaves**
When the seed imbibes water, the leaf primordia that are present in the embryo resume their development. More leaves are also initiated at the shoot apex as the seedling germinates, emerges and grows. Leaf initiation continues until about four to five weeks after sowing, at which time the apex has typically produced about 20 leaf primordia and about eight leaves have opened. The apex then switches to initiating flower primordia (floral initiation). The number of leaves initiated depends on cultivar, temperature and day length. Late sown crops tend to have fewer leaves.

Leaf primordia develop and expand before young leaves become clearly visible to the naked eye. The first pair of leaves begins to unfurl shortly after the cotyledons open and then successive leaves unfurl about every three days until the 20 or so leaves have all emerged. During this phase, the progress of development is often described by the number of leaves that have unfurled from the apex (for example, 4-leaf point or 6-leaf point).

Leaves are arranged spirally on the stem to minimise leaf shading. Leaves also move to track the sun and leaflets open and close during the day so that, depending on water status, they can maximise or minimise exposure to the sun.

**Stem elongation and branching**
When the seedling reaches floral initiation, it is only about 5 to 10 cm high and has little separation between nodes (the points of attachment between leaves and the stem). After floral initiation the stem between nodes (internodes) successively expands, from the bottom upward, leading to stem elongation. Final main stem length is achieved soon after flowering begins. Plants grow taller under short days than long days and plants sown near the end of June tend to be taller than plants sown earlier or later. Plants are also taller in dense crops than in sparse crops.

While leaves are appearing on the main stem, branches are also being initiated in most of the leaf axils being formed by leaves on the stem. These branches go through a similar developmental sequence to the main stem, but fewer leaves are formed (typically only five to six leaves on the highest branch of each of the first-, second- and third-order branches) and not all get through to flowering. The extent to which branches grow and become visible to the naked eye depends on factors such as position on the plant, density of the crop and mineral nutrition. First-order branches at the bottom (basal branches) and top (apical branches) of the main stem are the most likely to develop through to flowering. Elongation of the apical branches further increases the height of the crop canopy.

The first three to four apical branches are the most likely first-order branches to flower and produce pods. Basal branches tend to produce pods only in sparse crops. Apical branches are also the most likely to form second-order branches. Similarly, third-order branches can form on apical second-order branches. Branch vigour declines with successive orders of branching. Apical first-order branches are the strongest with largest leaves and longest internodes.

**Root growth**
Lupin has a taproot that grows about 2.5 cm per day under optimum conditions. The taproot can reach 70 cm within a month and over 2.5 m at maturity. Lupin can, therefore, extract water from deeper in the soil than many other species of annual plant.

First-order lateral roots begin appearing about 10 cm behind the root tip, although they can be closer if root extension is impeded for any reason such as by soil compaction. The taproot grows mainly downward and the laterals grow approximately horizontal. The first-order lateral roots are thinner than the taproot (Figure 2.4). In time, first-order laterals produce second-order laterals which in turn produce third-order laterals, getting thinner with successive orders of branching and growing in apparently random directions. Lateral roots are particularly prolific near the soil surface, growing preferentially in moist layers of soil with high nutrient levels. At flowering almost half of the root length is within 20 cm of the soil surface. By the time the crop reaches the point of pronounced leaf drop, there can be almost 2 km of root under each square metre of crop.

When the surface is especially moist, adventitious lateral roots may also form. These roots grow from the hypocotyl rather than the taproot and do not branch.
Some lupin species form **cluster roots** soon after the first-order lateral roots are produced. Cluster roots, sometimes called proteoid roots, are a dense cluster of short rootlets, about 2 to 3 cm long, that protrude for a distance of about 2 to 5 cm along a lateral root (Figures 2.5 and 2.6). Cluster roots form concentrated areas of root exudates that cause intense mobilisation of plant nutrients (phosphorus, iron, zinc, manganese) from the soil. Narrow-leafed lupin does not form cluster roots but they are common in albus lupin and sandplain lupin.

**Nodules** usually become visible on the taproot within three to four weeks of sowing (Figure 2.4) and start fixing nitrogen within five weeks. The nodules are rugged outgrowths on the top 5 to 10 cm of taproot and in a healthy crop eventually girdle it. Nodules are sparse on the laterals unless the taproot is lost.

The plant invests a lot of its resources in the nodules and root system, leading to comparatively slow early shoot growth. By six weeks over half of the plant’s weight is in roots, and nodules consume up to one-fifth of the plant’s sugars. The plant allocates an even greater proportion to roots under difficult soil conditions, such as dry or infertile soil, which aids exploration for moisture and nutrients. Root growth is reduced by factors that reduce leaf area, such as predation or disease.
Inflorescence and flower development
Inflorescence and flower development begins with floral initiation. This is when the apex of the main stem changes from creating leaves to flowers. It commonly occurs four to five weeks after sowing. The apex initiates many flowers over a number of days to form an inflorescence (or raceme) of 40 or more flowers. The apex then degenerates.

While flowers are being initiated upwards on the inflorescence, leaves continue to grow and emerge at the shoot tip. Eventually, after elongation of the stem and emergence of most leaves, the young inflorescence bud becomes visible (Figure 2.7). The number of flowers that develop and become visible depends on the size and vigour of the plant and the competition from lateral branches.

Individual flowers on the main stem inflorescence open (flower) from the bottom upward, starting about 75 to 100 days after sowing and continuing for about 20 days. Flowering is earlier in the north than in the south of Western Australia due to higher temperatures and longer days. Anthesis, which is when the pollen is shed from the anthers, occurs one to two days before flowering so that cross-pollination with other plants is rare.

Pod and seed development
About 30 flowers open on the main stem inflorescence but most drop off despite being fertilised (Figure 2.8). Flowers drop about 10 days after anthesis. Some of the pods that begin to develop are shed before maturity and some of the seeds inside pods also abort. At maturity, only a few pods are likely to remain on the main stem. These are generally located at the base of the inflorescence and each contains about three to four seeds. Shedding of flowers and pods and
the abortion of seeds are related to competition with branches for resources. It is exacerbated by stresses such as drought or poor nutrition. Strong competition for resources in particularly thick lupin canopies often leads to complete shedding of pods from the main stem. If there is strong competition for resources late in pod development, pods may remain attached even though all their seeds have aborted.

In the early stages of pod development, pod walls become very fleshy, as nutrients are transferred to them from elsewhere in the plant. This transfer process extracts nutrients from leaves before they drop off. However, with a sudden stress, such as from a hot windy dry day, leaves can drop without transferring their nutrients. The pod walls serve as a reservoir of nutrients for the developing seeds and reach maximum weight before seeds are even half their final weight. Thereafter, the walls turn from green to khaki to pale brown as they transfer nutrients to the seeds. Similarly, the seeds remain green until they reach maximum weight (physiological maturity), when they contain 62 per cent moisture. Thereafter, they dry and cotyledons turn to yellow and then golden by harvest. Harvested seeds average 120 to 150 g per 1000 seeds and contain about 12 per cent moisture.

Pods and seeds on branches develop like those on the main stem, but their growth rate is faster. Their seeds reach maximum weight and harvest maturity at about the same time as those on the main stem even though they started growing later. Pods and seeds also grow faster as the soil dries so they reach harvest maturity earlier in a dry environment than in a moist environment. Most pods tend to be on first- or second-order branches, but the main stem and first-order branches tend to have the most seeds in each pod and the heaviest seeds.

Further reading


3 Environmental influences on lupin growth

Bob French and Peter White
Lupin growth is driven by environment. In common with other crops, lupin requires sunlight, water, carbon dioxide, oxygen and various mineral nutrients. It is also important that temperature is neither too high nor too low. Where lupin crops differ from other crops is in their ability to efficiently use the resources of particular environments and the adaptations they have evolved to cope with resource shortages.

**Sunlight**

Solar radiation is the energy source for all crop growth. It is captured by crop leaves which transform it into chemical energy by the process of photosynthesis. This uses the captured light energy to convert carbon dioxide (CO₂) into sugars, which provides the energy source for the various metabolic processes within the plant and the basic building blocks for the plant’s structure. Cellulose, a major constituent of plant structure, is simply a very large and complex sugar molecule.

The availability of solar radiation rarely limits lupin growth in Western Australia. However, the crop’s ability to capture it may limit growth. Total leaf area and the orientation of leaves are the main things governing a plant’s ability to capture solar radiation. Under ideal conditions the leaves of a lupin crop sown in narrow rows spread quickly to completely shade out the ground (full canopy cover). Leaves also track the sun during the day so the largest area of the leaf’s surface is exposed to the sun’s rays. Leaf diseases that reduce the green area of the leaf and other factors that inhibit plant growth will limit the ability of the crop to capture solar radiation. Lupin crops grown in wide rows grow more slowly at first than lupin crops in narrow rows because they take longer to achieve full canopy cover (that is, to grow into the large space between the rows). The wide row crops may catch up later, when other resources such as water become limiting (Figure 3.1).

The efficiency with which energy from solar radiation is converted into biomass also varies. **Radiation use efficiency (RUE)** is defined as the amount of biomass produced per unit of radiation intercepted by the crop. It varies between plant species and between cultivars within a species. It may even vary during the life of a crop. It is highest when no other resources, such as water or nutrients, are limiting growth. In Western Australia RUE of lupin is highest in winter and early spring before water stress begins to curtail growth (Figure 3.2).
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Water use and water use efficiency

Water plays a number of essential roles in lupin growth. The mechanical rigidity of tissues such as leaves and young stems is maintained by water pressure inside their cells and water is required for the uptake of mineral nutrients from the soil. These nutrients and metabolites generated within the plant itself are then transported throughout the plant dissolved in water. Most of the biochemical reactions that drive plant growth also only occur in aqueous solution.

The vast bulk of water used by the crop passes through it incidentally as a consequence of photosynthesis. Photosynthesising leaves absorb CO₂ from the air through tiny pores called stomata. These provide a direct path between the leaf’s moist interior and the dry air outside and some water vapour inevitably escapes. More water must be drawn from the soil to replace it and maintain the plant’s internal hydration. The process whereby water passes from the soil to the atmosphere through the plant is called transpiration and the combination of transpiration and the evaporation that occurs directly from the soil surface is called evapotranspiration.

Water loss and CO₂ absorption occur across the same pathway and it is not surprising that the two are closely related. Crops that produce a lot of biomass (and hence a lot of grain) also use a lot of water (Figure 3.3). Water use efficiency (WUE) is usually defined as the amount of biomass or grain produced per millimetre (mm) of water used in evapotranspiration. WUE for lupin in Western Australia ranges from about 3 to 12 kg grain/ha/mm. WUE calculations take into account water that passes through the plant (transpiration), as well as water that evaporates directly from the soil which makes no useful contribution to plant growth. At least 30 per cent of the evapotranspiration of most crops in Western Australia is water evaporating directly from the soil surface.

The close relationship between water use and yield means that an estimate of rainfall and soil evaporation can provide a good estimate of the yield potential of crops. The well-known French-Schultz approach to estimating yield potential assumes a set amount of soil evaporation for any given environment. Water used in excess of this amount is assumed to pass through the plant as transpiration, which then produces grain at a constant rate. This rate is assumed to be 15 kg/ha/mm for lupin in Western Australia.

The line in Figure 3.3 shows the estimated grain yield for lupin using the French-Schultz approach, assuming 70 mm soil evaporation. The points represent actual grain yields harvested from experimental plots. Most points do not fall on the line. The points above the line may come from sites with very low soil evaporation or, more likely, from sites with soil water stored from rain falling before April.

Figure 3.2 Growing lupin in narrow rows maximises the interception of solar radiation by the crop but may also cause earlier water stress. This results in a more rapid decline in RUE in narrow row crops than wide row crops.

Source: Data R French Merredin 2004
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Points below the line may come from sites with higher amounts of soil evaporation or where factors other than water shortage limit the yield.

Management practices that minimise soil evaporation (for example, stubble retention, narrow row spacing and high crop density) can improve WUE by ensuring that the saved water passes through the crop instead of evaporating directly from the soil. However, these practices may influence crop growth in other ways that offset the gains from reducing soil evaporation. This is most obvious in the cases of high crop density and narrow row spacing where high demand for water may lead to premature exhaustion of stored soil water before grain filling is complete.

Other factors that influence WUE are the dryness of the atmosphere and the efficiency with which biomass is converted into grain. The hotter and drier the air, the faster water will evaporate from the inside of the leaf for the same rate of CO₂ assimilation. WUE will, therefore, be greatest when air is cool and humid during winter or early in the morning.

The efficiency of biomass conversion to grain will also affect WUE for grain production. Typically, about 30 to 35 per cent of total above-ground biomass is converted to grain in modern lupin varieties in Western Australia. This ratio is called the harvest index (HI) and factors that reduce it, such as frost or severe drought before the completion of grain filling, will also reduce WUE.

Adaptations to water shortage

Water shortage is the most important environmental constraint to lupin production in Western Australia. Coping with water shortage has had profound effects on the evolution of lupin species and on their continued improvement by plant breeding. It also has important implications for the management of lupin crops.

Three broad categories of adaptation to drought are commonly recognised in plants. They are drought escape, dehydration postponement and dehydration tolerance. Drought escape is by far the most important for lupin in Western Australia, followed by dehydration postponement. Lupin species have little dehydration tolerance.

Drought escape is the strategy of matching a crop’s development to the pattern of water supply, so that its life cycle is completed while water remains available. In Western Australia’s environment this is achieved by planting in early autumn and using cultivars that flower and mature early. Grain growth can, therefore, be completed in spring before the plant runs out of water. It is also important that as much growth as possible occurs during the cool, moist winter and early spring to maximise WUE. The fact that the most recent lupin cultivars in Western Australia flower 30 days earlier than the first released cultivars and 10 days earlier than most cultivars grown at the beginning of the 1990s emphasises the importance of drought escape for lupin species in Western Australia.

Early sowing is also a strategy that helps plants to escape drought. It allows the crop to grow over a longer period and produce more biomass before the drought arrives at the end of the season.

Dehydration postponement occurs when plants delay the development of water deficits in their tissue by either enhancing water uptake from the soil or by restricting water loss from their leaves. Lupin crops enhance water uptake by growing very deep roots (more than 2.5 m), which allows them to make full use of water stored in deep sandy soils.

The first response of lupin to receding water supply is to close their stomata in order to restrict water loss. All lupin species grown as crops in Western Australia begin stomatal closure at milder stress levels than wheat and will complete stomatal closure over a narrower range of stress.
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levels than wheat. As water becomes scarcer, lupin species reduce their transpirational demand by turning leaves away from the sun, rolling leaflets and wilting, all of which reduce the amount of sunlight falling on the leaf surface (Figure 3.4). These responses also reduce CO₂ assimilation and, therefore, reduce crop growth. However, they are worthwhile because restricting transpiration and photosynthesis during the hottest and driest part of the day (that is, when relative humidity is lowest) means that most crop growth occurs in the early morning under conditions favouring high WUE. When water is almost completely exhausted, further water use is restricted by shedding leaves. There is almost no further growth after this happens, but some reallocation of biomass from vegetative tissues to grain continues while plants are still alive.

Dehydration tolerance is displayed by plants that continue to grow, usually at a reduced rate, even when their tissues become severely stressed. Cereals and some legumes such as chickpea exhibit this adaptation but it does not occur in lupin.

Temperature and photoperiod

Normal plant growth processes only occur in a fairly narrow range of temperatures, roughly 0°C to 35°C for temperate crop plants. Within this range, plant processes generally accelerate as temperature rises until an optimum is reached. Above the optimum temperature, growth and development rates usually flatten out or even begin to decline. In lupin the optimum temperature for many processes is about 20°C.

Processes that respond to temperature in lupin include germination, leaf growth and plant development (for example, time to flowering). When the weather is warm, as usually occurs in the northern wheatbelt, or when a crop is sown very early during warm autumn days, lupin will germinate and emerge quickly. The leaves expand rapidly and more solar radiation is captured to fuel rapid crop growth. When the weather is cooler—such as in the central eastern wheatbelt and in mid-winter—lupin grows slowly. In these environments, plants may not grow fast enough to keep ahead of brown spot (if this disease is present) and are less competitive against some weed species.

Plants will cease growing and may die if temperatures remain outside their suitable range. Reproductive tissues are particularly sensitive to temperature extremes. Frost can kill flowers and temporarily prevent pod set. Severe frost will also kill small seeds in pods that have already set. Yellow lupin and sandplain lupin are more sensitive to frost than other lupin species. In Europe some cultivars of albus lupin will survive in the vegetative state over winter under snow, but their reproductive tissues are still sensitive to frost. Excessively high temperatures will cause premature cessation of flowering and shedding of flowers and young pods. Short bursts of temperatures above 35°C can cause seed abortion and impair seed filling. High temperature usually occurs at the same time as water deficit in Western Australia so it is difficult to separate out the effects of each stress. Furthermore, each stress reduces the plant’s capacity to cope with other stresses.

Flowering time in lupin depends on both temperature and day length. Day length is often referred to as photoperiod in the scientific literature (note that plants actually perceive the length of the dark period rather than the light period, even though we talk about photoperiod and day length).

Within the favourable temperature range, plants flower sooner when the temperature rises. Lupin belongs to a group known as long-day plants so flowering is also stimulated as days become longer. Lupin sown on the same date will flower earlier in the northern wheatbelt, where it is warmer and winter days are longer, than in the central and southern wheatbelt where days are cooler and shorter (Table 3.1). Late sown lupin usually takes less time after sowing to flower, even under colder conditions, because days are longer.

Figure 3.4 Leaflets of yellow lupin folding inwards in response to water deficit

Photo: P White
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This photoperiod sensitivity of lupin species contributes to their drought escape strategy. By reducing the time taken to reach flowering, late sown crops can still complete much of their grain filling under reasonably favourable conditions before it gets too hot and dry. However, this leaves less time for vegetative growth so the plants are smaller when they flower and are able to fill fewer pods.

European lupin varieties need to experience a certain amount of time at low temperatures before they will flower. This is known as vernalisation and the effect is strongest at temperatures below 11°C. The first lupin cultivars grown in Western Australia required vernalisation to flower, but modern cultivars do not. Some cultivars grown in eastern Australia still have a small vernalisation requirement.

Balancing vegetative and reproductive growth

Lupin exhibits a rather blurred transition from vegetative to reproductive growth, in contrast to cereals. First flower may be quickly followed by pod set and rapid grain filling, or it may be followed by further branch growth and further bouts of flowering before decisive pod set and grain filling. The transition depends on environmental conditions at and soon after flowering. Although the processes controlling this are imperfectly understood, water deficit and warm temperatures tend to hasten the onset of grain filling, and cool, moist conditions favour continued branch growth at the expense of pod set.

This is not related to the control of flowering time by temperature and day length mentioned in the previous section.

The continued vigorous growth of branches after first flower sometimes leads to abundant vegetative growth but relatively few filled pods. The harvest index of plants is consequently low and yields disappointing. This occurred often enough during the 1980s that lupin crops were identified as having a harvest index problem. The problem was more frequent in the cooler southern parts of the wheatbelt and on duplex soils where there was a rapid transition from water-adequate to water-limited conditions. The problem occurs less frequently in modern lupin cultivars, such as Mandelup, that are more dominant in setting and filling their pods than older cultivars.

Soil preferences

Lupin species can be grown on a wide range of soils. In the wild they are found growing on very acid as well as calcareous soils and on deep sands as well as clay loams. There are distinct preferences between species. Of the important species in Western Australian agriculture, yellow lupin has the strongest preference for acid soils and coarse sands and is more likely to be found growing on imperfectly drained soils than the other common lupin species. Sandplain lupin is more likely to be found growing on sandy calcareous soils and albus lupin has a stronger preference for loamy soils.

### Table 3.1 Low temperatures delay flowering of Belara lupin

<table>
<thead>
<tr>
<th>Location</th>
<th>Sowing date</th>
<th>Flowering date</th>
<th>Days to flowering</th>
<th>Average temperature – sowing to flowering (°C)</th>
<th>Average day length – sowing to flowering (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mingenew</td>
<td>11 May</td>
<td>19 July</td>
<td>70</td>
<td>14.4</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>1 June</td>
<td>9 August</td>
<td>69</td>
<td>12.8</td>
<td>10.4</td>
</tr>
<tr>
<td>Wongan Hills</td>
<td>6 May</td>
<td>22 July</td>
<td>78</td>
<td>13.0</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>4 June</td>
<td>1 September</td>
<td>89</td>
<td>11.2</td>
<td>10.5</td>
</tr>
<tr>
<td>Merredin</td>
<td>8 May</td>
<td>7 August</td>
<td>91</td>
<td>12.7</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>4 June</td>
<td>24 August</td>
<td>81</td>
<td>11.8</td>
<td>10.4</td>
</tr>
<tr>
<td>Esperance</td>
<td>13 May</td>
<td>11 August</td>
<td>92</td>
<td>12.8</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td>10 June</td>
<td>31 August</td>
<td>82</td>
<td>12.2</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Source: Data taken from sowing time trials in 1999 (R French)
As a grain crop, lupin is most profitably grown on deep acid to neutral sands or sandy loams. Lupin is better adapted to these soils than most other species of grain legume. When grown on deep acid sands lupin will usually produce higher and more consistent yields than other species of grain legume.

Lupin is less well adapted to shallow, neutral to alkaline or fine-textured soil. When grown on these soils lupin species are very sensitive to either too much or too little rainfall. Yields are therefore often lower and more variable than for other grain legume species grown on fine-textured alkaline soils.

Lupin species are well adapted to acid sandy soils because they are able to produce very deep roots, often more than 2.5 m deep (Figure 3.5). The growth of lupin roots is not inhibited by acidity as much as that of most other grain legume species. This is particularly the case for yellow lupin which has roots that can grow into acid soils with levels of aluminium that are toxic to other species. The *rhizobium* species that nodulate lupin also persist in acid soils for long periods. Rhizobium species that nodulate other grain legume species grown in Western Australia do not survive or form symbioses well in soils with a pH less than about 6.0.

The agricultural areas of Western Australia have a greater expanse of deep sandy soils than other agricultural areas of Australia and the state dominates lupin production in Australia. Approximately 14 per cent (2.5 million ha) of the arable land in the south-west agricultural region is classed as highly capable for lupin production and much of this occurs in the northern wheatbelt (Figure 3.6). A further 22 per cent of the land is classed as fairly capable.

Not all sandy soils in the wheatbelt produce good lupin crops. Lupin species produce lower yields on deep, coarse white sands than on deep yellow sands because the coarse white sands hold less water and nutrients. Lupin can grow well on sandy gravel soils, but often not as well as on the deep yellow sands. There are sometimes root restricting layers in sandy gravel soils and the presence of gravel reduces the amount of water the soil can store. Sandy duplex soils will produce varying lupin yields depending on the depth of sand over clay. The depth of sand often varies over...
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Figure 3.6 Percentage of land in Western Australia with high, fair to high or low capability for producing lupin
Source: Map generated by D van Gool and P White from DAFWA Map Unit database

Figure 3.7 Deep yellow sand (left) from the Eradu sandplain near Geraldton which is highly capable for lupin production compared with a deep sandy duplex (right) from Donnybrook which is variable in depth and classed as fairly capable for lupin production. Lupin yields depend on the depth of sand over the clay. Photos: N Schoknecht
Environmental influences on lupin growth

a paddock so lupin yield will also vary over the paddock. High yields will occur where the sand is deep (Figure 3.7).

Sparse, deep roots are not well suited to fine-textured or shallow soils. On these soils, lupin uses water less efficiently than field pea and will usually produce lower yields, especially in low rainfall environments. Commonly, lupin grows well on these soils during the cool winter months and early spring, but once the temperature rises and soil begins to dry, growth is severely reduced. On these soils lupin species are not able to postpone dehydration by accessing water deep in the profile as they can on deep sands. In high rainfall environments or seasons which have a cool and mild finish, lupin crops may still yield well on these soils because they do not need to rely so heavily on water stored deep in the soil profile.

Fine-textured and shallow soils also present other risks to lupin production. In high rainfall environments shallow soils are prone to waterlogging. Narrow-leafed lupin and albus lupin tolerate waterlogging less well than most other grain legume species. Yellow lupin is relatively tolerant of waterlogging.

Lupin will also suffer from iron deficiency if grown on water saturated soils containing CaCO$_3$. Small amounts of CaCO$_3$ (pH only slightly above 7.0) combined with slight water saturation (about 15 per cent above field capacity) will induce iron deficiency. Plants grown under these conditions will show bright yellow chlorosis (Figure 3.8). If soil saturation persists, plants will die. Once the soil dries, however, plants will usually recover and grow normally.

It is more difficult for lupin to emerge from fine-textured soils than for most cool season grain legumes, particularly if the soil forms a crust. Lupin species force their cotyledons to the soil surface whereas other species, such as field pea, leave their cotyledons in the soil and only force their emerging shoot to the surface. In fine-textured soils, the emergence of lupin requires considerable energy and may cause damage, resulting in fewer plants established and lower seedling vigour (Figure 3.9). Modern cultivars of narrow-leafed lupin have higher rates of emergence and seedling vigour than yellow lupin or albus lupin.

Figure 3.8 Bright yellowing of young leaves is a common symptom of iron (Fe) deficiency in narrow-leafed lupin (top) and pearl lupin (bottom) caused by saturation of soil containing CaCO$_3$. Photos: P White

Figure 3.9 Two examples of damage suffered by lupin seedlings during emergence, particularly if cotyledons are caught under soil crusts, even on sandy soils. Photos: P White
Environmental influences on lupin growth
4 Rotations and farming systems

Martin Harries and Caroline Peek
Lupin crops are always grown in rotation with other crops, usually cereals. Incorporating lupin into rotations confers benefits to the farming system that include reduced disease in cereal crops, increased supply of organic nitrogen, increased supply of high quality sheep feed and more options to control weeds.

In the early years of the lupin industry in Western Australia, 1:1 rotations with lupin and cereals grown in alternate years were very common. This rotation is still practised in some areas on sandplain soils today, but lupin crops are usually sown less frequently in rotations. The second lupin crop in rotations is often replaced by extending the cereal phase or incorporating canola or pasture phases in the rotation.

**Rotations and plant diseases**

Many common diseases and pests of wheat including take-all, crown rot, common root rot, septoria, yellow spot, barley yellow dwarf virus, rusts, mildew, root lesion nematode and cereal cyst nematode are not carried by lupin. A wheat crop grown after lupin will be affected less by these pests and disease than if grown after wheat. Rhizoctonia bare patch, however, has a wide host range. It affects lupin and wheat so rotations are not an effective method of control (Table 4.1).

**Nitrogen fixation**

**Nitrogen budgets**

Lupin crops require a large amount of nitrogen for normal growth. They obtain most of this nitrogen from the atmosphere through symbiotic nitrogen fixation (see Chapter 7 Plant nutrition). After the crop is harvested a significant proportion of this nitrogen remains behind as decaying roots, fallen leaves and stubble. Over time the nitrogen in these plant residues becomes available to crops that are subsequently grown in the paddock.

In general, the higher the lupin yield, the more nitrogen left behind in the paddock. This is because a high yielding crop will need lots of roots, branches and leaves to support a large amount of grain. The nitrogen stored in the stubble, fallen leaves and decaying roots after harvest will more than compensate for the amount of nitrogen exported in the grain.

Figure 4.1 shows how residual nitrogen depends on grain yield. Equation 4.1 is used to generate Figure 4.1. Note that this relationship also depends on harvest index (the ratio of grain to total above-ground biomass), which determines the proportion of the plant’s nitrogen that is removed in the grain. Harvest index in Western Australian lupin crops usually varies between 0.30 and 0.35.
Equation 4.1

\[
N_{\text{resid}} = \frac{GY}{\text{HI}} \left( 0.0275 - 0.05 \right)
\]

\(N_{\text{resid}}\) is residual nitrogen; \(GY\) is grain yield (kg/ha); HI is harvest index between 0 and 1. We have assumed that total lupin above-ground biomass is 2.75 per cent nitrogen and lupin grain is 5 per cent nitrogen.

An alternative method for assessing the nitrogen input of a lupin crop is as follows.

1. Cut and dry one square metre of crop just before leaf drop starts (maximum biomass). Be sure to do this in several locations to get a true representation of the crop.
**Case Study**

**Lupin – the sustainable option**

Lupin crops are an essential part of the rotation on the Michael family’s farm near Mingenew. Clancy Michael’s long-term lupin yields are greater than 2.0 t/ha. Lupin underpins wheat production. Clancy reckons that the rotational benefits of lupin are generally undervalued. He has found that lupin gives up to one tonne per hectare more yield and extra protein in the following wheat crop. He has observed that he does not get the same response in wheat after a pasture phase as he does from lupin.

The Mingenew sands are well suited to lupin. Lupin crops make up 35 to 40 per cent of Clancy’s cropped area. He uses a range of rotations with the traditional lupin:wheat as the main one. Pasture:lupin:wheat is becoming increasingly popular in the quest for a long-term sustainable rotation.

**Good nutrition helps weed management**

To gain the best yields Clancy believes that you have to set the crop up at sowing. Grain legumes are phosphorus responsive and Clancy supplies up to 21 units of P to ensure that the crop’s potential is not inhibited. He tries to sow into wet soil to increase herbicide efficacy and to achieve an initial knockdown of weeds.

The Michael family have been growing a percentage of Kalya for its metribuzin tolerance, which is used for doublegee and radish control. It works for the Michaels but they have also been impressed with the performance of Mandelup and will start growing more of it. Mandelup is consistently yielding 10 per cent better than Kalya in trials. It has a better metribuzin tolerance and, with its shorter growing season, it makes crop topping a more economical option.

People often ask Clancy why his lupin yields are increasing. From his experience, a crop that does not lack for nutrients seems to be better able to handle the pressures of disease and herbicides and the variations in the season. Clancy does not let weeds limit the yield potential as he does not skimp on rates and he rotates a range of herbicides to help in combating herbicide resistance. He uses as many tools as possible including windrowing behind the harvester to reduce the reliance on herbicides.

Clancy is convinced that lupin is by far the best grain legume that he can grow. He finds that lupin is relatively easy to establish and his machinery easily converts between cereals and lupin. Lupin crops are more forgiving than other grain legumes when conditions become adverse. Even in a dry year they yield enough to return a profit.

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2. Weigh this material and calculate the weight in kg/ha. For example, 500 g/m² equals 5000 kg/ha.

3. Record the grain yield, for example, 1500 kg/ha.

Residual organic nitrogen equals the amount of nitrogen in the biomass minus the amount of nitrogen exported in the grain.

To calculate residual organic nitrogen for the above example, use Equation 4.2.

**Equation 4.2**

\[
N_{\text{resid}} = (5000 \text{ kg/ha} \times 2.75\% \text{ N}) - (1500 \text{ kg/ha} \times 5\% \text{ N})
\]

\[
= 62.5 \text{ kg/ha N}
\]

The calculation again assumes that above-ground biomass contains 2.75 per cent nitrogen and that the grain contains 5 per cent nitrogen.

These calculations give the total amount of residual nitrogen left by a lupin crop, but only a portion of this, usually about 40 per cent, becomes available for uptake by the crop grown the following season. The rest remains in the soil as organic nitrogen and slowly becomes available to crops over several years. In the example above, therefore, only 25 kg/ha of nitrogen will be available to the following year’s crop.

The percentage of the organic nitrogen that is released from the crop residues is higher in warm, moist soil. More nitrogen may, therefore, be released from residues after a wet summer, but this has to be balanced against the possibility that some of this nitrogen may then be lost through leaching.
Comparing nitrogen input from pastures and lupin

The amount of residual nitrogen left by a pasture depends on biomass production and legume content. A 1.5 t/ha lupin crop adds approximately 60 kg/ha of nitrogen. To obtain a similar amount of residual nitrogen from a 20 per cent legume pasture you would need to be growing 4 t/ha. Figure 4.2 is used to estimate the amount of residual organic nitrogen produced by a pasture based on the biomass production and legume percentage. Figure 4.2 does not account for nitrogen losses from grazing. There are no definitive guidelines to estimate the losses of nitrogen from grazing and this will depend on stocking rates, the amount of nitrogen in the pasture and grazing management. Also, most of the nitrogen in the feed passes through the animal. It is suggested that unless better information is available it should be assumed that approximately one-third of the pasture's nitrogen will be used by stock.

Nitrogen fixation and subsequent wheat production

Each tonne of cereal grain requires about 45 kg of nitrogen for its production. Table 4.2 shows how much of this requirement lupin crops can satisfy. For example, a well-grown lupin crop yielding 1.5 t/ha will provide about 25 kg/ha of available nitrogen to the following crop, the nitrogen equivalent to 52 kg/ha urea. This is enough to produce approximately 500 kg/ha of wheat.

<table>
<thead>
<tr>
<th>Lupin grain yield (kg/ha)</th>
<th>Residual nitrogen (kg/ha)</th>
<th>Nitrogen available for following crop (40% of residual)</th>
<th>Urea equivalent (kg/ha)</th>
<th>Contribution to cereal grain yield in following year (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>21</td>
<td>8</td>
<td>17</td>
<td>174</td>
</tr>
<tr>
<td>1,000</td>
<td>42</td>
<td>17</td>
<td>35</td>
<td>370</td>
</tr>
<tr>
<td>1,500</td>
<td>62</td>
<td>25</td>
<td>52</td>
<td>543</td>
</tr>
<tr>
<td>2,000</td>
<td>83</td>
<td>33</td>
<td>69</td>
<td>717</td>
</tr>
<tr>
<td>2,500</td>
<td>104</td>
<td>42</td>
<td>87</td>
<td>913</td>
</tr>
<tr>
<td>3,000</td>
<td>125</td>
<td>50</td>
<td>104</td>
<td>1,087</td>
</tr>
<tr>
<td>3,500</td>
<td>146</td>
<td>58</td>
<td>121</td>
<td>1,261</td>
</tr>
</tbody>
</table>

Controlling weeds through rotations

Rotating different types of crops on the same patch of land is one of the most powerful tools available for managing weeds. Through the 1980s and 1990s weed control in the wheat/lupin rotation was very effective and relatively trouble free. Grass weeds were easily controlled in the lupin phase and broad-leafed weeds were easily controlled in the wheat phase. Unfortunately, on most farms this system no longer works as effectively or easily as it once did.
Weeds, particularly ryegrass and radish, have become increasingly more resistant to many of the herbicides commonly used in the wheat:lupin rotation. Weeds are now more difficult and more expensive to kill. In response farmers are growing a greater range of crops in their rotations. They can use a wider range of methods to control weeds instead of relying on the narrow range of herbicides applicable to wheat:lupin rotations.

Widening rotations adds stability to weed control because if one method fails, others can compensate to keep weed levels low, and there is less pressure on weeds to develop resistance to any one method. Rotations incorporating triazine-tolerant canola, swathed barley hay and well managed annual pastures are being used to widen the traditional wheat:lupin system and to clean up weedy paddocks. More detailed information and case studies on how rotation can contribute to weed management are given in Chapter 8 Weed management.

**The value of grain and stubble for grazing**

Lupin stubble and grain are a valuable source of summer feed used to carry sheep over summer, another important reason why many farmers include lupin in their farming system (Figure 4.3). In particular, lupin provides a good source of the protein necessary to maintain healthy rumen function when sheep are grazing cereal stubbles and protein is scarce. This enables the sheep to digest the stubble material more completely. Further details on the feed value of lupin, and how best to use each species, are given in Chapter 12 End uses for lupin.

**Further reading**


5 Seed testing and seed treatments
Geoff Thomas, Marcia Vistisen, John Howieson, Glen Riethmuller, Amelia McLarty and Greg Shea
High-quality seed should always be used to sow lupin crops. Using inferior-quality seed can result in poor germination and reduced vigour, causing thin stands and lower yields. Poor seed quality can result from fungal or viral infection, poor nutrient status, physical damage or bad weather at harvest time.

Seed tests
It is not always possible to judge the quality of seed from its appearance, so test the seed before sowing. There are several tests that will assess the physical and disease status of seed. These can be conducted by Agwest Plant Laboratories at DAFWA or by commercial seed testers.

Sampling guidelines
Obtaining a representative sample of a seed lot is the most important part of a seed test. Even the most accurate test is meaningless if it is conducted on a sample that is not representative of the seed lot.

Submit samples for testing as soon as possible after harvest. Samples can be taken from the seed stream as seed is being transferred to a silo or holding bin or into bags.

When sampling seed from streams of seed entering bulk containers, the minimum sampling intensity requirement is as follows:
- up to 500 kg: take at least five primary samples
- 501 to 3000 kg: take one primary sample for each 300 kg, but no fewer than five
- 3001 to 20,000 kg: take one primary sample for each 500 kg, but no fewer than 10
- 20,001 kg or more: take one primary sample for each 700 kg, but no fewer than 40.

When sampling seed in bags (or other containers of uniform size), the minimum sampling intensity is as follows:
- up to four containers: take three primary samples from each container
- five to eight containers: take two primary samples from each container
- nine to 15 containers: take one primary sample from each container
- 16 to 30 containers: take 15 primary samples in total
- 31 to 59 containers: take 20 primary samples in total
- 60 or more containers: take 30 primary samples in total.

Thoroughly mix all the primary samples and divide each one in half. Take one of the half-samples, thoroughly mix and halve again. Repeat the mixing and halving until you are left with 3 kg of lupin seed. One sample cannot properly represent more than 25 tonnes of lupin. If there is more than this quantity of seed, submit more than one sample.
Germination

Lupin has large seeds that are prone to mechanical damage during harvesting and subsequent handling, which may reduce seed viability. Other factors such as wet weather prior to harvest, effect of chemicals and the age of seeds can also affect viability. A germination test is a guide to the proportion of seeds that will produce normal seedlings. The result of the test is used to calculate seeding rate (see Chapter 6 Crop establishment).

The germination test is carried out over a 10-day period and will classify a sample into normal seedlings, abnormal seedlings, dead seed, fresh seed and hard seed (Figure 5.1). Fresh and hard seed are mostly irrelevant in lupin germination tests. Normal seedlings are fully viable and abnormal seedlings show significant defects that will prevent the plant from growing into a normal productive plant, even under ideal conditions. Examples of abnormal seedlings include ones with missing or damaged root systems, missing or damaged first leaves and missing or damaged growing points (Figure 5.2).

During the 1990s and 2000s lupin germination test results from farmers’ seed have generally been in the 80 to 90 per cent range. Samples with lower germination percentages than this should not be used for sowing.

Seed size

Research has shown that sowing medium to large seeds of a given variety increases yield potential. Grading lupin seed before sowing in order to separate and discard the small seeds is likely to enhance crop productivity. Most benefit occurs when germination and growth are constrained by factors such as deep sowing, root disease, cold weather or brown spot. Small seeds give rise to seedlings that may not be vigorous enough to overcome these constraints. Benefits from grading the seed also occur when the average size of the ungraded seed is below the average size for that variety.

If possible, do not use seed of narrow-leafed lupin smaller than 140 g/1000 seeds.

Disease status

Disease tests are available for cucumber mosaic virus and anthracnose. Both tests are quantitative: they measure the amount of pathogen DNA in a standard size seed sample and express the results as percentage of seeds infected. Samples in which pathogen DNA is not found are reported as not detected. It is important to understand that the tests report the level of infection found in the sub-sample of seed. If a very low level of infection exists in the whole seed lot, it is possible that the sub-sample will not contain an infected seed. Therefore, the not detected result indicates that either there is no infection in the whole seed lot or it is less than the level of detection of the test.
Cucumber mosaic virus
In narrow-leafed lupin, cucumber mosaic virus (CMV) is transmitted via seed, so it is best to use seed that has as low a rate of CMV infection as possible.

Always ascertain the CMV status of any lupin seed that is purchased. In high risk parts of the agricultural area, use seed in which CMV cannot be detected. In areas that are not high risk, 0.5 per cent infection is normally regarded as the upper limit for reasonable safety from CMV (see Chapter 9 Diseases of lupin).

Anthracnose
Anthracnose is a fungal disease of lupin which can be seed-borne. The use of clean seed is a key component of the management strategy for this disease. Sowing seed infected with anthracnose means the disease is present from the beginning of the season, which maximises spread of the disease and yield loss. Transport of infected seed can also introduce the disease onto properties where it was previously absent (see Chapter 9 Diseases of lupin).

Using totally clean seed is preferable in all varieties; however, under some circumstances a low degree of seed infection can be tolerated. The level of seed infection that can be tolerated depends on the susceptibility of the variety sown, the environment in which the seed will be sown (rainfall is most critical) and the use of a dressing of fungicide on the seed. A matrix outlining possible yield losses in a range of environments associated with levels of seed infection is provided with seed testing results.

Nutrient content
Germination and subsequent growth of seedlings is reduced when the manganese concentration in lupin seed is less than 13 mg/kg. Applying manganese fertiliser at sowing does not correct the effects of low concentration of manganese in the seed.

Plants without visible symptoms of manganese deficiency (split seed syndrome) may still contain less than 13 mg/kg of manganese in the seed so if in doubt, have it tested. The easiest way to ensure next year’s seed has sufficient manganese is to harvest it from an area of the crop that has been adequately fertilised with manganese.

Using seed with phosphorus concentrations below 0.25 per cent will produce small seedlings that will not cope with stresses during early growth. Trials have recorded up to 25 per cent yield reduction when seed with low concentrations of phosphorus was sown. If in doubt, test seed to ensure it has at least 0.25 per cent phosphorus and harvest next year’s seed from an area of the paddock that has an adequate history of fertiliser application.

Seed storage and handling
Low temperature and low relative humidity provide the safest storage conditions for lupin seed. Lupin harvested at 15 per cent moisture or above cannot be stored safely in unaerated storage, because the viability of the seed will rapidly decline. If the moisture content of the seed is 15 per cent or above, it must be dried to enable safe storage. As a general rule, the moisture content of lupin to be stored and sown next year should be no greater than 13 per cent.

Do not store lupin seed contaminated with green radish pod. High temperatures volatilise toxic compounds from the radish pod which will kill the lupin seed. If you need to store the seed for a short period (no more than one or two days) before the radish pod is graded out from the seed, do not use a sealed silo.

Minimise the handling of lupin seed as much as possible. Mechanical damage that occurs during handling can reduce seed viability. Screw augers are the most damaging. To reduce the damage, slow down the auger and make sure it runs full. It is easier to reduce the speed of augers driven by petrol engines than augers driven by electric motors. Augers should also be as short as possible and used at the lowest possible angle.

Avoid worn augers. The clearance between the auger flighting and the tube wall is normally about 6 mm, but in a worn auger this clearance is greater. A large clearance will increase the amount of churning of the seed, resulting in more damage. In addition, avoid augers with a diameter smaller than 125 mm.

Remember to take care when seeding. Excessive air pressure in airseeders can cause significant seed damage. The air pressure should be no greater than the minimum needed to ensure reliable operation.
Loading and unloading
Silos are designed to withstand uniform downward and outward forces. To keep these forces uniform, silos must only be loaded from the central top hatch. Loading from the side top hatch will unbalance the lateral forces on opposite sides of the silo, which could distort the shell of the silo and place extreme pressure on the side of the silo holding the high side of the stack.

The same principles apply when out-loading. Only empty the silo from the bottom central opening. Do not use the bagging off chute unless the silo is designed to withstand off-centre loads. Off-centre pressures applied to the support frame also exert uneven forces on the concrete pad. Failure to construct a pad to the correct design specifications may result in foundation failure, suddenly unbalancing the distribution of forces on the silo. Failure or collapse of the silo could follow.

The physical characteristics of lupin grains mean they exert higher than normal pressures on silo walls. When transferred to the lower sections of the silo wall, these forces may cause crimping or pleating of the walls. This has been observed in elevated as well as flat bottom silos. The silo may lean or collapse if it occurs on only one side, so do not store lupin in older type silos with thin walls.

Rhizobium inoculation
Lupin and other legumes have the ability to fix their own nitrogen. Rhizobium are required for nodulation and nitrogen fixation by lupin (Figure 5.3). All lupin sown in a paddock for the first time should be inoculated with rhizobium. On acid soils (pH below 6.5) once a well nodulated lupin crop has been grown in the paddock, a lupin crop will not need to be inoculated for the next five years. If more than five years has passed, seed should be inoculated. On neutral and alkaline soils (pH above 6.5), the rhizobium do not survive in the soil for long, and seed must be inoculated every time a lupin crop is grown.

Lupin should be inoculated with Group G inoculant. Serradella inoculant (Group S) is also compatible with lupin and can be used as a substitute if necessary.

Inoculants come in several forms. Two common forms are moist peat and dry clay granules, both of which produce very good nodulation on lupin if they are handled and applied according to the manufacturer’s instructions.

The inoculants contain high numbers of living bacteria and their effectiveness relies on maintaining these high numbers.

Moist peat inoculants are applied to the seed. Dry clay granules can be drilled with the seed or with the fertiliser although contact with the fertiliser should be limited to less than four weeks. See Chapter 7 Plant nutrition for more information about dry clay granules.

The bacteria in peat cultures are very vulnerable to their surroundings and should be protected from harsh environments such as heat or excessive sunlight. The bacteria will survive in large numbers if the peat is stored in a refrigerator at 5°C until it is used. Do not freeze peat inoculum or keep it after the expiry date.

Inoculation with peat may be carried out using a water slurry or gum slurry. Gum slurry (usually methyl-cellulose) provides the best results and also protects the rhizobium when it is on the seed.

Dry dusting peat inoculum onto the seed is not an effective way of inoculating lupin seed. The survival rate of rhizobium on slurry-inoculated seed that is sown into dry soil is lower than if it is sown into moist soil. The rate of inoculation for dry sowing, therefore, should be doubled to improve the chances that sufficient rhizobium will survive to nodulate the crop.

Fungicide seed dressings are antagonistic to rhizobium. If the seed has been dressed with fungicide, increase the rate of inoculum and sow seeds into moist soil as soon as possible after slurry-inoculating. Do not sow seed that is slurry-inoculated with fungicide, as this will reduce the number of rhizobium available to nodulate the crop.
Case Study

Gum slurry technique
The gum slurry technique works well provided the seed is inoculated within 24 hours of planting, for example, the night before sowing. Large quantities of seed can be quickly inoculated using the following technique.

To inoculate 10 t of lupin seed
Heat 20 L of clean water to near boiling point and dissolve 2 kg of methocel or methofas gum, and 2 kg of sugar to provide nourishment for the rhizobium.
Pour into a 200 L drum with tap.
Add a further 160 L of cold water to the drum while stirring, and allow to cool. An electric drill with a long stirrer is an excellent mixer. Failure to allow the adhesive to cool before adding the inoculant will kill the rhizobium.
Add 25 kg of lupin peat inoculum. Use the electric drill to mix thoroughly. The inoculant will disperse more readily if it is mixed into a heavy paste with a small amount of water before it is added to the adhesive solution.
Calibrate lupin flow from silo to truck bin via an auger.
Allow gum slurry to enter auger at the rate of 1.0 L/50 kg of seed (20 L/t).
Check that all seeds are mixing evenly, that is, all seeds should receive speckles of the black gum slurry.

Inoculated and dressed into dry soil. It is unlikely the rhizobium will survive to nodulate the crop because the dry conditions combined with the fungicide are very harmful to rhizobium. Fungicides dressed on the seed will not harm rhizobium in the dry clay granules.

It is better to use dry clay granules if you are sowing lupin into dry soil or are using seed that has been dressed with a fungicide. Rhizobium inside the clay granules are well protected and will be less affected by these stresses.

Copper is toxic to rhizobium so trace element fertilisers containing copper should not be sown with slurry-inoculated lupin seed. Lime pelleting reduces the toxic effect of copper but persistent lime pellets are difficult to produce on lupin seeds.

Fungicide treatments
Seed dressing with fungicide is registered for controlling brown spot and anthracnose. Fungicides used for brown spot primarily protect lupin seedlings from spores splashed from the soil onto the plant by raindrops. Fungicides for anthracnose reduce disease transmission from infected seed to emerging seedlings. Fungicides used for one disease have little effect on the other disease. To protect against both diseases, more than one fungicide must be applied.

Fungicides containing iprodione or procymidone are recommended for the management of brown spot in all but very low risk situations. These fungicides provide significant protection in cotyledons and seedling leaves, up to about the 6-leaf point of the crop. These fungicides are primarily to protect against catastrophic plant losses caused by widespread seedling infection in conditions highly favourable to disease. A range of rates of iprodione and procymidone products are registered. Rates at the lower end of the range generally provide significant protection. Higher rates are more appropriate under very high risk conditions or when also seeking protection from pleiochaeta root rot or rhizoctonia hypocotyl rot.

Thiram-based seed dressings are registered for managing seed-borne anthracnose. Using these fungicides reduces anthracnose transmission from seed by an average of 75 per cent. Thiram is not systemic and does not protect seedlings from splash-borne infection after emergence. You should use seed dressings where there is a risk of seed-borne infection, particularly in susceptible varieties. As thiram seed dressings do not protect seedlings systemically, using them on disease-free seed will provide no benefit in anthracnose control.
Treatment method
Seed can be treated at any time before sowing. Apply the fungicides as recommended on the product label. Generally, they are mixed with water and applied to ensure thorough coverage of seed. Fungicides to control brown spot and anthracnose can be mixed together in a slurry without reducing efficacy.

Do not store treated seed for the following year. Children, wildlife and domestic animals must not have access to treated seed. You cannot deliver fungicide treated seed to commercial grain receival points. Do not use it for animal feed.

Compatibility with inoculum
Fungicide seed dressings (iprodione, procymidone and thiram) do not interfere with the rhizobium population present in the soil from previous lupin crops, but they are toxic to the rhizobium applied to the seed. If you inoculate seed that has been dressed with fungicide and you are coating with peat-based inoculum, it is recommended that:

- the fungicide is applied to the seed and allowed to dry before the inoculum is applied
- the inoculum is applied at double the standard rate
- the inoculum is applied immediately prior to seeding, no earlier
- the seed is sown into moist soil.

Alternatively, use a dry clay granule inoculum.
6 Crop establishment

Martin Harries, Bob French and Peter White
Successful crop establishment is the cornerstone of profitable lupin production. The keys to good lupin crop establishment are:

- effective pre-sowing weed control
- early sowing
- optimum plant density (usually 45 plants/m²)
- incorporation of pre-planting residual herbicides
- surface stubble retention
- placement of the seed at the correct depth
- loose soil below the seed
- adequate fertiliser, that may be placed separately from the seed
- relatively loose soil above the seed.

Not all can be achieved in all situations and some may conflict with others. A compromise is usually necessary and each individual situation should be carefully examined.

### Sowing time

Lupin crops are best sown early. They are indeterminate plants and yield is closely linked with the duration of flowering. Crops should be sown as early as possible: any time after 25 April in the north or early May in the south. If weed control is a priority, sow after the break of season to obtain an effective weed knockdown. This ensures good soil moisture is available to activate soil herbicides such as simazine. Effective use of pre-emergence herbicide results in fewer weeds in the crop. This places less pressure on post-emergence, selective herbicides.

Lupin grows rapidly when temperatures are higher during May. Rapid germination, emergence and seedling growth allow seedlings to grow away from brown spot disease. Growth is slower during the cold winter months and if seedlings are not already established they may struggle with brown spot. Early sowing brings earlier flowering and a longer effective growing season. Early sowing also ensures that a good number of pods are set before plants become stressed from water deficit and rising temperatures.

### Sowing time and rainfall zone

Early sowing is more critical in low rainfall environments than in high rainfall environments because potential yield is lower (Figure 6.1). In low rainfall environments such as Buntine the highest rates of yield loss caused by delayed sowing begin to occur early in the season. In high rainfall environments such as Mingenew the highest rates of yield loss caused by delaying sowing do not start occurring until the latter half of May. This means delaying sowing for improved weed control is a more practical option in high rather than in low rainfall environments.

### Sowing time and variety

Early maturing varieties such as Belara and Mandelup flower five to six days earlier than other varieties which reduces the requirement for very early sowing. This provides greater opportunity to delay sowing later in May, allowing for better pre-planting weed control, without compromising yield.
Branch growth is very sensitive to moisture and temperature stress, so earlier sowing and flowering allows the production of more branches. Belara and Mandelup also carry a high proportion of yield on the main stem relative to other varieties, which is an additional advantage. They can produce good yields without relying heavily on late maturing lateral branches, which also reduces the need for very early sowing. Varieties such as Tanjil and Wonga rely more on the lateral branches for yield. They perform better at high and medium rainfall locations where the season length is long and early sowing is not as critical to ensure that seed in lateral pods will fill.

Nevertheless, the interaction of sowing time with variety is usually much less than the interactions between sowing time and location.

**Sowing time and location**
Yield losses are greatest in the short season, low rainfall northern wheatbelt. Sowing lupin after the first week of June is not recommended in any part of the northern wheatbelt. It is still viable to sow lupin in June in some parts of the southern wheatbelt because losses from delayed sowing in these areas are not as great as in the northern wheatbelt.

Optimum flowering time varies little throughout the state. Generally, flowering should start in early August. Crops sown in early April can be very short when they flower. The main stem pods of these crops will be difficult to harvest. Very early sown crops will also be more exposed to frost damage during flowering and early podding. Furthermore, there is a small chance of losing a very early sown crop to drought if there is insufficient soil moisture to keep it alive until the next rain.

In areas with long growing seasons, such as the south coast, sowing too early can result in excessive vegetative growth and lodging.

**Dry sowing**
Dry sowing is used far less often than it was during the 1990s (Figure 6.2). Dry sowing reduces the ability to adjust cropping programs and inputs to match the season. It also usually results in higher weed burdens. Ideally, lupin should be sown into moist soil, after a knockdown of the first flush of germinating weeds.
If lupin is sown dry, take the following precautions.
- Sow into paddocks with good stubble cover to avoid wind erosion.
- Sow into paddocks with low weed burdens.
- Increase seed rate by 10 per cent to buffer against poor establishment.
- Apply slightly more herbicide (+0.2 to 0.4 L/ha of simazine).
- Retain as much anchored cereal stubble as possible.
- Do not dry sow into paddocks where there are sandplain lupin which cannot be controlled with selective herbicides in the crop. In such paddocks, sandplain lupin must have germinated and been killed before the narrow-leafed lupin crop is sown.

**Sowing rate**

**Sowing rate and optimum plant density**

The recommended plant density for narrow-leafed lupin crops is 40 to 45 plants/m². Trials have shown, however, that optimum plant densities change depending on location and season (Figure 6.3). There is usually little or no yield penalty if plant densities are higher than the recommended range (up to 70 plants/m²) but yield losses can be substantial if plant populations decline below 40 plants/m². Anecdotal accounts from growers suggest that low plant densities (25 plants/m²) are preferable in some environments, for example, the high rainfall south coast, but this has yet to be verified from research data.

In most situations plants in a low-density crop may look impressive with many pods, but yields will usually disappoint. A high-density crop (40 to 45/m²) will produce fewer pods/plant, but have more pods/m² and a higher yield than a low-density crop.
Recommended plant density for albus and yellow lupin is 45 plants/m², but this recommendation has been derived from a smaller data set and a more limited range of environments than was the case with narrow-leafed lupin.

Plant density does not only affect yield. Recent research shows that keeping lupin density high can substantially suppress weed growth and reduce the effects of competition on the crop (Figure 6.4).

There are other good reasons for keeping lupin crop density high.

- On soils susceptible to wind erosion, sandblast damage will be more severe in low-density crops.
- Non-wetting sands are prone to variable germination, and a high seed rate provides a buffer for areas where germination is poor.
- Brown spot is spread by raindrops hitting the soil surface and splashing spores onto leaves. Thin crops that cover the ground slowly are exposed for a longer period to the spread of this disease from rain-splash.
- Root diseases can reduce plant numbers and higher plant densities allow the crop to compensate for this loss.
- Cucumber mosaic virus is a seed-borne disease that produces stunted plants in the crop. These plants are reservoirs of the virus that aphids transmit to other plants in the crop. Dense crops shade out the infected seedlings, reducing spread of the disease.
- It is usually easier to harvest dense crops because they are more uniform.
- Higher-density crops compete better with weeds and help to buffer against loss of plants from herbicide damage.

### Calculating sowing rates

To calculate a sowing rate, first determine the desired number of plants/m²—the target plant density. The sowing rate (kg/ha) depends on the average seed size (weight per seed), the target density, the **germination rate** (percentage) and the **establishment rate** (percentage).

**Seed size.** There is a large variation in seed size between seasons and paddocks. Seed weight may vary from 130 g/1000 seeds (7690 seeds/kg) to 180 g/1000 seeds (5600 seeds/kg). A sowing rate of 80 kg/ha could deliver 44 to 61 seeds/m² across this range of seed sizes (Table 6.1). Seed size should be measured when seed is tested for germination.

**Germination rate.** The visual appearance of seed is not a good guide to its germination rate. A germination test with an accredited seed laboratory is the best way to determine the germination rate of seed (see Chapter 5 Seed testing and seed treatments). It takes about 10 days to obtain a result once seed is received by the laboratory. Seed with a germination rate below 80 per cent should not be used to sow a lupin crop. If seed has been stored for long periods or carried over a season, germination should be re-tested to ensure the seed has not deteriorated.

**Establishment rate.** A germination test determines the proportion of seeds that will germinate and produce normal seedlings under laboratory conditions. Under field conditions, not all of these seedlings will establish to produce a plant. Establishment rate varies depending on the conditions at sowing and the methods used. Higher rates of establishment are achieved with knife points sown into wet soil, compared with sowing into dry soil or using less precise machines such as a culti-trash. Generally, the establishment rate will be 90 to 95 per cent of the germination rate when sowing into wet soil or 85 to 90 per cent when sowing into dry soil.

**Equation 6.1** is a typical sowing rate calculation.

\[
\text{Sowing rate (kg/ha)} = \frac{\text{Seed size (g/1000 seeds)} \times \text{Target density (plants/m²)} \times 100}{\text{Germination rate} \times \text{Establishment rate} \times 100}
\]

**Equation 6.2** calculates an actual example.

\[
\text{Sowing rate} = \frac{170 \times 45 \times 100}{90 \times 90} = 94 \text{ kg/ha}
\]
Monitoring establishment rate
Monitoring the establishment rate (target plant density) over several years will provide feedback on how seasonal conditions affect field establishment with the machinery used. Count the number of seedlings established at about six weeks after sowing. Use a half square metre quadrat (50 x 100 cm). Throw the quadrat at random and count the number of seedlings within the quadrat area. Repeat this 10 times across the paddock and calculate the average number of seedlings per quadrat. Multiply the average value by 2 to convert to seedlings/m².

Seed increase areas
When multiplying seed of a new variety, the objective is to maximise yield per unit of seed sown rather than per unit area so it is often a good idea to use lower sowing rates than for a normal crop. About 20 to 30 plants/m² is recommended. Plants grown at low density will produce more pods per plant, which means a greater return for the amount of seed sown. However, as mentioned above, the number of pods/m² will be low, so the yield on an area basis will be lower than if sown at a high rate.

Low sowing rates should not be used where the weed burden is expected to be high or where there is a high risk of cucumber mosaic virus. In fact, such areas should be avoided for seed multiplication.

Row spacing
There has been considerable interest in growing lupin in wide rows in Western Australia. In the early 1990s this was driven by the need to handle large amounts of stubble. More recently, the promise of more stable yields in low rainfall environments and being able to control troublesome weeds by interrow spraying has been important. Nineteen field trials comparing lupin growth in rows spaced from 18 to 100 cm apart were conducted between 2002 and 2005. These trials showed that on average grain yield did not differ significantly between 50 cm rows and narrower (18 to 25 cm) rows. However, sometimes there were large differences in individual trials. It has become apparent that environment has a large influence on yield response to row spacing (Figure 6.5).

Wider rows are more likely to yield better than narrow rows in the warm dry environments of the medium and low-rainfall northern wheatbelt. This is because the crop uses less water during winter when grown in wide rows. More water is,
therefore, available for the crop at the end of the season when the plant fills its pods. The extra water is vital in these environments where winters are mild and the end to the season can be sharp.

Narrower rows are most likely to yield better in cooler longer season climates, such as the Lakes district (Lake Grace, Newdegate) and areas further south. These environments have cold winters and softer finishes in comparison to the northern wheatbelt. Under these conditions maximising early plant growth, ground cover and ultimately yield potential prior to the onset of winter is critical. There is much less risk that this early growth and setting of yield potential will be curtailed by a sharp finish to the season.

Figure 6.5 Effect of row spacing on lupin yield in the northern wheatbelt at Mullewa (a) and in the southern wheatbelt at Newdegate (b) in 2003

Source: R French

Case Study

New challenges demand new systems
Ray Fulwood’s lupin growing at Meenaar, west of Meckering, began with the advent of simazine in 1980. He had some previous experience at Cunderdin in the 1970s, growing the first narrow-leafed lupin varieties released in Western Australia. Then problems arose with weeds, blocked nozzles and diuron fallow.

New herbicides
The advent of glyphosate and selective grass herbicides in the late 1980s followed by selective radish herbicides made the lupin rotation attractive and apparently invincible. Ray stuck to this successful package, using herbicide Groups A, B, C and later F in most years.

Sandy soils became water repellent and grasses skipped the lupin phase in dry soil and germinated in the cereal phase. Ryegrass with resistance to Groups A and B was diagnosed in 1987, although certain gravelly soils on Ray’s farm had resilient populations five years earlier. The big three ‘dims’ were still effective on ryegrass, but radish had developed moderate levels of B and F resistance.

In 1993 Ray reached a milestone in lupin production, with Merrit lupin averaging 2.45 t/ha over 520 ha. One 40 ha paddock yielded 3 t/ha. These yields were achieved again in 1999 and 2005. In spite of this success, Ray embraced no-till with tines in 1994, confident that furrow seeding and water harvesting would improve seed germination. This continuing stubble retention, together with the use of trifluralin in wheat, preserved the lupin package. Non-wetting sands and potential failure of dims were still a challenge.

New strategies for weed control
In 2002 Ray agreed to collaborate with DAFWA’s Mike Collins in a wide row lupin trial to help combat herbicide resistant weeds. He used Mike’s ‘row crop rockets’, which are wheeled spray shields.

Continued over…
Case Study cont.

Ray’s first 27-row trash drill (1981), which was reduced to 18 rows for no-till in 1994, shrank to 9 rows at about 550 mm spacings. The seeder had Ray’s visual guidance and the ute-mounted 8-shield sprayer straddled the centre lupin row. The rocket’s strongly cambered wheels tracked in the seed rows, and knockdown herbicides were used between rows within the shield. The guess row was unsprayed as it varied too much in width.

In 2003 Ray purchased a 51-tine air seeder bar and used every third tine to seed lupin on variable rows averaging 680 mm width. Spacings were symmetrical about the centre tine and the shield rig was half the width of the bar. The shield boom was mounted on a 1000 L sprayer with a ground drive pump, pulled by a large 4WD motorbike. The seeder had sub-metre visual guidance and the bike straddled a set row. Considerable concentration and skill was required to avoid damage of lupin plants. Due to the limited scale and capacity of the rig, only selected weedy crop areas were sprayed.

In the same year, Ray’s brother Greg purchased an 11 m 3-point linkage, wide row lupin seeder bar and a shield sprayer all working on 2 cm RTK autosteer. Technology was now inventing new lupin agronomy. Collateral lupin damage became an issue with glyphosate, but nozzle selection and pressure has overcome this. However, trials with 5 to 10 mL/ha glyphosate sprayed on lupin at budding showed that extra-shield drift could inflict damage.

In early June 2005, Ray took late delivery of a locally made 12 m 3-point linkage, wide row seeder bar that with some modification doubled as a shield sprayer. The sub-10 cm autosteer required visual adjustment when spraying. Late sown Mandelup on wide rows yielded 70 per cent of early sown Mandelup on narrow rows.

Most commercial shields have about 120 mm spacing over the seed row to prevent crop damage. This strip receives no knockdown spray, but it is the disturbance zone where ryegrass and radish are the thickest. Ray opted for a 120 mm wide, ribbon seeded row (or trench) with shields touching the lupin plants at the edge of each row. A centre row and two split rows make up the ribbon. Slight crop damage is compensated for by high seed rates and other plants in the ribbon seeded row.

All lupin crops receive simazine or atrazine (to suppress early weed competition) with the initial glyphosate knockdown at seeding, hopefully after a weed germination. Simazine and soil wetter is added back to the seed trench and shoulder (200 mm wide), along with a grass residual or diflufenican. Crop damage has not been an issue. Early post-emergence removal of thick ryegrass or radish with a selective herbicide is imperative, and is followed up with shield spraying to mop up.

Weed numbers are low on the undisturbed inter-row and in the bottom of the seed trench, but high on the shoulder of the trench where soil is thrown. Ray suspects that this zone is hard to access with all brands of shields. Crop topping is done, if necessary, by tracking the boom spray on the prescribed wheel track area.

Figure 6.6 Ray Fulwood Photo: P Maloney
Sowing time and sowing rates for wide rows

While yields sometimes differ between row spacings, responses to sowing time and sowing rates are similar in wide and narrow rows (Figures 6.5 and 6.7). The recommendations for time of sowing and sowing rate are, therefore, the same for all row spacings. The same basic principles of sowing early and using a seed rate to achieve 45 plants/m² should be adhered to when sowing wide row lupin crops. Weeds, however, may be more difficult to manage in wide rows (see Chapter 8 Weed management).
Row spacing and pod height
Trials and observations by growers show that pods in crops sown in 50 cm rows are about 5 cm higher than in 25 cm rows (Figure 6.8). Higher pods make harvesting easier and reduce losses, particularly in low rainfall areas where plants are usually short.

Sowing depth
Sow seeds 3 to 5 cm below the soil surface.

Sowing very deep, below 5 cm, will reduce the occurrence of pleiochaeta root rot. Deep sowing places seed below most of the Pleiochaeta spores which have fallen to the ground from previous brown spot infections. Shallow sowing (2 to 3 cm) will reduce rhizoctonia hypocotyl rot disease because the stem or hypocotyl of the seedling has less soil to grow through and less chance coming in contact with the Rhizoctonia fungus (see Chapter 9 Diseases of lupin). Because the ideal seed depths to avoid for these two diseases are incompatible, a compromise is needed, hence the recommendation of 3 to 5 cm.

Deep sowing to chase moisture can be attempted but the risk of hypocotyl rot is increased. Seed should never be sown deeper than 7 cm as establishment is very uneven and weak.

Land preparation
The first agronomic practices used in lupin production included tillage as a method of weed control. On sandplain soils this caused major soil erosion and wind blasting as well as high incidence of brown spot. Growers have moved to sowing systems that retain stubble.

Sowing into the standing cereal stubble is now common practice. As a guide, retaining 20 per cent or more of an average standing cereal stubble reduces sandblasting of seedlings and the spread of brown spot.

Recently, the practice of sowing lupin rows between rows of standing cereal stubble has become possible with precision guidance technology. This method has some major advantages. Retaining all of the cereal stubble as standing stubble dramatically reduces the incidence of wind blasting and brown spot. Thick stubble can be sown into easily because it is not disturbed. The cereal stubble acts as a guard to stop soil being thrown from one furrow to the next. This improves herbicide safety because soil with pre-sowing applied herbicide does not land on the furrow, even if seeding at high speed.

Planting machinery
The ideal machine for sowing lupin is able to:
- handle thick stubble
- uniformly incorporate simazine into the top 5 cm of soil
- kill germinated weeds
- place the seed and fertiliser uniformly at the desired depth or depths
- leave a good seedbed with water-harvesting furrows
- leave loose soil above the seed to reduce soil water evaporation and allow easy emergence
- sow quickly and cheaply.

Most lupin crops are sown with tined machines and most often with press wheels. This provides good seed:soil contact. It also forms a furrow that harvests water (which is particularly important in
achieving a uniform establishment in non-wetting sands) and protects seedlings from sandblasting.

Knife point machines offer good stubble handling and reasonable incorporation of herbicide, depending on the row spacing. They kill germinating weeds within the seeded row and allow flexibility for placing seed and fertiliser. They are relatively fast and easy to use compared to culti-trash or full cut machines. The weight of the press wheel should be set no higher than 2 kg/cm width of the press wheel.

Where furrows are created there is a danger that soil-applied herbicides such as simazine will wash into them and concentrate at toxic levels. With knife points this is avoided by applying the herbicide prior to sowing before throwing the chemical out of the row during the sowing operation. There are two disadvantages to this sowing method.

- If furrows are deep the herbicide may not be thrown clear and can still wash back into the furrow.
- Weed control within the row is reduced because the herbicide has been thrown out. Dragging a ring harrow (Figure 6.9) attached to a short length of chain behind the press wheel will drag some soil and herbicide back into the row. Weed control in the row may still be a problem.

Disc machines are ideal for stubble retention. However, triple discs are less efficient at herbicide incorporation and pre-planting weed control than tined or culti-trash machines.

Culti-trash machines can be used to overcome heavy stubble. However, seed depth cannot be precisely controlled and inversion of the soil may bring pleiochaeta root rot into contact with seedlings. Inconsistent establishment due to excessive sandblasting and root disease was common when culti-trash machines were the standard equipment.
7 Plant nutrition

Ross Brennan, Mike Bolland and Bill Bowden
Lupin crops are well adapted to infertile sandy soils. Their roots have many long root hairs. Some species produce specialised root structures called cluster roots and secrete organic acids that help solubilise soil nutrients. Lupin seeds are relatively large and store nutrients to sustain the growth of seedling roots while they initially forage through infertile soils. Importantly, lupin species are legumes and do not depend on soil nitrogen as long as rhizobia are present to form a nitrogen-fixing symbiosis with the plant.

There are important differences between lupin species in the structure and function of roots that affect nutrient uptake and absorption. Cluster roots are a good example. The cluster roots of albus lupin and sandplain lupin are distinct regions of dense rootlets on secondary roots and are more obvious than the simple cluster roots of yellow lupin, which look like third-order lateral roots on secondary roots (see Figures 2.5 and 2.6). Narrow-leafed lupin does not form cluster roots, but it does secrete citrate from its roots. In phosphorus-deficient soil, exudation rates of citrate are often faster from roots of narrow-leafed lupin than from the cluster roots of albus lupin. Nevertheless, narrow-leafed lupin is less efficient at acquiring phosphorus from low-phosphorus soils than albus lupin.

Many of the soils used for agriculture in Western Australia are ancient, highly weathered and very infertile. Lupin species grow well on these soils but the application of several nutrients as fertiliser is required to maximise profitability. Phosphorus, manganese and molybdenum are the nutrients most likely to be deficient and have received the most research. These nutrients are discussed first.

Nitrogen, potassium and sulfur are also important and need to be carefully monitored, but these nutrients are rarely deficient for lupin because either rhizobium (for nitrogen fixation) are present in the soil or potassium and sulfur fertiliser have been applied to other crops (wheat or canola) in the rotation.

Most of the research and information described below applies to narrow-leaved lupin.

**Fertiliser requirements of lupin**

**Phosphorus**

Phosphorus is an essential component of cell membranes and plant genetic material and in the energy storage and transfer system in plant cells. Leaves of phosphorus deficient, narrow-leaved lupin plants frequently drop (Figure 7.1) after first beginning to die back from the tips (Figure 7.2). Leaves of albus lupin show yellow mottling before dying from the tips (Figure 7.3) while leaves of yellow lupin show distinct purpling around the leaf margins (Figure 7.4). Phosphorus deficiency causes poor growth of lupin roots and shoots (Figure 7.5), leading to decreasing grain yields. Early plant growth is particularly dependent on phosphorus because of the need for rapid cell division and expansion. Compared with cereals, lupin also has a high phosphorus requirement for grain production.

Phosphorus is mobile within plants and can be re-mobilised from leaves, roots and stems to the grain but lupin usually has insufficient amounts of phosphorus within the plant to satisfy its requirements. So phosphorus needs to be continually taken up from soil for grain production.
Figure 7.1 Symptoms of phosphorus deficiency in narrow-leafed lupin. Photo: F O’Donnell

Figure 7.2 Leaf tips of narrow-leafed lupin dying in response to phosphorus deficiency. Photo: P Scanlon

Figure 7.3 Phosphorus deficiency in albus lupin showing yellow mottling and death beginning at the tips of the leaves. Photo: P White

Figure 7.4 Phosphorus deficiency in yellow lupin showing distinct purple discolouration around leaf margins. Photo: P White

Figure 7.5 Effects of phosphorus on growth of roots and shoots of narrow-leafed lupin. Severe P deficiency is shown on the left, moderate P deficiency in the middle and adequate phosphorus on the right. Photo: F O’Donnell
Correcting phosphorus deficiencies

The best way to apply phosphorus fertiliser to lupin crops depends on rainfall and the capacity of the soil to retain (sorb, adsorb, fix) phosphorus.

On sandy soils

On sandy soils with low capacities to retain phosphorus, it is best to separate the seed and fertiliser by spreading the fertiliser over the soil surface (topdressing) in front of the seeding tines, or by placing the fertiliser below the seed (deep banding) while sowing. If the fertiliser is placed with the seed on these soils, it can be toxic to seedlings because much of the fertiliser remains in the soil solution. The problem is particularly acute when using narrow tines or knife points for no-till cropping so the fertiliser and seed are in close proximity. Lupin is more sensitive to phosphorus/salt toxicity than cereals.

Topdressing phosphorus fertiliser is an option only in high rainfall areas, such as Eradu, Badgingarra or Eneabba. Long histories of fertiliser application and leaching means that there is enough phosphorus already at depth in most of the sandy soils in these areas to supplement plant requirements. Topdressing fertiliser is not effective in lower rainfall areas.

For sandy soils in the lower rainfall areas, banding phosphorus below the seed is usually the most effective method of applying fertiliser phosphorus to lupin crops. This is particularly so in dry years and in sandy soils with larger capacities to retain phosphorus. Deep banding places the fertiliser in soil that remains moist for longer periods, making the fertiliser more accessible to the plant roots. Placing fertiliser about 8 cm below lupin seed is best. For a lupin crop typically sown 2–5 cm deep, phosphorus fertiliser is placed 10–13 cm below the soil surface.

On soils that retain phosphorus

On soils with large capacities to retain phosphorus, such as lateritic ironstone gravel soils east of the Darling Range, it is best to drill the fertiliser with the seed. Most of the phosphorus released from fertiliser granules in these soils is retained by the soil. Placing fertiliser granules close to the germinating seedlings increases the proportion of phosphorus that is taken up by plant roots before it can be retained by soil. Topdressing fertiliser on these soils leaves the fertiliser in the dry surface soil where much of it remains unavailable to the plant. Deep banding may result in phosphorus deficiency during early growth before seedling roots reach the deeply placed phosphorus.

How much phosphorus to apply?

The most profitable rate of fertiliser required for lupin production depends on:

- the amount of phosphorus already present in soil from fertiliser applied in previous years (usually indicated by a soil test)
- the different capacities of the soil to retain phosphorus, usually indicated by the Phosphorus Retention Index (PRI)
- the cost of purchasing and applying the fertiliser relative to the returns obtained for lupin grain.

Using Tables 7.1, 7.2 and 7.3 to determine optimum application rate for phosphorus

Firstly, estimate the price ratio with Equation 7.1 (below) where \( x \) is the on-farm cost of applying fertiliser phosphorus per hectare and \( y \) is the on-farm maximum gross return per hectare obtained for harvested lupin grain.

**Equation 7.1**

\[
\text{Ratio} = \frac{x}{y}
\]

Equation 7.2 calculates an actual example, in which a price ratio of 10.4 is obtained for triple superphosphate (20 per cent P) costing $500/t on-farm and a yield of 1.5 t/ha of lupin which receives a price of $160/t on-farm.

**Equation 7.2**

\[
\text{Ratio} = \frac{100/20 \times 500}{160 \times 1.5}
\]
Next, choose the appropriate soil type from a soil description or from a measure of PRI (below).

- **Low phosphorus retention soils (PRI < 2)**. These soils include leaching grey and yellow sands such as those found on the Swan Coastal Plain and the Eradu sandplain, on the south coast, in the midlands and sometimes in the lower rainfall areas.

- **Moderate phosphorus retention soils (PRI from 2 to 8)**. These soils include sandy loams and duplexes. They occur on the south coast and in the wheatbelt and originally may have grown York gum, jam, mallee, white gum and tamma.

- **Medium phosphorus retention soils (PRI from 9 to 15)**. These soils include some of the transitional and medium salmon gum and York gum soils of the wheatbelt.

- **High phosphorus retention soils (PRI from 16 to 35)**. These soils include salmon gum/gimlet soils, acidic sandy loams and acidic loams of the eastern wheatbelt, as well as jarrah–marri gravelly loams of the forest country on the western margins of the wheatbelt.

- **Very high phosphorus retention soils (PRI > 35)**. These soils are found mainly in the higher rainfall regions and include jarrah and karri loams, as well as clay loams and clays of the river flats. In lower rainfall areas, these may include white gum and dryandra loams.

Last, find the optimum rate of phosphorus from tables 7.1, 7.2 or 7.3.

The optimum rate of phosphorus (kg P/ha) is found at the intersection of the soil test column with the price ratio row in the appropriate soil type table. To convert this value to kilograms of fertiliser per hectare, divide it by the fractional P composition of the fertiliser. For example, for triple superphosphate with 20 per cent phosphorus, the calculation 17 kg P/ha divided by 0.2 equals 85 kg triple superphosphate/ha.

### Table 7.1 Calculating the most profitable rate of superphosphate (kg/ha) to apply at sowing for optimum lupin grain production on low phosphorus retaining soils with PRI <2

These soils include leaching grey and yellow sands such as those found on the Swan Coastal Plain, the Eradu sandplain, the south coast, in the midlands and sometimes in lower rainfall cropping areas.

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<th>Price ratio</th>
<th>Optimum relative yield (%)</th>
<th>Colwell soil test P for top 10 cm of soil (mg/kg)</th>
<th>Optimum rate of phosphorus (kg/ha) to drill with seed while sowing the next lupin crop</th>
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</table>

Note: Tables 7.1, 7.2 and 7.3 were prepared by Bill Bowden, Chris Shedley, Steve Burgess and Craig Scanlan from DAFWA.
### Table 7.2 Calculating the most profitable rate of superphosphate (kg/ha) to apply at sowing for optimum lupin grain production on moderate to medium phosphorus retaining soils with PRI 2 to 15

These soils can be divided into two groups: soils with PRI values from 2 to 8, including sandy loams and duplex soils that previously grew York gum, jam, mallee, white gum and tamma; and soils with PRI values from 9 to 15, including those that were marginally acidic to neutral and previously grew salmon gum and York gum.

<table>
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<th>Price ratio</th>
<th>Optimum relative yield (%)</th>
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<tr>
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<td>Optimum rate of phosphorus (kg/ha) to drill with seed while sowing the next lupin crop</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>66.7</td>
<td>12 11 9 5 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>40</td>
<td>73.3</td>
<td>15 14 11 7 2 0 0 0 0 0 0</td>
</tr>
<tr>
<td>30</td>
<td>80.0</td>
<td>18 17 15 10 5 0 0 0 0 0 0</td>
</tr>
<tr>
<td>20</td>
<td>86.7</td>
<td>22 21 19 15 10 5 0 0 0 0 0</td>
</tr>
<tr>
<td>10</td>
<td>93.3</td>
<td>30 29 27 22 17 12 6 1 0 0 0</td>
</tr>
<tr>
<td>7</td>
<td>95.3</td>
<td>34 33 31 26 21 16 10 5 1 0 0</td>
</tr>
<tr>
<td>5</td>
<td>96.7</td>
<td>38 37 35 30 25 20 13 8 5 2 0</td>
</tr>
<tr>
<td>4</td>
<td>97.3</td>
<td>40 39 37 33 28 22 16 11 7 5 1 0</td>
</tr>
<tr>
<td>3</td>
<td>98.0</td>
<td>43 43 40 36 31 26 19 14 10 8 5 0</td>
</tr>
<tr>
<td>2</td>
<td>98.7</td>
<td>48 47 45 40 36 30 23 18 15 12 9 5</td>
</tr>
</tbody>
</table>

*Note:* Do not place on the seed more than 20 kg P/ha at 18 cm row spacings or more than 10 kg P/ha at 36 cm row spacings. The yield potential of crops is normally increased if P fertiliser is banded below the seed. Therefore, if the fertiliser is banded, use a lower price ratio. For example, a 30 per cent yield increase would mean a reduction in the chosen price ratio from 10 to 7.

### Table 7.3 Calculating the most profitable rate of superphosphate (kg/ha) to apply at sowing for optimum lupin grain production on high phosphorus retaining soils with PRI 16 to 35

These soils include those that originally grew salmon gum and gimlet, acidic sandy loams and acidic loams of the eastern wheatbelt and jarrah–marri gravelly loams on the western margins of the wheatbelt. They also include jarrah and karri loams and clay loams and clays of the river flats, and the white gum and dryandra loams in lower rainfall areas.

<table>
<thead>
<tr>
<th>Price ratio</th>
<th>Optimum relative yield (%)</th>
<th>Colwell soil test P for top 10 cm of soil (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2</td>
<td>5</td>
<td>10 15 20 25 30 35 40 45 50 55</td>
</tr>
<tr>
<td></td>
<td>Optimum rate of phosphorus (kg/ha) to drill with seed while sowing the next lupin crop</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>66.7</td>
<td>12 12 11 9 7 1 0 0 0 0 0 0</td>
</tr>
<tr>
<td>40</td>
<td>73.3</td>
<td>15 15 14 12 9 4 0 0 0 0 0 0</td>
</tr>
<tr>
<td>30</td>
<td>80.0</td>
<td>18 18 17 15 12 7 0 0 0 0 0 0</td>
</tr>
<tr>
<td>20</td>
<td>86.7</td>
<td>22 22 21 20 17 12 5 0 0 0 0 0</td>
</tr>
<tr>
<td>10</td>
<td>93.3</td>
<td>30 30 29 28 24 19 12 5 1 0 0 0</td>
</tr>
<tr>
<td>7</td>
<td>95.3</td>
<td>34 34 33 31 28 23 16 8 5 1 0 0</td>
</tr>
<tr>
<td>5</td>
<td>96.7</td>
<td>38 38 37 35 32 27 20 12 8 5 2 0</td>
</tr>
<tr>
<td>4</td>
<td>97.3</td>
<td>40 40 39 38 35 30 22 15 11 7 5 2</td>
</tr>
<tr>
<td>3</td>
<td>98.0</td>
<td>43 44 43 41 38 33 26 18 14 10 8 5</td>
</tr>
<tr>
<td>2</td>
<td>98.7</td>
<td>48 48 47 46 42 37 30 22 18 15 12 9</td>
</tr>
</tbody>
</table>

*Note:* Do not place on the seed more than 20 kg P/ha at 18 cm row spacings or more than 10 kg P/ha at 36 cm row spacings.
**Phosphorus in the seed**

Adequate concentrations of phosphorus in the seed help seedlings to grow vigorously. The phosphorus concentration in the seed should be greater than 0.25 per cent. Smaller seedlings produced from seed with less than 0.25 per cent phosphorus will not cope well with stress occurring during early growth. Up to 25 per cent yield reduction has been recorded in trials where seed with low concentrations of phosphorus have been sown. Only use good quality seed to sow lupin crops. Do not use seed harvested from crops grown on very sandy soils with a low phosphorus status.

**Manganese**

The role of manganese in plants is not fully understood, but it is part of many metabolic processes and important in the production of chlorophyll.

Grain yields of lupin can be substantially reduced by manganese deficiency, but shoot yields are generally not affected. Narrow-leafed lupin has a poor ability to accumulate manganese in its grain. Concentrations of manganese in the grain of narrow-leafed lupin are usually much lower than concentrations of manganese in the grain of albus lupin, sandplain lupin and yellow lupin.

Manganese deficiency causes lupin grain to split and sometimes to discoulour around the margins of the seed (Figure 7.6). The seed may also be small, shrivelled and poorly developed (Figure 7.7). Plants suffering manganese deficiency show delayed maturity (that is, they stay green longer) and produce lower yields.

The occurrence of the split seed disorder of lupin varies with the maturity of the lupin variety, the planting date, the amount of rainfall received during and at the end of the growing season, and the soil type. The split seed problem occurs mainly in slightly acidic grey sand, yellow sands and gravelly sands common in the south-west, where the average annual rainfall is more than 450 mm. Split seed disorder has also shown up in patches of the low rainfall wheatbelt in some seasons, usually on coarser, deeper, more leached sands. As the percentage split seed increases, the grain yield of lupin decreases (Figure 7.8).

Early sowing and the use of early maturing varieties reduce the risk of split seed developing. This allows the seed to fill and mature before soil moisture is exhausted in spring. Manganese is very immobile in plants and needs to be taken up from soil as the grain fills and matures. Sandy soils rapidly dry between rain events in spring.
when the grain is filling. This restricts nutrient uptake because plant roots cannot take up manganese (or any other nutrient) from dry soil.

Application of lime to the soil has often induced split seed in lupin crops where it had not occurred before. Lime raises soil pH and increases the capacity of soil to retain manganese. This reduces manganese uptake by the plant causing split seed. Conversely, as soils acidify the capacity of soil to retain manganese is reduced and more becomes available to plants.

**Correcting manganese deficiencies**

Split seed disorder is treated by applying manganese fertiliser to soil or by spraying onto lupin foliage. Manganese sulfate is usually used. Fertiliser applied to the soil has a good residual value lasting for several years. The foliar spray supplies manganese only to the crop on which it is applied. Manganese fertiliser is relatively expensive costing about $30/ha for the average lupin crop. Commercial superphosphates that contain manganese sulfate are available with a range of manganese concentrations in the fertiliser.

**Applying manganese to the soil**

On grey sands, gravels and yellow sands north of Perth, 30 kg/ha of manganese sulfate drilled with the seed in wet years reduces the proportion of split seed in lupin grain to 5 per cent or less. Applications of more than 30 kg/ha of manganese sulfate drilled with the seed will not increase yields further. Along the south coast and on the yellow sands of the eastern edge of the west midlands, 15 to 20 kg/ha of manganese sulfate drilled with the seed is recommended.

The residual value of manganese allows one application of fertiliser to supply several subsequent lupin crops. After the initial application, manganese sulfate rates can be halved for each succeeding crop.

Research on grey sands in the west midlands showed that 60 kg/ha of manganese sulfate applied in 1978 was still fully effective for maximum grain yields 16 years later. As a rule of thumb, when a cumulative total of 60 kg/ha of manganese sulfate has been applied it is unlikely that more manganese sulfate will be required for lupin production for several years. A stem test can be used to monitor the manganese status of crops to determine when re-application is required (see Soil and tissue test values following).

**Deep banding**

Deep banding is the best way of applying manganese fertiliser. Manganese drilled with the seed is less effective than deep banding at supplying manganese to the plant. This is because the lupin roots cannot access manganese from dry surface soil near the end of the growing season when grain is being produced. Manganese is immobile in the plant, so it needs to be continually taken up from soil as the grain is being produced.

Deep banding fertiliser about 8 cm below the seed places the manganese in soil that stays moist for longer, making it more available to the plant during grain production. Trials have consistently shown that deep banded manganese sulfate is more effective than fertiliser placed with the seed. Topdressed fertiliser is least effective (Figure 7.9).

**Applying manganese as a foliar spray**

Spraying 4 kg/ha of manganese sulfate in 75 to 100 L of water directly onto the foliage of lupin crops is an effective method of controlling split seed disorder. But foliar sprays sometimes fail. The development stage of the seed at the time of spraying is critical. Spray when the pods on the main stem are 2 to 3 cm long and the secondary stems have nearly finished flowering. Use aerial application to avoid mechanical damage to the crop. Foliar sprays have negligible residual value and must be applied to each crop.
Experience has shown that foliar sprays applied at the correct rate and correct time are as reliable as deep banded manganese fertiliser. Increasing the rate beyond 4 kg/ha does not significantly increase the effectiveness of the foliar spray. Other compounds (for example, manganese chelate) can be used provided the rate of manganese is equivalent to that in 4 kg/ha of manganese sulfate (1 kg/ha of elemental manganese).

**Soil and tissue test values**

Soil tests do not reliably indicate whether the manganese concentration in the soil is adequate for grain production in lupin. Tissue tests are the most reliable indicator of manganese deficiency. Tests are conducted on lupin main stems at mid-flowering. All branches, leaves, flowers and roots are removed from lupin plants at mid-flowering to leave only the main stem. About 20 to 30 stems are required for each test. The critical value for manganese in the main stem is 20 mg/kg of dry matter.

The concentration of manganese in lupin grain is also an unreliable indicator of split seed. Often the difference in manganese concentration between normal seeds and split seeds from the same plant is negligible. Usually 10 mg/kg in seed is used as a guide for split seed; however, some crops with seed manganese concentrations of 7 mg/kg show no evidence of split seed while others have high levels of split seed when the manganese concentration in grain is 11 mg/kg.

**Manganese in the seed**

The concentration of manganese in lupin seed used for sowing a crop can have a substantial effect on the germination of the seed and subsequent crop establishment and seedling growth. Trials have shown that germination and seedling growth is decreased when lupin seed has a manganese concentration less than 13 mg/kg. Applying manganese fertiliser at sowing does not correct the effects of low concentration of manganese in the seed. When establishing a crop, always use seed with a manganese concentration of more than 13 mg/kg.

Coating manganese sulfate on lupin seeds before sowing has resulted in delayed and poor emergence of seedlings due to salt and/or toxicity effects on the seedlings.

**Molybdenum**

Molybdenum is required by all plants when nitrogen is taken up from soil in the nitrate form, because it is a critical constituent of the enzyme nitrate reductase, which catalyses the reduction of nitrate to nitrite so it can be used by plants. Molybdenum is also required in the nodules of nitrogen-fixing legumes as a constituent of the nitrogenase enzyme. Legumes require molybdenum for nitrogen fixation and to reduce soil-acquired nitrate. Nitrogen fixation has the highest requirement for molybdenum.

**Correcting molybdenum deficiency**

Molybdenum is strongly retained by soils at low pH (below 5.0). Molybdenum deficiency in Western Australia was first seen on wodjil soils of the eastern wheatbelt. These are yellow sandplain soils which are naturally very acidic. Molybdenum is deficient for lupin on wodjil soils and large increases in grain yield can be achieved by applying molybdenum fertiliser. But responses are very variable and depend on the concentration of molybdenum present in the sown seed. High concentrations of molybdenum in lupin seed can supply the crop's total requirement, including that required for grain production, and molybdenum fertiliser is not required. Lupin seed grown on soils with pH values greater than 5.5 usually contain sufficient molybdenum to supply the crop's needs.

As agricultural soils have acidified over time molybdenum deficiency has occurred in areas that previously had adequate levels of molybdenum for lupin production. Lime application raises soil pH so molybdenum again becomes available to the plant. But lime can also induce manganese or zinc deficiency in lupin. This can be avoided by applying manganese or zinc fertiliser when liming soils used to grow lupin.

**How to supply molybdenum**

Coating seed with molybdenum fertiliser is one way to supply molybdenum to deficient seeds. However, coating seeds with a solution of sodium molybdate has resulted in nodulation problems, possibly due to the molybdenum salt killing the *Bradyrhizobium* bacteria in the inoculum. The molybdate solution (5 to 6 per cent molybdenum) is also alkaline (pH 9 to 10) causing a breakdown of the Rovral® seed dressing used to control brown spot disease of lupin (*Pleiochaeta setosa*).
Too much molybdenum fertiliser can induce copper deficiency in *ruminants* (cattle, sheep, goats) when grazing pasture growing on the soil. This is called molybdenosis. It becomes a major problem for farmers in higher rainfall areas when too much molybdenum fertiliser is applied. Applying lime to paddocks with a molybdenosis problem will make molybdenum more available, accentuating the problem.

**Yellow lupin and molybdenum**
Lupin generally grows poorly on wodjil soils even when seed with high molybdenum concentrations is used or molybdenum fertiliser is applied. This is because very acid soils also have toxic levels of aluminium in the soil solution. Aluminium toxicity stunts roots and reduces the volume of soil explored by plant roots to take up water and nutrients. The roots of yellow lupin grow better than the roots of many other plant species in soils with high levels of aluminium.

Organic acids secreted from the roots of yellow lupin are thought to help the plant cope with aluminium toxicity in acidic soils. The organic acids also help *desorb* (mobilise) phosphorus retained by soil, helping the plant take up more phosphorus. These organic acids may also help desorb molybdenum from the soil, making it more available.

**Nitrogen**
Nitrogen is an essential component of amino acids and proteins. It has an important role in the production of chlorophyll, a compound that gives the plant its green colour and is vital in photosynthesis.

A well-nodulated lupin crop obtains its nitrogen from the atmosphere by symbiotic nitrogen fixation. Applying nitrogen fertiliser to lupin crops has not been shown to consistently increase grain yield or grain protein. Small amounts of nitrogen (10 kg/ha) are sometimes applied at sowing to boost seedling growth, particularly in the colder areas of the central and southern wheatbelt, where plants may be slow to nodulate. This amount of nitrogen is small so it will not inhibit nodulation, but it stimulates weed growth and there is no clear evidence that it increases crop yields. Applying more than 10 kg/ha of nitrogen can delay nodulation and fixation of nitrogen.

![Figure 7.10 ALOSCA® granules compared in size to narrow-leafed lupin seed](Photo: P White)

**Inoculating lupin**
The rhizobium that nodulate lupin species survive in acid soils for at least five years. It is not necessary to inoculate lupin seed if it is to be grown on soil with a pH below 6.5 in a paddock where a well nodulated lupin crop was grown in the past five years. If more than five years have passed, the seed must be inoculated. On neutral and alkaline soils (pH above 6.5), the rhizobium do not survive in the soil for long and the seed must be inoculated every time a lupin crop is grown.

Inoculate with Group G inoculant. Serradella inoculant (Group S) is also compatible with lupin and can be used as a substitute if necessary. Two common forms of inoculants are moist peat and dry clay granules. Both forms of inoculant will produce very good nodulation on lupin if they are handled and applied according to the manufacturer’s instructions.

Moist peat inoculants need to be coated onto the seed immediately before sowing. Procedures for doing this are described in Chapter 5 Seed testing and seed treatments. Dry clay granules can be drilled with the seed, similar to fertiliser.

ALOSCA® granules are a readily available form of dry clay inoculants (Figure 7.10). They contain rhizobium inoculant embedded in a peat and clay matrix. The granules can be mixed either with the seed, with the fertiliser or sown through a separate box. Apply ALOSCA® at 10 kg/ha and place the granules as close as possible to the seed in the seed bed. ALOSCA® can be used with fungicide treated seed without affecting nodulation.
It is important to keep the clay granules dry because wet clay will block the chutes of the seeder.

**Potassium**

Potassium is a major plant nutrient used in many plant processes, including photosynthesis, transport of sugars, enzyme activation, maintenance of plant turgor and regulation of stomata. Plants that are deficient in potassium will use other nutrient elements and water less efficiently than plants with adequate potassium. They are also less tolerant of stresses such as drought, waterlogging, diseases and insect pests.

**Correcting potassium deficiency**

During the early period of cropping in Western Australia, most soils had sufficient potassium for crop production. Over time, with the continual removal of potassium in crop products, many sandy soils have now become deficient in potassium for wheat, barley and canola production. Potassium levels in these soils, measured by the Colwell test, have fallen below 50 mg/kg, and profitable responses to potassium fertiliser are common. Lupin crops still do not yet show potassium deficiency on many of these soils. In some cases, this is because the potassium fertiliser applied to wheat, barley or canola crops provides enough potassium for lupin grown in rotation with these crops. Research on deep sandy soils has shown that potassium fertiliser applied at 50 kg/ha potassium has a residual value of at least two years before re-application is necessary.

In field experiments on sandplain soils, the rooting depth of narrow-leafed lupin and sandplain lupin has been shown to be important for recycling potassium from the subsoil to the topsoil. In a glasshouse study in which rooting depth was not a confounding factor, it was found that the roots of narrow-leafed lupin and yellow lupin took up less potassium from the soil than wheat and canola roots. However, both lupin species used the potassium more effectively within the plant than wheat or canola to produce shoots. Compared to wheat and canola, lupin appears to have a lower external efficiency for potassium uptake, but a higher internal efficiency for potassium use.

**How to supply potassium**

Potassium chloride and potassium sulfate are the main fertilisers used in Western Australia. Potassium chloride (muriate of potash) contains 50 per cent potassium and potassium sulfate contains 41.5 per cent potassium. Both fertilisers are equally effective per unit of applied potassium for plant production.

Potassium chloride can be toxic when drilled with the seed. It is best to topdress potassium four weeks after sowing. Excessive leaching of potassium fertiliser can occur if it is applied earlier than four weeks after sowing on very sandy soils in high rainfall areas, because roots are not yet sufficiently developed to capture all of the potassium.

**Cobalt**

Cobalt is not required by lupin plants. It is required by the rhizobium bacteria in root nodules. Seed with adequate concentrations of cobalt is sufficient to allow normal nodule development and nitrogen fixation. Seeds with low cobalt concentrations sown into soils deficient in cobalt will produce poorly-nodulated lupin roots with ineffective nodules and the crop will be nitrogen deficient. Always use seed with cobalt levels greater than 0.13 mg/kg.

**Sulfur**

Sulfur is an essential part of certain amino acids such as methionine, cystine and cysteine. When sulfur is deficient, the production of sulfur-containing amino acids is reduced. This in turn reduces the quality of proteins and the value of lupin as animal feed.

Plants obtain most of their sulfur from the soil. In areas close to the sea or industrial pollution, there can be significant input of sulfur from the atmosphere. Lupin crops have not yet shown sulfur deficiency in Western Australia.

Single superphosphate contains about 10.5 per cent sulfur and there are a range of other fertiliser products that contain sulfur as a by-product. When these fertilisers are used, they help maintain adequate sulfur levels in soils for cropping. Gypsum contains about 17 per cent sulfur and is the most widely used sulfur fertiliser for canola. Large amounts of gypsum (typically 300 to
500 kg/ha gypsum) are applied to canola crops which maintain sulfur levels in the soil for other crop species, including lupin, grown in rotation with canola. Deficiencies of sulfur are most likely to occur in crops grown on deeper sandy soils in higher rainfall areas when fertilisers containing negligible sulfur, such as triple superphosphate (about 1.5 per cent sulfur) or DAP (di-ammonium phosphate) (about 1 per cent sulfur) have been used for several years.

Copper

Copper is only required by plants in very small amounts, but it is an essential component of many plant enzymes that control chemical reactions in the plant. In yellow lupin, it has a function in nitrogen fixation. Copper also provides the plant with structural strength through a role in lignification.

Copper deficiency has yet to be encountered for lupin in Western Australia, even when lupin is grown on soils that are deficient in copper for other species. Copper fertiliser is commonly applied to the soils as an insurance against deficiency for these species. Consequently, there is probably enough copper in the soil for lupin and deficiency is very unlikely.

Zinc

Zinc is an important component of enzymes, which are proteins that enable chemical reactions to take place in the plant. Many of the physiological effects caused by zinc deficiency are associated with the disruption of normal enzymatic activity, including photosynthesis, membrane leakiness, auxin metabolism and reproduction.

Lupin crops are less susceptible to zinc deficiency than wheat or oats. Albus lupin, however, is more susceptible to zinc deficiency than narrow-leaved lupin. Zinc fertiliser is regularly applied to cereal crops as an insurance against deficiency. Zinc fertiliser has a good residual value so zinc deficiency in lupin crops is very rare.

Boron

Lupin has yet to show shoot and grain yield responses to applied boron fertiliser. A major problem for boron in most crop species is that the range of boron levels in soil for deficiency and toxicity for plant production is very small. Indiscriminate use of boron fertiliser is not advised because toxicity problems will be induced, which are difficult to ameliorate.

Iron

Iron deficiency is one of the causes of the poor growth of lupin on alkaline soils. There are a complex series of interactions which combine to reduce the availability of iron to lupin. The deficiency will usually occur in lupin grown on soils with a pH above 7.0 if the soil aeration is reduced slightly and temperatures are cold. Lupin crops grown on fine-textured, alkaline soils that become saturated with water in winter will usually show bright yellowing of young leaves which is typical of iron deficiency (Figure 7.11). Plants will grow out of the deficiency when the soil dries (which improves soil aeration), or when temperatures increase. However, the growth of lupin roots is also impeded on alkaline soils, so in spring these plants suffer early water stress and yield poorly.

Foliar application of iron will reduce symptoms of deficiency and improve plant growth, but have not been shown to increase grain yields. The yield potential of lupin on alkaline soils is lower than most other grain legumes.

Nutrient sprays for pod formation and seed filling

Grain production of lupin occurs in late spring when fertilised surface soils are usually drying out. Plant roots cannot take up nutrients from dry soil. It is often thought that spraying lupin foliage with nutrients during this period may aid seed formation and produce higher yields. Research has shown that foliar applications of nitrogen, sulfur, potassium, phosphorus or boron (single sprays for each element or a combination of sprays with some or all of the elements) sprayed at flowering and at two weeks and six weeks after flowering failed to increase lupin grain yields. This contrasts with the foliar application of manganese at early pod filling which substantially reduced split seed of lupin grain.

Figure 7.11 Bright yellowing of young leaves, typical of iron deficiency in narrow-leaved lupin Photo: P White
Analysis of nutrient concentrations in plant tissue

Nutrient deficiency can be diagnosed using plant analysis. However, critical plant levels cannot be extrapolated from one plant species to another and they are not constant throughout the life cycle of a plant. Information on the plant part sampled and used for the diagnosis of the nutrient deficiency assists in the interpretation of the analytical results. Table 7.4 summarises the known critical concentrations for several nutrient elements in various plant parts of narrow-leaved, sandplain or yellow lupin. Limited research has gone into defining critical concentrations (CC) in narrow-leaved lupin so they may vary slightly from those listed in Tables 7.4 and 7.5. Even greater variations occur for yellow lupin, albus lupin and sandplain lupin. Table 7.5 lists the adequate, deficient and toxic concentrations of a range of nutrient elements for albus lupin.

<table>
<thead>
<tr>
<th>Element</th>
<th>Species</th>
<th>Plant part</th>
<th>Stage of growth</th>
<th>Critical Concentration (CC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus</td>
<td>Narrow-leaved lupin</td>
<td>WS</td>
<td>Vegetative (up to 80 DAS)</td>
<td>2.7 to 3.7 g/kg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Narrow-leaved lupin Sandplain lupin Yellow lupin</td>
<td>WS</td>
<td>Vegetative (80 to 170 DAS)</td>
<td>1.3 to 2.3 g/kg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Narrow-leaved lupin</td>
<td>Grain</td>
<td></td>
<td>2.5*</td>
</tr>
<tr>
<td>Potassium</td>
<td>Narrow-leaved lupin</td>
<td>Young leaf</td>
<td>84 DAS</td>
<td>11.3 g/kg</td>
</tr>
<tr>
<td></td>
<td>Narrow-leaved lupin</td>
<td>Petiole</td>
<td>84 DAS</td>
<td>11.2 g/kg</td>
</tr>
<tr>
<td></td>
<td>Narrow-leaved lupin</td>
<td>Shoot tips</td>
<td>84 DAS</td>
<td>21.0</td>
</tr>
<tr>
<td></td>
<td>Narrow-leaved lupin</td>
<td>WS</td>
<td>28 DAS</td>
<td>31 g/kg</td>
</tr>
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<td>Narrow-leaved lupin</td>
<td>WS</td>
<td>56 DAS</td>
<td>29 g/kg</td>
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<td></td>
<td>Narrow-leaved lupin</td>
<td>WS</td>
<td>84 DAS</td>
<td>15 g/kg</td>
</tr>
<tr>
<td></td>
<td>Narrow-leaved lupin</td>
<td>WS</td>
<td>112 DAS</td>
<td>12 g/kg</td>
</tr>
<tr>
<td></td>
<td>Narrow-leaved lupin</td>
<td>WS</td>
<td>140 DAS</td>
<td>9 g/kg</td>
</tr>
<tr>
<td>Calcium</td>
<td>Narrow-leaved lupin</td>
<td>WS</td>
<td>43 DAS</td>
<td>1.0 g/kg</td>
</tr>
<tr>
<td>Manganese</td>
<td>Narrow-leaved lupin</td>
<td>Stem</td>
<td>Mid-flowering</td>
<td>20 mg/kg</td>
</tr>
<tr>
<td></td>
<td>Narrow-leaved lupin</td>
<td>YFEL</td>
<td>Pre-flowering</td>
<td>30 mg/kg</td>
</tr>
<tr>
<td></td>
<td>Narrow-leaved lupin</td>
<td>Grain</td>
<td></td>
<td>8 to 10 mg/kg</td>
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<tr>
<td>Magnesium</td>
<td>Narrow-leaved lupin</td>
<td>YOL</td>
<td>Pre-flowering</td>
<td>17 to 20 g/kg</td>
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<td>Copper</td>
<td>Narrow-leaved lupin</td>
<td>YOL</td>
<td>Pre-flowering</td>
<td>1.0 to 1.2 mg/kg</td>
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<tr>
<td>Zinc</td>
<td>Narrow-leaved lupin</td>
<td>YOL</td>
<td>Pre-flowering</td>
<td>12 to 14 mg/kg</td>
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<td>Boron</td>
<td>Narrow-leaved lupin</td>
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<td>Pre-flowering</td>
<td>15 to 18 mg/kg</td>
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<tr>
<td>Cobalt</td>
<td>Narrow-leaved lupin</td>
<td>Grain</td>
<td></td>
<td>0.13 mg/kg</td>
</tr>
</tbody>
</table>

CC = Critical concentration is the concentration in plant parts that was related to 90 per cent of the maximum yield achieved when no nutrient elements were deficient.
DAS = days after sowing
WS = whole shoots
YOL = youngest open leaflets
YFEL = youngest fully emerged leaf
* for seedling vigour
Source: Reuter & Robinson 1997
Table 7.5 Summary of concentrations of nutrient elements in shoots of albus lupin (L. albus) which are deficient, adequate and toxic for growth

<table>
<thead>
<tr>
<th>Element</th>
<th>Age of plant (days)</th>
<th>Plant part</th>
<th>Deficient</th>
<th>Adequate</th>
<th>Toxic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Concentration (g/kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphorus</td>
<td>35</td>
<td>WS</td>
<td>1.3</td>
<td>2.2</td>
<td>21.4</td>
</tr>
<tr>
<td>Potassium</td>
<td>35</td>
<td>WS</td>
<td>45</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Sulphur</td>
<td>54</td>
<td>WS</td>
<td>1.1</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>39</td>
<td>YOL</td>
<td>1.0</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td>29</td>
<td>YOL</td>
<td>1.1</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Iron</td>
<td>28</td>
<td>WS</td>
<td>28</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>28</td>
<td>YOL</td>
<td>5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>40</td>
<td>WS</td>
<td>245</td>
<td>&gt;7724</td>
<td></td>
</tr>
<tr>
<td>Molybdenum</td>
<td>45</td>
<td>YOL</td>
<td>0.016</td>
<td>0.036</td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td>46</td>
<td>YOL</td>
<td>11.5</td>
<td>68</td>
<td>1013</td>
</tr>
</tbody>
</table>

WS = whole shoots  
YOL = youngest open leaflets  
Source: Snowball & Robson 1986

**Further reading**


Bowden, JW, Shedley, C & Burgess, SJ 1984, *Soil test and phosphorus rate*, Farmnote 92/84, Western Australian Department of Agriculture, South Perth.

Brennan, RF 1993, *Symptoms of manganese deficiency (split seed) in narrow leafed lupins*, Farmnote 70/93, Western Australian Department of Agriculture, South Perth.

Brennan, RF 1993, *Treatment of manganese deficiency (split seed) in narrow leafed lupins*, Farmnote 71/93, Western Australian Department of Agriculture, South Perth.


Brennan, RF 1999, ‘Lupin grain yields and fertiliser effectiveness are increased by banding manganese below the seed’, *Australian Journal of Experimental Agriculture*, vol. 39, pp. 595–603.


Snowball, AD & Robson, K 1986, Symptoms of nutrient deficiencies–lupins, University of Western Australia Press, Nedlands.

8 Weed management

Martin Harries, Peter Newman and Abul Hashem
There are three main benefits from controlling weeds in lupin crops.

1. **Higher yields**: Controlling weeds in lupin crops results in higher yields because more nutrients, sunlight and water are available to the crop. Yield losses at harvest are also reduced.

2. **Higher prices**: Lupin grain delivered to Cooperative Bulk Handling with excessive weed contamination will receive lower prices due to dockage.

3. **More productive systems**: Preventing weeds from growing and setting seed in a lupin crop makes it easier and less costly to control weeds in following cereal crops. This is becoming more important as weeds, particularly annual ryegrass (*Lolium rigidum* Gaud.) and wild radish (*Raphanus raphanistrum* L.), continue to develop resistance to commonly used herbicides.

Controlling weeds in lupin involves several key steps which are summarised below and discussed in this chapter. The Weed Management Time Line at the end of the chapter summarises each event. It is important to remember that physical, cultural and chemical methods of control are all needed for effective management of weeds over the long term.

**Key steps to controlling weeds in lupin**

- Plan rotations in advance to minimise weed challenges.
- Control weeds before or at sowing using physical, cultural and chemical methods.
- Enable crops to compete strongly with weeds by ensuring they are planted early, are vigorous and have a dense stand.
- Understand how to maximise the efficacy of herbicides to control weeds in the crop.
- Reduce the amount of seed set by weeds by using crop topping or swathing.
- Reduce the number of weed seeds in the paddock by using chaff carts, burning windrows left by headers or baling lupin straw.

**Rotations**

On many farms a simple crop rotation of wheat:lupin has served growers well. This rotation helped to manage diseases and wind erosion effectively and was very profitable. It allowed a greater focus on crops rather than stock and simplified farm management.

This system relied heavily on a few herbicides. Now that weeds such as ryegrass and wild radish are developing resistance to many of these commonly used herbicides, many growers are rethinking the way in which lupin is grown in the crop rotation.

Some growers are maintaining continuous cropping strategies with successful rotations such as lupin:wheat:canola:wheat or including swathed barley, Clearfield® wheat or hay production as clean-up crops. Others are using well-managed pastures which are spray-topped to stop seed set. Typically, this is a pasture:wheat:lupin:wheat:lupin rotation or, in a paddock with severe weed problems, a two or three-year pasture phase is employed. Once weed numbers are under control, a cropping phase can recommence.

Wild radish and ryegrass are the major weeds of lupin crops and both severely reduce yield. It is critical to select a paddock for lupin where these weeds can be well controlled.
Case Study

Managing weeds through rotations
These case studies describe several methods to control ryegrass that is developing resistance to grass herbicides (Newman & Adam, 2005). Each example is from a paddock in the northern agricultural region where ryegrass numbers were very high. The farmers’ reports emphasise that the keys to reducing weed numbers involve changing the range of crops and pastures grown and employing integrated weed management tools.

Continuous cropping

Rod Birch, Coorow lupin:wheat:canola:wheat rotation
In the 1990s when we were no longer able to control ryegrass in the paddocks, we decided to take an aggressive approach. We found that a lupin:wheat:canola:wheat rotation is good for ryegrass control because it enabled us to use different weed management tools each year. In the wheat rotation we use high seeding rates combined with trifluralin. We swath canola and often crop top lupin to stop ryegrass setting seed. We burn the header windrows of all our crops. Using these tactics we have driven ryegrass numbers from above 300 plants/m² down to a few plants/m².

Obst Family, North Mingenew lupin:canola:wheat:lupin:wheat rotation
In 1999 ryegrass numbers blew out when grass selective herbicides failed. By 2001, numbers were still around 450 plants/m² in the lupin crop but herbicides, crop topping and the use of a chaff cart helped bring numbers down. By dropping the paddock out for only one year and using a range of weed control measures in subsequent crops, we successfully controlled the ryegrass. We no longer use a chaff cart but are able to keep weed numbers at low levels through other measures such as swathing canola and crop topping lupin.

Using pastures

Piers Blake, Mingenew 3-year pasture:wheat:lupin:wheat:lupin:wheat rotation
In 1998 we had a spray failure in a canola paddock that caused a huge ryegrass seedbank. In 1999 about 1000 to 2000 ryegrass plants/m² emerged. The paddock was dropped out of crop to Cadiz pasture for three years. The Cadiz pasture was spray topped twice each year to stop the ryegrass setting seed. This reduced ryegrass numbers to 10 to 20 plants/m² and we started cropping again. A chaff cart was used in all crops and effectively maintained ryegrass at low numbers. From now on a pasture phase will be used to reduce weed numbers followed by a chaff cart to keep them low. Chaff carts and sheep are not for everyone but ryegrass and radish are no longer a major problem for us.

Steve Brindal, South Mingenew volunteer pasture:lupin:wheat:lupin:wheat rotation
The problem paddock had been in a lupin:wheat rotation for many years when we bought the property. In 2001 over 300 ryegrass plants/m² were in the lupin crop in August. The lupin paddocks were crop topped and a chaff cart was used to reduced numbers for the following wheat crop. Our rotation now is volunteer pasture:lupin:wheat, with the occasional canola. We typically grow two to four crops and then go back to pasture for a year. We rotate herbicides and use many integrated weed management tactics including sheep, spray topping, crop topping, burning of windrows and rotation of chemicals. We do not use the chaff cart anymore. Instead, we are windrowing most of the lupin and burning the windrows. This rotation is very good for weed management and appears to be good for the crops. We seem to be getting a lot less root disease, particularly in the lupin crops.
Weed control before sowing

Summer weeds
There are many reasons to reduce the growth of summer weeds.
- If allowed to grow unchecked, summer weeds will require a high rate of herbicide to achieve a knockdown prior to seeding.
- Large taprooted species will not be well controlled by knife point cultivation at seeding.
- Sowing problems may occur, particularly with melons or wireweed, requiring a delayed or reduced speed seeding operation.
- Soil moisture and nitrogen will be used by summer weeds, reducing moisture and nutrients available for the crop.
- Some summer weeds are known to have allelopathic effects (secrete toxins that inhibit the growth of nearby plants), and reduce lupin emergence.

Control of common summer weeds
Weed growth rates after summer rain are extremely high due to the high temperatures. It is important to target weeds soon after germination, particularly if herbicide rates at the lower end of the range are to be used (Table 8.1).

Simazine can be applied in February/March with little loss up until May. Use 1 L/ha for summer weed control and 1 to 1.5 L/ha prior to seeding.

If simazine, atrazine or diuron is applied for summer weed control, the paddock can not be used for cereal production. In addition, Group B herbicides can not be used for summer weed control on a paddock to be sown to lupin.

Cultivation
Very few lupin paddocks are tilled prior to seeding. Most lupin crops are grown on sandy soils which are prone to wind erosion if left exposed. Pre-seeding cultivation can only be recommended in areas that are not prone to erosive wind damage, where the farmer wants to obtain a mechanical weed knockdown, needs to provide good seedbed tilth to sow the crop, or has machinery which cannot handle the stubble. Caution should be taken to ensure that at least 20 per cent of the soil surface remains covered with stubble to reduce the spread of Pleiochaeta setosa (brown spot).

A light cultivation with harrows, called an autumn tickle, can cover weed seeds with soil which provides ideal germination conditions and an early flush of germinating weeds. This germination of weeds can be controlled with non-selective herbicides and cultivation during the seeding operation, if sowing after the break. An autumn tickle is most effective when the soil is moist for two weeks after tickling and prior to the knockdown. This allows a reasonable time for weed seeds to germinate. This requirement for a delay in sowing

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Rate/ha</th>
<th>Target weeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spray. Seed®</td>
<td>1000 to 2000 mL</td>
<td>All except taprooted species such as wireweed</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>400 to 600 mL 800 to 1200 mL 2000 mL</td>
<td>Small Medium Large</td>
</tr>
<tr>
<td>2,4-D amine</td>
<td>600 to 1000 mL</td>
<td>Radish. Spray graze all broad-leaved weeds.</td>
</tr>
<tr>
<td>2,4-D ester</td>
<td>300 to 500 mL</td>
<td>Radish, Afghan melon, other broad-leaved weeds</td>
</tr>
<tr>
<td>Glyphosate + ester</td>
<td>1000 + 300 mL</td>
<td>Many weeds including melons and caltrop</td>
</tr>
<tr>
<td>Diuron + amine</td>
<td>250 + 500 mL</td>
<td>Most broad-leaved weeds</td>
</tr>
<tr>
<td>Atrazine + ester</td>
<td>1000 + 300 to 500 mL</td>
<td>Most weeds with good residual effect. Use glyphosate instead of atrazine if many grass weeds have already germinated.</td>
</tr>
<tr>
<td>Atrazine + oil</td>
<td>100 to 2000 + 500 mL</td>
<td>Many weeds. Use glyphosate if many grass weeds have already germinated.</td>
</tr>
</tbody>
</table>
often deters the use of this tactic, particularly in low rainfall areas. This operation is not suited for use on non-wetting sands where stimulation of weed germination is extremely unpredictable.

**Pre-emergence herbicides**

Pre-emergence selective herbicides used include simazine, diuron, atrazine, triallate, pendimethalin and trifluralin.

**Simazine**

Simazine is the basic herbicide used in lupin crops (Table 8.2). It is a Group C broad-spectrum residual herbicide which will control a wide range of broad-leaved weeds and grass weeds for four to six weeks. It is absorbed by the roots and interferes with the plant’s photosynthetic system, resulting in the plant starving to death. Consequently, it may take several weeks for simazine to kill growing weeds.

Simazine rates tolerated by the crop will vary with seeding conditions, soil type and conditions after seeding. To get the best performance out of simazine it is important to understand the following principles.

- Simazine is not very soluble in water (5 ppm) so does not leach readily in the soil.
- For best results, apply onto dry soil before the break. If simazine is left as a band on the soil surface it will wash into the soil when the first rains come. This enables simazine to be incorporated effectively during the sowing operation.
- Simazine is not actively absorbed by plants from dry soil. In areas where the surface soil dries out frequently after seeding, simazine will be inactive near the soil surface. Weeds may continue to grow during dry periods if their roots are growing below the dry surface layer. Weed control with simazine is most erratic when lupin crops are sown into marginal moisture and dry conditions prevail, a common occurrence when dry sowing.
- Simazine works best on germinating weeds. A weed seedling must germinate and its root system must absorb simazine before it can be killed.
- Simazine alone will not kill emerged weeds. A knockdown herbicide such as Spray.Seed® or glyphosate should be tank-mixed with simazine in this situation.

Simazine has a half life of four to six weeks and therefore weeds germinating after this time may not be killed.

Soil type and season will influence the maximum rate of simazine (600 g/kg) that can be applied before it causes crop damage.

- **On deep white, grey and gritty sands** simazine can damage lupin at low rates (0.8 L/ha or less) (Figure 8.1). Where these soils occur as patches in paddocks, the best options are to:
  - delay sowing, use an increased rate of knockdown and reduce simazine. Higher rates of post-emergence herbicide may be needed
  - avoid high weed burden paddocks.
- **On yellow sandplain soils** crop damage may be observed at 1.25 L/ha, especially after wet sowing followed by warm, dry weather (northern areas).
- **On yellow loamy sands**, gravelly loams and sand over clay, simazine rates of 1.5 L to 2.5 L/ha can generally be used with good crop safety.
- **On very gravelly soils** associated with breakaways and heavier loams, 1.5 L/ha of simazine is often inadequate for good weed control.

**Using trifluralin in lupin**

Take steps to avoid weeds developing resistance to trifluralin. The occurrence of trifluralin-resistant weeds may be accelerated if trifluralin is used with lupin as well as with other crops in the...
Weed management

Table 8.2 Pre-emergence herbicides for use in lupin

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simazine</td>
<td>A Group C herbicide. The major herbicide used to control a range of broad-leaved weeds and grass weeds at emergence. Herbicide activity is determined by soil texture, organic matter and moisture. Lower simazine rates are used on sandy soils and soils with low levels of organic matter to avoid damage to the crop. Best weed control is obtained when simazine is thoroughly incorporated into moist soil.</td>
</tr>
<tr>
<td>Atrazine</td>
<td>A Group C herbicide similar to simazine and mixed in varying proportions with simazine. In general, it is more damaging to the crop than simazine and consequently it is not recommended for grey or pale sands. Label rates stipulate 500 mL/ha to 1 L/ha should be mixed with simazine at rates of 500 mL/ha to 1 L/ha. Rates of atrazine at the higher end of the label recommendation can cause unacceptable crop damage in warm wet seasons. It is advised to use low rates of atrazine as a spike rather than risk unacceptable crop damage.</td>
</tr>
<tr>
<td>Diuron</td>
<td>Diuron is a Group C herbicide with a different mode of action to the triazines (simazine, atrazine and metribuzin). It can be used as a pre-emergence herbicide at rates up to 2.0 L/ha. It is not commonly used because it often gives poorer grass weed control than simazine. Diuron should not be used on grey or white sand as it can cause unacceptable crop damage.</td>
</tr>
<tr>
<td>Trifluralin (e.g. Treflan®)</td>
<td>Trifluralin can be mixed with other pre-emergence herbicides to increase ryegrass control if simazine is not expected to provide adequate control.</td>
</tr>
<tr>
<td>Pendimethalin (e.g. Stomp®)</td>
<td>Pendimethalin can be used for increased ryegrass control if simazine is not expected to provide adequate control and is particularly useful for wireweed control.</td>
</tr>
<tr>
<td>Triallate (e.g. Avadex®)</td>
<td>Wild oat control. Will suppress annual ryegrass.</td>
</tr>
</tbody>
</table>

Dry sowing
Traditionally, a large proportion of lupin crops were sown before the break of the season into dry soil. This has some advantages. Lupin emerges at the first opportunity in warm growing conditions and other crops can be sown as soon as it rains because lupin sowing is already complete. Weed control can be effective if pre-emergence herbicides work well, but often they do not. The main reasons why pre-emergence herbicides can fail to control weeds adequately in dry sown lupin crops are listed below.

1. Low soil moisture limits the uptake of pre-emergence herbicides such as simazine, atrazine and diuron. Weeds that do not accumulate enough chemical are not controlled.
2. The incorporation of these herbicides into the soil is not as even if they are applied dry and tilled in dry soil compared to being washed into the soil by rain and tilled in moist soil. Poor incorporation will reduce the amount of chemical that weed seedlings accumulate.
3. Surviving weeds may be resistant to selective post-emergence herbicides. This is an increasingly common problem.

Dry sowing is only recommended on land where few weeds are expected and there is good stubble cover (Figure 8.2). Simazine should be applied before sowing and rates increased by 200 to 400 mL/ha. Land with sandplain lupin should not be dry sown because this species cannot be controlled with selective herbicides.

Wet sowing on the break
Wet sowing enables a confident decision as to when the soil is moist enough to successfully sow the crop; there is no risk of a false break. If simazine is applied onto dry soil before the break and left as a band on the soil surface it will wash into the soil when the first rains come. This enables simazine to be incorporated much more effectively during the sowing operation. When simazine is well incorporated it will be taken up by weeds as they germinate. For this reason sowing on the break makes better use of soil incorporated herbicides than dry sowing.

Because of this many growers now prefer to wet sow on the break and do not set a date by which they will start sowing lupin (for example, Anzac Day). Instead, many set a date after which they will...
no longer sow lupin. This allows the logistics of the operation to be taken into account and leaves dry sowing as a late last resort if an opportunity for wet sowing has not occurred earlier.

**Delaying sowing to control a flush of germinating weeds**

If sowing is delayed until after the first flush of weed seedlings emerge, a large proportion of the weed population can be controlled effectively using non-selective herbicides. However, in most years delaying sowing leads to reduced yield, and in some years a sowing opportunity may be lost if there is a long time between the break and follow-up rain events.

**Double knockdown**

Double knockdown is the practice of applying a full label rate of glyphosate, followed one to 14 days later by a full label rate of Spray.Seed®. It reduces the likelihood of weeds developing resistance to glyphosate. It can be used in all cropping phases including lupin depending on the timing of the break to the season.

**Cultivation knockdown with delayed seeding**

For many good reasons, seeding operations have moved from full cut to minimum or no-till. The contribution that tillage makes to weed control at seeding has been reduced and more emphasis has been placed on herbicides. One method of incorporating a mechanical tillage operation into the seeding operation is to use wide sweep points (Figure 8.3). These points kill weed seedlings and seeds that have recently germinated but are still under the soil surface without the soil disturbance caused by traditional full cut cultivation.

**When does delayed sowing pay off?**

Delaying sowing will be beneficial if the yield increase achieved by better weed control exceeds the yield reduction caused by delayed sowing. For example, simulation modelling in the low rainfall environment of Buntine suggests that ryegrass densities must be reduced by at least 60 plants/m², or radish densities by at least two plants/m², to compensate for the yield loss caused by delaying sowing for one week.

In medium and high rainfall zones the yield loss from weed competition is potentially higher, but the yield loss from delayed sowing is proportionally lower. At Mingenew delaying sowing for a week is compensated for by controlling less than 20 ryegrass plants/m², or less than one radish plant/m².

Therefore, delaying sowing by one week to allow weeds to germinate before sowing is unlikely to pay off in low rainfall environments, unless seeding into a very weedy paddock. Conversely, it will probably pay off most years in medium to high rainfall environments where only a relatively small reduction in weed numbers makes it worthwhile.

One risk of delaying sowing is that the seedbed will quickly dry after the break so that the sowing opportunity may be lost. This risk is reduced if
Table 8.3 Yield loss of different varieties when sowing was delayed by one week (12 to 19 May 2005) at Mingenew

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Yield loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandelup</td>
<td>0</td>
</tr>
<tr>
<td>Belara</td>
<td>2</td>
</tr>
<tr>
<td>Wonga</td>
<td>7</td>
</tr>
<tr>
<td>Coromup</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 8.4 Summary of positive and negative aspects of seeding options

<table>
<thead>
<tr>
<th>Dry sowing</th>
<th>Wet sowing on the break</th>
<th>Delayed sowing for one week after the break</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>POSITIVES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logistically easy</td>
<td>No risk of false break</td>
<td>No risk of false break</td>
</tr>
<tr>
<td>Longest season length</td>
<td>Effective incorporation of simazine and reliable weed control</td>
<td>Effective incorporation of simazine and reliable weed control</td>
</tr>
<tr>
<td>Warm germinating conditions</td>
<td>Even lupin establishment</td>
<td>Even lupin establishment</td>
</tr>
<tr>
<td>Control over emergence date. In a late break year, avoids expenditure on crops with poor yield potential</td>
<td>Control over emergence date. In a late break year, avoids expenditure on crops with poor yield potential</td>
<td></td>
</tr>
<tr>
<td>Can use trifluralin effectively</td>
<td>Can use trifluralin effectively</td>
<td></td>
</tr>
<tr>
<td>Better assessment of paddock weed status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opportunity for a knockdown and weed control through tillage at sowing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less chance of expensive salvage operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Better weed control and less weed seed set</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No need to apply simazine to dry soil and lock paddocks out of cereal cropping until season’s prospect are clear</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NEGATIVES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk of false break and uneven establishment</td>
<td>Less crop in the ground from the first rain if sowing has to stop because the soil dries</td>
<td>Less crop in the ground from the first rain if sowing has to stop because the soil dries</td>
</tr>
<tr>
<td>Poor simazine incorporation</td>
<td>Drying of the soil caused by the sowing operation</td>
<td>Drying of the soil caused by the sowing operation</td>
</tr>
<tr>
<td>Crop may have to establish in drying soil which reduces simazine efficacy</td>
<td></td>
<td>In low rainfall areas large numbers of weeds must be controlled to compensate for yield loss caused by delaying sowing</td>
</tr>
<tr>
<td>No mechanical kill of weeds through tillage at sowing</td>
<td></td>
<td>There can be a long gap between the first two sowing opportunities</td>
</tr>
<tr>
<td>No control over time of emergence</td>
<td></td>
<td>Less suitable for low rainfall zones</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can delay sowing of cereals</td>
</tr>
</tbody>
</table>

There are good opening rains and soil moisture is maintained at adequate levels for sowing for several weeks without further rain. When this happens, sowing can be confidently delayed. In low rainfall areas the break often brings lighter rains than in medium and high rainfall areas and the likelihood of frequent follow-up rains is not so good. This is another reason for being cautious about delaying sowing for weed control in low rainfall areas.
Early maturing varieties
The cost of delayed sowing is reduced by using early maturing varieties. Varieties such as Belara and Mandelup flower five to six days earlier than other cultivars, reducing the requirement for very early sowing. This provides a better opportunity to delay sowing into May while maintaining yields (Table 8.3).

Poor weed control at sowing
If weeds are not controlled at sowing they have to be controlled by some other method, for example, extra post-emergence herbicide sprays or increased rates of application. Other costs may include crop topping, swathing, burning paddocks, burning windrows or using chaff carts. If weed seeds do return to the soil there will be increased costs for controlling weeds in future rotations and possibly restricted rotational options. These costs are difficult to predict and quantify. However, with increasing awareness of herbicide resistance there is generally a philosophy that weed seedbanks should be reduced and maintained at low levels. Blow-outs in weeds are no longer acceptable and this has been the major reason for the trend away from dry sowing (Table 8.4).

Crop competition
Researchers and agronomists have traditionally advised growers that lupin species are poor competitors with weeds. However, trials clearly show that weed growth can be reduced by selecting the right variety, seeding rate and row spacing.

Table 8.5 Effect of radish density on percentage yield lost from different lupin varieties

<table>
<thead>
<tr>
<th>Wild radish density (plants/m²)</th>
<th>Mandelup</th>
<th>Belara</th>
<th>Tanjil</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>16%</td>
<td>16%</td>
<td>24%</td>
</tr>
<tr>
<td>14</td>
<td>27%</td>
<td>37%</td>
<td>40%</td>
</tr>
<tr>
<td>28</td>
<td>32%</td>
<td>42%</td>
<td>49%</td>
</tr>
</tbody>
</table>

Lupin variety
More vigorous varieties are better able to compete with weeds. Mandelup will lose less yield due to competition from radish than Belara, and Belara will lose less yield due to competition from radish than Tanjil.

- Mandelup is the best lupin variety for weed control.
- It has excellent early vigour and competes strongly with weeds (Table 8.5).
- Its short duration allows delayed seeding without significant yield loss. Mandelup suffered no yield penalty as a result of being sown on 19 May compared to being sown on the 12 May at Mingenew in 2005. Belara and Wonga suffered 2 per cent and 7 per cent yield reductions (Table 8.3).
- It tolerates metribuzin well (Figure 8.4).
- It is well suited to crop topping or swathing because it flowers and matures early. Belara and Mandelup reach the 80 per cent leaf drop point seven to 10 days earlier than Tanjil.

Figure 8.4 Mandelup in the background is more tolerant of metribuzin than Tanjil in the foreground. Photo: M Harries
Row spacing

Weeds

Only sow lupin in wide rows (wider than 25 cm) if the paddock has few weeds, if selective herbicides still work well, or if a shielded sprayer will be used to control the weeds between the rows. Weeds germinating between widely spaced rows will experience minimal competition and will grow vigorously. Do not leave tines in the ground that are not used for seeding (Figure 8.6). They stimulate the germination of ryegrass and throw herbicides out of the furrow, encouraging the ryegrass to grow unchecked. Removing tines also saves fuel and allows faster and easier seeding.

Yields

In central and northern parts of the wheatbelt, lupin can be grown in wide rows, 50 cm apart, without compromising yield. Plants grown in wide rows are generally taller than those in narrower rows which reduces harvest loss (Figure 8.7). See Chapter 6 Crop establishment for more information on row spacing.

Impact of ryegrass and radish on lupin yields

Ryegrass and wild radish compete for space, light and nutrients with the lupin crop. For each radish plant/m², there is a 5 per cent reduction in lupin yield (Figure 8.8). Similarly, for every 25 ryegrass plants/m² there is a 5 per cent reduction in lupin yield (Figure 8.9).
Post-emergence chemical weed control

Tips for the best use of broad-leafed herbicides

- There is a very low incidence of weeds with resistance to triazine herbicides (simazine, atrazine and metribuzin). Maximise the effectiveness of these herbicides by wet sowing and by sowing varieties with good tolerance to triazines.
- Spray when the weeds are small. Diflufenican, simazine and metribuzin will not kill large radish (refer to labels for details).
- Prior to weeds developing resistance to diflufenican, low rates of diflufenican gave acceptable control. This no longer applies. High rates must be used on radish that is no bigger than 4-leaf point.
- Early germinating radish plants produce more seed than those that germinate later. Also, a higher proportion of the seeds set on early germinating radish plants are dormant. Hence, it is more important to kill early germinating seedlings rather than wait for another germination (Figure 8.10).
- Maximum label rates of diflufenican and metribuzin are 100 mL/ha diflufenican and 150 g/ha metribuzin. Safe rates will vary.
- Metribuzin causes more crop damage in colder climates.
- Do not use metribuzin on Tanjil or Wonga lupin.
- Mandelup is the variety with the best tolerance to broad-leafed herbicides. Use Mandelup wherever anthracnose is not a major consideration.
- Radish that are resistant to Group B herbicides (for example, chlorsulfuron and triasulfuron) can also be resistant to metosulam (for example, Eclipse®).
- Picolinafen (for example, Sniper®) kills radish more rapidly than diflufenican and should be used if radish are getting large. However, more crop damage can be expected when using picolinafen compared to diflufenican.
- Radish populations resistant to diflufenican are also likely to be resistant to picolinafen.
Weed management

- Take care if plants have been damaged by insects. Leaf damage caused by redlegged earth mite and lucerne flea can cause increased herbicide uptake and plant damage.
- Do not apply post-emergence simazine if the crop is suffering from simazine damage.

**Tolerance of varieties to herbicides**

Not all lupin varieties have the same tolerance to herbicides and tolerance will vary strongly with seasonal conditions. Furthermore, the way herbicide tolerance trials are conducted may also affect the response of varieties to herbicides. Sometimes trials are seeded late in the year so that weed populations can be controlled prior to commencement of the trial. This can restrict yields and means that the timing of application of some chemicals is different to the usual application on a commercial crop. It is also difficult to include all varieties in the same herbicide tolerance trial.

For these reasons the results from herbicide tolerance trials must be carefully interpreted. Table 8.7 presents an interpretation of varietal responses to herbicides based on the results of herbicide tolerance trials and the experience of farmers and consultants. When using herbicides it is important to always follow instructions on the label. Tables 8.6 and 8.8 list information on post-emergent herbicides for lupins.

**Tips for the best use of grass herbicides**

- Know the resistance status of your weeds. In most cases, it is best to use the highest rate permitted on the label of Group A herbicides with a Dim chemistry, for example, clethodim.
- Old advice given when grass selective herbicides were very effective was not to spray too early. It was advised to wait for multiple germinations to control a large proportion of the weeds. Current advice is to spray no later than mid-tillering.
- It is now common for ryegrass to have a level of resistance to the herbicides. It is very difficult to control these weeds if they are left to grow into large plants. Current advice is to spray selective herbicides on ryegrass at or before mid-tillering, no later.
- Grass weeds need to be actively growing. Avoid spraying plants stressed by dry soil, cold weather or frost. Higher rates of herbicide will be required if weeds are stressed.

- Always use the recommended adjuvant and do not skimp on application rates.
- Do not mix grass selective herbicides and broad-leaved herbicides. This severely damages the crop.

**Spray drift and spray unit contamination**

Lupin crops can be seriously damaged by some herbicides from spray drift or contaminants in spraying equipment.

Lupin crops are susceptible to all the hormone herbicides, such as 2,4-D, dicamba, MCPA and 2,4-DB. Spraying these chemicals directly on the crop or spray drift in strong winds will cause severe damage to lupin. Highly volatile (easily vaporised) chemicals such as 2,4-D ester may drift several kilometres under still conditions (for example, if there is an inversion layer of air on a cool morning). If 2,4-D is to be used in an area where lupin is grown, the 2,4-D amine 50 per cent (very low volatility) or 2,4-D LV ester 60 per cent formulations must be used.

**Figure 8.11 A shielded sprayer** Photo: P Newman

Misters and boom sprays should always be cleaned out after use to ensure all tanks, hoses, filters and nozzles are free of chemical residues.

**Shielded spraying**

When lupin is sown in rows that are 50 cm or wider, shielded sprayers (Figure 8.11) can be used very effectively to control weeds. Plastic shields covering the spray nozzles travel between crop rows. This stops herbicides drifting onto the crop and allows cheap, non-selective herbicides to be used between crop rows. The use of costly selective herbicides is reduced while the range of chemicals that can be used to control weeds is increased. The technology for shield sprayers is developing at a rapid pace alongside advances in tractor guidance systems.
### Table 8.6 Post-emergence broad-leaved herbicide options

<table>
<thead>
<tr>
<th>Post-emergence herbicide</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simazine top-up</td>
<td>Cheapest option for post-emergence weed control in lupin. Up to 1 L/ha four weeks after emergence. Do not use if the crop is suffering from damage caused by earlier simazine application. Gives some grass weed control. Use lower rates for furrow sown crops. Works by root uptake so will not control large emerged weeds.</td>
</tr>
<tr>
<td>Diflufenican</td>
<td>Group F herbicide to control wild radish and turnip. Residual activity, so best control will be achieved by spraying early when most radish plants are still emerging, 2- to 4-leaf stage. Less effective under cold, dry conditions. Suppresses capeweed but does not kill it; has little effect on doublegee. Tank mixes with simazine or metribuzin improve the control of doublegee.</td>
</tr>
<tr>
<td>Picolinafen</td>
<td>Group F herbicide with very similar chemistry to diflufenican registered for use at the 2- to 4-leaf stage of the crop. At label rates of 33 g and 50 g it is more damaging than diflufenican at the corresponding rates of 100 mL/ha and 200 mL/ha. Generally speaking, picolinafen has greater knockdown activity but less residual than diflufenican.</td>
</tr>
<tr>
<td>Metribuzin</td>
<td>Group C herbicide, the same as simazine and atrazine. Metribuzin should not be used on susceptible varieties including Wonga and Tanjil. Mandelup and Coromup are the most tolerant varieties. Higher rates of metribuzin can be used in northern regions without causing crop damage. In the central wheatbelt a recommendation of 70 mL/ha tank mixed with diflufenican is common. In northern areas rates of 100 mL/ha and above, tank mixed with diflufenican, are common. It is more damaging to the crop in areas south of the Great Eastern Highway. In these areas often it is best to spray simazine and diflufenican on small weeds rather than waiting for lupin to be big enough to spray with metribuzin.</td>
</tr>
<tr>
<td>Metosulam</td>
<td>Group B herbicide used as a late post-emergence application for control of radish and suppression of other broad-leaved weeds including doublegee, capeweed, mustard and wild turnip. Resistance to this group of herbicides has developed rapidly. Radish that are resistant to Group B herbicides (for example, chlorsulfuron and triasulfuron) can also be resistant to metosulam.</td>
</tr>
<tr>
<td>Diflufenican or picolinafen mixed with metribuzin</td>
<td>A common post-emergence herbicide application at the 4- to 8-leaf stage is 100 mL/ha diflufenican combined with 70 g/ha to 120 g/ha metribuzin, depending on location. Use only on varieties that tolerate metribuzin (not Tanjil and Wonga). Picolinafen can be applied in combination with metribuzin. However, this mixture has poorer crop safety than diflufenican and metribuzin.</td>
</tr>
</tbody>
</table>
Weed management

Producing lupins

Reducing weed seed set
Lupin can be swathed or crop topped in order to reduce seed set of late germinating weeds, particularly ryegrass.

Swathing
Traditionally, swathing is used to harvest poor crops in order to obtain enough bulk to process through the header. More recently, it is being used as a method to reduce weed seed set and to concentrate weed seeds within a manageable area.

Timing for efficient swathing is critical. Swathing too early results in seed with green cotyledons and yield loss. Swathing too late causes yield loss through pod drop and shattering. Swathing can be carried out earlier than crop topping, near the start of leaf drop when the stems and leaves have turned light green. Depending on the season and variety the window for safely swathing is one to two weeks. Most losses occur when picking the swath up; this should be done as soon as grain has dried down enough to meet receival standards (14 per cent moisture). Extra care will need to be taken with varieties that shed seed easily, such as Kalya.

Crop topping

Timing
Desiccant herbicides Gramoxone® and Reglone® can be applied at the 80 per cent leaf drop point of the lupin crop with little yield loss (Table 8.10 and Figure 8.14). Short season varieties like Belara and Mandelup reach 80 per cent leaf drop stage seven to 10 days earlier than longer season varieties like Tanjil and are well suited to crop topping.

The ideal timing to control seed set of ryegrass is from flowering to the soft dough stage of the ryegrass. If dough can not be squeezed from the ryegrass seed it will be viable even if crop topped. In wet spring conditions the duration of flowering and podding of the lupin crop can be extended due to the indeterminate growth habit of the crop. This prolongs the time until 80 per cent leaf drop of the crop. In this situation ryegrass can develop past the dough stage before the crop is ready to crop top. Hence, crop topping is a seasonally dependent tool that cannot be relied upon each year.

Table 8.7 Varietal tolerance to registered broad-leafed herbicides

<table>
<thead>
<tr>
<th>Herbicides</th>
<th>Varietal tolerance</th>
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</thead>
<tbody>
<tr>
<td>Before sowing</td>
<td>After sowing</td>
</tr>
<tr>
<td>simazine⁴</td>
<td>simazine simazine 500 mL/ha 2- to 6-leaf</td>
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<tr>
<td>simazine</td>
<td>Brodal® 200 mL/ha 2- to 6-leaf</td>
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<tr>
<td>simazine</td>
<td>Sniper® 50 g/ha 2- to 6-leaf</td>
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<tr>
<td>simazine</td>
<td>metribuzin¹ 80 to 120 g/ha 2- to 6-leaf</td>
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<tr>
<td>simazine</td>
<td>Brodal® 100 mL/ha + simazine 500 mL/ha 4- to 8-leaf</td>
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<tr>
<td>simazine</td>
<td>Brodal®100 mL/ha + metribuzin 70 to 110 g/ha 4- to 8-leaf</td>
</tr>
<tr>
<td>simazine</td>
<td>Sniper® 30 g/ha + metribuzin 70 to 100 g/ha 4- to 8-leaf</td>
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<tr>
<td>simazine</td>
<td>Eclipse® 10 g/ha 8- to 12-leaf</td>
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</table>

A Safe simazine rates before sowing will vary depending on soil type. Refer to label.
B High rates of metribuzin can be used in northern regions without causing crop damage. In the central wheatbelt or areas further south, a recommendation of 70 mL/ha tank mixed with diflufenican is common.
C Metribuzin should not be used on Tanjil or Wonga.
### Table 8.8: Registered herbicides for use in lupin

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<thead>
<tr>
<th>Group</th>
<th>Ryegrass</th>
<th>Brome grass</th>
<th>Barley grass</th>
<th>Silver grass</th>
<th>Wild oat</th>
<th>Wild radish</th>
<th>Wild turnip</th>
<th>Wild mustard</th>
<th>Doublegrass</th>
<th>Capeweed</th>
<th>Wire weed</th>
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<table>
<thead>
<tr>
<th>Timing</th>
<th>PRE-EMERGENCE</th>
<th>POST-EMERGENCE</th>
<th>PRE-HARVEST</th>
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</table>

**U** = useful, **S** = suppression
Case Study

Effective shielded spraying

In 2005 a paddock known to have ryegrass resistant to clethodim (for example, Select®) and radish resistant to metosulam (for example, Eclipse®) and developing resistance to diflufenican (for example, Brodal®) was sown to a variety of crops. Shielded spraying on a wide row lupin crop gave the most effective control of ryegrass and produced the highest gross margin of all methods tested (Table 8.9, Figures 8.12 and 8.13). Wide row lupin had two shielded spraying operations on 7 July and 17 August. Each shielded spraying operation included a knockdown between rows and strong rates of selective herbicides applied to the rows. Narrow row lupin were managed conventionally.

Figure 8.12 Weed burden after shielded spraying on wide row lupin. Yield 3.6 t/ha. Photo: M Harries

Figure 8.13 Weed burden after conventional spraying on narrow row lupin. Yield 2.3 t/ha. Photo: M Harries

Table 8.9 Yield, quality and gross income of crops grown in a paddock with herbicide-resistant ryegrass at Wongan Hills

<table>
<thead>
<tr>
<th>Variety</th>
<th>Ryegrass plants/m²</th>
<th>Ryegrass seed production/m²</th>
<th>Yield (t/ha)</th>
<th>Gross Income ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erica and Margurita (pasture)</td>
<td>52</td>
<td>14,500</td>
<td>1.2</td>
<td>0</td>
</tr>
<tr>
<td>Wyalkatchem (wheat)</td>
<td>112</td>
<td>27,500</td>
<td>2.2</td>
<td>389</td>
</tr>
<tr>
<td>Shielded spraying (Mandelup lupin in 50 cm wide rows)</td>
<td>47</td>
<td>4,000</td>
<td>3.3</td>
<td>415</td>
</tr>
<tr>
<td>Conventional spraying (Mandelup lupin in 25 cm wide rows)</td>
<td>123</td>
<td>19,000</td>
<td>2.3</td>
<td>290</td>
</tr>
<tr>
<td>Beacon: canola</td>
<td>66</td>
<td>24,000</td>
<td>1.2</td>
<td>396</td>
</tr>
</tbody>
</table>
Herbicides
Registered herbicides include Reglone® (diquat) at 1 to 2 L/ha and Gramoxone® (paraquat) at 400 to 800 mL/ha. Gramoxone® is registered for ground application only. Reglone® is registered for misting and aerial spraying.

Efficacy
Usually 50 to 95 per cent of the ryegrass will be between flowering and soft dough stages at the same time and can be controlled by crop topping. Radish seed set control ranges widely from 15 to 85 per cent. This is because radish germinates throughout the year and sets seed on many branches. Recent research and farmer observations suggest that radish germination is less staggered and easier to target with early weed control strategies in the year after crop topping. There is evidence that this occurs because crop topping stops the formation of pod wall. Seed contained in a pod with a thinner wall is likely to have reduced physical dormancy.

Other considerations
- Yield losses from wheel tracking can be as high as 10 per cent when using conventional booms in tall crops and about 3 to 5 per cent when using self-propelled sprayers. Aerial application is preferred if a self-propelled boom is not available.
- Crop topping when sandplain lupin is present will reduce shedding of its seed and may cause a grain contamination issue.
- Seed from crop topped paddocks should be kept for seed because germination and vigour of the seed may be reduced.

Crop topping with other weed management practices at harvest
Crop topping increases the speed at which weeds die off and weed seeds drop to the ground. Because of this the use of crop topping reduces the effectiveness of any method that captures seed at harvest. If capturing weed seed at harvest after crop topping, by using a chaff cart, baling lupin straw or making windrows, the crop should be harvested as soon as possible. This will ensure the maximum possible amount of weed seed is processed through the header.

Removing and destroying weed seed
Catching weed seed at harvest
Catching weed seed and destroying it substantially reduces the carryover of seed from the lupin crop into the next crop. Burning chaff that has been caught in a chaff cart or placed in windrows is an effective method of destroying seed.

Chaff carts
Chaff carts offer a reliable method of catching seed and are very effective at rapidly decreasing large banks of weed seed (Figure 8.15). Chaff carts will only catch seed that has not fallen to the ground so to use them most effectively the crop should be harvested as soon as it is ready. Typically, 45 to 75 per cent of ryegrass seed and 70 to 80 per cent of wild radish seed is collected in a chaff cart.
Hay cutting and baling
Baling behind the header is a successful method to reduce weed seed banks. It can remove up to 98 per cent of the weed seed that enters the header. Increased mineral nutrient input is required to budget for exported nutrients in the straw and a powerful header is required to tow the baler. To make this operation viable a market for the hay must be in place, such as an export hay market or feed processing plant.

Destroying weed seed after harvest
Paddock stubble burning
Burning entire paddocks on sandplain soils needs to be carried out with extreme caution. It is generally undertaken very close to seeding, if at all.

Burning narrow windrowed lupin stubble
Burning lupin chaff that has been placed in a narrow windrow is another effective method to destroy ryegrass and radish seed (Figure 8.16). The burn kills almost all the seed in the windrow. Seed that has dropped to the ground before going through the header is not controlled. Therefore, to get the most from this operation the crop should be harvested as soon as it is ready. It is best to harvest weedy paddocks first to minimise shedding of weed seed.

The art of burning
It is important to burn only the fraction of stubble and chaff that contains weed seed and leave the majority of the paddock alone. A successful burn depends on a fire that burns hot enough for long enough to guarantee destruction of weed seed. The easiest way to achieve this is to concentrate as much dry matter (stubble residue) into as small an area as possible along with the weed seed (Figure 8.17). This is why burning narrow windrows is so effective.

- Concentrate crop residues into 500 mm to 600 mm wide windrows using a simple chute mounted to the rear of the header. Narrow windrows concentrate stubble to 20 to 40 t/ha and cover about 5 per cent of the paddock.
- Harvest low to minimise the risk of the fire spreading into adjacent stubble. This also maximises the amount of fuel for burning.
- Windrows should be aligned so that they can be burnt diagonally into the prevailing winds. This reduces the speed of travel of the fire while allowing wind to fuel the fire from the side of the windrow. The result is a hot, slow burn which effectively kills all weed seed (Figure 8.18).

Figure 8.15 Chaff piles ready for burning
Photo: W Parker

Figure 8.16 Creating a windrow and burning lupin stubble kills over 95 per cent more radish seed than a simple whole-paddock burn.
Source: D Chitty and M Walsh
• When windrows are burnt across the direction of the prevailing wind, the efficiency of the burn is reduced. There is also greater likelihood of fire escapes and wind erosion problems after the burn.
• Do not compromise. Make sure conditions are right for burning, that is, warm weather with a light wind. Otherwise, weeds will not be killed and will germinate in high numbers the following year (Figure 8.19).
• It is easier to contain the fire in lupin stubble than in wheat or barley stubble because it contains less leaf.
**Weed Management Time Line**

<table>
<thead>
<tr>
<th><strong>PRE-SOWING</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paddock selection</strong></td>
<td>Target a low weed burden paddock. Less than 20 to 30 ryegrass plants/m² or less than 1 radish plant/m²</td>
</tr>
<tr>
<td><strong>Early herbicide application</strong></td>
<td>Apply simazine on dry soil up to three weeks before sowing. Opening rains will incorporate simazine into the soil. Further incorporation by seeding after the break will ensure many weed seedlings will come in contact with the herbicide and be killed.</td>
</tr>
<tr>
<td><strong>Variety selection</strong></td>
<td>Use Mandelup for improved competition against weeds except where the risk from anthracnose is high.</td>
</tr>
<tr>
<td><strong>Seed quality</strong></td>
<td>Check germination percentage to ensure good crop emergence. Germination can be reduced by crop topping, storage and handling conditions, moisture content at harvest, seasonal growing conditions, seed size and insect damage.</td>
</tr>
<tr>
<td><strong>Clean seed</strong></td>
<td>Only sow clean seed—do not introduce weed problems.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>CROP ESTABLISHMENT</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dry sowing</strong></td>
<td>Only dry sow lupin into a paddock that has a very low weed burden. Simazine requires moisture to be most effective. Weed control after dry sowing is likely to be variable.</td>
</tr>
<tr>
<td><strong>Wet sowing</strong></td>
<td>Wet sowing provides more even germination of weeds and lupin. Wet sowing allows simazine to work more effectively.</td>
</tr>
<tr>
<td><strong>Target crop density</strong></td>
<td>Aim for 45 plants/m² to ensure the crop is competitive against weeds.</td>
</tr>
<tr>
<td><strong>Row spacing</strong></td>
<td>Row spacing will influence crop competitiveness. Narrow rows ensure the crop is competitive against weeds due to higher plant densities. Use wide rows only if the paddock is very clean or shielded spraying is planned.</td>
</tr>
<tr>
<td><strong>Pre-emergence weed control</strong></td>
<td>If unsure of ryegrass numbers, use trifluralin. If using trifluralin in more than one cropping phase, consider resistance risk.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>POST-EMERGENCE</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Insect pest management</strong></td>
<td>Damage by redlegged earth mites or lucerne fleas can result in increased post-emergence herbicide uptake and damage to the crop. Damage by insects may make the crop less competitive.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>POST-EMERGENCE BROAD-LEAFED WEED CONTROL</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2- to 6-leaf crop</strong></td>
<td>Available options include simazine top-up; diflufenican (for example, Brodal® Options); or picolinafen (Sniper®). Apply early as these options are most effective on small radish. Do not apply simazine to plants showing symptoms of simazine damage.</td>
</tr>
<tr>
<td><strong>6-leaf crop</strong></td>
<td>Use metribuzin in a mixture with diflufenican (for example, Brodal® Options) on tolerant varieties. Mandelup and Coromup are the most tolerant varieties. Metribuzin is more effective on weeds and less damaging to the crop in the northern wheatbelt.</td>
</tr>
<tr>
<td><strong>8-leaf to flower bud</strong></td>
<td>Use metosulam (Eclipse®) for radish plants that have up to eight leaves or are about 20 cm in diameter. Radish that are resistant to Group B herbicides (for example, chlorsulfuron and triasulfuron) can also be resistant to metosulam.</td>
</tr>
</tbody>
</table>
Weed Management Time Line cont.

**POST-EMERGENCE GRASS WEED CONTROL**

<table>
<thead>
<tr>
<th>Herbicide Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simazine top-up</td>
<td>Very limited benefit for grass weeds. Some late emerging or very small 1- to 2-leaf ryegrass may be controlled. Simazine has limited activity on larger grass weeds.</td>
</tr>
<tr>
<td>Grass selective herbicides</td>
<td>Where herbicide resistance is not a problem, grass selective herbicides (Group A herbicides with a Fop or Dim chemistry) can be used. The most effective grass weeds herbicides are often strong rates of Dim herbicides. However, be sure to know the resistance status of your weeds and choose the most effective chemical. Lupin crops provide an important opportunity to manage brome grass with Group A grass selective herbicides. Do not mix post-emergence grass selective herbicides with broad-leafed herbicides because crop damage will occur.</td>
</tr>
</tbody>
</table>

**FLOWERING**

- **No suitable selective weed control options**
  - Herbicide application during flowering may result in flower loss and reduced yield.

- **Cut your losses**
  - If weed numbers have exploded out of control this is the time to green or brown manure a failed lupin crop to maximise renovation benefits. When brown manuring, use a double knockdown strategy to ensure that none of the weeds set seed.

**LEAF DROP**

- **50 per cent leaf drop**
  - Swathing will reduce seed set in ryegrass effectively, but will not control a high proportion of seed set in radish. Yield losses can occur when picking up swaths. Swathed lupin should be harvested as soon as possible.

- **80 per cent leaf drop**
  - Crop topping will reduce seed set in ryegrass, but often will not control a high proportion of seed set in radish. Yield losses of 5 per cent are common. Do not keep seed from topped areas because viability may be reduced.

**HARVEST**

- **Timing**
  - Harvest as early as possible before weed seeds fall to the ground.

- **Residue management**
  - Catch or minimise spread of weed seed by using chaff carts or by concentrating residues in windrows (narrow header trails) for burning in autumn.

**Further reading**


Newman, P & Adam, G 2005, Case Studies of Integrated Weed Management. GRDC project DAW 672, Department of Agriculture and Food, Western Australia, South Perth.

Newman, P 2006, Focus Paddocks, Case studies of integrated weed management, Department of Agriculture and Food, Western Australia, South Perth.


9 Diseases of lupin
Geoff Thomas, Roger Jones and Vivien Vanstone
Lupin species are susceptible to a wide range of diseases, most of which are caused by fungal or viral pathogens. Roots, hypocotyls, stems, pods and seeds of lupin are all subject to infection by disease organisms. Several of these diseases have the capacity to cause catastrophic losses, but this is rare if management guidelines are followed. Key steps in the integrated management of lupin diseases include crop rotation, stubble management, fungicide or pesticide application, variety selection and seed testing. Table 9.1 summarises root and hypocotyl diseases of lupin, Table 9.2 presents anthracnose risk in lupin zones and Table 9.3 summarises stem, leaf and pod diseases of lupin.

**Fungal diseases**

**Root and hypocotyl diseases**

*Pleiochaeta root rot*

Pleiochaeta root rot is caused by the fungus *Pleiochaeta setosa*, the same fungus that causes brown spot.

**Symptoms**

Plants affected by pleiochaeta root rot are usually widespread within a paddock and generally appear weak and frail. Severely affected plants wilt and die. Infection can begin shortly after germination and produces dark brown or black lesions on the taproot that can completely rot off the root. Less severe lesions strip off the outer layer or cortex of the taproot which prevents nodulation in this part of the root. As the taproot thickens, after the 6- to 8-leaf point, susceptibility to infection declines. Lateral roots, however, are susceptible for longer periods and are often pruned off. The *Pleiochaeta* fungus does not infect the hypocotyl.

**Disease cycle**

Leaves infected with *Pleiochaeta setosa* drop to the ground where the fungus sporulates (Figure 9.1). Disturbing the soil through cultivation and sowing will incorporate the spores into the surface layer. Spores remain dormant in the soil over summer and survive through non-lupin crops sown in the paddock (although their population declines over time). When the next lupin crop is sown, spores germinate and infect the lupin roots causing pleiochaeta root rot. Raindrops also splash spores from the soil surface up onto new leaves where they infect and cause brown spot, thus continuing the disease cycle.

**Disease risk and predisposing factors**

Disease severity is determined by the number of spores and their distribution in the soil. A high number of spores distributed close to the seed will cause severe disease. Spores of *P. setosa* are present in all paddocks that have previously grown lupin but their numbers decline over time when lupin is not grown. High numbers of spores are most likely where lupin is grown in close rotation. Pleiochaeta root rot may also be worse in soils with a higher clay content.

**Losses**

Pleiochaeta root rot reduces yield by killing seedlings, which decreases plant density. In paddocks with severe pleiochaeta root rot, plant density may be halved which cuts the crop’s yield potential by 20 to 40 per cent. Plant vigour and grain filling may also be reduced in plants that have rotted tap and lateral roots.
Management

Managing crop rotations is the key to controlling pleiochaeta root rot. The number of spores in the soil halves every year lupin is not grown; consequently, long intervals between lupin crops will reduce pleiochaeta root rot. Spore numbers are usually high directly after a lupin crop and double cropping is not recommended for lupin. If the spore population is very high, a two- or even three-year break from lupin may be necessary to reduce the spore population to safe levels (spore population can be determined by a soil test).

Reduced tillage also helps to manage pleiochaeta root rot. Most Pleiochaeta spores are deposited close to the soil surface and remain there if the soil is not disturbed. Seed placed below the main spore layer (> 3 cm) using reduced tillage implements will have a much lower exposure to infection.

Most varieties of narrow-leafed lupin are susceptible to pleiochaeta root rot. Kalya has the highest level of resistance of the commercial varieties available; it is classified as moderately resistant. Albus lupin varieties are also susceptible but yellow lupin is immune. Fungicide seed treatments containing iprodione or procymidone (used to control brown spot) do not give consistent control of pleiochaeta root rot. However, partial control has occurred occasionally at high rates.

**Rhizoctonia bare patch**

Rhizoctonia bare patch is caused by a strain of the fungus *Rhizoctonia solani* called either ZG1 or AG8. Rhizoctonia bare patch is seen throughout the wheatbelt. It occurs on most soil types and causes similar patches in all crop and pasture species (not just lupin). All varieties and species of lupin are equally susceptible.

**Symptoms**

Plants affected by the disease are stunted and occur in distinct patches. The patches are roughly circular with a diameter varying from 0.5 m to 5 m. Patches may be elongated in the direction of sowing. The tap and lateral roots of stunted plants are pinched off by a characteristic dark brown
spear-tipped lesion. As the season progresses damaged plants often die. The patches appear more spectacular as the crop matures, but infection actually starts in the seedling stage, usually before the 2- to 4-leaf point.

**Disease cycle**
Rhizoctonia bare patch has a wide host range and is as damaging to cereal and pasture species as it is to lupin. The fungus survives between seasons as tough hyphae in crop debris or in particles of soil organic matter that it has colonised. It is stimulated to grow in the following season once the soil becomes moist.

**Losses**
Yield loss from rhizoctonia bare patch is related directly to the size and number of patches in the paddock. The yield from within the patches is close to zero.

**Management**
Rhizoctonia bare patch has a wide host range and cannot be controlled by rotating crops. It is most severe in crops established with zero or minimum tillage. Tillage to a depth of 10 to 15 cm at about the time of sowing reduces the number and severity of patches. Modification of seeding machinery to cultivate 5 to 10 cm below the sowing depth will provide effective disease control in a *direct drilling* (one pass) operation. Patches can also be controlled by deep ripping (25 to 30 cm) immediately before or after seeding.

**Eradu patch**
Eradu patch is caused by a thin binucleate *Rhizoctonia*. It causes patches in narrow-leaved lupin crops that are similar to rhizoctonia bare patch. It does not cause patches in canola or wheat crops. Patches in barley are indistinct areas of weak plants. Eradu patch affects all varieties of narrow-leaved lupin equally, but does not affect albus or yellow lupin. It is most common on the sandplain soils in the northern agricultural area and has also been identified in narrow-leaved lupin crops around Badgingarra, Wubin, Wongan Hills and Merredin.

**Symptoms**
Roughly circular patches with diameters of 0.5 m to 10 m and distinct edges become apparent in the crop seven to eight weeks after sowing (Figure 9.2). Patches may have a doughnut appearance with severely stunted or dead plants near the edge and less stunted plants near the centre. Several patches close by may coalesce into large irregular areas of stunted plants. Taproots are not usually severed but often have red or brown lesions with the outer layer (cortex) of the root stripped off (Figure 9.3). Lateral roots can be pinched off by red or brown spear-tipped lesions. Nodulation is also reduced.

**Disease cycle**
The fungus survives between seasons as resistant hyphae in fragments of dead root colonised by the fungus or in particles of organic matter in the soil. After the break of the season the fungus grows out of these spaces to infect roots of susceptible plants.

**Losses**
Loss of yield is related to the area of a paddock affected by the patches. Yields within the patches vary, but are usually low depending on the severity of the infection.
Management
Rotating crops effectively manages Eradu patch. Two years of pasture, wheat or canola prior to lupin reduces the severity of the disease but a barley crop prior to lupin increase the severity. Barley is only slightly affected by the disease but is an excellent host that builds up the fungus. Yellow lupin and albus lupin are resistant to Eradu patch and can be substituted for narrow-leafed lupins in disease prone paddocks, provided anthracnose is not endemic (see Anthracnose below). The fungus can also spread with infected soil carried on machinery.

All varieties of narrow-leafed lupin are equally susceptible to Eradu patch. Neither soil cultivation nor fungicide seed dressing will reduce the disease.

Rhizoctonia hypocotyl rot
Three separate strains of the soil-borne fungus *Rhizoctonia solani* (ZG3, ZG4 and ZG6) cause hypocotyl rot of lupins (ZG6 causes hypocotyl rot and root rot). The symptoms and management for all three strains of hypocotyl rot are the same. This disease is common on the sand and sandy loams of the northern wheatbelt, west Midlands and the South Coast sandplain. All lupin species and many other legume species are susceptible to this pathogen.

Symptoms
Reddish-brown lesions that develop on the hypocotyl are characteristic of this disease (Figure 9.4). The hypocotyl is the below-ground portion of the stem of lupins. Seedlings are infected soon after they germinate. Sometimes they completely rot before they emerge. From emergence to the 10-leaf point, infected seedlings wilt and die as the lesions grow and eventually rot through the hypocotyl. Infected plants that survive past the 10-leaf point often remain stunted and are less productive than healthy plants. Diseased plants occur generally as individual plants throughout the crop but may have a clumped distribution with several seedlings in a row showing symptoms.

Disease cycle
These strains of *Rhizoctonia* fungus infect the hypocotyls and roots of many species of crop and pasture legume but cause negligible damage to cereals. The fungus can survive in soil in the absence of legumes and can still infect lupin crops after two or more cereal crops. Most of the fungal inoculum is found in the top 5 cm of soil.

After the break of the season the fungus grows out to infect hypocotyls of lupin plants soon after germination. Plants are most susceptible in the two weeks after germination.

Losses
Most yield is lost from poor vigour and death of seedlings producing a low crop density. In severely affected paddocks plant establishment has been reduced by as much as 80 per cent.

Management
A range of techniques contributes to the management of this disease. Rotating crops is one of the most effective because the disease most often occurs in lupin after a legume pasture. The fungus is more active with warm soil temperatures and will be more prevalent in early sown crops. Damage to seedlings by pre-sowing herbicides can also increase incidence of hypocotyl rot. Sowing lupins less than 24 hours after applying glyphosate to a sandy soil can increase the incidence and severity of hypocotyl rot. Deep sowing increases the length of the hypocotyl and exposes more tissue to possible infection (except for ZG6, see below). If a disease-prone paddock is used, increase seed rates by 10 to 25 per cent to compensate for loss of seedlings during establishment. Finally, both iprodione- or procymidone-based seed dressings, which are applied for brown spot control, can reduce the severity of hypocotyl rot.

All varieties of narrow-leafed lupin are equally susceptible to rhizoctonia hypocotyl rot and soil cultivation will not reduce the disease.
Rhizoctonia ZG6
The ZG6 strain of *Rhizoctonia solani* causes rotting on the root and hypocotyl. Hypocotyl lesions appear identical to those caused by the ZG3 and ZG4 strains of the fungus. Root lesions are reddish-brown and if severed have more stubby ends than lesions caused by rhizoctonia bare patch fungus or pleiochaeta root rot. Major losses appear to result from reduced plant vigour and lower establishment. Management to minimise the effects of the ZG6 strain of this disease is similar to that for ZG3 and ZG4. However, because ZG6 attacks both the roots and hypocotyl, shallower sowing will reduce hypocotyl rot but may increase root rot. Furrow sowing techniques which allow seed to be sown deeper while being covered with less soil may be beneficial.

Sclerotinia collar rot
Sclerotinia collar rot is caused by the fungus *Sclerotinia minor* and should not be confused with *Sclerotinia sclerotiorum*, which causes a stem rot higher up the plant (see Stem, leaf and pod diseases below). *Sclerotinia* collar rot occurs most often in lush, wet crops in spring. Infected plants have a characteristic white fungal growth that attacks the stem at ground level (Figures 9.5 and 9.6). The fungal growth contains small black fruiting bodies, about the size of a pinhead, called sclerotia. Infected plants wilt and senesce prematurely. They become clearly noticeable in contrast to the healthy plants, particularly after the start of flowering. Often several closely grouped plants will be infected as the fungus grows between adjacent plants.

The fungus survives between seasons as sclerotia in trash and soil. The sclerotia germinate under suitable environmental conditions and infect plants as fungus grows out from the sclerotia. *Sclerotinia minor* can infect many broad-leaved crop and pasture species and is likely to be more prevalent in rotations containing broad-leaved species in close succession (for example, lupin following canola). Cereals do not host the fungus and will help reduce inoculum levels. It is rare for sclerotinia collar rot to cause large reductions in yield.

Minor root rots
*Pythium root rot* of lupin occurs on shallow duplex soils and other areas where the subsoil becomes saturated with water. Roots develop a black rot or the roots and hypocotyl develop water-soaked lesions. Infection can kill seedlings as they emerge or can create weak and stunted plants that wilt once the stem begins to elongate. Yellow lupin tolerates waterlogging better than narrow-leaved lupin or albus lupin and is probably less affected by pythium infection.

*Charcoal rot* is caused by *Macrophomina phaseolina*, which is a widespread soil-borne fungus but a weak pathogen. It attacks plants that are moisture-stressed late in the season when soil temperatures are warm. The stem and taproot near the soil surface become infected and when split open may have an ash-grey discolouration, partly caused by masses of tiny black microsclerotia embedded in the tissue. Charcoal rot does not usually reduce yields because infection takes place after the plant has completed pod set and the crop is approaching maturity. *M. phaseolina* has a wide host range, although cereal species are not normally infected.
<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Symptoms</th>
<th>Hypocotyl</th>
<th>Taproot</th>
<th>Lateral roots</th>
<th>Other hosts</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pleiochaeta root rot</strong></td>
<td>Thin stand, wilted plants, seedling death</td>
<td>Normal</td>
<td>Normal</td>
<td>Dark brown lesions stripping outer layer or completely rotting taproot</td>
<td>All agricultural plants</td>
<td>Deep sowing (~5 cm) and reduced incorporation of surface soil</td>
</tr>
<tr>
<td><strong>Rhizoctonia solani</strong> (AG8, ZG1)</td>
<td>Patches in the crop with distinct edges, elongated along the direction of cultivation, apparent 3 to 4 weeks after sowing</td>
<td>Normal</td>
<td>Reddish-brown lesions stripping outer layer of taproot</td>
<td>Dark brown lesions stripping outer layer or completely rotting root</td>
<td></td>
<td>Tillage below seeding depth (10 to 15 cm or deep rip) Avoid movement of infected soil between paddocks</td>
</tr>
<tr>
<td><strong>Eradu patch</strong></td>
<td>Patches in the crop with distinct edge, and sometimes a doughnut appearance; most severely stunted plants at edge, apparent 7 to 8 weeks after sowing</td>
<td>Normal</td>
<td>Reddish-brown lesions stripping outer layer of taproot</td>
<td>Dark brown lesions stripping outer layer or completely rotting root</td>
<td></td>
<td>No effect</td>
</tr>
<tr>
<td><strong>Rhizoctonia hypocotyl rot</strong></td>
<td>Thin stand, wilted plants, seedling death</td>
<td>Normal</td>
<td>Reddish-brown lesions stripping outer layer of taproot</td>
<td>Dark brown lesions stripping outer layer or completely rotting root</td>
<td></td>
<td>Shallow sowing seed dressed with fungicide Avoid early sowing on high-risk paddocks Avoid stressing seedlings with pre-sowing herbicides</td>
</tr>
<tr>
<td><strong>Rhizoctonia ZG6</strong></td>
<td>Thin stand, wilted plants, seedling death</td>
<td>Normal</td>
<td>Reddish-brown lesions stripping outer layer of taproot</td>
<td>Dark brown lesions stripping outer layer or completely rotting root</td>
<td></td>
<td>Furrow sowing seed dressed with fungicide Avoid early sowing on high-risk paddocks Avoid stressing seedlings with pre-sowing herbicides</td>
</tr>
<tr>
<td><strong>Sclerotinia collar rot</strong></td>
<td>Wilted plants, premature senescence, white fungal growth at ground level</td>
<td>Normal</td>
<td>Reddish-brown lesions stripping outer layer of taproot</td>
<td>Dark brown lesions stripping outer layer or completely rotting root</td>
<td></td>
<td>No effect</td>
</tr>
</tbody>
</table>

**Table 9.1 Root and hypocotyl diseases of lupin**

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Symptoms</th>
<th>Hypocotyl</th>
<th>Taproot</th>
<th>Lateral roots</th>
<th>Other hosts</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pleiochaeta setosa (same fungus as brown spot)</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>Rhizoctonia solani</strong> (ZG3 and ZG4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rhizoctonia solani</strong> (ZG6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sclerotinia minor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Lupin species**

<table>
<thead>
<tr>
<th>Lupin species</th>
<th>Narrow-leaved</th>
<th>Albus</th>
<th>Yellow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susceptible</td>
<td>Susceptible</td>
<td>Susceptible</td>
<td>Susceptible</td>
</tr>
<tr>
<td>Susceptible</td>
<td>Resistant</td>
<td>Susceptible</td>
<td>Susceptible</td>
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<tr>
<td>Susceptible</td>
<td>Resistant</td>
<td>Susceptible</td>
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<td>Susceptible</td>
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</tbody>
</table>

**Diseases of lupin**

Producing lupins 107
Stem, leaf and pod diseases

Brown spot

Brown spot is caused by the fungus *Pleiochaeta setosa*, the same fungus that causes pleiochaeta root rot. It is the most widespread disease of lupin in Western Australia. Any paddock that has grown lupin will have *Pleiochaeta* spores present in the soil. The disease has the greatest impact on yield when it occurs at the seedling stage and severe cases can kill large areas of crop.

**Symptoms**

Infected cotyledons develop dark brown spots, then rapidly die and drop off. Leaves develop dark brown spots, often net-like in appearance and can be distorted and reduced in size before prematurely dropping off (Figure 9.7). Small brown flecks may be evident on the stems that occasionally develop into large brown and black cankers which kill the stem above the infection point. Pods, particularly those set closer to the ground, may be flecked or develop large brown lesions (Figure 9.8).

**Disease cycle**

Leaves and other tissue infected with brown spot drop to the ground. The spores produced on this dead tissue become incorporated into the surface layers of the soil and remain dormant there over summer. They persist in the soil for several years through non-lupin crops, although their population reduces over time. After a lupin crop is sown, spores that are splashed upwards by rain droplets infect the cotyledons, leaves and stems of the new lupin plants. Newly infected leaves fall to the ground and with moist conditions large quantities of new spores are produced. These can in turn be spread by rain-splash to cause secondary infection throughout the crop.

**Disease risk and predisposing factors**

The number of *Pleiochaeta* spores in the soil, stubble coverage, climate and soil type have a large bearing on the severity of brown spot in a lupin crop.

*Pleiochaeta* spore numbers are greatest following a lupin crop. Spore numbers in the soil approximately halve every year under a non-lupin crop or pasture.

In the northern wheatbelt, because of higher winter temperatures, lupin grows rapidly out of the susceptible seedling stage and develops tall dense stands which reduce rain-splash of spores from the soil onto the foliage. In colder areas, growth rates are slower and plants remain small with prolonged exposure to rain-splash at the most susceptible 0- to 4-leaf point. They also take longer to grow away from disease on the lower leaves. In the lower rainfall areas, crops are less able to compensate for early setbacks in vigour because of the shorter growing season and early brown spot has a greater impact on grain yield. On unfavourable soil types, plants remain shorter and exposed to rain-splash for longer and do not finish as well, providing less opportunity to compensate for earlier disease.

Other stresses that reduce crop growth, such as phosphorus or potassium deficiency, waterlogging and herbicide damage, will make lupin more vulnerable to brown spot disease.
Management
Brown spot can be managed by combining several techniques. Extending the length of time between lupin crops reduces the number of spores in the soil. Retaining cereal stubble reduces the amount of rain hitting the soil and splashing spores onto plants. Usually, the greater the stubble cover, the better the disease control. Dressing seed with iprodione or procymidone fungicides protects the cotyledons and leaves of seedlings and should be used in conjunction with stubble retention for prolonged protection (Figure 9.9). Ensuring rapid growth and canopy closure of the crop by providing adequate fertiliser, high seeding rates and early sowing will help reduce the impact of the disease.

All varieties of narrow-leafed lupin and albus lupin are currently susceptible to brown spot infection. Yellow lupin is resistant.

Anthracnose
Anthracnose is caused by the fungus Colletotrichum lupini. All lupin species are affected, but generally albus lupin, yellow lupin and sandplain lupin are more susceptible than narrow-leafed lupin. It is potentially a damaging disease in all areas of Western Australia, but it is usually only a serious disease in the high rainfall areas of the northern agricultural region.

Symptoms
Anthracnose lesions can form on all above-ground parts of the lupin plant. The most distinctive symptom is the bending and twisting of stems with a lesion in the crook of the bend.
Diseases of lupin

(Figure 9.10). This is particularly noticeable when the crop is flowering. Stem lesions are usually dark brown and up to 2 cm long. A pale pinkish or sometimes orange spore mass develops within the lesions. The stem is often girdled by lesions or is so weakened that it breaks. Both the main stem and lateral branches can be affected and close inspection will often show similar symptoms on leaf petioles. Bean yellow mosaic virus can produce similar shepherd’s crook symptoms on stems, but will not produce lesions or spores.

Leaf lesions are not common but may occur. They are beige spots with a dark brown border. Pods develop lesions similar to stems and are often twisted and distorted (Figure 9.11). Pod infections can result in complete loss of pods or production of infected seed. Infected seeds can be malformed and can have brown lesions, fungal mycelium or pink spores on the seed surface. Seeds can also be infected without showing symptoms (Figure 9.12).

Disease cycle
Infection comes into a crop from two main sources: as infected seed or as spores spread from nearby infected lupin, such as sandplain lupin.

Seedlings growing from infected seed can develop lesions on the root, hypocotyl, cotyledons, leaf petioles or stems. After a few days, these lesions produce an abundance of spores, which are

![Diagram of the disease cycle](image)

*Figure 9.12 Seeds of narrow-leaved lupin infected with anthracnose* Photo: G Thomas

*Figure 9.13 Life cycle of the anthracnose fungus (Colletotrichum lupini)*
Source: M Sweetingham
spread through the crop by rain-splash (Figure 9.13). Most spores spread only a few metres, but some travel further when they are blown as aerosols by strong winds. Spread of more than 100 m has been recorded. Anecdotal reports suggest spores can spread more than 500 m as aerosols. Spores can be spread even longer distances by farm machinery, animals and insects.

Spores need a film of moisture on the plant surface for at least four hours to germinate and penetrate the tissue. More infection will result from longer periods of wetness. After penetration, the fungus colonises the plant tissue and develops a lesion within a few days. Warmer temperatures increase the rate of symptom development and spore production.

Stubble is not a major source of infection for lupin crops. Only a few spores survive on stubble over summer.

**Disease risk and predisposing factors**

The level of infected seed sown, climatic conditions, susceptibility of variety sown and proximity of other infected lupin all contribute to anthracnose risk (Table 9.2). Flower heads and pods of all varieties (including resistant varieties) are more susceptible to infection than stems and lateral branches. Pod set can be substantially reduced by infection on flower heads and pods. Consequently, yield loss will be greatest where infection within a crop or adjacent sandplain lupin becomes severe before flowering.

**Losses**

Severe anthracnose infection can kill seedlings and young plants. It limits yield of mature plants by reducing pod set—indirectly through weakening and breaking main stems and lateral branches and directly through infection of flowers and pods. The impact of anthracnose on yield is influenced by the source and level of inoculum, the variety sown and seasonal conditions, particularly rainfall (see Table 9.2). Complete crop loss is possible with very susceptible varieties grown in high-risk environments. Varieties with improved tolerance to the disease can lose 25 per cent of their yield when grown with high inoculum levels in wet seasons.

**Management**

The major steps for management of anthracnose are:

- use resistant varieties (for example, Tanjil)
- sow uninfected seed or seed with very low infection level
- apply thiram fungicide seed dressing
- control or avoid adjacent sandplain lupin.

All of these steps are required to manage anthracnose in high-risk areas.

Varieties that are susceptible to anthracnose should not be grown in high-risk areas but can be grown safely in lower risk areas. Very susceptible varieties should be grown only in low-risk areas using completely clean seed. Using totally clean

<table>
<thead>
<tr>
<th>Lupin zone*</th>
<th>Overall risk</th>
<th>Risk factors</th>
<th>Sandplain lupin</th>
<th>Rainfall</th>
<th>Winter temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 High rainfall–North</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Warm</td>
<td></td>
</tr>
<tr>
<td>2 Medium rainfall–North</td>
<td>High-moderate</td>
<td>Medium</td>
<td>Medium</td>
<td>Warm</td>
<td></td>
</tr>
<tr>
<td>3 Low rainfall–North</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Warm</td>
<td></td>
</tr>
<tr>
<td>4 High rainfall–Central and Great Southern</td>
<td>Moderate</td>
<td>Very low</td>
<td>High-medium</td>
<td>Cool</td>
<td></td>
</tr>
<tr>
<td>5 Medium rainfall–Central</td>
<td>Moderate-low</td>
<td>Very low</td>
<td>Medium</td>
<td>Cool</td>
<td></td>
</tr>
<tr>
<td>6 Medium rainfall–Great Southern and South Coast</td>
<td>Low</td>
<td>Very low</td>
<td>Medium</td>
<td>Cool</td>
<td></td>
</tr>
<tr>
<td>7 Low rainfall–East</td>
<td>Low</td>
<td>Very low</td>
<td>Low</td>
<td>Cool</td>
<td></td>
</tr>
<tr>
<td>8 South Coast</td>
<td>High-moderate</td>
<td>Very low</td>
<td>High</td>
<td>Cool</td>
<td></td>
</tr>
</tbody>
</table>

* See Figure 1.13 Lupin Zones map
seed is ideal in all varieties. However, under some circumstances a low level of seed infection can be tolerated. The amount of seed infection that can be tolerated depends on the susceptibility of the variety sown, the environment in which the seed will be sown (rainfall is most critical) and the use of a seed dressing of fungicide. Seed can be tested to determine the presence and quantity of anthracnose infection (see Chapter 5 Seed testing and seed treatments).

Fungicide seed treatments with the active ingredient thiram (used at a rate of 100 g active ingredient per 100 kg seed) reduce transmission of anthracnose from infected seed to seedlings by approximately 75 per cent. Thiram gives poor control of brown spot and should be used in conjunction with fungicides containing iprodione or procymidone where protection from that disease is required.

Application of fungicide sprays can reduce yield loss associated with anthracnose. The best responses in trials have occurred when fungicides are applied to protect flowers and pods. Crops in which this technique is likely to work are those with infection present prior to podding or those adjacent to infected sandplain lupin.

Fungicide registered for use on lupin will protect the plant from infection but will not stop infection developing once it has already occurred. Only the parts of the plant covered with the fungicide are protected. New growth that has appeared after a fungicide has been applied is not protected from infection.

Timing the application of fungicides so they protect most flowers and pods will have a large bearing on the effectiveness of fungicide sprays. Spraying fungicide before a rain front is most effective because it will protect plants from the infection that occurs when they are wet. Spraying when conditions are fine is less effective because anthracnose will not spread under dry conditions. When it does eventually rain, parts of the plant that have grown since the fungicide was applied will not be protected.

Sandplain lupin in pastures, along roads or in raceways are major reservoirs of infection. These patches should be destroyed if possible. Other strategies such as long-term storage of seed to reduce seed infection, rotation of paddocks to avoid the possibility of stubble-borne infection and taking care not to transport the fungus on vehicles and equipment will also help manage anthracnose disease.

**Phomopsis**

Phomopsis is caused by the fungus *Diaporthe toxica* which produces a mycotoxin when it grows in mature lupin stems. The toxin causes lupinosis in livestock grazing the infected stubble. Livestock can become sick or die from lupinosis, depending on the level of infection and how grazing is managed.

Sometimes phomopsis reduces crop yields. This occurs if lesions develop on a stressed plant prior to maturity which then causes the plant to lodge.

**Symptoms**

Symptoms of colonisation by *D. toxica* normally appear as purplish or grey lesions containing black fruiting bodies on dry stems, pods and stubble at the end of the growing season (Figure 9.14). The fungus infects the lupin plant while it is growing but rarely causes lesions unless the plant is stressed by drought, herbicide or frost. Occasionally lesions develop as the crop dries out. Small black fruiting bodies inside the lesions develop at varying rates depending on rainfall and humidity during the summer. If lesions develop on pods prior to harvest, seed can become infected and will show gold or brown discolouration. The seed may be shrivelled and contain low levels of mycotoxin.

**Disease cycle**

*Diaporthe toxica* survives between seasons as black fruiting bodies on colonised stubble. From early winter air-borne spores are produced from these fruiting bodies that then spread and infect lupin plants. The infection remains latent...
as microscopic structures until senescence of the plant tissue. Moisture on the mature infected tissue allows the fungus to grow as a saprophyte and produce new fruiting bodies.

**Management**
Choosing to grow resistant varieties is the easiest and most effective way to reduce phomopsis. Resistance of stems and pods to infection are controlled by separate genes. All modern lupin varieties have moderate levels of resistance to stem and pod infection.

If conditions favour the pathogen, modern varieties can still be infected by phomopsis. If there is sufficient rainfall during late spring and early summer, the stubbles of these crops can become toxic requiring care with grazing. Usually, however, modern lupin varieties do not produce highly toxic stubbles.

Specific strains of *D. toxica* are virulent on narrow-leafed, albus or yellow lupin. Within Western Australia the narrow-leafed strain occurs in most areas and usually does not infect albus or yellow lupin stems. Pods of albus lupin, however, are susceptible to all strains.

**Sclerotinia stem rot**
Sclerotinia stem rot is a disease of broad-leafed crops caused by the fungus *Sclerotinia sclerotiorum*. This disease is most common in higher rainfall areas and usually only affects plants after flowering. Lesions usually occur in the upper half of the main stem or in branches. The fungus produces a white cottony-looking growth that girdles the stem, causing the plant parts above the lesion to wilt and die. Hard, black, spherical resting bodies, 2 to 8 mm in diameter, called sclerotia, are often produced among the fungal growth or in the cavities of infected stems or pods. Sclerotia can become mixed with the seed during harvest.

The fungus survives between seasons as sclerotia in trash and soil. Sclerotia can survive for three to four years. In spring when conditions are warm and moist, sclerotia germinate and air-borne spores are released. If these spores land on senescing petals or leaves they will germinate and infect the dying plant material. When the infected tissue falls onto healthy branches or stems, the fungus will move to the healthy plant tissue and new sclerotia are produced.

*S. sclerotiorum* will infect many broad-leafed crop and pasture species. The disease is more common in rotations containing broad-leafed species in close rotations (for example, canola followed by lupin), compared to rotations with lengthy cereal phases.

Outbreaks of the disease are sporadic and usually only affect a small percentage of the crop so the loss of yield is low. In severe cases many sclerotia become mixed with harvested seed. This is inconvenient and incurs the extra cost of grading seed to remove sclerotia.

All species and varieties of lupin are susceptible to *S. sclerotiorum* infection. Rotation with non-host crops (for example, cereals) will allow the breakdown of diseased residues and sclerotia.

**Minor leaf and stem diseases**
**Grey leaf spot** is a disease caused by the fungus *Stemphylium botryosum*. Small circular lesions appear on the leaves and sometimes pods. In severe cases plants lose all their leaves. The disease was first recorded in Western Australia in 1972 and during the 1970s it periodically appeared in tall, late flowering varieties grown on the South Coast. All lupin varieties released since 1979 are believed to carry genes for resistance to grey leaf spot and this disease is now rarely seen.

**Cladosporium leaf spot** (*Cladosporium* sp.) causes dark grey spots on flowers, young leaves and the growing points of lupin plants when grown in warm and wet conditions. The disease rarely reduces yields because the drier conditions of spring stop the spread of the fungus and allow plants to compensate for damage.

**Grey mould** of lupin is caused by *Botrytis cinerea*. The fungus infects flowers and pods in humid spring conditions causing them to abort. Large sunken lesions that girdle and kill branches may also appear (Figure 9.15). Mature lesions are characterised by grey, fuzzy mould that may contain large black sclerotia (similar to *S. sclerotiorum*). Grey mould is most likely to occur where the crop canopy is dense and humid. Albus lupin may be more susceptible to infection than narrow-leafed lupin. Grey mould is rare in lupin crops in Western Australia and does not cause much economic damage.
Powdery mildew (Erysiphe polygoni) affects all lupin species. Typically, it is seen as a white powdery growth on leaves, stems and pods. Very rarely has serious crop damage been reported in Western Australia.

Virus diseases

Cucumber mosaic virus

Cucumber mosaic virus (CMV) is capable of causing yield losses of up to 60 per cent in lupin crops. It is seed-borne in lupin and is spread by a range of aphid species. Transmission is non-persistent by aphids. This means that when an aphid picks up the virus by feeding on an infected plant it will only retain it for one or two probes on healthy plants before ceasing to transmit it. Careful management of the disease has successfully decreased the occurrence of severe losses, particularly in the high rainfall zones where crops are most at risk. Sowing healthy seed is the key to managing this disease.

Symptoms

Plants grown from seed infected by the virus are stunted and have bunched leaves that are pale, have faint mottling and curl downwards (Figure 9.16). Plants grown from healthy seed that subsequently become infected are not stunted but young leaves that emerge after infection are bunched, pale and down curled (Figure 9.17).
### Table 9.3 Stem, leaf and pod diseases of lupin

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen</th>
<th>Symptom</th>
<th>Importance</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown spot</td>
<td><em>Pleiochaeta setosa</em></td>
<td>Dark net-like spots on leaves causing distortion of leaves; premature defoliation of cotyledons and leaves; chestnut-brown lesion on stems and pods.</td>
<td>Widespread; a more serious disease in cooler regions and when crops are grown on soils not well suited to lupins.</td>
<td>Rotate lupins with non-host crops; dress seed with fungicide; retain cereal stubble; supply adequate fertiliser; sow early.</td>
</tr>
<tr>
<td>Anthracnose</td>
<td><em>Colletotrichum lupini</em></td>
<td>Stem bending with a lesion in the crook of the bend and pink to orange spores visible in lesions; abortion of flowers; pods distorted and containing lesions with pink to orange coloured spore masses; shrivelled and discoloured seed.</td>
<td>Important in warm and wet regions, particularly where sandplain lupin is abundant. Low incidence in other wheatbelt areas.</td>
<td>Use resistant varieties; use seed that has been tested and found clean of the fungus; dress seed with fungicide; remove sandplain lupin.</td>
</tr>
<tr>
<td>Phomopsis</td>
<td><em>Diaporthe toxica</em></td>
<td>Grey to purple lesions on stems prior to maturity; black fruiting bodies in lesions on mature lupin stems; golden-brown seed with green cotyledons.</td>
<td>Very common. The toxin produced by the fungus can cause lupinosis in stock.</td>
<td>Use resistant varieties; carefully monitor and manage stock grazing lupin stubbles.</td>
</tr>
<tr>
<td>Sclerotinia stem rot</td>
<td><em>Sclerotinia sclerotiorum</em></td>
<td>White fungal growth containing black sclerotia in upper stem or branches; stem death above the lesion; sclerotia contaminating harvested seed.</td>
<td>Minor; most common in higher rainfall areas.</td>
<td>Do not sow lupins after a broad-leaved crop or pasture (particularly canola).</td>
</tr>
<tr>
<td>Grey leaf spot</td>
<td><em>Stemphyllium botryosum</em></td>
<td>Small, grey, circular lesions on leaves and pods.</td>
<td>Minor</td>
<td>Not economically damaging; no control measures recommended.</td>
</tr>
<tr>
<td>Cladosporium leaf spot</td>
<td><em>Cladosporium sp.</em></td>
<td>Dark-grey spotting on leaves when conditions are humid in spring.</td>
<td>Minor</td>
<td>Not economically damaging; no control measures recommended.</td>
</tr>
<tr>
<td>Grey mould</td>
<td><em>Botrytis cinerea</em></td>
<td>Browning and abortion of flowers and pods; large lesions girdling stems and branches; grey, fuzzy fungal growth in mature lesions.</td>
<td>Minor</td>
<td>Not economically damaging; no control measures recommended.</td>
</tr>
<tr>
<td>Powdery mildew</td>
<td><em>Erysiphe polygoni</em></td>
<td>White powdery fungal growth on leaves, stems and pods.</td>
<td>Minor</td>
<td>Not economically damaging; no control measures recommended.</td>
</tr>
</tbody>
</table>
The older leaves appear normal. As the plant grows, these symptoms become more widespread in the infected plant.

**Disease cycle**
The only significant source of CMV for crops in Western Australia is lupin seed. The virus persists between growing seasons in infected seed stocks. Plants grown from infected lupin seed act as a potent primary infection source for aphids to acquire the virus and spread it to healthy plants within the crop. This results in patches of infection spreading around isolated seed-infected plants within the crop. As the CMV epidemic progresses, the whole crop may become infected and all plants may develop symptoms. Weeds within the crop often become infected during the growing season, adding to the epidemic.

CMV is spread by many aphid species. This includes the three that commonly colonise lupin, green peach aphid (*Myzus persicae*), blue green aphid (*Acyrthosiphon kondoi*) and cowpea aphid (*Aphis craccivora*) as well as non-colonising species, such as the oat aphid (*Rhopalosiphum padi*) and turnip aphid (*Lipaphis erysine*). Non-colonising species do not settle permanently on lupin plants, but move between them, making brief probes as they move. They may, therefore, infect several plants before leaving the crop and can spread the virus to a greater extent than colonising aphid species.

**Disease risk and predisposing factors**
Several factors determine how damaging CMV becomes in lupin crops. The primary factors are the level of infection in the seed sown and the time of arrival of aphids. A high level of infection in the seed and the early arrival of aphids both favour early and extensive spread of the virus throughout the crop. The earlier the virus starts to spread, the higher the final virus infection level in the crop will be. High virus levels reduce yields more and produce a greater amount of newly infected seed. Secondary factors favouring development of an epidemic include greater abundance of non-colonising than colonising aphids, absence of groundcover, sparse stands of lupin plants and poor canopy development.

Rainfall before the growing season starts is a critical factor determining when aphids first arrive. Good rains in late summer and early autumn are normally associated with greater spread of CMV in lupin. The rain stimulates early germination and growth of pasture plants, weeds and volunteer crop plants. This produces a green ramp leading up to the start of the growing season and allows aphids to multiply rapidly on green plant material under the warm conditions. Aphid flights from such plants to lupin crops occur shortly after the crop emerges. This starts the virus spreading early. In contrast, a dry start to the growing season means that pastures, weeds, volunteer crop plants and lupin crops germinate simultaneously on the first substantial rains. Consequently, there are no early flights of aphids.

Factors that favour the survival of infected seedlings in the crop will also cause greater spread. For example, good rainfall at the start of the season results in high soil moisture during early growth. This allows the less vigorous seedlings infected with CMV to survive. In contrast, dry conditions during early growth diminish the survival of infected seedlings, thereby decreasing the magnitude of the primary virus source. Deep sowing also diminishes survival of CMV-infected seedlings.

Historically, high risk zones have been the high rainfall northern agricultural zones and the high rainfall South Coast and central zones. Low risk areas have been in the lower rainfall parts of the central and Great Southern agricultural zones.

**Losses**
If substantial virus spread occurs within lupin crops, yield losses from current season infection with CMV are high (up to 60 per cent). Individual plants that develop symptoms before or during flower initiation have greater losses (55 to 75 per cent) than those that develop symptoms after flowering (about 20 per cent losses). The yield losses result from fewer seeds being formed on CMV-infected plants and from decreased seed size. Seed-infected plants rarely contribute to grain yield.

**Control**
A representative sample of seed must be tested to determine its level of CMV infection (see Chapter 5 Seed testing and seed treatments). In lower risk zones, in all but abnormal years of exceptional pre-growing season rainfall, a threshold of < 0.5 per cent seed infection is sufficient to avoid serious yield losses. For high risk zones, the threshold level is < 0.1 per cent CMV infection (that is, a zero test result on a
Some cultivars (Wonga, Tanjil) have lower rates of transmission of the virus to their seed. These cultivars should be considered for high risk areas.

Other control measures to include as part of an integrated strategy to manage CMV are listed in Table 9.4 which gives a rationale for selecting each control measure together with its mode of action. A predictive simulation model and decision support system has also been developed to forecast aphid outbreaks and spread of CMV in lupin crops (http://www.agric.wa.gov.au/cropdisease).

Bean yellow mosaic virus

There are two forms of bean yellow mosaic virus (BYMV): the necrotic (BYMV-N) form which is the most common and the non-necrotic form (BYMV-NN). BYMV-N kills infected plants while BYMV-NN stunts plants and reduces yields by up to 80 per cent. The virus is spread by a range of aphid species from nearby pasture containing BYMV-infected clover. As with CMV, virus transmission by aphids is non-persistent, which means that when an aphid picks up the virus by feeding on an infected plant, it will only retain it for one or two probes on healthy plants before ceasing to transmit it. The strains of BYMV that are endemic to south-western Australia are not seed-borne in lupin. As with CMV, knowledge of the source of infection and spread of this disease are important in its control.

Symptoms

Symptoms caused by the BYMV-N form of the virus start with necrotic streaking of the youngest portion of the shoot, which bends over causing a characteristic shepherd’s crook (Figure 9.18). The growing tip dies and leaves become pale, wilt and fall off. Necrotic streaking and blackening then spread throughout the stem causing the plant to die. Plants that are infected early do not produce seed. When old plants are infected, the necrotic symptoms are slower to spread and may remain restricted to some branches or sections of the plant close to the site of infection. The tips of these shoots die and pods blacken and fail to fill, while the rest of the plant grows normally and produces grain.

BYMV-NN strains causes a range of symptoms in lupin. These include chlorosis and mottling of younger leaves, leaf deformation and stunting, dead growing points and fleshy expanded leaves. Few seeds develop on the infected plants (Figure 9.19).

Disease cycle

Local BYMV strains are not seed-borne in lupin but are seed-borne in clover and the virus is spread to lupin crops by aphids flying from pastures which contain clover plants infected with BYMV. The main vectors that spread BYMV to lupin are green peach, blue green and oat aphids. Other types of aphids, however, can also transmit BYMV to lupin.
Once plants become infected within a crop they are a source for further infection. With BYMV-N, there is a brief period between initial development of symptoms and onset of generalised necrosis. Only during this period can BYMV-N be acquired by aphids and transmitted to other lupin plants. In contrast, plants infected with BYMV-NN remain a source of infection throughout their life enabling aphids to probe them, acquire the virus and spread it further.

Different spatial patterns of infection occur, depending on the form of virus and whether the virus is brought in from outside the crop or acquired internally. With BYMV-N, most infection occurs at the edge of the crop next to an infected pasture. Infection declines rapidly with increasing distance into the crop. With BYMV-NN, infection is initially greatest at the edge of the crop adjacent to the infected pasture, but it spreads deeper into the crop. Spread is patchy at first, but eventually evenly distributed. The windward edges of crops that are close to pastures are most affected because they receive aphids brought in by the prevailing wind.

**Disease risk and predisposing factors**

Primary factors that determine how damaging BYMV will be to the crop include:

- the source of the virus—a large number of BYMV-infected clover weeds within the crop will cause greater spread than if the source of the virus is entirely from plants external to the crop.
- the form of the virus—BYMV-NN spreads faster than BYMV-N.
- the time of arrival of aphids—early aphid arrival favours earlier and more extensive spread of infection.

Important secondary factors favouring epidemic development include abundance of colonising and non-colonising aphids, absence of groundcover, sparse stands, poor canopy development, heavy grazing of nearby pasture and prolonged growing seasons.

As with CMV, good rains early in the year are normally associated with greater spread of BYMV in lupin. This is because aphids multiply on the pastures, weeds and volunteer crop plants that germinate with the early rains. They are then in high numbers and quickly move into lupin crops as the plants emerge. A dry start prevents the early build-up in aphid numbers and consequently there are no early flights of aphids to infect the crop with BYMV.

**Losses**

Infecting plants with BYMV when they are young will cause greater yield losses than infecting plants when they are old. Young plants infected with BYMV will often not produce any yield (Figure 9.20). On an individual plant basis, BYMV-N will also produce higher yield losses than BYMV-NN. However, despite the higher impact of BYMV-N on yield of individual plants, the BYMV-NN form has a greater potential to cause high crop losses. This is because the BYMV-NN form spreads faster and more extensively through the crop than the BYMV-N form.

The amount of yield lost from BYMV infection decreases as the crop density increases. This is because at high plant densities more plants are present so more infective aphids are required to establish the same proportion of infection. Furthermore, as BYMV kills plants in dense stands, compensatory growth from neighbouring plants quickly fills in the gaps, especially with early infection.
### Table 9.4 Components of integrated management strategies for cucumber mosaic virus (CMV) and bean yellow mosaic virus (BYMV) in narrow-leafed lupin

<table>
<thead>
<tr>
<th>Control measure</th>
<th>Mode of action</th>
<th>CMV</th>
<th>Necrotic BYMV</th>
<th>Non-necrotic BYMV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensure that infection levels in seed are as low as possible.</td>
<td>Minimises initial sources of infection within the crop.</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>In regions where there is a high risk from viruses sow cultivars that have a low rate of transmission of the virus to their seed.</td>
<td>Minimises initial sources of infection within the crop.</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Sow plants that do not host the virus between the lupin crop and adjacent pasture.</td>
<td>Decreases spread of the virus into crop from the pasture.</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Promote early development of the crop canopy.</td>
<td>Removes infection sources within crop by shading over the unthrifty seed-infected or early infected plants. It also reduces aphid landing rates.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sow at high seeding rates to generate high plant densities.</td>
<td>Removes infection sources within crop by shading over the unthrifty seed-infected or early infected plants. Reduces aphid landing rates. Dilutes numbers of infected plants.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sow at narrow row spacing (healthy seed) or at wide row spacing without lowering the seeding rate (untested seed).</td>
<td>Narrow spacing diminishes aphid landing rates. Wide spacing with high plant densities within rows shades over seed-infected plants.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Maximise stubble groundcover.</td>
<td>Reduces aphid landing rates until the crop canopy develops.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Spray high value seed crops with pyrethroid insecticide.</td>
<td>Suppresses virus spread by killing or repelling aphids.</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Spray adjacent pasture with pyrethroid insecticide in regions where there is a high risk from viruses.</td>
<td>Suppresses virus spread by killing colonising aphids.</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sow non-host plants between the crop and a potential virus source.</td>
<td>Reduces virus spread.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Avoid fields with large perimeter to area ratios that are adjacent to pastures in regions where there is a high risk from viruses.</td>
<td>Decreases ingress of virus into crop from the pasture.</td>
<td>N/A</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sow early maturing cultivars.</td>
<td>Decreases final infection incidence, especially in prolonged growing seasons.</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Isolate from neighbouring lupin crops.</td>
<td>Decreases ingress of virus from any external infected crop source.</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Maximise weed control.</td>
<td>Minimises potential weed virus infection sources within crop (especially clovers for BYMV).</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

1 Based on results from large-scale replicated field experiments
N/A = not applicable
Control
An integrated management strategy that combines several methods to reduce the spread of the virus is the best way to control BYMV in lupin. These methods are listed below.

- Sow plants that do not host BYMV between the lupin crop and adjacent pasture.
- Avoid long, narrow paddocks that have a large perimeter to area ratio.
- Use high sowing rates and narrow row spacing to achieve early canopy coverage.
- Direct drill into retained stubble.
- Sow early maturing cultivars.
- Control weeds effectively.

Insecticide application aimed at killing aphids is not an effective way of managing BYMV in lupin. However, repeatedly spraying virus-infected pastures next to lupin can reduce aphid numbers and BYMV transmission into the crop. Table 9.4 provides details of the range of methods used to control BYMV in lupin.

Nematodes of lupin
There are two main types of plant-parasitic nematode that reduce yields of broadacre crops grown in Western Australia. These are the root lesion nematode (*Pratylenchus* spp.) and the cereal cyst nematode (*Heterodera avenae*).

Lupin will not host cereal cyst nematode. This nematode only infects grasses (wheat, barley, oat and some weeds, particularly wild oat). Lupin will act as a disease break for cereal cyst nematode in cereal rotations.

At least 60 per cent of Western Australian cropping paddocks are infested with one or more species of root lesion nematode (RLN). These nematodes are estimated to occur at damaging levels in at least 40 per cent of paddocks. Yield losses to wheat and barley crops from these nematodes are estimated to be at least 5 per cent annually and losses as high as 15 to 20 per cent have been recorded.

*Pratylenchus neglectus* dominates (detected in 40 per cent of paddocks), followed by *P. teres* (detected in 10 per cent of paddocks). A further 10 per cent of paddocks contain a mix of RLN species. *P. penetrans* occurs infrequently, but severe damage has been observed to the roots of wheat, oat and field pea. *P. thornei* occurs rarely in Western Australia and if present is usually found in mixed infections with other RLN species.

Two species of burrowing nematode (*Radopholus*) have been identified in Western Australian wheat and barley crops, where they can reach high levels and cause significant crop damage. Burrowing nematode has also been detected in lupin grown in rotation with cereal, but it is not yet known how damaging these nematodes are to the lupin crop. Cereal:lupin rotations should be monitored in paddocks where these nematodes have been identified.

Disease risk and predisposing factors
All RLN species have wide host ranges, but there are preferences within species. Lupin is resistant (that is, a poor host) to *P. neglectus* and to *P. thornei*, moderately susceptible to *P. teres* and susceptible (that is, a good host) to *P. penetrans*.

Populations of *P. neglectus* are reduced under a lupin crop. Lupin, therefore, is a useful tool for managing this nematode. It is important, however, to accurately identify the nematode species present when devising rotational strategies to manage RLN. While lupin will decrease populations of *P. neglectus*, it will increase populations of *P. penetrans*.

Symptoms
In most crops the above-ground symptoms of nematode infection are indistinct. Plants may show a combination of uneven growth, yellowing, stunting or wilting. All of these symptoms can be confused with, or exacerbated by, nutrient deficiencies.

The best way to determine if nematodes are present within a crop is to dig up the plants, wash the soil carefully from the roots and examine the roots for damage. Suspected infestations of RLN can be confirmed by laboratory tests, and the species of RLN identified.

Management
Rotating resistant crops with susceptible crops or cultivars is the only practical method of managing RLN. It is important to monitor the numbers and type of nematodes in the soil and devise appropriate crop rotations. Be aware that populations of nematodes can rapidly multiply on a good host, but it may take two or more successive years of a poor host for numbers to decline again below damaging levels. Planting a susceptible crop into a paddock that already has high numbers of nematodes will not only restrict the yield of that crop but allow the nematodes to multiply to very high numbers.
10 Insect and allied pests

Peter Mangano, Svetlana Micic and John Botha
Lupin crops are more prone to pest damage than cereal crops. Check lupin crops for pest damage during emergence and for the three weeks following emergence. This will enable control measures to be taken early and prevent excessive damage. Later in the season, regularly inspect the crop during flowering and pod filling.

It is important to correctly identify the pest causing the damage in order to choose the right control measure. To assist in this process, the appearance and type of damage caused by caterpillars, lucerne fleas, mites, slugs, snails, aphids and thrips is described under three stages: seedling stage, flowering stage and podding stage. A key to the damage caused by these pests is provided at the end of the chapter.

Seedling stage
Caterpillars

Cutworms

Description
Cutworms (Agrotis spp.) usually feed at night and hide under debris or the soil during the day. They can sometimes be found by scratching the soil surface near the base of freshly chewed plants. They grow to 50 mm long and are smooth bodied with most having a uniform colour ranging from pinkish-brown to black. Their heads are slightly darker and they have dark lines or spots along their body (Figure 10.1). They curl up and remain still if disturbed.

Life cycle
Eggs are laid on plant material near the ground. The caterpillars emerging from the eggs grow with several moults until they are full size and pupate in the ground. Adult moths emerge from the pupae usually after a month. Several generations are possible in one season.

Damage
Damage is often seen as bare or thinned patches in the crop. The caterpillars often chew through or cut-off the stems of young seedlings, hence the name cutworm (Figure 10.2). Numbers can be easily underestimated because they can be

Figure 10.1 Cutworm with herringbone pattern
Photo: P Mangano
insect and allied pests

Producing lupins

hard to find. They are most damaging when large caterpillars (> 20 mm) transfer from weeds onto newly emerged lupin seedlings.

Control
Cutworms are easily controlled by insecticides. Inspect paddocks for cutworms, especially weedy pastures, prior to sowing lupin. Where required, a suitable insecticide can be incorporated with the knockdown herbicide.

Brown pasture looper

Description
The brown pasture looper (*Ciampa arietaria*) is grey or dark brown with yellow lines along its back, either side of a dark band (Figure 10.3). Young caterpillars move with a characteristic looping motion. When the caterpillars reach full size at 35 mm long, they cease to move in this looping motion.

Life cycle
Eggs are laid in early to mid-autumn. The caterpillars that hatch from the eggs grow to full size in about two months when they pupate and remain in the pupal stage over spring and summer. They emerge as moths in the following season. Brown pasture loopers have only one generation per year.

Damage
Caterpillars chew the leaves of crops. They are often present around crop edges, having moved into the crop from adjacent pasture. They are most damaging when large sized caterpillars (> 20 mm) transfer from early season weeds onto newly emerged lupin seedlings.

Control
Brown pasture loopers are easily controlled by insecticides. Inspect paddocks for brown pasture loopers, especially weedy pastures, prior to sowing lupin. Where required, a compatible insecticide can be incorporated with the knockdown herbicide.

Lucerne fleas

Description
Lucerne fleas (*Sminthuris viridis*) grow up to 3 mm in length and have a round, plump body. They vary in colour, but are mainly greenish with a mottled pattern of brown and yellow (Figure 10.4). Lucerne fleas often jump upwards when disturbed.
Life cycle
The first soaking rains at the start of the growing season cause the over-summering eggs of lucerne fleas to hatch. Several generations may develop over the growing season depending on the weather. At the onset of warmer and drier conditions in spring, over-summering eggs are produced.

The pest is more common on heavier soils and rarely present on very sandy soils with low clay content.

Damage
Lucerne fleas feed on the outer tissue of green leaves. This produces a whitish layer on the leaf that looks like a window (Figure 10.5). Affected areas of the leaf may also look bleached and can resemble redlegged earth mite damage.

Control
Lupin crops are most likely to be damaged by lucerne fleas if planted in a paddock that grew a weed infested crop or a pasture in which lucerne fleas were not controlled in the previous spring. In these high risk situations, plan in advance and control lucerne fleas in the season prior to growing lupin. Lucerne fleas can be controlled by grazing pastures or using insecticides to reduce spring populations and the number of over-summering eggs that are produced.

If there are high numbers of lucerne fleas in the paddock in the year when lupin crops are planted, they will need to be controlled with insecticides. Be aware that insecticides that control mites do not necessarily control lucerne fleas. In particular, commonly used rates of synthetic pyrethroid will not control lucerne fleas. If lucerne fleas and redlegged earth mites are present in damaging numbers, ensure that the rates and type of insecticide(s) you choose are effective against both pests.

Mites
Redlegged earth mites

Description
Redlegged earth mites (RLEM) (Halotydeus destructor) are pinhead sized (up to 1 mm), with a velvety black body and eight red-orange legs (Figure 10.6). They are often found in high numbers.

Life cycle
Mites hatch from over-summering eggs, after adequate exposure to moisture and low temperatures. Several generations (usually three) develop over winter and spring. Towards the end of spring, mites produce thick-walled, over-summering eggs that can resist dry summer conditions and carry the mite population to the next season.

Damage
RLEM may cluster on the young seedlings, rupturing cells and sucking the juices. This leads to a leathery and silvery appearance of the leaves. Lupin has large, robust cotyledons and is relatively tolerant of RLEM. Lupin plants can often grow away from the damage that RLEM cause.

Severe symptoms of RLEM damage include white bleached leaves and slow growth. A heavy infestation of RLEM may decrease plant density, retard the development of the crop or even kill seedlings.
Early sown lupin crops have the best chance of growing away from RLEM before the populations increase to damaging levels. It is usually only necessary to spray RLEM if lupin seedlings are being attacked and damaged at emergence. The best way to control RLEM is to reduce mite numbers in the spring of the year prior to cropping lupins. Decreasing the number of over-summering eggs greatly reduces the population of mites in the following autumn. This can be done by:

- controlling weeds in the crop. Weed-free crops, especially cereal crops, will have very few mites and over-summering eggs to carry through to the next season.
- grazing pastures throughout the previous spring to less than 2 t/ha Feed on Offer (dry weight). This will reduce mite numbers and control RLEM as effectively as chemical sprays.
- spraying for RLEM at the correct time before summer eggs are laid. TIMERITE® is a package that provides a date in spring for a single spray to stop females from producing over-summering eggs. For further information visit the TIMERITE® website <www.timerite.com.au> or contact DAFWA.

If a pasture was grown prior to growing lupin and no control was used in the preceding season, consider spraying an insecticide if RLEM have hatched. Compatible insecticides can be applied with knockdown herbicide spray or as a bare earth spray prior to emergence.

**Blue oat mites**

**Description**

Blue oat mites (BOM) (Penthaleus spp.) are the same size (up to 1 mm) and almost the same colour as redlegged earth mites except for a small oval red area in the middle of their back (Figure 10.7).

**Life cycle**

Blue oat mites are active in autumn, winter and spring. They have a similar life cycle to redlegged earth mites, but have up to four generations per year.

**Damage**

Damage to plants from BOM is indistinguishable from redlegged earth mite damage. BOM damage gives lupin cotyledons a leathery and silvery appearance and in high numbers they cause bleaching of the leaves and even death of seedlings. Under good growing conditions lupin plants often grow away from the damage caused by BOM.

**Control**

The same chemical and cultural controls for redlegged earth mites are applicable for BOM. Refer to the RLEM section for further information.

**Balaustium mites**

**Description**

Balaustium mites (Balaustium medicagoense) are often confused with redlegged earth mites. However, these mites grow to be twice the size of a redlegged earth mite (about 2 mm in length). They have a rounded body, densely covered with stout hairs when viewed under magnification (Figure 10.8).
Life cycle
Balaustium mites survive all year round if green plant material is present. Unlike the eggs of redlegged earth mites, the eggs of balaustium mite do not require cold temperature to stimulate hatching. The over-summering eggs are laid in late spring or summer as pastures deteriorate. These eggs hatch the next year as soon as there is sufficient moisture for plants to germinate.

Damage
Balaustium mites cause the cotyledons and leaves of lupin plants to have a leathery, silvered appearance (Figure 10.9). If mites are in high numbers, leaves and cotyledons may be bleached. Lupin crops are usually able to grow away from balaustium mite damage.

Control
Balaustium mites are often found in southern coastal areas, following early autumn germinations before redlegged earth mites appear. They may transfer from weeds to emerging lupin seedlings and they are usually less abundant than other pest mites. Balaustium mites are not susceptible to the chemicals used to control other mites but are susceptible to high rates of some synthetic pyrethroid chemicals. Killing all weeds several weeks in advance of seeding lupin will effectively manage balaustium mites.

Clover mites (Bryobia mites)

Description
Clover mites (Bryobia praetiosa) grow up to 1 mm in size. They are reddish-grey, pie-shaped, with red legs and two long forelegs (Figures 10.10. and 10.11). They are often confused with redlegged earth mites.

Life cycle
Adult clover mites are most active in warm conditions especially in autumn, late spring and summer. They usually do not survive cold winters or very dry summers. In areas protected from these extremes, all life stages of the mites may be present if there is sufficient green plant material available. Over-wintering eggs are most likely laid early to mid-winter and hatch as conditions warm up in spring. Over-summering eggs are laid as pastures deteriorate in late spring. These eggs hatch as soon as there is sufficient moisture for plants to germinate.
Damage
clover mites cause similar damage to lupins as redlegged earth mites. Clover mites create long trails composed of whitish grey spots on the top leaf surface.

Control
clover mites can become a serious pest of lupin in years when there are early autumn rains. Early rain allows weed growth that leads to early establishment of clover mite populations. It is a difficult pest to control and is best dealt with by killing all weeds well before seeding and by applying a suitable insecticide to the weeds with the knockdown herbicide.

Slugs

description
the most common species of slugs are the black keeled slug (Milax gagates) and the reticulated slug (Derocerus reticulatum). Both species grow to 25 mm long. Black keeled slugs are black to brown with a ridge down the back. Reticulated slugs have dark brown mottling and range from light grey to fawn (Figure 10.12).

life cycle
slugs inhabit the heavier-textured soils, especially soils that form cracks or large clods that the slugs use as refuges from hot and dry conditions. Slugs may move to a depth of 20 cm or more and re-emerge when conditions improve.

Slugs are hermaphrodites and both members of a mating pair can lay eggs. Mating usually takes place when favourably moist conditions occur after summer. Eggs are laid into moist soils in mid-autumn to mid-winter. They hatch in two to four weeks. The eggs cannot survive a hot dry summer or lay dormant in the soil. Young slugs become sexually mature at one year old.

Damage
irregular pieces chewed from leaves and shredded leaf edges are typical of slug damage, but many seedlings will be eaten down to ground level and will be difficult to detect. Sometimes slugs eat lupin seeds at seeding. The slugs hide under trash, clods or rocks during the day and are active at night, especially on moist, warm and still nights. Their fresh trails of white and clear slime visible in the morning indicate their presence.

Control
ten large slugs/m² may destroy an emerging crop. However, it is difficult to accurately establish the population of slugs in a paddock, especially in cracking soils. A useful method to detect areas infested with slugs before 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. An alternative method to gain an indication of the numbers of slugs present in a paddock is to place carpet squares or tiles on the soil surface, with pellets under them. After a few days, count the number of slugs under and around each square. When the crop has been seeded and germination is commencing, crops should be examined at night for slug activity.

application of slug pellets is the most reliable method to control slugs. Copper sprays are available but have produced variable results. apply slug pellets at 5 kg/ha to the parts of the paddock where slugs are a problem. The best time to apply pellets is early in the season after good germinating rains. This is when slugs are emerging from their hiding places and are looking for food. Late applications are less effective at attracting the slugs because there is a lot of green material that provides an alternative food source. Large slugs are surprisingly mobile in moving to pellets and plants.
Apply pellets several times because the pellets lose their effectiveness after a few nights. Pellets may become covered by soil during rain and some may decay after wetting. Consider reapplying pellets after large rainfall events.

**Snails**

*Description*

There are three snail species in Western Australia that may attack lupin seedlings or contaminate lupin grain at harvest. The **small pointed snail** (*Cochlicella barbara*) (also known as the **small conical snail**) is most common in the higher rainfall regions of Western Australia. It has a light brown conical shell up to 10 mm long (Figure 10.13).

The **white Italian snail** (*Theba pisana*) has a white shell up to 24 mm in width. They range from all white to having broken brown bands in the line of the spiral (Figure 10.14). These snails are easily confused with the **vineyard snail** (*Cemuella virgata*). Vineyard snails have shells up to 20 mm in width, with most having a continuous brown band in the line of the spiral (Figure 10.15).

*Life cycle*

Snail activity is triggered by the onset of cool, moist conditions in autumn. Only 1 to 2 mm of rain is required to trigger activity. The snails begin to feed on decaying organic matter and green plant material.

Mating and egg laying starts about two to three weeks after the first heavy autumn rains and continues through to late spring. The hatchlings emerge from eggs about two weeks after they are laid. Juvenile snails do not become sexually mature until the following autumn.

As conditions begin to dry and temperatures increase in summer, the white Italian and vineyard snails move up the vegetation to avoid water loss. The small pointed snail may move up vegetation or harbour underneath stubble to retain moisture. Summer rains may trigger short periods of activity, but the rain is not likely to trigger breeding.

*Damage*

Snails cause very similar damage to slugs. Irregular pieces are chewed from leaves and their edges become shredded. Snails tend not to eat seedlings down to ground level, unless the seedling has just emerged. Also, unlike slugs, snails are more easily found near where the crop has been damaged.
Control
Sample the paddock for snails prior to seeding (March or April). Consider controlling snails if there are five vineyard or white Italian snails/m² or about three conical snails per seedling. Apply snail pellets at 5 kg/ha to areas of the paddock where snails are a problem. Spreading pellets early can reduce snails numbers, but may be difficult to obtain good control because snails feed on green plant material as well as decomposing organic matter. Spread pellets several times because they lose their effectiveness after a few nights. Pellets may become covered by soil during rain and decay after wetting. Reapply pellets after it has rained heavily.

Other measures in addition to baiting are required to effectively control snails over the long term. These include heavily grazing pastures and burning stubble. The advantage of controlling snails using these methods must be weighed against the adverse effects of these practices.

Flowering stage
Aphids
Description
Aphids are small soft-bodied insects that grow up to 3 mm long. Adults can be winged or wingless. All immature forms are wingless. Three types of aphids are responsible for most of the infestations (see below). Other species rarely attack lupin.

Cowpea aphids (Aphis craccivora) are charcoal grey to shiny black and infest the growing points of plants (Figure 10.16). These aphids tend to colonise single plants or groups of plants in hot spots within the crop.

Blue green aphids (Acyrthosiphon kondoi) have a bluish-green colour, the same colour as the lupin leaves (Figure 10.17). They distribute themselves more evenly in the crop than cowpea aphids, although certain plants sometimes support heavy populations while those around it may have only a few.

Green peach aphids (Myzus persicae) have a pale green colour, the same as the lupin stem (Figure 10.18). Green peach aphids can be found on the underside of older leaves and usually cause less feeding damage than other aphid species.
Life cycle
Cowpea, green peach and blue green aphids have numerous generations throughout the year and survive the summer on alternative hosts.

Damage
Aphids may be present on seedlings but they commonly occur in lupin crops during budding and flowering (Figure 10.19). Lupin crops attacked by aphids in high numbers may have distorted leaves and stunted growth (Figure 10.20). Flowering and pod set may be affected.

Some lupin cultivars are more susceptible to aphid feeding damage than others. Modern, sweet cultivars of yellow lupin are more susceptible than narrow-leafed lupin.

Aphids also transmit two important diseases in lupin: cucumber mosaic virus and bean yellow mosaic virus. Refer to Chapter 9 Diseases of lupin for more information.

Control
Control aphids in lupin crops at flowering if more than 30 per cent of the crop is infested with colonies of aphids. The best way to estimate numbers is to look at numerous spots throughout the paddock and inspect flowering heads at random. When deciding on control measures, keep in mind other beneficial insects such as hover flies, ladybirds, lacewings and parasitic wasps that attack aphids and keep populations low. Use sprays that target aphids only and leave beneficial insects unharmed.

Thrips

Description
Adult onion thrips (Thrips tabaci) and plague thrips (Thrips imaginis) are 2 mm long and cigar shaped and range from yellowish-orange to dark grey (Figure 10.21). It is difficult to differentiate between the two species in the field.

Life cycle
Thrips breed all year round on green plant material, especially flowering plants.

Damage
Adults and nymphs pierce plant tissue and suck sap, producing distorted leaves (Figure 10.22). In extreme cases, high numbers at the flowering stage of lupin may cause flower abortion.
Native budworms

Description
Native budworm larvae (*Helicoverpa punctigera*) are shades of orange, brown and green and usually have dark stripes along the body (Figure 10.23). They grow to 40 mm long.

Life cycle
Native budworms can develop large populations over extensive areas on native plants. These populations often migrate into agricultural regions in late winter and spring. Migratory flights are unpredictable, because moths are carried hundreds of kilometres from breeding areas by high altitude currents.

Damage
Narrow-leafed lupin will not be damaged by native budworms until plants are close to maturity and the pods are losing their green colouration. Pod walls are not penetrated until the caterpillars are over 15 mm long. A decision to spray a lupin crop should not be made until damage is about to occur. Natural mortality of budworm populations is sometimes sufficient to prevent economic damage.

Control
This pest rarely causes damage sufficient to warrant control.

Podding stage

Caterpillars

Native budworms

Description
Native budworm larvae (*Helicoverpa punctigera*) are shades of orange, brown and green and usually have dark stripes along the body (Figure 10.23). They grow to 40 mm long.

Life cycle
Native budworms can develop large populations over extensive areas on native plants. These populations often migrate into agricultural regions in late winter and spring. Migratory flights are unpredictable, because moths are carried hundreds of kilometres from breeding areas by high altitude currents.

Damage
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Control
Sample the crop to estimate the number of caterpillars present. If possible, use a sweep net. The amount of caterpillars caught in 10 sweeps is about equivalent to the amount in one square metre of crop. At least five lots of 10 sweeps are needed in several parts of the crop for an adequate sample. Lupin crops are sometimes difficult to sample with a sweep net because the plants are stiff and the pods are spiky. In these cases, cut plants at their base from several places in the crop and shake the caterpillars off into a bin. Approximately 40 plants is equivalent to one square metre of crop.

If eight native budworms over 15 mm in length are found in a square metre of crop and the lupin pods are close to maturity, consider using a chemical spray. This economic threshold is based on a farm gate price of $175/t and chemical and application costs of $10/ha. If the price of grain increases or the cost of application decreases, the economic threshold levels decrease (see Equation 10.1). For example, if the farm gate price of lupin increases to $250/t, the economic threshold level for control of native budworm decreases to six native budworms/m².

Equation 10.1

\[ ET = \frac{C}{(K \times P)} \]

- ET = economic threshold
- C = cost of control, that is: chemical + application costs ($/ha)
- K = a constant that indicates the amount of grain eaten by caterpillars. For lupin this is 7.
- P = price of grain per kg (price per t/1000)
The decision to spray for native budworms in lupin should be left until pods are beginning to mature. If caterpillar numbers are below threshold limits, the decision to spray should be delayed and periodic sampling continued. One well-timed spray is sufficient to control caterpillar populations.

**Lucerne seed web moths**

**Description**
The larvae of the lucerne seed web moth (*Etiella behrii*) (also called etiella web moth) grow to 20 mm long and are a cream to green colour with a reddish-brown head and light red stripes running along the back (Figure 10.24). These stripes are more pronounced in young larvae.

Adults are first seen late in the season. Adult females lay about 200 eggs which may hatch within 24 hours in warm weather, but may take up to two weeks to hatch in cool weather. Four to seven days is common. Each egg hatches into a small larva which constructs a tunnel-like silk tube around itself, with one end attached to the surface of the pod.

**Life cycle**
Lucerne seed web moths have three to four generations each year in spring, summer and autumn.

**Damage**
Newly hatched larvae feed on the seed within the pods. The damaged seeds have jagged edges similar to native budworm damage. These are distinguished from native budworm by the presence of webbing in the pod (Figure 10.25).

A single larva may enter a number of lupin pods. During the early stages of an attack, there are few signs of damage. Often the pods must be pulled apart before evidence of damage can be seen.

The larvae usually remain in the pods until most seeds have been eaten. The fourth and fifth larval stages are too large to enter pods. Instead, the larva meshes several pods together and eats into the surrounding pods.

In most seasons, the pest causes little damage to seed. It is only in those years when numbers are high that significant yield losses have been reported. Unless the crop is carefully monitored at regular intervals, considerable damage may occur.

**Control**
In Western Australia, lucerne seed web moths are a sporadic pest. Removing early season volunteer legume plants near lupin crops may help control them. The source of most lucerne seed web moths in crops is probably from nearby legume crops or volunteer plants.

Monitoring in lupin crops should aim at detecting the presence of webbing in flowers and in the growing points of the plant. Early detection is important for insecticide sprays to be effective. Lucerne seed web moths do not usually cause economic damage in lupin unless there are crops growing over summer (for example, lucerne) that host the pest. This allows them to build up over summer and attack nearby winter crops.
Table 10.1 Identification of lupin pests and their control by chemicals

<table>
<thead>
<tr>
<th>Pest</th>
<th>Appearance</th>
<th>Damage</th>
<th>Where found</th>
<th>Thresholds¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seedling pests</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutworms (Agrotis spp.)</td>
<td>Stout-bodied caterpillars up to 50 mm in size found in soil at the base of plants.</td>
<td>Chewed through stems at ground level.</td>
<td>Feeding on plants at night. Hidden in soil during the day.</td>
<td>2 to 3 cutworms/m². Apply as soon as pest is noticed at threshold levels.</td>
</tr>
<tr>
<td>Brown pasture looper (Ciampa arietaria)</td>
<td>Thin caterpillars up to 35 mm in size that walk with a looping motion.</td>
<td>Chewed cotyledons and first leaves.</td>
<td>On crop and weeds, especially capeweed. Larvae may migrate into crop edges from nearby capeweed.</td>
<td>10 to 12 loopers/m²</td>
</tr>
<tr>
<td>Lucerne flea (Sminthuris viridis)</td>
<td>Plump, roundish body, up to 3 mm in size. Greenish in colour with brown and yellow mottled pattern. Jumps upward when disturbed.</td>
<td>White windows on leaves.</td>
<td>On weeds and seedlings. Commonly found on soils with loam or clay texture.</td>
<td>Consider control measures if holes are increasingly being found on leaves.</td>
</tr>
<tr>
<td>Redlegged earth mite (Halotydeus destructor)</td>
<td>Very small mite up to 1 mm with a black body and red-orange legs.</td>
<td>Cotyledons appear leathery, silvered, twisted or shrivelled and seedlings may die. Damage may occur before seedling emergence.</td>
<td>On weeds, soil and seedlings.</td>
<td></td>
</tr>
<tr>
<td>Blue oat mite (Penthaleus spp.)</td>
<td>Very small mite up to 1 mm with a black body and red-orange legs. Can be distinguished from redlegged earth mite by a small oval red area in the middle of the back.</td>
<td>Same as for redlegged earth mite.</td>
<td>On weeds, soil and seedlings. Same as for redlegged earth mite.</td>
<td></td>
</tr>
<tr>
<td>Balaustium mite (Balaustium medicagoense)</td>
<td>Round body (up to 2 mm) with stout hairs, brownish-red.</td>
<td>Cotyledons and first true leaves appear silvered and leathery; sometimes may shrivel and seedling may die. Damage occurs post-emergence.</td>
<td>On weeds, soil and seedlings. Look for silvering on extensive areas of cotyledons and leaves and stress caused to plants.</td>
<td></td>
</tr>
<tr>
<td>Clover mite (Bryobia mite) (Bryobia praetiosa)</td>
<td>Very small mite (up to 1 mm) with a grey body and orange legs. Front pair of legs are very long.</td>
<td>Same damage as redlegged earth mite. White lines often seen on top of cotyledons. Seedling may shrivel and die.</td>
<td>On weeds, soil and seedlings. Look for silvering on extensive areas of cotyledons and leaves and stress caused to plants.</td>
<td></td>
</tr>
</tbody>
</table>
### Table 10.1 Identification of lupin pests and their control by chemicals cont.

<table>
<thead>
<tr>
<th>Pest</th>
<th>Appearance</th>
<th>Damage</th>
<th>Where found</th>
<th>Thresholds¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Slugs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black keeled slug <em>(Milax gagates)</em></td>
<td>Black to pale grey slugs.</td>
<td>Chewed leaves or whole plants. Slugs sometimes feed on lupin seeds at seeding. Slime trails may be seen.</td>
<td>On plants at night. Hidden under clods, trash or other objects during the day.</td>
<td>10 or more slugs/m²</td>
</tr>
<tr>
<td>Reticulated slug <em>(Derocerus reticulatum)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Snails</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small pointed snail <em>(Cochlicella barbara)</em></td>
<td>Light brown conical shell up to 10 mm long.</td>
<td>Chewed leaves. Slime trails may sometimes be seen. A range of control measures in addition to baiting is required to achieve long-term control. Baits are best applied prior to seeding. Multiple applications are recommended.</td>
<td>On leaves, stems or other nearby objects.</td>
<td>3 or more snails/m²</td>
</tr>
<tr>
<td>White Italian snail <em>(Theba pisana)</em></td>
<td>White shells up to 24 mm in width, mostly with broken brown bands in the line of the spiral. Some are all white.</td>
<td></td>
<td></td>
<td>5 or more snails/m²</td>
</tr>
<tr>
<td>Vineyard snail <em>(Cernuella virgata)</em></td>
<td>Shells up to 20 mm wide with a continuous brown band.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flowering and podding pests</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Aphids</strong> <em>(various species)</em></td>
<td>Small bugs that grow up to 3 mm long, with or without wings. Usually grey or green.</td>
<td>Leaves may be distorted and the growth of plants stunted. Flower may be damaged and lost.</td>
<td>Clustered together on flower heads.</td>
<td></td>
</tr>
<tr>
<td><strong>Thrips</strong> <em>(various species)</em></td>
<td>Adults 2 mm long, cigar shaped and range in colour from yellowish-orange to dark grey.</td>
<td>Rarely cause economic damage. Sometimes leaves are distorted.</td>
<td>In growing points and flowers.</td>
<td>Consider control measures if obvious damage is occurring and thrips are in very high numbers.</td>
</tr>
<tr>
<td><strong>Native budworm</strong> <em>(Helicoverpa punctigera)</em></td>
<td>Dark brown to light green caterpillars (larvae) with longitudinal stripes up to 40 mm in size.</td>
<td>Penetrated pods and eaten seeds.</td>
<td>On pods, flowers and leaves.</td>
<td>8 native budworm/m² of crop that are over 15 mm and lupin pods are close to maturity. Sample several spots across the whole paddock.</td>
</tr>
<tr>
<td><strong>Lucerne seed web moth</strong> <em>(Etiella behrii)</em></td>
<td>Caterpillars (larvae) 20 mm long with reddish-brown head and pinkish-green body and several light brown stripes running along its length.</td>
<td>Penetrated pods and eaten seeds. Webbing found in pods.</td>
<td>In pods only.</td>
<td></td>
</tr>
</tbody>
</table>

¹ Thresholds are an estimate of the minimum number of pests or amount of crop damage that is likely to cause economic loss. Control measures should be taken if pest numbers or crop damage exceed the threshold.
Figure 10.26 Key to the insect and allied pests of lupin. Photo: P Mangano
Chemical control
Routine spraying without monitoring pest numbers may increase the likelihood that insects will develop resistance to insecticides. Consider spraying only if there is economic damage occurring to the crop. Table 10.1 presents thresholds to use when assessing the level of damage.

An effective way to monitor potential insect damage is to regularly observe a number of random sites within a paddock. The more sample sites, the better. Pests are not always uniformly distributed in a crop. Sampling only one or two sites may give a misleading impression of pest density.

An up-to-date listing of registered chemicals for application to lupin is available on the Department of Agriculture and Food website <www.agric.wa.gov.au> and the website of the Australian Pesticides and Veterinary Medicines Authority <www.apvma.gov.au>.

Further reading
Baker, GH & Hopkins, DC 2003, Bash 'Em, Burn 'Em, Bait 'Em: Integrated snail management in crops and pastures, South Australian Research and Development Institute, Urrbrae, South Australia.
Berlandier, F 2003, Insect and allied pests of lupins, Farmnote 21/2003, Department of Agriculture, Western Australia, South Perth.
Mangano, P, Michael, P & Hardie, D 2006, Management of native budworm in pulse and canola crops in the south-west of Western Australia, Farmnote 184/2006, Department of Agriculture and Food, Western Australia, South Perth.
11 Harvesting

Glen Riethmuller
Harvest lupin crops as soon as they are ripe. Delays can result in significant loss of yield due to lodging, pod shattering and pod drop. Lupin must be harvested within three weeks of maturity.

Use a moisture meter to determine when the lupin crop is ready. Start harvesting as soon as the moisture content reaches 14 per cent. In some seasons this will occur when the stems are still pale green.

Seed losses can be substantially reduced by harvesting when humidity is high. Lupin plants strip well during the night and early morning. If possible, do not harvest in the middle of the day when it is very hot.

In cooler southern environments, daytime temperatures often do not become warm enough to cause major problems for harvest. In these areas it may be better to harvest the crop as quickly as possible rather than swapping between lupin and cereals. However, with the increasing number of belt front harvesters, changing between lupin and cereals requires less time than it used to with auger or tin fronts.

Harvesting seed for next year
Take special care when harvesting seed for next year’s crop. Harvest it as soon as it is mature. Set the harvester drum or rotor speed to a minimum and the concave opened fairly wide. This will reduce damage to the embryo and help to ensure a high germination percentage. The seed embryo is very sensitive to impact if it becomes dry and brittle. Even seed with no visible damage may have low percentage germination if it suffered a high impact when its moisture content was low.

As a general guide to reduce damage to lupin seed, the peripheral speed of the harvester drum or rotor should not be greater than 12 m/s. This compares with 20 to 30 m/s for cereals.

Equation 11.1 shows that the drum speed will be different for each drum diameter.

Equation 11.1

\[
\text{Drum speed (rpm)} = \frac{60,000 \times \text{peripheral drum speed (m/s)}}{3.14 \times \text{drum or rotor diameter (mm)}}
\]

Harvesters have a range of drum or rotor diameters so this will have to be checked in order to start at around the correct rotational speed (Table 11.1).

If necessary, harvest lupin at a higher rather than a lower moisture content and dry the seed in aerated silos or on fertiliser shed floors before grading and storage in sealed silos.

Reducing harvesting losses
The main causes of high losses at harvest are:
- the action of the cutter bar on the plant stem, which shakes the plant and sheds pods
- poor removal of cut material from the comb platform.

Some precautions will help reduce these losses. Make sure the header knife is sharp, timed correctly and cutting closely to the ledger plate below the knife. Damaged knife sections or too much clearance between the knife and ledger plate will cause a rough cut, which will increase front losses.
Match ground speed with the capacity of the table auger and crop density rather than the loading of the drum. If the ground speed is too slow, the plants will not have enough momentum to carry to the front. If it is too fast the cut crop will not be cleared from behind the knife.

Keep the table of tin or conventional fronts shiny. This will aid the movement of material across the table. If the table is rough or rusted, polish or sand it at the start of the season with a sanding disc. At the end of the season, spray the table with a protective coating to stop rusting.

Types of harvester fronts

Closed (comb) fronts

Closed (comb) fronts were used on early harvesters as they coped adequately with light, short crops (Figure 11.1). Most losses from closed fronts are caused by the plant impacting with the spiral. To reduce this make sure the height between the point of cut on the stem and the top of the crop is less than the distance between the knife and centre point of the spiral.

Losses may also be reduced by increasing the finger gap to 16 mm. Remove a finger as necessary. When re-adjusting the front for wheat or barley, make sure the knife is timed so it stops behind a finger.

Open fronts

Open fronts have largely replaced closed fronts because they offer more flexibility for a wide range of crops. They are essential when harvesting a heavy, dense crop. There are generally two types: conventional auger or tin fronts and the more recent draper or belt fronts.

Conventional auger or tin fronts

The following suggestions may help reduce harvesting losses on conventional auger or tin fronts.

- Fit double density (quad) knife guards with the original single density knife (Figure 11.2). This will limit the sideways throw of the plant during cutting. Do not use a double density knife with double density knife guards because it may cause problems with the knife drive.
- Use a finger or tine reel because they feed the lupin plants more gently into the front compared with batt reels (Figure 11.3).
- Extend the table and knife forward by up to 300 mm to allow the crop to come under the auger, depending on the crop density (Figure 11.4).

Table 11.1 Drum or rotor diameters and rotational speed for a selection of harvesters

<table>
<thead>
<tr>
<th>Make</th>
<th>Model</th>
<th>Drum or rotor diameter (mm)</th>
<th>Drum or rotor speed for 12 m/s peripheral speed (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case IH</td>
<td>2388/AFX8010</td>
<td>762</td>
<td>300</td>
</tr>
<tr>
<td>Cat Lexion</td>
<td>480</td>
<td>600</td>
<td>380</td>
</tr>
<tr>
<td>Claas</td>
<td>116CS</td>
<td>450</td>
<td>510</td>
</tr>
<tr>
<td>Gleaner</td>
<td>R65/75</td>
<td>635</td>
<td>360</td>
</tr>
<tr>
<td>John Deere</td>
<td>9860 STS</td>
<td>750</td>
<td>305</td>
</tr>
<tr>
<td>Massey Ferguson</td>
<td>9790</td>
<td>700</td>
<td>325</td>
</tr>
<tr>
<td>New Holland</td>
<td>CR970</td>
<td>560</td>
<td>410</td>
</tr>
</tbody>
</table>

Note: Trade names are used for clarity and do not imply endorsement of those products over other products.

Figure 11.1 Closed front harvester Photo: G Riethmüller
• Fit Lupin Breakers® on the table auger (Figure 11.9). This will help feed the cut material along the table.
• Use a large capacity auger that has one and a half pitches per rotation (instead of one pitch per rotation). This will move cut material quickly.
• Fit a reduced diameter auger barrel with larger flights than the conventional auger barrel so there is more room for the bulky lupin crop.
• Raise the auger to give a larger gap between the table and the auger flighting. This works well for bulky material and helps maintain optimum auger speed (for example, driven by hydraulic motor). It will also improve feeding of cut material across the table and reduce losses.
• Alter the retractable finger timing when fully retracted at the 2 o'clock position (viewed from driver’s left-hand end). This may reduce repeats over the auger and give the fingers more reach over the platform to grip incoming material.
• Replace standard reels with air reels, particularly if you have a light crop. Air reels direct a blast of air into the front and are very good for blowing shed seed into the table. There are two types of air reels: manifold and full-width fan. Both work well depending on power available (Figure 11.5).
• Use a Vibra-Mat® which is a vinyl mat that oscillates with the knife. The mat helps clear cut material to stop it bunching at the knife. It is relatively cheap and can be good in light crops (Figure 11.6).

**Draper or belt fronts**
The following suggestions may help reduce harvesting losses on draper or belt open fronts.
• Fit double density finger guards with the original single density knife. This will limit the sideways throw of the plant during cutting. Do not use a double density knife with double density guards because it may cause problems with the knife drive.
• Raise the knife to be level with the belts to aid flow. Some knife guard manufacturers offer this as a kit such that the knife guard is bolted on top of, rather than under, the mounting bar.
• Use a finger or tine reel (Figure 11.7) because they feed the lupin plants more gently into the front compared with batt reels (Figure 11.8).
• Move augers that are over the feeder house forward. This will help grab the material coming along the belts. In addition, fitting Lupin Breakers® to this small auger may feed in heavy crops (Figure 11.9).
Figure 11.5 Manifold air reel (left) and full-width fan air reel (right) Photos: G Riethmuller

Figure 11.6 Vibra-Mat® attached to the knife back Photo: G Riethmuller

Figure 11.7 Finger reel on a draper front Photo: G Riethmuller

Figure 11.8 Batt reel on a draper type front Photo: G Riethmuller

Figure 11.9 Lupin Breakers® fitted to the centre auger on a draper front Photo: G Riethmuller
Case Study

Lupin – a profitable option for sandy soils of the south coast

Nils Blumann farms acid soils on the south coast at Gibson just north of Esperance in a 550 mm rainfall zone. Lupin is the only grain legume cash crop that fits into his family’s integrated cropping/livestock enterprise and he has been growing this crop consistently since 1989. Input costs are lower than any crop within his rotation.

For Nils, lupin provides a break crop between cereals or canola. Two bonuses are that the stubble readily fattens weaners while the crop increases soil organic carbon and significantly increases soil nitrogen.

Apart from bean yellow mosaic virus (BYMV), Nils finds there are no diseases that his enterprise cannot easily manage. Sclerotinia has been a problem in heavy crops over 4 t/ha while brown spot, lupin anthracnose and cucumber mosaic virus (CMV) are easily handled with appropriate precautions.

High yielding and profitable

In each of the past four years (2002–06), Nils has averaged better than 3 t/ha, with the best at 3.6 t/ha. With current practices and varieties, 4t/ha over a whole paddock seems to be the upper limit, although yield maps have shown areas yielding 5 tonnes. In 2005, one 60 ha paddock yielded 3.94 t/ha with an estimated 300 kg/ha on the ground. Nils believes that the new black pod syndrome resistant variety, Jenabillup, will be the key to pushing lupin crops beyond the 4 t/ha average on the south coast.

Nils has found another attraction of growing lupin associated with claying deep sand. In the first growing season after incorporating approximately 5 per cent clay into the top 100 mm of soil, lupin crops give more profitable returns than other crops.

Tanjil has out-performed other varieties on Nils’ farm. He has been sowing them at progressively lower rates from an initial 100 kg/ha to the point that 55 to 60 kg/ha at 7.5 inch row spacing gives good yields without excessive vegetative growth. He uses a John Deere 1890 disc seeder with a John Deere 1910 air cart, which gives precise seeding depth and superb establishment. This unit works well in 5 t/ha cereal stubbles on the Blumann’s sandy soils.

No fungicide or rhizobia inoculant is used on the seed, which is sown with 15 to 20 units of phosphorus. Nils uses manganese for the first two lupin crops on a paddock but none thereafter.

Weed and pest management

Lupin seed is sown into previous season’s cereal stubble anywhere between 10 May and 20 May following a knockdown herbicide if the season has broken. Otherwise, weeds are controlled in-crop. Simazine is used if silver grass is a problem, Verdict® is applied for grass and erodion control, and Brodal® for other broad-leaved weeds. Most years Nils gets away with only an application of glyphosate for the knockdown control of weeds. Early weed germination has increased dramatically since overcoming non-wetting by claying. This has in turn led to vastly improved herbicide efficacy. Compared to the northern sandplain, radish to date has not been a major problem in the lupin phase of the rotation. Consequently, Nils has not switched to Mandelup with its metribuzin tolerance.
However, he does foresee that radish will become more of a problem weed in the future as herbicide resistance kicks in.

Insects cause few problems. In the past 10 years, Nils has encountered one year in which bean root maggot affected establishment and in another year he sprayed for budworm after pod set.

**Swathing or direct heading**

Nils has swathed before harvesting but he found that direct harvesting with a 30 ft extended open front was cheaper with higher yields. The number of primary pods lost during swathing the 3+ t/ha crops was unacceptable. Nils found that most of his production is derived from pods on secondary, tertiary and even quaternary branches which mature later than those on the primary spike. This means that swathing is not viable.

**Swathing**

Swathing lupin involves cutting the crop and laying it in a windrow. The crop is swathed when the seed is close to physiological maturity. At this point the seed is fully formed and no longer increases in weight, but is too moist to harvest with a conventional harvester. The crop dries out in the windrow and is harvested later. Success depends on swathing at the correct time.

**When to start swathing**

Swathing can start when the average moisture content of all seed is 65 per cent. This usually occurs at the start of leaf drop. The stems and leaves of the lupin plant will be light green to yellow. The cotyledons of the seed will usually be green, but this may vary depending on where the seeds are held on the plant. Seeds on the main stem will be more advanced and more yellow than those on the lateral branches (Figure 11.11).

**When to stop swathing**

A lupin crop will be at a point suitable for swathing for about seven to 16 days, depending on the season and location. Do not swath a crop if the seed moisture content is less that 50 per cent because yield will be lost through pod drop during the swathing operation and as the plants dry in the windrow.

**The swathing operation**

The crop should be cut 10 to 20 cm above the ground. A large width of crop compacted into a small, dense windrow reduces the loss of yield through pod drop. Windrows will be ready to harvest between 10 and 30 days after the plants have been cut. Take care when harvesting the windrow because most yield is lost during this operation (60 to 80 per cent of all losses).

---

### Figure 11.11 Swathing can start when the cotyledon colour of seed from each branch approximately matches this example.

Source: DAFWA
Harvesting

Producing lupins
12 End uses for lupin
Sofia Sipsas and Marion Seymour
Worldwide, almost all lupin production is used for stockfeed with only a small amount consumed by humans in the food market.

Lupin is very suitable as a feed for ruminants. It is a high protein, high energy grain that has virtually no starch. The composition of carbohydrates in lupin seed makes it more suited to fermentative digestion than monogastric intestinal hydrolysis. As a consequence, the energy value of lupin for ruminants is quite good and roughly equivalent to that of cereals.

For pigs, lupin is discounted by the proportion of energy recovered. For poultry, the energy values of lupin are significantly compromised by the lack of any effective fermentative function within the avian stomach. The value of lupin can be improved for monogastrics by removing the hull, although there is no benefit in doing this for ruminants. The hulls can be used in ruminant diets.

The economic viability of de-hulling is linked to the nutritional value of each fraction being fully recognised in the pricing by respective end users. Currently, it depends on the protein content of the whole grain as the most valuable fraction.

The international demand for vegetable protein is a large and growing market. Western Australia’s lupin production represents only a very small segment of this sector with less than 1 per cent of total trade in vegetable protein. Therefore, because lupin is a minor grain, lupin prices are driven by soybean (Glycine max), the largest vegetable protein source in the world. Different end users require different characteristics from lupin to receive maximum benefit (Table 12.1).

**Nutrient content of lupin**
The nutrient content of lupin in terms of protein, amino acids, energy and minerals has been well established and widely accepted by stockfeed manufacturers. Table 12.2 compares modern lupin cultivars and advanced breeding lines with respect to seed weight, seed protein, seed oil and alkaloids.

When compared with soybean, lupin has significant advantages as a whole grain. However, stockfeed manufacturers have developed processing techniques for soybean that largely eliminate the negatives associated with that product.

<table>
<thead>
<tr>
<th>Table 12.1 End user requirements for lupin</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key quality factors</strong></td>
</tr>
<tr>
<td>Cattle and sheep</td>
</tr>
<tr>
<td>Pigs and poultry</td>
</tr>
<tr>
<td>Aquaculture</td>
</tr>
</tbody>
</table>
The positive elements for lupin include:
- a concentrated source of protein and energy
- a lack of any major anti-nutritional factors (for example, trypsin inhibitors)
- no requirement for heat treatment
- desirable handling and storing attributes due to the robust seed coat.

The composition of narrow-leafed lupin (*L. angustifolius*), albus lupin (*L. albus*) and yellow lupin (*L. luteus*) is outlined in Table 12.3.

### Using lupin as animal feed

#### Ruminants

All components of narrow-leafed lupin seed are readily digested by ruminant animals whose resident microbial populations provide the enzymes required to degrade the soluble and insoluble complex carbohydrates. An important advantage of lupin is that ruminants do not normally need a period of introduction to avoid acidosis. Furthermore, the content of lignin (the compound which usually limits the digestion of

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<table>
<thead>
<tr>
<th>Table 12.2 Comparison of recent cultivars for seed weight, seed protein, seed oil and seed alkaloids</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variety</strong></td>
</tr>
<tr>
<td>Merrit</td>
</tr>
<tr>
<td>Mandelup</td>
</tr>
<tr>
<td>Belara</td>
</tr>
<tr>
<td>Đanđa</td>
</tr>
<tr>
<td>Kalya</td>
</tr>
<tr>
<td>Quinlock</td>
</tr>
<tr>
<td>Tallerack</td>
</tr>
<tr>
<td>Tanjil</td>
</tr>
<tr>
<td>Coromup</td>
</tr>
</tbody>
</table>

Note: Figures are taken as a percentage of Merrit as the standard: seed weight (145 mg); seed protein (36 per cent dry weight basis); seed oil (7 per cent dry weight basis); seed alkaloids (0.012 per cent).

<table>
<thead>
<tr>
<th>Table 12.3 Proximate analysis of three lupin species (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L. angustifolius</strong></td>
</tr>
<tr>
<td><strong>Whole seed (%)</strong></td>
</tr>
<tr>
<td>Seed coat</td>
</tr>
<tr>
<td>Moisture</td>
</tr>
<tr>
<td>Crude protein</td>
</tr>
<tr>
<td>Fat</td>
</tr>
<tr>
<td>Ash</td>
</tr>
<tr>
<td>Lignin</td>
</tr>
<tr>
<td>Polysaccharides</td>
</tr>
<tr>
<td>Oligosaccharides</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
fibre) is very low (< 1 per cent) and the overall digestibility of lupin seed is about 90 per cent. This high digestibility combined with the moderate oil content of lupin results in a metabolisable energy value (in vivo) of 13 MJ/kg which is higher than cereal grains.

In ruminant animals, the composition of the protein is of less importance, though the content of methionine may be limiting for wool production in sheep and milk production in high producing dairy cows. However, a high proportion of dietary protein is undegraded in the rumen and can increase the overall nutritive value of the feed. Narrow-leafed lupin seed supplements used in sheep and cattle reproduction have been attributed to this undegraded portion.

Grazing lupin stubbles
Lupin seed losses during harvesting often exceed 150 kg/ha (Figure 12.1). It is generally safe to graze lupin stubbles down to 50 kg/ha. Lupin stubbles are, therefore, a very nutritious livestock fodder. Remove sheep from lupin stubbles when there is less than 50 kg of seed/ha or when the amount of groundcover is 50 per cent or less, whichever develops first.

The seed remaining on the ground has the greatest influence on the paddock’s carrying capacity because it has a high digestibility and a high proportion is used by the animal (Table 12.4). This seed quantity should be assessed to ensure best management of stubbles. The amount of seed remaining on the ground can be measured using a tenth of a square metre quadrat. The quadrat is placed on the ground and the seed lying inside it is counted. Seeds in whole pods must also be counted. This should be done at 30 random sites across the paddock.

Case Study

An integrated crop-livestock system
Will Carrington-Jones and his family farm a mixed livestock-cropping enterprise near Kojonup – a 2835-ha operation with 50/50 sheep and cropping. He reports benefits from growing lupin.

The family’s sheep enterprise is 50/50 merino lamb and cross-bred long-tail lamb. The family runs 10,000 sheep and has the main shearing in April. The cross-bred lambs are shorn in September. Ewes that are not on lupin stubbles are fed a base rate of 100g grain/head/day, which varies depending on the season.

The cropping program is around 1120 ha with an additional 360 ha share-cropped on another farm. They grow from 120–150 ha of lupin a year and mate around 2500 ewes on the stubbles. So far they have avoided lupinosis and Will thinks this is because they always have run-off pasture or stubble paddocks to supplement the lupin stubbles.

Will has found one of the best things about lupin is its long-term storage. It does not attract insects – which Will reckons makes up for having to deal with heliothis during podding. He said the worst thing about lupin in his farming system is its lack of consistent high yield but they are trying Jenabillup for the second year and so far this variety looks promising.

Will reports that lupin benefits the farm’s sheep enterprise because it is an excellent protein source and ewes can be mated on the stubble. Growing stockfeed on the farm is important because they do not have to buy in feed product which could be contaminated with weeds such as doublegeee not found on the farm.
Calculate the average number of seeds inside the square. Eight seeds per quadrat equates to 100 kg/ha.

Grazing sheep will eat more than 250 g/head/day of lupin seed. Therefore, if 200 kg/ha of seed remains after harvest, sheep grazing at 10 DSE/ha will eat down to 50 kg/ha within eight weeks, if grazing is uniform. Generally, six weeks is the maximum length of grazing on lupin stubble.

If animals are grazed early to avoid lupinosis, lupin stubbles can maintain or increase the weight and condition of all classes of sheep. Lupin stubbles are a very good summer feed source for weaners. Weaners can gain up to 200 g/head/day on lupin stubbles, but more commonly weight gains are in the order of 100 to 150 g/head/day in weaners. Lupin stubbles are also useful paddocks for joining as the good quality feed increases ovulation rates in ewes.

The key to successful use of lupin stubbles is to minimise the risk of lupinosis (see Chapter 13 Lupinosis) and prevent soil erosion.

**Advantages of lupin for supplemental feeding**

The nutritional composition of lupin seed makes it an invaluable on-farm feed supplement for sheep and cattle.

Lupin is a safe grain to feed to sheep and cattle. There is little risk of acidosis because of the low starch level and relatively high digestible crude fibre content (13 to 17 per cent). The crude protein content of 28 to 34 per cent means that lupin grain is a protein concentrate.

Where fed as a supplement, lupin has the two-fold benefit of boosting the overall protein content of the total diet and inducing an increased appetite for roughage, encouraging grazing of the pasture or stubble.

Lupin is a better source of protein than most other feeds. It stimulates microbial activity in the rumen, which helps to break down cereal stubble. The low levels of starch in lupin mean that the rumen pH does not drop as much as it does with cereal grains (so that the rumen contents are less acidic). This also has a positive effect on the rumen’s ability to break down roughage.

Lupin seeds are large and highly palatable so growers can broadcast lupin into thick cereal stubble and, once trained, sheep will eat almost all the seed. This encourages stubble break down as sheep forage for seed and it can discourage sheep from grazing the bare areas.

Scattering the seed amongst the stubble encourages shy feeders and curbs greedy sheep. Lupin is particularly high in metabolisable energy for sheep and cattle due to its high digestibility. Sheep are very efficient at digesting whole lupin and there is no need to process the seed.

Acidosis has occurred rarely when feeding large amounts of lupin seed to hungry sheep and cattle without an introductory phase.

Lupin has a good balance of calcium to phosphorus making calcium deficiency unlikely. To better use the nitrogen content of lupin, a sulfur supplement is beneficial, for example, feeding a lick containing gypsum.

<table>
<thead>
<tr>
<th>Table 12.4 Use of lupin stubble by merino weaners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stubble components</td>
</tr>
<tr>
<td>Seed</td>
</tr>
<tr>
<td>Pods</td>
</tr>
<tr>
<td>Leaves</td>
</tr>
<tr>
<td>Stems</td>
</tr>
<tr>
<td>All components</td>
</tr>
</tbody>
</table>
Improving reproduction in sheep

Feeding lupin as a paddock supplement to rams at the rate of 800 g/head/day for eight weeks before joining has been shown to improve testicle size and condition and to encourage maximum fertility. Feeding lupin to ewes as a paddock supplement at 400 to 500 g/head/day for two weeks before and after joining begins can significantly increase lamb marking percentages. A similar result may be achieved by putting the ewes onto lupin stubble containing adequate lupin seed.

The nutrition of pregnant ewes influences lamb birth weight, which in turn can have a significant effect on lamb survival. The feeding level should depend on the condition of the ewes, stage of pregnancy, proportion of twins and the amount and quality of dry paddock feed. The feeding rate should be from 100 to 450 g/head/day.

During lactation, feed 300 to 450 g/head/day depending on the available paddock feed.

Improving the performance of weaner sheep

Weaner ill-thrift (a general inability of young sheep and cattle to thrive following weaning) is a common problem and is particularly acute when stock are weaned when paddock feed is lacking in quantity or quality.

Feeding lupin helps weaners to maintain weight or grow on without a major setback following weaning. A lupin seed supplement of about 50 g/head/day should maintain the liveweight of weaner sheep grazing cereal stubble for several weeks, after which the quantity fed will need to be increased, up to 150 g/head/day, as the stubble quality dwindles.

At present prices it costs less to maintain weaner liveweight with lupin seed than with feed blocks. Lupin can be successfully fed out to weaners at intervals of up to one week. It is worthwhile feeding the lupin supplement for a week or two before weaning so that the young animals learn how to eat the supplement from the adults.

Feeding for sheep production

At times it may be necessary to grow or finish animals to meet a particular market requirement, such as live export of wethers or sale of prime lambs.

Lupin is an excellent basis for finishing sheep. A high energy, medium protein (minimum for adults 12 per cent, weaners 15 per cent) ration such as lupin–cereal grain mixtures should be fed. A good rule of thumb is to use a ration of three parts cereal to one part lupin.

Stock fed lupin or rations containing lupin usually adapt to the high level of grain feeding quickly, although care should be taken to avoid acidosis when cereal is included. Sheep will grow more quickly on rations containing lupin than on cereal grain concentrates.

Feedlots are generally unnecessary, as grazing sheep fed grain from self-feeders placed in stubble or dry pasture paddocks are likely to do better than in feedlots. If the supplement is fed on stubbles or dry pastures, no additional roughage should be necessary.

Lupin for drought feeding

There are substantial benefits from including some lupin in drought rations for pregnant and lactating sheep. Lupin should be included in drought rations of breeding sheep at levels of at least 10 per cent of the ration (depending on the relative price of lupin and cereal grain). Because lupin does not cause grain poisoning it can be conveniently used as a means of conditioning stock to cereal-based rations by changing gradually from lupin to cereals.

Traditionally, supplementary feeding has involved trailing out seed twice a week or putting blocks out every three to four weeks. However, the most efficient way to feed lupin is to spread it on dry pasture or cereal stubble paddocks with a fertiliser spreader once a week. Supplementation as low as 75 g/head/day on good pasture or oat stubbles is beneficial, while 150 g/head/day is necessary on poor pastures and wheat stubbles.

It is important to start feeding early, before body condition declines. Use 150 g/head/day of lupin for dry sheep. Aim to maintain condition score 2 and monitor the condition of the animals closely. Adjust feed accordingly.

Lupin for milk and cattle production

Feeding lupin has been shown to increase the milk production of beef and dairy cattle. Lupin is better than cereals because it does not lower the fat content of milk as high levels of cereals do. As a result of the improved nutrition (and increased milk production) following lupin supplementation, there may be a marked boost in the growth of the suckling calves.
Lupin is an excellent supplement for finishing cattle which will grow more quickly on rations containing lupin than on cereal grain concentrates. As with sheep, a good rule of thumb is to use a ration of three parts cereal to one part lupin.

Feeding lupin in a trough or on the ground at 3 kg/head/day will maintain cattle weight on dry summer pastures. Lupin is a more effective supplement for cattle than cereal grains when there is an abundance of poor quality dry pasture.

**Pigs and poultry**

Non-ruminant animals lack the enzymes required to digest complex carbohydrates in the stomach and small intestine. Unless there is fermentation in the lower tract (for example, in pigs), the digestibility of energy from lupin seed in these species is much lower than in ruminants.

Even where substantial fermentation in the lower tract does occur, the net energy yield from lupin is lower than for grains which are largely digested in the upper tract. Furthermore, there is evidence for pigs that this value may be influenced by other components in the diet.

For pigs and poultry, narrow-leafed lupin must be supplemented with free lysine and methionine or combined with a protein source rich in these amino acids.

Commercial pig growers have successfully used up to 30 per cent whole lupin seed in pig rations. It is often not economical to de-hull lupin to enhance their feeding value. While the digestible energy is compatible to other legumes, commercial feed formulators tend to discount this by 1 to 1.5 MJ because so much of the carbohydrate is fermented in the hind gut and the energy is not fully available.

Poultry rations normally contain less than 10 per cent lupin, frequently kernels, because of the associated problem of sticky or wet droppings. While aesthetically undesirable and a potential health risk to the birds, through respiratory stress from ammonia and coccidiosis, this is not known to affect feed conversion.

Albus lupin has a higher protein and crude fat content than narrow-leafed lupin. The energy value is higher and digestibility is similar. There is little data on energy use at present for ruminant animals for the two species of lupin but they may be regarded as interchangeable. There is apparently poor acceptance of albus lupin by pigs because the growth rate is lowered if included at more than about 15 per cent of the ration. Extensive studies have shown that this is not related to any anti-nutritional factor such as alkaloids, manganese or amino acid deficiency.

Yellow lupin offers potential advantages over narrow-leafed lupin and albus lupin to the intensive animal industries. The crude protein content is higher than either narrow-leafed lupin or albus lupin. A further advantage is the higher amounts and digestibility of the three important amino acids: lysine, methionine and threonine. The digestible energy for pigs and Apparent Metabolisable Energy for poultry are both higher than for narrow-leafed lupin (Table 12.5).

**Aquaculture**

The demand for alternative protein resources to fishmeal in aquaculture diets has stimulated substantial interest in the potential of lupin in Australia. Some major international feed companies routinely use lupin kernel meal in their formulations. The salmonid and prawn feed markets have been identified as two key prospective markets for value-added lupin products. These two markets are technically the most advanced aquaculture feed markets in the world. Together they constitute about 3.6 million tonnes of feed each year. Although significant volume exists in other markets such as tilapia and catfish species, the feed requirements are for low protein and low energy and, therefore, the cost sensitivity of ingredient choice is high. Conversely, salmonid and prawn feeds are high in protein and have little formulation flexibility. This allows increased marketability of such products and an increase in the value per unit of protein or energy.

Lupin has been examined to test the influence of removing the seed coat (de-hulling) on its nutritional value. Both narrow-leafed lupin and albus lupin varieties in their whole seed and kernel meal forms were studied by feeding the ingredients to silver perch (*Bidyanus didyanus*), an omnivorous species. Clear nutritional advantages from de-hulling lupin were observed irrespective of the lupin species evaluated. Improvements with de-hulling were seen in the digestibility of dry matter, nitrogen and energy (Table 12.6).
## End uses for lupin

### Table 12.5 Analysis of three lupin species (whole seed) for nutrient and anti-nutritional factors

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>L. angustifolius</th>
<th>L. albus</th>
<th>L. luteus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude fibre (%)</td>
<td>15.4</td>
<td>10.6</td>
<td>16.25</td>
</tr>
<tr>
<td>ADF (%)</td>
<td>19.7</td>
<td>14.6</td>
<td>24.87</td>
</tr>
<tr>
<td>NDF (%)</td>
<td>23.5</td>
<td>17.6</td>
<td>34.3</td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>0.22</td>
<td>0.2</td>
<td>0.22</td>
</tr>
<tr>
<td>Phosphorus (%)</td>
<td>0.3</td>
<td>0.36</td>
<td>0.43</td>
</tr>
<tr>
<td>Alkaloid (%)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>DE pigs (MJ/kg)</td>
<td>14.6</td>
<td>16.9</td>
<td>16.4</td>
</tr>
<tr>
<td>ME cattle (MJ/kg)</td>
<td>12.0</td>
<td>11.9</td>
<td>n/a</td>
</tr>
<tr>
<td>ME sheep (MJ/kg)</td>
<td>12.2</td>
<td>12.5</td>
<td>n/a</td>
</tr>
<tr>
<td>AME poultry (MJ/kg)</td>
<td>10.4</td>
<td>13.2</td>
<td>11.4</td>
</tr>
</tbody>
</table>

ADF = acid detergent fibre  
NDF = neutral detergent fibre  
DE = digestible energy  
ME = metabolisable energy  
AME = apparent metabolisable energy  
Source: Petterson Sipsas & Mackintosh 1997

### Table 12.6 Digestibility (%) of *L. angustifolius* and *L. albus* (whole and kernel meal) in silver perch

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>L. angustifolius</th>
<th>L. albus</th>
<th>L. albus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Whole seed</td>
<td>Kernel</td>
<td>Whole seed</td>
</tr>
<tr>
<td>Dry matter</td>
<td>50.3</td>
<td>67.6</td>
<td>64.7</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>96.6</td>
<td>100.3</td>
<td>96.1</td>
</tr>
<tr>
<td>Energy</td>
<td>59.4</td>
<td>74.0</td>
<td>72.7</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>71.8</td>
<td>80.1</td>
<td>77.5</td>
</tr>
</tbody>
</table>

### Table 12.7 Digestible nutrient contents (g/kg dry matter) for rainbow trout and red seabream of key lupin species kernel meals compared to solvent-extracted soybean meal and wheat gluten

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Albus lupin (L. albus)</th>
<th>Narrow-leafed lupin (L. angustifolius)</th>
<th>Yellow lupin (L. luteus)</th>
<th>Soybean (G. max)</th>
<th>Wheat gluten</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rainbow trout</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic matter</td>
<td>571</td>
<td>561</td>
<td>533</td>
<td>597</td>
<td>877</td>
</tr>
<tr>
<td>Energy (MJ/kg DM)</td>
<td>14.8</td>
<td>12.9</td>
<td>13.6</td>
<td>14.4</td>
<td>20.5</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>5.0</td>
<td>4.0</td>
<td>5.0</td>
<td>3.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Protein</td>
<td>402</td>
<td>383</td>
<td>473</td>
<td>437</td>
<td>846</td>
</tr>
<tr>
<td><strong>Red seabream</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic matter</td>
<td>509</td>
<td>481</td>
<td>584</td>
<td>679</td>
<td>928</td>
</tr>
<tr>
<td>Energy (MJ/kg DM)</td>
<td>14.1</td>
<td>12.9</td>
<td>14.6</td>
<td>15.6</td>
<td>21.7</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>5.0</td>
<td>4.0</td>
<td>4.5</td>
<td>5.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Protein</td>
<td>455</td>
<td>407</td>
<td>485</td>
<td>484</td>
<td>868</td>
</tr>
</tbody>
</table>
In a recent report on the nutritional variability of lupins as an aquaculture feed ingredient, the digestible values of the kernel meals of three species of lupin (L. angustifolius, L. albus and L. luteus) were compared both against each other and with a reference ingredient of solvent-extracted soybean meal and wheat gluten (Glencross, et al. 2003). These diets were fed to rainbow trout (Oncorhynchus mykiss) and red seabream (Pagrus auratus) (Table 12.7).

The digestibility of protein of all lupin kernel meals is generally better than that of the soybean meal. The digestibility of dietary energy from each of the lupin kernel meals is typically less than that obtained from soybean. However, the higher gross energy content of most lupin kernel meals means that a level of digestible dietary energy similar overall to soybean meal is obtained. The key finding was the excellent overall nutritional attributes of yellow lupin kernel meal.

**Human consumption**

Lupin grain is uniquely high in protein (30 to 40 per cent) and dietary fibre (30 per cent) and low in fat (6 per cent). It contains minimal starch and, therefore, has a very low glycemic index. In nutritional terms, lupin seed is an attractive alternative to soybean for human consumption.

Food laboratory studies have shown that the protein and fibre components have excellent functional properties. Lupin ingredients have been included in a range of highly palatable breads and other baked goods, meat products and beverages.

Studies have also indicated the substantial health attributes of lupin. In particular, it is useful in managing obesity and the related metabolic syndrome including a cluster of factors such as being overweight, high blood pressure, insulin resistance and elevated blood cholesterol.

Lupin enriched foods have the potential to provide the following benefits.

- **Influence satiety** (appetite suppression) and energy balance. Subjects reported a significant decrease in hunger after a breakfast that included lupin and consumed 300 less calories at the subsequent lunch.

- **Influence glycemic control.** Lupin flour included in white bread significantly reduced the blood glucose response and the insulin response.

- **Improve blood lipids.** Lupin fibre acts as a soluble fibre and lowers the total cholesterol without affecting the HDL cholesterol.

- **Improve bowel health.** Lupin foods reduce transit time, lower colon pH (anti cancer) and act as a pre-biotic.

**Further reading**

Butler, R & Croker, K 2006, Stubbles—their use by sheep, Farmnote 188/2006, Department of Agriculture and Food, Western Australia, South Perth.


End uses for lupin
13 Lupinosis

Marion Seymour
Lupinosis is caused by toxins produced by the fungus *Diaporthe toxica* (formerly known as *Phomopsis leptostromiformis*), which grows mainly within lupin stems. The disease is still commonly referred to as phomopsis. Ingesting too much toxin causes liver damage which can result in disorientation, blindness, lethargy and eventually death in severe cases. It also results in significant production losses without any other obvious symptoms. Any animals grazing lupin stubble may be affected, but sheep are affected most severely because they are most sensitive to the toxins.

Lupinosis was first diagnosed at Dandaragan in 1948 and became a widespread problem with the spread of sandplain lupin during the 1950s and 1960s. The fungus was identified in 1970, and this was soon followed by techniques to estimate disease severity and to minimise the disease by managing animals grazing lupin stubbles.

Severe lupinosis problems occurred in the developing narrow-leaved lupin industry, particularly in the summers of 1974–75 and 1988–89. All narrow-leaved lupin cultivars released since 1988 have some resistance to *D. toxica*, but this has not removed the danger of lupinosis altogether.

With careful planning and good management it is possible to graze lupin stubbles while minimising production losses from lupinosis.

### Factors affecting lupinosis

**Presence of the fungus**

Nearly all stands of lupin in Western Australia will be infected by *Diaporthe toxica* to some degree. However, this does not mean that lupinosis is inevitable: its occurrence depends on complex interactions between the fungus, the amount of toxin present, the weather, the feed available in the stubble and the grazing behaviour of the sheep. Consequently, the severity of symptoms of phomopsis cannot be used to predict which stubbles will cause problems. All stubbles should be regarded as potentially dangerous.

**Varietal resistance**

All narrow-leaved lupin varieties currently grown in Western Australia have some resistance to phomopsis. However, they are not immune to the fungus, and lupinosis still occurs.

**Weather**

Temperature, rainfall, humidity and dew all influence the production of toxin by the fungus. Rainfall, high humidity or consistent dews when daily maximum temperatures are about 25°C create ideal conditions for toxin production in stubble. Lupinosis most commonly occurs in the first few days following more than 10 mm of summer rain.

**Time of grazing**

Generally, the risk of toxicity increases as summer progresses.
Alternative feed
Most of the fungus and most of the toxin is in the lupin stem. Generally, sheep will eat other plant material in preference to the stem. Thus, lupinosis risk is lowest in lupin stubbles with a low proportion of stem. Stubbles from weedy lupin crops with high harvest losses are less risky than efficiently harvested, weed-free crops. Stock should never be allowed to graze stubble if residual lupin seed is not readily available. Lupin stubbles are not safe to graze if there are fewer than 40 lupin seeds/m² (or four in a 0.1 m² quadrat).

Stocking rates
High stocking rates increase the risk of lupinosis because increased grazing pressure forces the sheep to eat more stem material. Stocking rates above 15 sheep/ha are particularly dangerous.

Sheep age
Weaners are more susceptible to lupinosis than adults. This is partly because they tend not to eat as much lupin seed as adults, but more stems. Weaners are also more likely than adults to develop nutritional white muscle disease (myopathy) and lupinosis associated myopathy. Weaners also have a much smaller fat reserve than adults, which makes the impact of lupinosis more severe.

Hunger
Hungry sheep are less selective grazers and should never be moved onto lupin unless good quality hay is provided. If it is not possible to remove them from lupin paddocks, sheep chasing a green pick after summer rain should be given hay to avoid increasing their intake of toxic lupin stubble.

Individual sheep habits
Sheep will graze lupin in preference to pasture or cereal stubble. If they have access to a small area of lupin in a large paddock of cereal stubble they may preferentially graze the lupin, artificially creating a high stocking rate and increasing the risk of lupinosis. Even under normal conditions some sheep eat more stem than others. This can be used to advantage because such sheep will act as early indicators of an impending outbreak of lupinosis.

Sheep or cattle
Sheep are more susceptible than cattle, but it should not be assumed that cattle will not develop the disease. In fact, cattle grazing lupin may frequently suffer liver damage which is not usually severe enough to produce disease symptoms but can still affect productivity. Lupinosis toxins produce two distinct syndromes in cattle: fatty liver syndrome and cirrhotic liver syndrome. Disease in cattle is often expressed as another disease such as copper poisoning or photosensitisation. Cattle are predisposed to both of these diseases by liver damage caused by lupinosis.

Grazing management to minimise lupinosis
Management is the key to preventing losses—the early detection of affected animals in flocks is important. Frequent observations of the flock are necessary to identify clinical signs and to monitor the rate of stubble usage. The following points should be considered:

- grazing order
- pre-feeding lupin seed
- water availability
- paddock assessment
- feed budgeting
- husbandry procedures
- stocking rates
- livestock classes
- stock observation.

Grazing order
Lupin stubble should always be grazed before cereal stubbles. Ideally, sheep should be put into lupin paddocks as soon as the paddocks are harvested. It is usually better to defer grazing cereal stubbles and put up with some loss in stubble quality than to defer grazing lupin stubbles and suffer increased risk of lupinosis.

Pre-feeding lupin seed
Before introducing sheep to lupin stubble, feed them some lupin seed on dry pasture or cereal stubble to teach them to search for seed in the stubble. This should reduce the intake of toxic stems and extend the safe period for grazing. This is essential for weaners, but applies to adults as well.
**Water availability**
Good quality stock water must be available close to the lupin stubble. Sheep grazing lupin stubble drink about twice as much water as sheep on cereal stubble, so extra water points should be provided.

Alternatively, water points can be moved around during grazing. This avoids the high stocking intensities which increase the risk of lupinosis and wind erosion often seen around water points.

If water supply is interrupted, sheep losses may follow (especially with weaners) within 24 hours, but perhaps not until several weeks later.

The likelihood of sheep eating toxic stems in the over-grazed surrounds of the water point can be reduced by:
- providing two or three round bales of hay around the water supply
- making the sheep walk to water in a nearby pasture or cereal stubble paddock (only for older, experienced sheep).

**Paddock assessment**
The amount of seed present on the ground, the amount of fungus on stems and the amount of non-lupin feed present can be assessed before grazing a lupin stubble, but toxin production by the fungus cannot be assessed visually. The interaction between paddock factors, the weather and animal factors is unpredictable.

As a general rule, do not graze lupin stubbles if there are fewer than 40 lupin seed/m² or if ground cover is less than 50 per cent.

**Feed budgeting**
Sheep should be well fed before entering lupin stubbles. An alternative feed should be available in case the lupin stubble becomes unusable. Some oats and hay should be stored for sheep suffering from clinical lupinosis as affected animals cannot tolerate high protein diets during the early stages of recovery.

**Husbandry procedures**
Pink-eye affected sheep should not be put on lupin stubbles, as they have trouble finding lupin seeds and will eat the stubble.

Licks or blocks containing copper or urea must not be fed to sheep on lupin stubbles. Lupinosis affected sheep are very susceptible to copper and urea toxicity.

**Stocking rates**
High stocking rates should be avoided even early in the season. When grazing pressure is high, sheep tend to eat more of the toxic stem material. More than 15 sheep/ha is dangerous.

Weaner mobs should contain less than 600 sheep. If only a portion of the paddock is lupin stubble, the stocking rate should be calculated on the lupin area, not the total area. This is because sheep often graze lupin stubbles in preference to other stubbles and dry pasture. Lupin straw has no useful value so the sheep should be removed when there are fewer than 40 lupin seeds/m².

**Livestock classes**
Heavily pregnant ewes should not be put onto lupin stubbles because even mild lupinosis can predispose them to pregnancy toxaemia. Weaners are more susceptible to lupinosis than older sheep.

**Stock observation**
Stock observation is the single most important aspect of lupinosis management. If possible, stock should be closely observed every day from the first day they go into the lupin stubble, so that signs of the disease can be detected before significant body weight losses or deaths occur. Regular inspection must be continued throughout the grazing period, including during holidays and harvest. As part of the inspection, move the mob several hundred metres and watch for weak and staggering sheep. Liver damage should be suspected in sheep with hollow flanks.

If portable yards are available, a sample of the mob should be condition-scored. Every two weeks or so, individuals should be examined closely to improve detection of lupinosis. Weighing 50 sheep from the mob every two weeks and removing sheep when they stop gaining weight will help prevent clinical lupinosis. Checking for any yellow in the membranes around the eye at this time will help determine if lupinosis is occurring.
As soon as any symptoms are noticed, remove stock from the lupin stubble. If they are not removed until some animals die there may be significant wool production and body weight losses in the mob.

Lupinosis is the most prevalent stock disease when grazing lupin stubbles, so interpret any sign of ill health as lupinosis and take appropriate action unless it can be confirmed that lupinosis is not the cause. Lupinosis is often seen in conjunction with other diseases, but it remains the primary problem.

**Symptoms and treatment**

Look for hollow flanks, lethargy when driving stock, noticeably poor growth rate, individuals not keeping up with the mob and individuals staying at the dam or water point when the mob is elsewhere.

In advanced cases, signs include disorientation, blindness, a hunched appearance and reluctance to move. The mucous membranes around the eye and mouth may become yellow. Sometimes an animal is found with its head caught in a fence. Some of these signs result from conditions which develop because of lupinosis. Severe acute lupinosis of sheep due to a sudden high intake of toxin, resulting in many deaths in three to 14 days, is less common.

**Remove stock from stubbles**

Remove stock from lupin stubbles:
- during and after more than 10 mm rainfall, when the lupin stalks will be more palatable
- immediately after the first signs of illness
- when there are fewer than 40 seeds/m².

**After removal**

During the convalescent period do not sell mobs containing clinically affected animals. If sold as stores, more animals may die at the new owner’s property. If sold for slaughter, condemnations can be expected at abattoirs because of jaundice in clinically affected animals.

Being able to hold sheep until they recover should be part of the management plan. Take the flock to a grassy paddock with adequate water and feed them oaten hay. They should not have access to green pick (melons, wireweed) or high protein feed for at least six weeks after they have been removed. This includes not feeding licks containing urea.

Green feed can cause photosensitisation in sheep with lupinosis. The skin on the face becomes red, swollen and crusty, and the ears swollen, crusty and pendulous. In cattle any white areas of hair may show these symptoms. All forms of copper must be avoided during the convalescent period. Drenches, injections, blocks, fertilisers and trough treatments to kill algae may contain copper.

**Treatment of clinical cases**

There is no antidote for lupinosis but nursing will improve the survival of mildly affected animals. Aim to minimise stress, restore appetite and avoid dehydration while the liver repairs itself. Animals with advanced signs should be shorn and euthanased because nursing is generally unsuccessful.

For large mobs, oats and good quality hay should be fed around water points to entice affected sheep to eat and to reduce the need for walking to graze. For small groups it may be practical to remove the sheep to a shaded area with adequate feed and water. After a gradual introductory period, oats may be fed freely.
If possible, separate affected animals to reduce the size of the group being nursed. This should be done carefully by drifting the mob between paddocks. Yarding is too stressful for sheep with lupinosis.

Sheep that recover from lupinosis regain weight quickly if their appetite can be restored during the convalescent period.

**Further reading**
Butler, R & Croker, K 2006, *Stubbles—their use by sheep*, Farmnote 188/2006, Department of Agriculture and Food, Western Australia, South Perth.

Jacob, R 2005 *Moving water points on lupin stubbles*, Farmnote 106/89 (revised 2005), Department of Agriculture, Western Australia, South Perth.
Glossary
**Glossary**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>allelopathic</td>
<td>the release by one plant species of chemicals which affect other species in its vicinity, usually to their detriment</td>
</tr>
<tr>
<td>anthesis</td>
<td>when pollen is shed from the anthers</td>
</tr>
<tr>
<td>apical branches</td>
<td>lateral branches at the top of the main stem</td>
</tr>
<tr>
<td>basal branches</td>
<td>lateral branches at the bottom of the main stem</td>
</tr>
<tr>
<td>biomass</td>
<td>living material, or material of a biological origin</td>
</tr>
<tr>
<td>CaCO₃</td>
<td>calcium carbonate</td>
</tr>
<tr>
<td>cellulose</td>
<td>complex carbohydrate that gives rigidity to plant cells; a component of fibre</td>
</tr>
<tr>
<td>cluster roots; proteoid roots</td>
<td>specialised root structures that secrete organic acids. They consist of a dense cluster of short rootlets that protrude for 2 to 5 cm along a lateral root.</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>cortex</td>
<td>outer layer of the taproot</td>
</tr>
<tr>
<td>cotyledons</td>
<td>two modified leaf structures that make up the bulk of the seed in legumes and provide a nutrient source for the developing seedling</td>
</tr>
<tr>
<td>crop density</td>
<td>the number of plants per unit area</td>
</tr>
<tr>
<td>deep banding</td>
<td>placing the fertiliser below the seed while sowing</td>
</tr>
<tr>
<td>de-hulling</td>
<td>removing the seed coat</td>
</tr>
<tr>
<td>dehydration postponement</td>
<td>a drought tolerance strategy whereby tissue water deficit is postponed by reducing water loss or increasing water uptake</td>
</tr>
<tr>
<td>dehydration tolerance</td>
<td>a drought tolerance strategy whereby plant function is maintained in spite of severe tissue water deficit</td>
</tr>
<tr>
<td>desorb</td>
<td>mobilise or remove a substance from the surface of the soil particle on which it is absorbed or adsorbed</td>
</tr>
<tr>
<td>direct drilling</td>
<td>when seed is sown directly into the soil without prior cultivation; wide points are used to achieve a full cut, that is, complete soil disturbance</td>
</tr>
<tr>
<td>drought escape</td>
<td>a drought tolerance strategy whereby the crop’s life cycle is completed while water is still plentiful</td>
</tr>
<tr>
<td>dry matter</td>
<td>in lupin, this term refers to any part of the plant once all water has been removed.</td>
</tr>
<tr>
<td>embryo</td>
<td>miniature plant within the seed, consisting of cotyledons, five or six leaf primordia and radicle</td>
</tr>
<tr>
<td>enzymes</td>
<td>proteins that enable chemical reactions in the plant</td>
</tr>
<tr>
<td>epicotyl</td>
<td>the shoot of the seedling occurring above the cotyledon which eventually becomes the main stem of the plant</td>
</tr>
<tr>
<td>epigeal emergence</td>
<td>cotyledons remain where seed was placed in soil and only the stem above them lengthens to protrude from the soil</td>
</tr>
<tr>
<td>establishment rate</td>
<td>the number of seedlings that establish as viable plants in the field; expressed as a percentage of the number of viable seeds planted</td>
</tr>
<tr>
<td>evapotranspiration</td>
<td>total water use: the combined water flow through the plant and evaporation directly from the soil surface</td>
</tr>
<tr>
<td>floral initiation</td>
<td>when the growing apex of the plant stops initiating leaves and begins to initiate flowers</td>
</tr>
<tr>
<td>full canopy cover</td>
<td>when leaves of a crop fully shade out the ground</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<td>-----------------------------</td>
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<tr>
<td>germination rate</td>
<td>the proportion of seed in a seed batch that germinates and produce a healthy looking seedling</td>
</tr>
<tr>
<td>germination test</td>
<td>a laboratory test that measures the proportion of seed in a seed batch that are dead, produce abnormal seedlings or produce healthy looking seedlings</td>
</tr>
<tr>
<td>harvest index (HI)</td>
<td>the percentage of above-ground biomass converted to grain in particular crop species, usually determined by dividing the total grain weight by the weight of total above-ground biomass</td>
</tr>
<tr>
<td>hyphae</td>
<td>fine filamentous, branching tubes which make up the body (or mycelium) of a fungus</td>
</tr>
<tr>
<td>hypocotyl</td>
<td>the shoot of the seedling from below the cotyledons to where it joins the root</td>
</tr>
<tr>
<td>hypogeal emergence</td>
<td>hypocotyl expands to push the cotyledons and growing apex above the soil surface</td>
</tr>
<tr>
<td>inflorescence</td>
<td>a cluster of flowers. In lupin, the inflorescence is arranged as a raceme.</td>
</tr>
<tr>
<td>internodes</td>
<td>the stem between the nodes</td>
</tr>
<tr>
<td>leaf primordia</td>
<td>microscopic structures on the growing apex that will develop into leaves</td>
</tr>
<tr>
<td>lignin</td>
<td>a complex non-carbohydrate compound that binds to cellulose fibres and strengthens the cell walls of plants</td>
</tr>
<tr>
<td>metabolisable energy value</td>
<td>the proportion of energy in grain that is available to be metabolised</td>
</tr>
<tr>
<td>myopathy</td>
<td>generic term for muscle disease</td>
</tr>
<tr>
<td>nitrogen fixation</td>
<td>biochemical conversion by bacteria of atmospheric nitrogen into a form plants can use</td>
</tr>
<tr>
<td>nodes</td>
<td>the points of attachment between leaves and the stem</td>
</tr>
<tr>
<td>nodules</td>
<td>bacteria-containing swellings on legume roots that enables them to fix atmospheric nitrogen</td>
</tr>
<tr>
<td>non-persistent transmission</td>
<td>when an insect retains a virus for only one or two probes on healthy plants before ceasing to transmit it</td>
</tr>
<tr>
<td>no-till cropping</td>
<td>when seed is sown directly into the soil without prior cultivation; narrow points are used so only a small proportion of the soil is disturbed.</td>
</tr>
<tr>
<td>Phosphorus Retention Index (PRi)</td>
<td>a measure of the capacity of soil to retain phosphorus</td>
</tr>
<tr>
<td>photoperiod</td>
<td>length of daylight</td>
</tr>
<tr>
<td>photosynthesis</td>
<td>the process in green plants where carbohydrates are synthesised from carbon dioxide and water, using light as an energy source</td>
</tr>
<tr>
<td>physiological maturity</td>
<td>when seeds reach maximum weight</td>
</tr>
<tr>
<td>raceme</td>
<td>an inflorescence with stalked flowers arranged singly along an unbranched axis</td>
</tr>
<tr>
<td>radiation use efficiency (RUE)</td>
<td>the amount of biomass produced per unit of radiation intercepted by the crop</td>
</tr>
<tr>
<td>radicle</td>
<td>embryonic root</td>
</tr>
<tr>
<td>reduction</td>
<td>conversion of a chemical compound that results in it gaining electrons. Usually the reaction combines hydrogen with the compound or removes oxygen from the compound.</td>
</tr>
<tr>
<td>rhizobium</td>
<td>a type of bacteria in the soil or inoculated onto the seed that will infect roots and form a beneficial symbiosis with plants to fix atmospheric nitrogen</td>
</tr>
<tr>
<td>ruminants</td>
<td>a group of animals that characteristically have a stomach divided into four compartments and chew a cud consisting of regurgitated, partially digested food, for example, cattle, sheep, goats</td>
</tr>
<tr>
<td>satiety</td>
<td>when eating, the condition of feeling satisfactorily full</td>
</tr>
</tbody>
</table>

**Producing lupins**
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>sclerotia; microsclerotia</td>
<td>hard, black spherical resting bodies of a fungus</td>
</tr>
<tr>
<td>sorb, adsorb, fix</td>
<td>to take up and retain a substance on the surface of a soil particle</td>
</tr>
<tr>
<td>split seed syndrome</td>
<td>visible symptoms of manganese deficiency</td>
</tr>
<tr>
<td>sporulate</td>
<td>to produce spores</td>
</tr>
<tr>
<td>stomata</td>
<td>tiny pores in leaves through which water and CO₂ are exchanged with the atmosphere</td>
</tr>
<tr>
<td>sweet seed</td>
<td>seed that is low in alkaloids</td>
</tr>
<tr>
<td>testa</td>
<td>seed coat</td>
</tr>
<tr>
<td>top-dressing</td>
<td>spreading fertiliser over the soil surface</td>
</tr>
<tr>
<td>transpiration</td>
<td>the process whereby water passes from the soil to the atmosphere through the plant</td>
</tr>
<tr>
<td>vernalisation</td>
<td>a plant’s requirement for exposure to low temperatures in order to flower</td>
</tr>
<tr>
<td>volatile</td>
<td>easily vaporised chemicals</td>
</tr>
<tr>
<td>water use efficiency (WUE)</td>
<td>the amount of biomass or grain produced per millimetre (mm) of water used in evapotranspiration</td>
</tr>
<tr>
<td>weaner ill-thrift</td>
<td>a general inability of young sheep and cattle to thrive following weaning</td>
</tr>
</tbody>
</table>
### Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOM</td>
<td>blue oat mite</td>
</tr>
<tr>
<td>BYMV; BYMV-N; BYMV-NN</td>
<td>bean yellow mosaic virus; necrotic form; non-necrotic form</td>
</tr>
<tr>
<td>CC</td>
<td>critical concentrations</td>
</tr>
<tr>
<td>CMV</td>
<td>cucumber mosaic virus</td>
</tr>
<tr>
<td>DAFWA</td>
<td>Department of Agriculture and Food, Western Australia</td>
</tr>
<tr>
<td>DAS</td>
<td>days after sowing</td>
</tr>
<tr>
<td>PRI</td>
<td>phosphorus retention index</td>
</tr>
<tr>
<td>RLEM</td>
<td>redlegged earth mite</td>
</tr>
<tr>
<td>RLN</td>
<td>root lesion nematode</td>
</tr>
<tr>
<td>RUE</td>
<td>radiation use efficiency</td>
</tr>
<tr>
<td>WS</td>
<td>whole shoots</td>
</tr>
<tr>
<td>WUE</td>
<td>water use efficiency</td>
</tr>
<tr>
<td>YFEL</td>
<td>youngest fully emerged leaf</td>
</tr>
<tr>
<td>YOL</td>
<td>youngest open leaflets</td>
</tr>
</tbody>
</table>
### Development stages used for managing lupin crops

#### Seedling stage
The seedling stage begins at emergence when at least one of the cotyledons is clearly visible at the soil surface. The cotyledon point occurs when the cotyledons have separated but the first two leaves have not yet unfolded and expanded. The seedling stage ends when four leaves of the plant have expanded and unfolded (4-leaf).

#### Vegetative stage
The vegetative stage begins when five leaves have expanded and unfolded (5-leaf) and ends when the flower bud first appears on the main stem. This is usually after 18 to 20 leaves have been produced (18- to 20-leaf).

#### Flowering stage
The flowering stage begins when the flower bud becomes visible (budding point). Petals of the flowers begin to expand and diverge to reach the open flower point. Petals then die and wither to reveal small pods. This signifies pod set point. When pods are being set, the open flower point and pod set point may occur on the raceme at the same time. The flowering stage ends when the last petals have begun to wither.

#### Podding stage
The podding stage begins with the rapid growth and thickening of the pods (pod fill point). Pod fill point extends from when pods are green and succulent through to when the colour of the pod changes to khaki and seeds are plump and firm. Near maturity leaves begin to drop from the plant (leaf drop point). Leaves drop from the lower part of the plant first. When leaves have dropped from the bottom half of the plant but remain on the top half, the plant has reached 50 per cent leaf drop. When most of the leaves have fallen from the plant and there are only a few leaves remaining on the tips of the branches, the plant has reached 90 per cent leaf drop. The dry pod point is reached when pods become dry and seeds are hard with yellow cotyledons.
Naming development stages

Seedling and vegetative stages
Each point is simply named depending on the plant’s development. For example, emergence, cotyledon point, 6-leaf point or 20-leaf point.

Flowering stage and podding stage
The main stem and branches will be at different points in the flowering stage or podding stage, depending on the development of the plant. The main stem and each of the branches should be coded separately and prefixed with M, P, S, T or B to indicate the following parts of the lupin plant: Main stem (M), Primary lateral branch (P), Secondary lateral branch (S), Tertiary lateral branch (T) and Basal branch (B).

For example, M-Pod fill/P-Pod fill/S-Pod set indicates that pods on the main stem and the primary lateral branches are at Pod fill point while the secondary lateral branches are at the pod set point. The tertiary or basal branches are not specified because they have not yet produced flower buds.

A shortened way of coding the same plant would be to indicate only the point of the highest order branch that has reached the budding point. For example, the code discussed in the previous paragraph could be shortened to S-Pod set which indicates the plant has green pods on the secondary lateral branches. The points of development of pods on primary lateral branches and the main stem are not stated but would be assumed to be at either the same or a more advanced point than the secondary lateral branches (for example, pod fill point).

Leaf drop point and dry pod point tend to occur simultaneously on all branches of the plant so it is rarely necessary to code these points separately for each branch.