PASTURE LEGUMES:

A NEW ERA FOR PASTURES IN SOUTHERN AUSTRALIAN FARMING SYSTEMS: SECOND GENERATION HARDSEEDED LEGUMES (G_2HSLs)

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

SOUTHERN AUSTRALIA

INFORMATION AND MANAGEMENT GUIDE

grdc.com.au

Title:
PASTURE LEGUMES:
A new era for pastures in southern Australian farming systems: second generation hardseeded legumes (G_2HSLs)

ISBN: 978-1-922342-48-5 (online)
978-1-922342-47-8 (print)

GRDC Contract Codes:
DAS1805-003RMX, UMU1805-001RMX

Published: December 2023

Authors:
Belinda Hackney, Select Carbon;
Robert Harrison, DPIRD, Murdoch University;
Bradley Nutt, Murdoch University;
Hayley Norman, CSIRO;
Angelo Loi, DPIRD;
Neil Ballard, Global Pasture Consultants;
Tyson Wicks, Select Carbon;
Susan Orgill, Select Carbon;
Jessica Rigg, Select Carbon;
John Piltz, formerly NSW DPI (retired);
Matt Wilmot, CSIRO;
Ronald Yates, DPIRD, Murdoch University;
John Howieson, Murdoch University.

The authors wish to thank the many farmers who have provided land for research trials and for their input on the practicalities of incorporating G_2HSLs into farming systems. We also wish to express our gratitude to the funding bodies who have contributed to research and extension efforts over the past two decades. This has included contributions from the GRDC, MLA, AWI and Pastures Australia'.

To order a copy: Freephone 1800 11 00 44
or email: ground-cover-direct@canprint.com.au
and quote GRDC Order Code GRDC1615

GRDC contact details:
Ms Maureen Cribb
Integrated Publications Manager
PO Box 5367
KINGSTON ACT 2604

Email: Maureen.Cribb@grdc.com.au

Design and production:
Coretext, www.coretext.com.au

COVER: Paddock of biserrula
PHOTO: John Howieson

Contents

Photo: Belinda Hackney

Foreword

This manual is relevant to farming systems in southern Australia in which a crop is grown every second year on a paddock (or more frequently) in rotation with self-regenerating pasture legumes. This manual describes a rich spectrum of new annual legume pasture species, which we have termed 'second generation hard-seeded legumes' (G_2HSLs). These species have been specifically domesticated, bred and selected for soil and climatic conditions in the large agricultural region of southern Australia. In parallel, high-quality strains of nodule bacteria (rhizobia) have been selected to ensure these new legumes can nodulate optimally whenever they are sown or allowed to regenerate.

Subterranean clover (*Trifolium subterraneum*) and annual medics (*Medicago* spp.) represent the first generation of annual legumes in southern Australia, having arrived by accident with early settlers. They have undergone substantial breeding since arrival and, where conditions suit these legumes, they have colonised and thrived, and in doing so become the backbone of Australian ley pasture systems. They have also supplied essential nitrogen for non-legume components of pastures, and for subsequent cereal and oilseed crops, which has been critical to prosperity.

However, over the past 30 years, increased cropping intensity combined with changing climatic, soil and farming conditions have reduced the reliability of these foundation pasture legumes in southern Australian farming systems. As a result, research efforts were redirected to broaden the suite of hard-seeded annual legumes and their rhizobial inoculants to ensure reliable production of pasture forage and atmospheric nitrogen. Seventeen cultivars, mostly from newly domesticated legume species, have been released to market as a consequence of this change of research focus.

John Howieson. Photo: Anvil Media

These G_2HSLs should be implemented on soils, or in situations, where subclover or medics do not perform well.

In a rare departure for researchers, a substantial part of the science reported in this manual was undertaken to overcome the sociological and economic barriers to pasture renovation. These barriers include the high cost of seed, the timing of seeding operations (crop versus pasture), and the growth penalty from winter-sown pastures that germinate under cold conditions.

Establishment of self-regenerating pastures carries the additional complexities of inoculation, sowing small seeds, weed management, compatibility with soil type, maintaining an ongoing seedbank, rotational sequences and grazing management. Maintaining productive novel pastures is critical to profit, and our economic analyses demonstrated the clear opportunity for pasture phases with novel G_2HSLs to increase profit in mixed farming systems.

As with all legume species, the G_2HSLs are niche species with respect to adaptation to soil, climatic, farming system and management conditions. This manual provides advice on how to select, establish and manage these new pasture legumes - the G_2HSLs - for maximum success in contemporary farming systems in southern Australia.

Most of the data accumulated and lessons learnt about the G_2HSLs were in experiments on growers farms, and for this the authors are very grateful.

Professor John Howieson
December 2023

Chapter 1:
The second generation hard-seeded legumes (G_2HSLs)

1.1 Why use hard-seeded pasture legumes?

Legumes are plants that enter symbiosis with rhizobia and fix atmospheric nitrogen. Many legumes produce abundant seeds and, for some legumes, this seed undergoes physical dormancy (which prevents germination). The term 'hard-seed' refers to this physical dormancy, which continues until the seed coat is penetrated by moisture. This may take from several months after seed maturity (subterranean clover) to more than a decade (as can happen with some legumes).

The principle of ley farming , where pastures are grown in rotation with crops without having to resow the pasture, relies on hard-seeded annual pasture legumes regenerating from a bank of dormant seeds in the soil. Historically, southern Australian ley systems have relied on the first generation hard-seeded legumes (G_1HSLs), subterranean clover and annual medics, which arrived to Australia by accident. Although subterranean clover was originally considered hard-seeded, a more informed understanding of this important characteristic places it at the lower end of the spectrum of hard-seeded legumes which challenges its persistence in longer crop-phases in contemporary farming systems.

For annual legumes to reliably regenerate on their own after a cropping phase, establishment (and replenishment) of an adequate seedbank is required. The second generation hard-seeded legume (G_2HSLs) cultivars described in this manual, have been selected for seeds that soften over several seasons, rather than all at once, thereby spreading the germination pattern across years.

1.2 Other characteristics important in developing new hard-seeded legumes

Pasture researchers became aware in the 1960s that evolving farming systems (such as increased cropping) and weather patterns were reducing the productivity of both subterranean clover and medics. By the turn of the century, selection programs had begun developing alternative annual pasture legumes and, as a result, a new ideal pasture 'ideotype' emerged. The characteristics sought (relative to subterranean clover and annual medics) were:

- production of seed in aerial flowering structures (to allow for harvesting with a conventional header rather than suction harvesting as required for subterranean clover and medic);
- higher hard-seed levels (to protect from false breaks);
- different hard-seed breakdown patterns (to allow different cropping options);
- deeper root systems (to provide drought tolerance and improve capacity for reliable seed-set);
- variation in maturity time (to suit different growing regions);
- capacity for longer periods of indeterminate growth (to make better use of rainfall when it occurs, reduce feedgaps and increase seasonal nitrogen fixation in the face of changing rainfall patterns);
- acid tolerance in both the plant and its symbiosis with rhizobia (to cope with acidifying soils);
- improved pest and disease resistance (to ensure maximum growth under stress); and
- improved biomass production and nutritional value across seasons without toxins and oestrogenic compounds.

The following section briefly discusses the rationale for farming with legume species and their rhizobia with these new characteristics.

Figure 1.1: The effect of a false-break on a regenerating subterranean clover stand (left) at Tincurrin, Western Australia in 2006. A rainfall event of 20mm was recorded on 7th February causing germination of both subterranean clover and an adjacent regenerating biserrula paddock (right). The next substantial rainfall event was recorded on 1st April by which time the subterranean clover seedlings had perished. The photographs were taken on 10th May.

Photos: Angelo Loi (left), John Howieson (right)

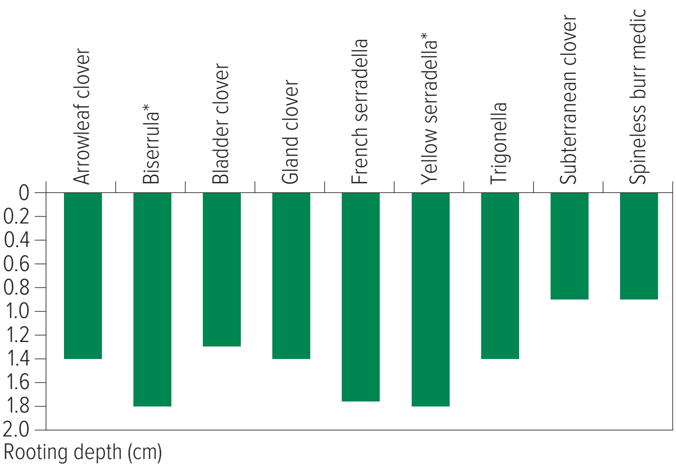
1.3 The factors driving change

1.3.1 The need for a resilient seed bank

Due to its hard-seed breakdown pattern, subterranean clover is prone to germination following late summer and early autumn rains, which are becoming more common in many parts of southern Australia. If follow-up rain is not received, many of the clover seedlings perish (Figure 1.1). This is known as a false break and is a consequence of the early softening of subterranean clover seed, coupled with its shallow and slowly developing root system. Although seedlings of subterranean clover require good soil moisture conditions for reliable establishment and regeneration, this is not the case for seedlings of other species.

The shallow root systems of subterranean clover and annual medics (Figure 1.2) can also result in greater susceptibility to moisture stress throughout the season, and a consequent weakening of the plants leaves them susceptible to root diseases. Further, moisture stress can be frequent in spring and can have a significant impact on the ability of subterranean clover and annual medics to produce sufficient hard seed to replenish the seedbank (Figure 1.3).

Figure 1.2: The rooting depth of a range of G_2HSLs compared to subterranean clover and spineless burr medic.



*The cores used for sampling were 1.8m long, roots of biserrula and yellow serradella were present at this depth and hence the rooting depth of these two species is underestimated in this figure.

Premature plant senescence caused by spring moisture stress also has negative impact on feed availability and feed quality for grazing animals (Figure 1.4). Additionally, only a low percentage of seed of subterranean clover or annual medics remains viable after ingestion by livestock, which further reduces seedbank replenishment.

1.3.2 Soil constraints

Soil acidification has also impacted the vigour and survival of subterranean clover and annual medics. This has been an additional driver to diversify the legume species available for farming systems. Major constraints to the production and persistence of the traditional legumes occur where soil pH_{Ca} <5.0. Low soil pH also impacts the rhizobia associated with subterranean clover and annual medics. In many (but not all) soils, where pH_{Ca} is below 4.8, aluminium availability in the soil solution can increase, which further reduces legume growth and rhizobial persistence. Low soil pH also limits the availability of key macro and micronutrients and, in eastern Australia, can be associated with toxic levels of manganese availability.

Figure 1.3: A mixed sward of French serradella and subterranean clover under dry conditions in spring at Badjingarra, Western Australia. Note that the French serradella is continuing to grow while the subterranean clover has died prior to setting seed.

Photo: Angelo Loi

Figure 1.4: An example of the difference in timing of senescence for G_1HSLs subterranean clover (cv. Dalkeith; left) and burr medic (cv. Cavalier, middle), compared to the G_2HSL, biserrula (cv. Casbah) in a field trial at Condobolin, NSW. Note the differences in ground cover, feed availability and the absence/presence of green herbage which will impact feed quality. Photos taken 29 October 2020.

Photos: Belinda Hackney

1.3.3 Changing farming systems

In medium and low-rainfall mixed farming areas of southern Australia, a reduction in the profitability of wool and an increased focus on grain production has led to longer cropping phases in rotations. The combination of more false breaks, susceptibility to disease and pests, regular moisture stress in spring and an increased length of the crop cycles has, over time, depleted the seedbanks and consequently the regeneration and production potential of subterranean clover and annual medic pastures.

1.3.4 Aerial seeding legumes to enable production of inexpensive seed

Apart from the biological limitations on the continued vigour and use of subterranean clover and medics, researchers were also aware of the higher cost of suction harvesting for these species. This was a major disincentive to the frequency of pasture renovation. Additionally, the damage to soil structure and exposure of harvested paddocks to wind and water erosion post-harvest were considerations in the pursuit of aerial seeding legumes. During the 1980s, the manufacture of the Horwood-Bagshaw suction harvester ceased (Figure 1.5), which also contributed to the need for aerial seeding legumes. Prior to this, pasture scientists believed that having seed heads exposed to grazing animals would compromise the persistence of the legume. However, with a general decrease in grazing pressure during spring (as a result of reduced animal numbers on-farm), the production of aerial seed by plants would not necessarily diminish their persistence. This has since been confirmed experimentally.

In a major departure from tradition, new G_2HSLs that produced their seed above ground and which could be harvested using conventional cereal headers were developed (Chapter 2). On-farm seed production was a significant improvement for accessibility to pasture seed, similar to bulking up a new line of wheat (Chapters 4 & 8). Running in parallel with the development of G_2HSLs were advancements in pasture establishment technology that allowed on-farm harvested seed to be sown without further processing. These technologies include dormant summer and dormant twin sowing (Chapter 5). Dormant summer sowing has greatly opened the sowing window for pastures, better utilising labour resources on-farm and reducing interference with autumn–winter cropping operations. Its adoption was expedited by the development of granular inoculants allowing delivery of essential rhizobia to optimise nitrogen fixation.

Figure 1.5: Suction harvesting of subterranean clover seed (left) and header harvesting of arrowleaf clover (right). Note the difference in dust generated by the two harvest methods and contrast in ground cover remaining post-harvest.

Photos: Kevin Foster (left), Craig Rodham (right)

Table 1.1: The new G_2HSLs species, currently available and soon-to-be released cultivars.

Species of G_2HSL	Common name	Cultivars available
Biserrula pelecinus	Biserrula	Casbah, Mauro, [1]Crown$_2$
Ornithopus sativus	[2]French serradella	Margurita[PBR], Erica, Fran$_2$o[PBR]
Ornithopus compressus	Yellow serradella	Charano, Santorini, Yelbini[PBR], King, Avila, SerraMax[PBR]
Trifolium spumosum	Bladder clover	Bartolo, [1]Diaman$_2$ti
Trifolium glanduliferum	Gland clover	Prima
Trifolium vesiculosum	Arrowleaf clover	Cefalu, Zeelu, Arrotas, Zulu, Zulu II
Trigonella balansae	Trigonella	[1]SA5045E

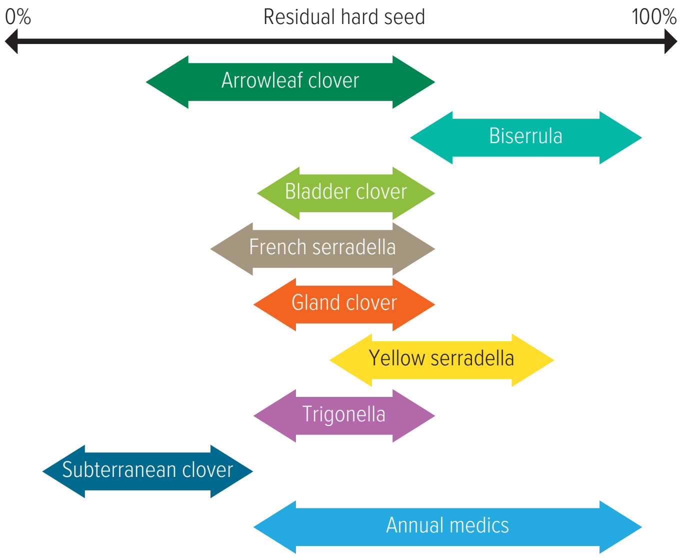
[1] These cultivars are expected to be released before 2025. [2] This publication refers to the hard-seeded French serradella cultivars shown in the table above. The French serradella cultivars Cadiz and Eliza are 100% soft-seeded and will not persist if used in the pasture-crop rotations described in this guide.

1.3.5 Understanding hard-seed breakdown patterns

While the G_2HSLs produced prolific quantities of header harvestable seed, pasture researchers realised the critical requirement for new legume species to have different patterns of hard-seed breakdown compared to conventional species. While species such as subterranean clover produce seed that initially have a high hard seed content, it breaks down rapidly making it susceptible to false breaks and meaning there can be relatively little residual hard seed in the seed bank (Figure 1.6). For improved persistence in the seed bank, researchers needed to develop cultivars of new species with seed that was protected from false breaks via slower release from dormancy in early summer. This meant that the G_2HSLs generally had higher residual hard seed by the following autumn (Figure 1.6).

More nuanced understanding of G_2HSL hard seed breakdown patterns saw researchers identify and develop cultivars that, while being well protected from false breaks, softened sufficiently over late summer and early autumn for the development of new pasture establishment methods such as dormant summer sowing. These innovations in establishment are covered later in this guide.

Figure 1.6: The residual hard seed (%) in early winter for a range of G_2HSLs and the G_1HSLs subterranean clover and annual medics.



1.4 G_2HSLs and contemporary farming systems

An exciting range of G_2HSLs has been developed, with 17 cultivars commercialised over the past 25+ years, all with very different characteristics (Table 1.1; Chapter 2).

The remainder of this guide describes the origins and attributes of these new G_2HSLs and indicates where they can be adopted and appropriate methods for their establishment and management (Chapters 3, 4 & 5). This guide emphasises establishment methods that overcome barriers to adoption and the way they can be integrated with cropping systems that exploit fixed nitrogen and weed control opportunities in the rotation (Chapters 6 & 7). The consideration of herbicides used in rotations is also discussed with reference to the potential of the residues of herbicides used in cropping systems to adversely impact the growth and nitrogen fixation of both G_2HSLs and traditional pasture legumes (Chapter 6). Tips for growing and harvesting seed on farm are also provided (Chapter 8), while the role G_2HSLs in supporting livestock production is discussed (Chapter 9)

Finally, all legumes (both G_2HSLs and traditional) are niche species that require a certain growing environment to be highly productive. Choosing which of the G_2HSLs to grow involves thorough consideration of your soil and climatic conditions, presence of specific rhizobia partners and future rotational requirements.

GRDC

Chapter 2:
The new suite of G_2HSLs

This chapter gives a brief overview of the species of G_2HSLs in alphabetical order and their key characteristics. In subsequent chapters, we discuss more fully which niche each species satisfies and how best to establish and manage them.

The following species will be covered:

- arrowleaf clover;
- biserrula;
- bladder clover;
- gland clover;
- French serradella;
- yellow serradella;
- trigonella; and
- other hard-seeded annual legumes.

2.1 Arrowleaf clover

Arrowleaf clover (*Trifolium vesiculosum*) is native to the Balkan peninsula, the Crimea and the Caucus regions but is naturalised through many areas of the Mediterranean basin. It has been introduced to many areas of the world with Mediterranean-type and temperate climates including Australia, North and South America and New Zealand.

Arrowleaf clover has large trifoliate leaves and can grow to more than one metre tall under optimal growing conditions (Figure 2.1). It is suited to loam and medium clay textured soils with good drainage. Arrowleaf clover is a relatively deep-rooted plant (1.3 to 1.5m), which enables it to better tolerate seasonal moisture stress compared to other shallower-rooted species. Arrowleaf clover forms an effective nitrogen-fixing symbiosis with and should be inoculated with Group C (WSM1325) inoculants.

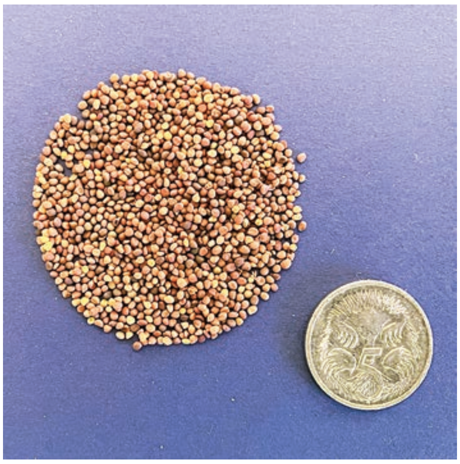
There are several arrowleaf clover cultivars available in Australia ranging from the earliest maturing Cefalu (130 days to flowering; DTF, Wagga Wagga) through to the very late maturing Arrotas (160 to 170DTF, Wagga Wagga). Earlier maturing cultivars are better suited to lower rainfall conditions as they can set seed before the growing season ends. Generally, the earliest maturing cultivars have shown reliable production and persistence in eastern Australia, as well as WA where annual rainfall exceeds 380 millimetres.

Arrowleaf clover generally produces a prolific quantity of seed (500 to 800 kilograms per hectare), which can be easily harvested with commercial cereal harvesters ('headers'). Many growers prefer to windrow arrowleaf clover to improve seed harvest. Direct heading is also possible; however, green stems can cause header blockages, therefore an application of a desiccant is recommended a few days prior to direct harvest. Seed harvested using a header typically has a hard-seed content of >85 per cent.

To achieve an acceptable standard level of seed germinability (>90 per cent), header-harvested seed needs to undergo further scarification for conventional sowing (in autumn-winter). However, arrowleaf clover can be established using unprocessed, header-harvested seed by sowing in summer in NSW at a seeding rate of 12 to 15kg/ha. Typically, if sown in mid-February to early March, approximately 40 to 50 per cent of the seed will be capable of germination by mid-April to late May, depending on seasonal conditions. Alternatively, seed can be scarified and sown conventionally in mid to late autumn at 5kg/ha.

Arrowleaf clover can be grown as a monoculture or in mixtures and produces sufficient hard seed to be suited to 1:1 rotations (one year pasture, 1 year crop) without requiring resowing after the cropping phase, provided sufficient seed is produced in the establishment year. In some areas, arrowleaf clover will successfully regenerate following two years of cropping (1:2 rotation). Seedbank longevity is dependent on the quantity of seed produced, the initial hard-seed content and the environmental influences (temperature and rainfall) on hard-seed breakdown.

Figure 2.1: Arrowleaf clover in the vegetative (left) and reproductive (middle) stages of growth. Seed is shown on the right.



Photos: Belinda Hackney

The growth habit of arrowleaf clover makes it ideal for silage or hay production for forage conservation. It tends to have a relatively high feeding value for sheep and cattle due to high energy and crude protein levels (see Chapter 9).

2.2 Biserrula

Biserrula (*Biserrula pelecinus*) is native to areas of the Mediterranean and north Africa. It has only been domesticated relatively recently, with the first cultivar (Casbah) developed by Dr John Howieson, Dr Angelo Loi and Dr Steve Carr in WA and released in 1997.

Biserrula has a bipinnate (fern-like) leaf and grows to a height of approximately 0.5m with a very dense canopy. It is suited to light to medium textured soils that are well drained (Figure 2.2). Biserrula has very poor tolerance of waterlogging. Biserrula is a deep-rooted plant (to 1.8m) and has great capacity to regulate moisture loss through its leaves; it can alter the angle of leaflets to minimise light interception under high temperature and low moisture conditions. These characteristics allow biserrula to withstand temperature and moisture stress better than most other annual legumes, improving survival and seed production, even under extremely adverse growing conditions. Biserrula should be inoculated with the Special inoculant WSM1497.

There are two biserrula cultivars available in Australia (Casbah and Mauro), with a third soon to be released ($Crown_2$). Casbah is the earlier flowering cultivar (105DTF), with $Crown_2$ flowering several days later and Mauro flowering two weeks later again. $Crown_2$ has been selected for improved seed harvesting attributes (Figure 2.3). It was developed by Dr John Howieson and Dr Bradley Nutt and will be released after seed increase in 2024. Although there is variation in time to flowering within cultivars of biserrula, it has an indeterminate growth habit that gives it the capacity to continue to flower and produce seed outside the growing season while there is moisture available. Under severe spring moisture stress, biserrula may appear to senesce (die-off) only to commence growing and setting pods again when rainfall is received (Figures 3.9 and 3.10; pages 30–31).

Biserrula is a prolific seed producer with 500 to 1000kg/ha seed generally produced in commercial stands, depending on seasonal conditions. Seeds are produced inside saw-toothed papery pods and are very hard. Biserrula seed is very small with approximately one million seeds per kilogram. Casbah normally produces seed that is at least 95 per cent hard at the end of spring–early summer. When left in the paddock, variation in temperature and moisture conditions influence the rate of hard-seed breakdown.

Figure 2.3: The biserrula cultivar $Crown_2$ has been selected for improved seed harvestability. The pods of this cultivar are held higher in the canopy.

Photo: John Howieson

In WA, where summer is typically dry and hot, more than 90 per cent of seed may still be hard by mid to late autumn. In contrast, in NSW seed typically breaks down more quickly with 20 to 40 per cent becoming soft by mid to late autumn. In NSW, hard-seed breakdown rates are higher where summer rainfall is greater.

Biserrula can be harvested on-farm using a cereal header. However, only 20 to 40 per cent of Casbah and Mauro seed will be captured when harvesting this way as the pods are very papery and many pass through the header unthreshed. $Crown_2$ holds its pods higher than the other two cultivars and the pod is easier to thresh, which improves capture by the header. Biserrula growers

Figure 2.2: Biserrula in the vegetative (left), reproductive (middle) stages of growth and seed (right).

Photos: Belinda Hackney

GRDC

who use a header to harvest generally commit to harvesting larger areas to obtain the quantity of seed they require. Greatest harvest efficiencies using a header are obtained where the biserrula is left to fully senesce and then is raked into windrows prior to harvesting. Hot dry conditions are best for harvesting as this helps to thresh the pod in the header. Seed harvested using a header undergoes minimal scarification with a very high proportion remaining hard. Where greater harvest efficiencies are required, biserrula seed can be collected using a modified clover suction harvester.

Biserrula can be established conventionally by sowing scarified seed in early to late autumn (5kg/ha), and this is recommended in WA. Growers are generally advised to sow biserrula as early as possible (following the same rules for canola crops) to maximise growth and seed production and to reduce weed competition as much as possible. As biserrula has a deep and rapidly developing root system, it is more tolerant to earlier sowing than traditional shallow-rooted species such as subterranean clover.

In some areas of NSW where higher moisture conditions in summer contribute to higher rates of hard-seed breakdown, biserrula has been successfully established via dormant summer sowing using unprocessed (header-harvested) seed.

Once first year seed-set has been achieved, it is generally advised to crop biserrula paddocks in the following year. This uses the large quantities of nitrogen fixed by biserrula and allows hard seed to breakdown. As biserrula has such high levels of hard seed, there is considerable capacity to vary the pasture–crop rotation system. If good seed-set is achieved in the first year, biserrula will withstand at least four years of cropping without the need for resowing after the cropping phase. However, most growers choose to run pasture–crop rotation systems ranging from 1:1 (one year pasture, one year crop) to 1:3 (one year pasture, three years crop) to maximise organic nitrogen efficiency.

Although the nutritive value of biserrula foliage and seed is very high (see Chapter 9), it has a tendency to become dominant in a sward. Therefore, sheep grazing biserrula are exposed to a higher risk than normal of phytosensitivity. However, there are management tactics that can be used to reduce the potential for outbreaks (see Chapter 9).

2.3 Bladder clover

Bladder clover (*Trifolium spumosum*) is native to the Mediterranean and parts of Eurasia. It was only recently domesticated, with the first cultivar, Bartolo, developed by Dr Angelo Loi and Dr Bradley Nutt in WA and released in 2008. A second cultivar, Diaman$_2$ti, with greater biomass and seed production, was developed by Robert Harrison and Dr Bradley Nutt and will be released in 2024.

Bladder clover stands can grow to a height of approximately 0.5m (Figure 2.4). For optimal performance, it requires soils that are well drained and with a pH_{Ca} >5.0. Bladder clover has a moderate to deep root system, reaching 1.3m in depth. This enables it to tolerate periods of moisture stress and achieve seed-set under variable spring rainfall conditions compared to shallow-rooted species. Bladder clover should be inoculated with Group C (WSM1325) inoculant.

Bladder clover is a prolific seed producer with seed yields of 500 to 1800kg/ha recorded in commercial paddocks. It can be readily harvested using a cereal header as the seed breaks free

Figure 2.4: Bladder clover in the late vegetative, early reproductive stage of growth (top left) and reproductive (top right) stages of growth. Senesced bladder clover (bottom left) and seed (bottom right).

Photos: Belinda Hackney, except for bottom left, Hayley Norman from the calyx easily, allowing for a high harvest efficiency using a cereal header. Bladder clover has a very thick seed coat and immediately after harvesting, seed is more than 90 per cent hard. In regenerating stands where seed remains in the paddock, 40 to 60 per cent of the seed will breakdown and regenerate in the following season.

Bladder clover has a hard-seed breakdown pattern that is well suited to summer and dormant twin sowing, where climatic and soil conditions are suitable. Bladder clover is also well suited to conventional sowing as scarified seed. As bladder clover has a very thick seed coat, it requires aggressive scarification.

Bladder clover, once a seedbank is established, is well suited to 1:1 rotations, although it will still regenerate well where two crops are occasionally sown between pasture years (that is, 1:2 rotations).

Bladder clover maintains high nutritional value for livestock during senescence and a a large proportion of the seeds pass through sheep and remain viable.

2.4 Gland clover

Gland clover (*Trifolium glanduliferum*) is native to countries of Eurasia with a Mediterranean climate. Gland clover was domesticated in WA by Dr Steve Carr and Dr Bradley Nutt with the first cultivar, Prima, released in 2001.

Gland clover grows to approximately 0.5m high with a root system that can extend to a depth of 1.4m. Gland clover should be inoculated with a Group C (WSM1325) inoculant. It is a relatively early maturing species with Prima flowering approximately 90 to 100 days after sowing (Figure 2.5).

Gland clover is a very versatile plant that has good tolerance to waterlogging but also grows well in soils that are freely drained. It grows well in soils with a pH_{Ca} range of 4.8 to 8.0.

Gland clover is relatively prolific in terms of seed production with yields of 300 to 900kg/ha common in commercial paddocks. It is very readily harvested using a cereal header where a harvest index exceeding 90 per cent is common. When harvested in this manner, more than 90 per cent of the seed is hard. Left in the paddock, 40 to 60 per cent of the seed will soften and be capable of germination in the following autumn.

In NSW, gland clover has been successfully established using unscarified seed by dormant summer sowing (12kg/ha) where 40 to 60 per cent of seed breaks down and becomes germinable over the late summer–early autumn period. In commercial situations when summer sown, gland clover is often grown in a mixture with other species having similar hard-seed breakdown patterns such as bladder clover and hard-seed French serradella. Gland clover is well suited in rotations similar to these two species.

In other areas, conventional sowing using scarified seed is the recommended method of establishment. Generally, when conventionally sown, gland clover will be mixed with other pasture species. In WA, gland clover is sometimes mixed with dehulled, scarified seed of yellow serradella (3kg/ha of gland and 2kg/ha of serradella). Dehulled yellow serradella is relatively expensive and using gland clover in the mixture allows for a higher pasture density in the establishment year at a more reasonable cost. Over time, yellow serradella then increases in density and begins to replace gland clover.

Gland clover was domesticated due to its resistance to redlegged earth mite, aphids and lucerne flea. Gland clover contains a small amount of coumarin, sufficient to prevent insect attack. Coumarin-containing plant species can be a potential issue for animal health, where spoilage occurs during haymaking and the coumarin can be converted to dicoumarol. Dicoumarol ingested in sufficient quantities by livestock can cause internal haemorrhage. Duty of care studies undertaken prior to the release of Prima found that coumarin levels were lower in Prima than in other agricultural species such as melilotus. It was also found that sheep grazing Prima residues maintained blood parameters that were considered normal. Due to the levels of coumarin in gland clover, it is recommended that this species not be used for silage and haymaking but it is better suited to general grazing.

2.5 French serradella

French serradella (*Ornithopus sativus*; sometimes called pink serradella) is an annual legume that has been used for several centuries as a fodder and green manure in the Iberian Peninsula, Atlantic Islands and central Europe. More recently it has been introduced and cultivated in the Mediterranean climatic zones of Australia and South Africa. Although a soft-seeded species, the hard seed trait was bred into French serradella by Dr Bradley Nutt in WA, making it suitable for pasture–crop rotations. This successful plant breeding program significantly increased the range of cultivars available to Australian and international agriculture. Selection for hard seed attributes has led to the development of the Margurita$^{\phi}$, Erica and Fran$_2$o$^{\phi}$ cultivars, which all have an initial hard seed content of >90 per cent. However, 40 to 60 per cent of this seed breaks down and is capable of germination by autumn. Depending on the cultivar, French

Figure 2.5: Gland clover in the vegetative (left) and reproductive (middle) stages of growth and seed (right).

Photos: Belinda Hackney

serradella flowers 90 to 125 days after sowing. The hard-seeded French serradella cultivars have been sown across one million hectares of WA and NSW since 2010. It is important to note that soft-seeded cultivars of French serradella (Cadiz and Erica) are available. The soft-seeded cultivars are not suitable for use in summer sowing or for the on-demand rotations described in this guide, therefore all further mentions of French serradella in this guide refer to the hard-seeded cultivars.

French serradella can grow to a height of approximately 50 to 70 centimetres and is well adapted to sandy and sandy–loam soils with a pH_{Ca} 4.5 to 7.0 (Figure 2.6). It has good tolerance to high levels of exchangeable aluminium but is intolerant of high levels of exchangeable manganese. French serradella should not be grown in alkaline soils and does not tolerate prolonged periods of waterlogging in WA. In NSW, it has shown poor tolerance to any period of waterlogging. Differences in waterlogging tolerance in WA compared to NSW may be due to differences in soil chemical and physical properties with the sandier textured A horizon of many WA soils providing some relief from waterlogging compared to higher clay content soils of NSW. Soils prone to waterlogging in NSW can also have higher levels of available manganese to which serradella shows poor tolerance.

French serradella has a rapidly developing, deep root system (1.8 to 2.0m), which means that it is less susceptible to mortality from false breaks in summer and autumn and more likely to set seed under adverse growing conditions in spring. French serradella should be inoculated with Group S (WSM471) or Group G (WU425) commercial inoculants. French serradella has an indeterminate growth habit, meaning it continues to grow and produce seed while moisture is available in spring and early summer. The capacity for indeterminate growth means French serradella can respond to late spring rainfall and provide high-quality feed for livestock into late spring and summer.

French serradella can be readily harvested using a cereal header with yields of 700 to 1000kg/ha pods common in commercial paddocks. Pods break into segments when harvested with each pod segment containing one seed. The pod of the hard-seeded cultivars segments readily and is well suited to dormant summer sowing. Pods can also be dehulled, the seed scarified and sown conventionally in autumn. By weight, approximately two-thirds of the pod is made up of seed, making dehulling efficiency higher for French than for yellow serradella. The pods offer a high-value supplement to livestock but a portion of the seeds are lost to digestion.

Once a seedbank of the hard-seeded cultivars is established, they can be used in 1:1 rotations with occasional instances of two years of cropping between pasture phases without needing to be resown.

French serradella contains some tannins, which means it is a much lower bloat risk than most other legume species.

French serradella pods are susceptible to attack by native budworm. Larvae can cause significant loss in seed yield. Stands should be monitored for the presence of pests and treated if required, especially first year stands as formation of a robust seedbank is essential for persistence in the future.

2.6 Yellow serradella

Yellow serradella (*Ornithopus compressus*) is native to the Mediterranean regions of western Europe and north Africa. It was recognised as a valuable pasture legume in Australia during the early 20th century, especially near Esperance in WA where Dr Mike Bolland and Dr John Gladstones identified it to be extremely phosphate efficient on the deep sandy soils of the region. However, many of the early cultivars (for example, Pitman, Avila and Paros) were restricted in their widespread use by being late in maturity, with pods that were strongly hook-shaped and which were prone to shedding. The species was therefore difficult to harvest, handle and dehull, which reduced its commercial success. A significant seed collection program from the Cyclades group of Greek Islands was undertaken by Dr John Howieson and Dr Mike Ewing in 1987. A breeding program subsequently conducted by Dr Bradley Nutt developed early maturing and vigorous cultivars well suited to agriculture in low and medium-rainfall zones. Cultivars released from this program were Santorini, Charano, Yelbini$^{\text{(b)}}$, King and SerraMax$^{\text{(b)}}$, with a range of maturities and hard-seed attributes. These cultivars have been sown across 2.8 million ha of WA and NSW since 1997.

Yellow serradella swards can grow to approximately 50cm in height (Figure 2.7). The species has a rapidly developing and deep root system (1.8 to 2.0m). Yellow serradella should be inoculated with Group S (WSM471) or Group G (WU425) commercial inoculants. It is well adapted to sandy and loam soils that are well drained with a pH_{Ca} of 4.0 to 7.0. It is tolerant of high levels of exchangeable aluminium (often present in low pH soils) but does not tolerate high levels of exchangeable manganese. Yellow serradella does not tolerate prolonged periods of waterlogging.

Yellow serradella pods contain approximately 40 per cent seed by weight and this seed is initially >90 per cent hard. The rate of

Figure 2.6: French serradella in the vegetative (left) and reproductive (middle) stage of growth. Pod segments and seed (right).

Photos: Hayley Norman (left), Rob Harrison (centre), Belinda Hackney (right)

Figure 2.7: Yellow serradella in the vegetative-early reproductive (left) and reproductive (middle) stages of growth. Pod segments and seed shown on right.

Photos: Belinda Hackney

hard-seed breakdown varies considerably between cultivars with 40 to >80 per cent remaining hard by the following autumn. Yellow serradella pods are more difficult to dehull than French serradella, which makes dehulled yellow serradella seed more expensive. Due to difficulty and costs associated with dehulling, pod segments are often partially processed and sold as 'enhanced pod', which contains some dehulled, partially dehulled and in-pod seed. Enhanced pod will provide an increase in germination when sown compared to unprocessed pods.

Only two cultivars of yellow serradella (Avila and SerraMax⁽ᵗʰ⁾) are suited to dormant summer sowing. Avila needs to be sown in areas with higher average annual rainfall (>500 millimetres), whereas SerraMax⁽ᵗʰ⁾ has been developed for use in lower-rainfall areas.

Sowing of dehulled, scarified seed is much more common in this species. Other legume species, such as gland clover and biserrula, are sometimes mixed with dehulled seed of yellow serradella to reduce overall seed costs. Yellow serradella will build up over time and gradually replace other legume species when sown on sandy soils.

Once a seedbank of yellow serradella is established, it is very persistent and can withstand a more intense cropping rotation (two to four years) and still be able to regenerate without the need for resowing.

Yellow serradella, similar to biserrula and French serradella, has an indeterminate growth habit, meaning it can effectively extend the growing season and provide high-quality feed into late spring and early summer. Due to the woody nature of the mature pods, they have lower feeding value than French serradella.

2.7 Trigonella

Trigonella (*Trigonella balansae*) is native to Eurasia and was identified to be of potential value for fine-textured soils in the low to medium-rainfall zone of southern Australia (300 to 450mm annual rainfall). It has also shown good adaptation to higher rainfall areas in NSW. The species was evaluated due to its potential to complement medics on fine-textured soils. Compared to medics, trigonella has improved pod retention, better processability and harvestability, is a more obligate fixer of nitrogen and can be dormant-summer sown.

Trigonella has an upright growth habit and can grow up to 60-80cm in height. It sets pods at the top of the plant, allowing easy harvest, and has a root system up to 1.4m deep (Figure 2.8). Trigonella forms an effective symbiosis with AL inoculant (RRI128) in soil with a pH_{Ca} >6.0 and Group AM (WSM1115) for more acidic soils (pH_{Ca} <6.0).

Figure 2.8: Trigonella in the vegetative stage (left), reproductive stage (middle) and seed (right).

Photos: Rob Harrison (left and right), Belinda Hackney (middle)

At flowering time, trigonella has a strong curry aroma, similar to fenugreek (*Trigonella feunum-graecum*) and attracts an abundance of bees, which improve pollination. It is important not to spray at flowering as without bees, there is a seed yield depression. Harvesting of trigonella is very similar to other G_2HSLs and the seed size is about one milligram (that is, 1,000,000 seeds/kg).

An early flowering selection from accession $Carn_2$ac (selected from accessions SA5045) was made by Dr Nutt and has been widely evaluated in WA and NSW. In research trials, trigonella has performed well on soils in NSW with a pH_{Ca} from 4.8 to 5.4 and in WA where pH_{Ca} is >5.5. Grazing studies have shown no ill effects to merino sheep or meat taint from the curry smells peculiar to the species. The first commercial cultivar is expected in 2024.

Trigonella can be established by dormant summer sowing. It has an initial hard seed content of >90 per cent with 30 to 60 per cent becoming germinable by the autumn break. Alternatively, trigonella can be sown using scarified seed in autumn.

2.8 Other hard-seeded annual legumes

Commercial seed is available for several other hard-seeded annual legumes. Rose clover (*Trifolium hirtum*) and cupped clover (*T. cherleri*) produce hard seed, which, as for the G_2HSLs, is held aloft after maturity in aerial structures that are accessible to cereal headers. Rose clover is very well adapted to acid sandy gravel and loam soils, both in low-rainfall environments. Rose clover is often sold as an admixture with subterranean clover and bladder clover. Annual medic species produce hard seed in pods; however, the pods drop to the ground and require suction harvesting to obtain seed. Further de-hulling of these species is a time-consuming process that adds to the cost of seed. Eastern star clover (*T. formosum*) produces hard seed in heads held aerially that can be harvested easily with a header, but its dormancy release mechanisms have proven difficult to understand and optimise.

There are also soft-seeded species of aerial seeding legumes commercially available. However, these species, such as balansa clover, Persian clover and crimson clover, are more suited to permanent pasture or sown forage situations as they have insufficient hard seed to survive strongly through a cropping cycle. They are therefore not covered further in this guide.

Gland Clover. Photo: Hayley Norman

Chapter 3:
Choosing which G_2HSL to grow

3.1 Making a decision

The main factors that need to be considered are:

- the soil niche required to be filled by the legume;
- the climate and rainfall zone of the farm;
- the farming system likely to be implemented; and
- what you want to achieve in your crop and/or livestock production enterprises.

The different species and cultivars vary in hard seed levels and hard-seed breakdown patterns, and therefore have different levels of persistence in the seedbank. Each of the above four factors will be discussed further in this chapter.

3.2 Understanding soil requirements of G_2HSLs

The main parameters that affect the soil niche are:

- soil texture;
- soil pH;
- soil fertility and its capacity to deliver nutrients; and
- soil drainage and salinity.

Although G_2HSLs may persist when grown outside their optimal niche, they do not excel in these environments and therefore both biomass production and nitrogen fixation are suboptimal. It is critical to consider both the soil physical and chemical requirements for successful long-term productivity from the G_2HSLs. Some of these important considerations are outlined in the following sections..

3.2.1 Soil texture

Soil texture and soil organic matter can have a considerable influence on the host legume, its rhizobia and the capacity to form and maintain an effective symbiosis. Coarse-textured soils have reduced capacity to store moisture and often have lower levels of soil organic matter. The latter is the most important reservoir of nutrients for plants and rhizobia. Conversely, soils with a fine texture (that is, higher clay content) have greater capacity to store soil moisture and often higher levels of soil organic matter. This creates more favourable conditions for plant growth and rhizobia survival.

The suitability of G_2HSLs to soils of various textures is shown in Figure 3.1. For example, only yellow serradella and French serradella are well suited to coarse-textured, low-fertility sands. Alternatively, many G_2HSLs can grow on sandy–loam to loam soils as these are generally more hospitable environments (for both plants and rhizobia). Serradella and biserrula are not well-suited to soils with a high proportion of clay, particularly when these are alkaline.

3.2.2 Soil pH

Soil pH is perhaps the most critical chemical factor in legume adaptation. There is variation between G_2HSLs species and their rhizobia in tolerance to soil pH (Table 3.1). As a result of breeding and selection programs, the G_2HSLs and their rhizobia have been selected to match each other for tolerance to pH where possible, so that they can thrive in the same soils, with minor variations. For example, commercial serradella and its rhizobia are more tolerant of low soil pH than all other agricultural legumes and their rhizobia. Yellow and French serradella can grow in soils with a pH_{Ca} as low as 4.0. Biserrula is the next most tolerant species, continuing to grow with minimal restriction at pH_{Ca} 4.2. All the hard-seeded clovers (arrowleaf, bladder, gland) tend to require soils with a pH_{Ca} >4.8. Although the legume may continue to grow acceptably at the soil pH indicated above, nodulation and nitrogen fixation will be limited as the pH approaches these thresholds. For example,

Figure 3.1: The suitability of G_2HSLs to soils of different textures.

Coarse-textured acid sands	Fine-textured acid sands	Sandy loams	Loams	Loamy clays – well drained	Clays
Yellow serradella	Yellow serradella	Yellow serradella	Yellow serradella	Arrowleaf clover	Gland clover
	French serradella	French serradella	French serradella	Gland clover	Trigonella
	Biserrula	Biserrula	Biserrula	Bladder clover	
		Arrowleaf clover	Arrowleaf clover	Trigonella	
		Gland clover	Gland clover		
			Bladder clover		
			Trigonella		

while serradella will grow well in soils with a pH_{Ca} as low as 4.0, its efficiency in fixing nitrogen declines where pH_{Ca} is <5.0. At the other end of the spectrum, where pH increases above 6.5, serradella nodulation decreases, even though the rhizobia can survive in alkaline soils.

Although the plant may continue to grow without nodules, it will use mineral nitrogen from the soil to fulfil any nitrogen needs that cannot be satisfied via nitrogen fixation. As soil pH becomes progressively more extreme and outside the ideal tolerance ranges of the host legume and rhizobia, the proportion of mineral nitrogen used by the plant will increase. Outside the tolerance range of the host legume and rhizobia, legumes may consume more nitrogen from the soil mineral nitrogen pool than they contribute via nitrogen fixation. This is common in some annual medics and they often receive the term 'lazy nodulators'.

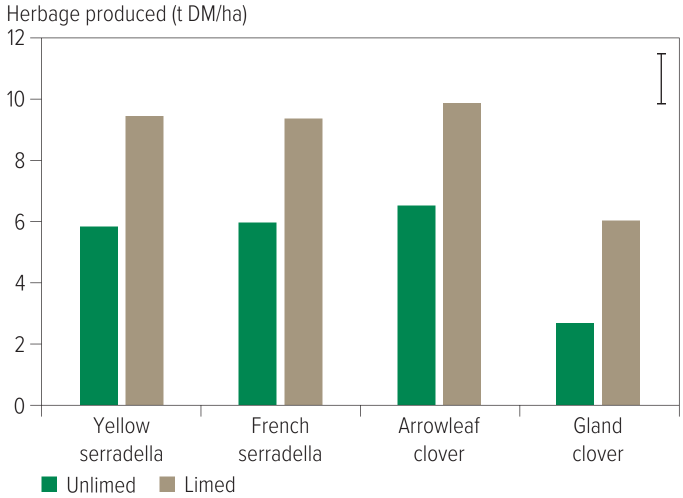
Although some of the G_2HSL species are highly tolerant of low soil pH conditions, productivity can be increased by amelioration of extreme acidity. For example, Figure 3.2 shows an increase of >2 tonnes of dry matter per hectare (t DM/ha) in herbage production for a range of legume species, including serradella, following amelioration of severe soil acidity.

It should be noted that there have been reports of failure in serradella nodulation when 3 to 5 tonnes of lime have been top-dressed without incorporation, causing the topsoil pH to rise above pH_{Ca} 7, which is detrimental to nodulation in this symbiosis.

Soil pH can also have indirect effects on plant and rhizobia survival and function as pH affects the solubility and uptake of many key nutrients (Figure 3.3). At low pH, phosphorus, sulfur, potassium, calcium and magnesium can become limiting. Additionally, micronutrients critical for nitrogen fixation, particularly molybdenum, can become limiting at low pH. In strongly alkaline soils, boron toxicity may occur whereas nutrients such as copper, zinc and manganese may become deficient.

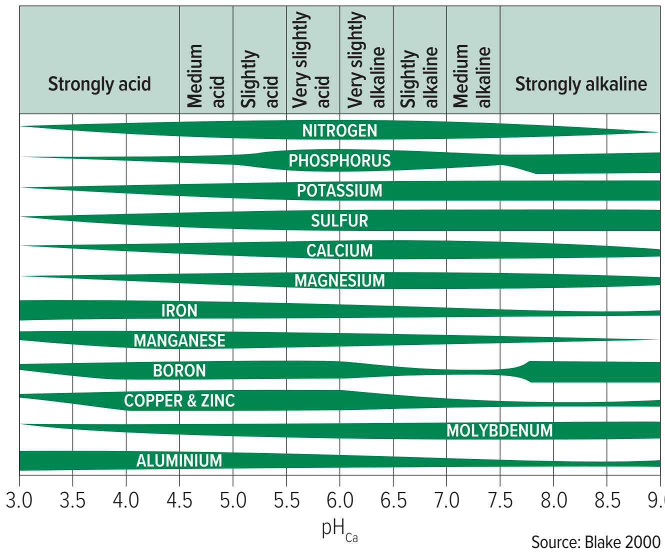
Nutrient-deprived host legumes will show symptoms of reduced growth and may become more susceptible to disease and pest attack. Under suboptimal nutrient conditions, the nutrient import–export systems of rhizobia are down-regulated and the motility (movement) of rhizobia is impacted, resulting in less contact between the host and its rhizobia and reduced opportunity to initiate nodulation.

Figure 3.2: The herbage produced (t DM/ha) for a range of hard-seeded annual legumes when grown in unlimed (pH_{Ca} 4.2, Al 18 per cent, Mn 0.21 cmol/kg) and limed soil (pH_{Ca} 5.3, Al 0 per cent, Mn 0 cmol/kg) at Binalong in NSW.



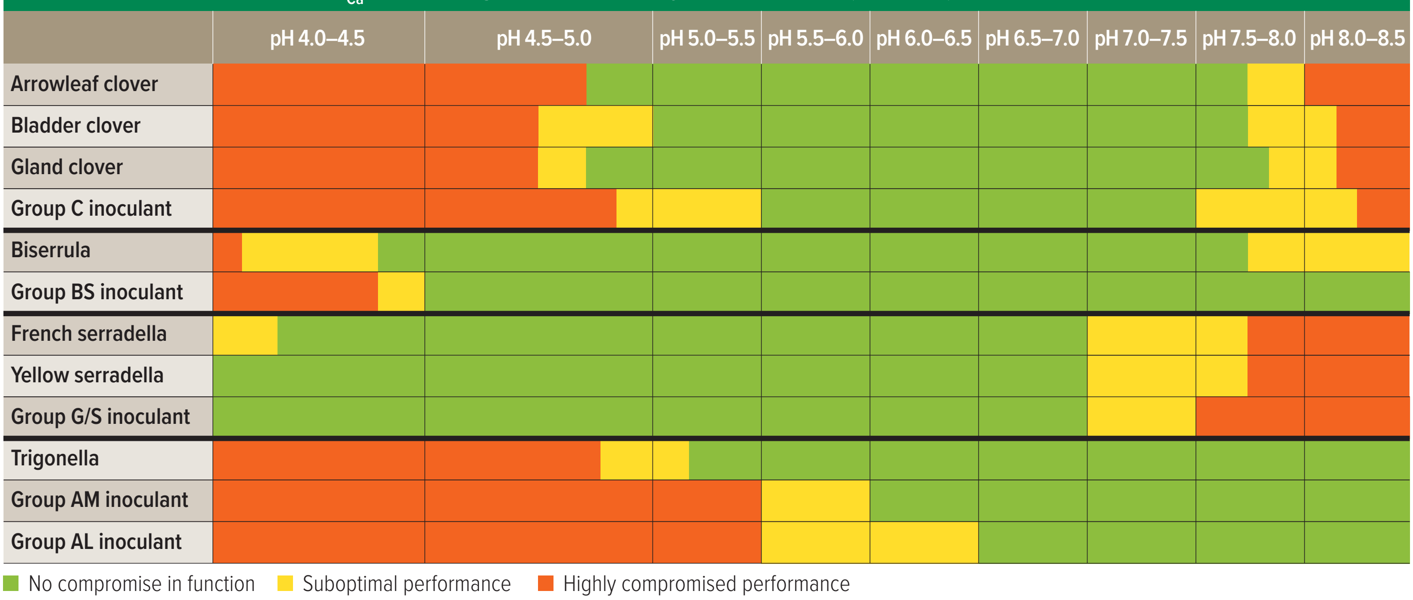
Source: Hackney et al. 2008

Figure 3.3: The effect of soil pH_{Ca} on the availability of key plant and rhizobia nutrients. The availability of aluminium, an element not required by plants or rhizobia, is also shown.



Source: Blake 2000

Table 3.1: The effect of soil pH_{Ca} on host legume productivity and inoculant (rhizobia) performance.



3.2.3 Aluminium and manganese

Although acidity alone can impact the survival and performance of legumes and rhizobia, in some soils low pH increases the availability of aluminium and/or manganese. When in excess, these elements can damage the host legume root systems, the survival and motility of rhizobia and/or the formation of an effective symbiosis. Consequently herbage production, nitrogen fixation and seed yield can be negatively affected.

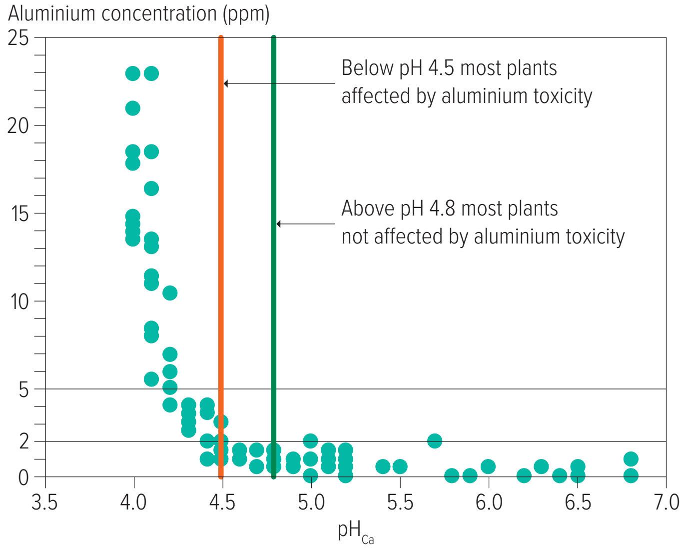
Where soil pH_{Ca} is <5.0, aluminium solubility may increase in soils where this element is present (Figure 3.4). Aluminium is not required by either plants or rhizobia but can damage both. Legume and rhizobia species differ in their tolerance to aluminium (Table 3.2). When the threshold tolerances of aluminium are reached and surpassed for a particular legume, root growth becomes affected. Plants exhibiting aluminium toxicity will generally appear stunted above ground. The root system will show a reduction in root development. Fine root hair density is affected with these roots either appearing shortened and/or thickened. The fine root hairs are important in the nodulation process as the rhizobia interacts with root hairs to form a nodule. Therefore, where these hairs are reduced or absent, the likelihood of nodulation is reduced. Plants affected by aluminium toxicity will have poorer capacity to access nutrients and moisture from the soil and may be more susceptible to pests and disease as well as having an increased mortality risk when rainfall is reduced.

The presence of aluminium in solution also affects the availability of key nutrients, particularly phosphorus, which may become bound in aluminium–phosphate complexes, which are unavailable to plants and rhizobia. Continued application of phosphorus fertiliser in such soils can result in reaching the sorption capacity of such soils and after this is reached, additional phosphorus applied becomes available. However, the quantities of phosphorus needed to achieve this can be significant and it represents a poor use of fertiliser resources. Despite this, even where the phosphate-sorption capacity of soil is reached in these acidic soils, the direct impact of low soil pH on both host legume and rhizobia and the availability of other nutrients remains.

Although there are legumes that are highly tolerant of low pH and high levels of exchangeable aluminium, these legumes are generally responsive to improvements in soil conditions (increases in soil pH and reductions in aluminium availability) and will produce more herbage and fix more nitrogen if soil conditions are improved (Figure 3.2).

Manganese is required by both plants and rhizobia but in some soils, particularly in south-eastern Australia, manganese can be present at levels that are toxic. Research by Bromfield et al. (1983, 1987) indicated that levels of manganese exceeding 0.3cmol/kg caused toxicity symptoms in pasture legumes. However, where high levels of aluminium also occurred, the threshold for manganese toxicity reduced to 0.2cmol/kg. Manganese undergoes oxidation/reduction reactions throughout the growing season, generally reaching highest available levels under hot, dry conditions (late summer in many areas). Soil testing in late summer is the most effective way to predict whether manganese toxicity is likely to be an issue.

Figure 3.4: The effect of soil pH_{Ca} on the availability of aluminium in soils where aluminium complexes are found in soil parent material.



Source: adapted from Gazey and Azam 2018

3.2.4 Alkalinity

Although soil acidity is a widespread problem in southern Australia, there are areas where soils are extremely alkaline, which can also create issues for legume and rhizobial performance (Table 3.1). Serradellas are best grown in soils where pH_{Ca} does not exceed 7.0. Biserrula, arrowleaf, gland and bladder clover are generally not suitable G_2HSLs where pH_{Ca} exceeds 8.0. The future release of the first cultivar of trigonella will provide a G_2HSL that will add to and complement the traditional annual medic options for alkaline soils.

3.2.5 Soil fertility

Legumes require adequate levels of the macronutrients phosphorus, sulfur and potassium to establish, form a symbiosis, grow and produce seed. It is important to test the soil prior to establishing a new pasture to determine whether adequate nutrients are available (see following section). Additionally, it is important to ensure that the legumes you intend to sow are compatible with the soil pH and other nutrient limitations, excesses or toxicities that might be related to soil pH.

Table 3.2: The level of aluminium (expressed as a percentage of effective cation exchange capacity) above which aluminium toxicity is likely to result in reductions in legume performance.

<5%	Lucerne, annual medics, trigonella
5–15%	Subterranean clover, bladder clover
15–20%	Gland clover, arrowleaf clover, biserrula
>20–60%	French serradella, yellow serradella

NUTRIENT AVAILABILITY

More than 15 nutrients are required by legumes and their rhizobia for growth and to fix nitrogen optimally. These include macronutrients such as phosphorus, sulfur, potassium, calcium and magnesium. Additionally, key micronutrients include molybdenum, copper, zinc, iron, cobalt, manganese, boron and nickel. The micronutrient selenium is required by rhizobia but is not essential for the host legume. Some nutrients, such as manganese and boron, are essential but can occur in excess amounts that become toxic. For example, some acidic soils of south-eastern Australia contain toxic levels of manganese, which can impair legume growth and nitrogen fixation. Conversely, some fine-textured alkaline soils, particularly in SA and WA, contain toxic levels of boron. Some acid well-drained sands in WA have insufficient molybdenum, which is required for nitrogen fixation.

Ensuring that enough key macro and micronutrients are available is critical to reach optimal production and nitrogen fixation. Soil testing is a reliable means of determining the availability of key macronutrients. However, for micronutrients, plant tissue testing is generally the preferred method to determine whether deficiencies are likely to be present. Also, review the paddock history and presence of any known micronutrient deficiencies or toxicities in other crops and seek the advice of local agronomists or advisers on micronutrient issues that may be present in your locality. There is no known benefit of applying nutrients in excess of those required by host legumes and rhizobia. In some cases, supplying nutrients in excess of requirements can lead to a deficiency of another nutrient due to competition between various nutrients for uptake by the plant. Such induced deficiencies can have implications for pasture, crop and livestock production. For example, calcium, potassium and magnesium compete for uptake by plants. Provision of excess quantities of potassium, which is preferentially taken up by plants over calcium and magnesium, can lead to grass tetany, a metabolic condition that can impact cattle and, in some cases, sheep. Similarly, application of excess quantities of molybdenum can induce a deficiency of copper in grazing animals.

PHOSPHORUS MEASUREMENT AND PLANT AVAILABILITY

Phosphorus is a critical nutrient required for root and shoot growth, for rhizobia survival and function and for the formation and maintenance of an effective symbiosis to drive nitrogen fixation.

There are two main methods used to determine the critical levels of phosphorus required for plant growth. These are the Olsen and the Colwell extraction methods.

If the Olsen extraction method is used, then the critical phosphorus value is 15 milligrams phosphorus per kilogram soil (mg P/kg). That is, at this level of phosphorus availability, 95 per cent of maximum production can be achieved assuming no other nutrient, soil, disease or climatic conditions are constrained.

For the Colwell extraction method, the determination of critical phosphorus levels requires consideration of the soil phosphorus buffering index (PBI; Table 3.3). The PBI is indicative of the soil's ability to adsorb (bind) phosphorus. That is, the higher the PBI, the higher the available phosphorus needs to be to overcome the soil's capacity to adsorb applied phosphorus. There is often confusion over interpreting the PBI and critical phosphorus requirement for a given soil. The PBI is essentially an inherent property of a given soil, that is, it is not something that can be readily changed. The available soil phosphorus level, however, can be changed through the use of fertiliser. As an example, the results of a soil analysis show that the PBI of the soil is 54 and the current Colwell phosphorus level is 16mg P/kg soil. The PBI of 54 indicates the soil is in the 'very low' PBI category and that the critical Colwell phosphorus predicted to give 95 per cent maximum pasture production is 29mg P/kg (with a range of 27 to 31mg P/kg). Therefore, with a current Colwell phosphorus of 16mg P/kg, it is probable that the paddock will be responsive to application of phosphorus fertiliser. Conversely, if the same soil had a current Colwell phosphorus of 40mg P/kg, then it is very unlikely that application of phosphorus fertiliser would lead to any increase in pasture production.

Table 3.3: The critical soil phosphorus test value (mg P/kg soil) predicted to be required to produce 95 per cent of maximum pasture yield for most legumes.

Phosphorus Buffering Index category		Critical Colwell P value (mg P/kg soil)
<15	Extremely low	23 (20–24)
15–35	Very very low	26 (24–27)
36–70	Very low	29 (27–31)
71–140	Low	34 (31–36)
141–280	Moderate	40 (36–44)
281–840	High	55 (44–64)
>840	Very high	n/a

The critical phosphorus value shown is the average of the midpoint for the shown PBI range with the range in predicted critical phosphorus shown in parentheses.
n/a – insufficient data for this PBI category to reliably predict critical phosphorus requirement

Source: Gourley et al. (2007)

Some legumes differ in their phosphorus use efficiency. Research at Esperance by Dr Michael Bolland in the early 1980s showed serradella requires 30 per cent less available phosphorus than subterranean clover to reach maximum production. However, selection of a legume should be made based on its collective suitability to climate, soil and farming system rather than any one attribute. Growing yellow serradella in a soil or climate to which it is not suited will not result in expression of a high phosphorus use efficiency.

SULPHUR MEASUREMENT AND PLANT AVAILABILITY

Sulphur is an essential nutrient for plant growth and development. Sulphur is required for protein formation, nodule formation in legumes, and essential enzyme function, including nitrogenase, an enzyme required for nitrogen fixation and chlorophyll formation.

Plants predominately use sulphur from soil in the sulphate form (termed 'available sulphur' on your agronomic soil test). Sulphur is made available through biochemical and biological processes in soil, with approximately 95 per cent of sulphur organically bound Sulphate is mobile in the soil solution, meaning it can leach down through the profile and accumulate in subsurface and subsoil layers. Its mobility means that you need to review soil test results within the context of when the sample was collected, as the sulphate may have leached beyond the 0–10cm soil sampling layer following rain. Risk of sulphate leaching is highest on lighter textured soils such as sands and sandy loams, in low organic matter soil and in soil with high phosphorus concentrations, as sulphate can be displaced by phosphate on clay surfaces. While sulphate that has accumulated deeper in the soil profile can be accessed by deeper-rooted plants when their roots reach that depth, germinating seeds and seedlings require sulphate in the surface soil. Where sulphate has accumulated at depth and there is a deficiency in the upper areas of the soil profile, plants will have to grow through the deficiency zone before they can access sulphate deeper in the profile. This can compromise plant growth and in legumes, nodule formation and capacity to fix nitrogen.

Traditionally, in Australia, single superphosphate which contains both phosphorus (usually around 8.8 per cent) and sulphur (11 per cent) has been used to supply sulphur. However, with an increased emphasis on cropping in mixed farming areas in recent decades, there has been increasing use of high analysis fertiliser products containing predominately nitrogen and phosphorus, such as monoammonium and diammonium phosphate (MAP and DAP) which only contain 1.5 to 1.6 per cent sulphur. Consequently, sulphur levels in many Australian soils have declined. A survey of 300 pasture paddocks across four regions of central and southern NSW in 2015 found 63 to 95 per cent had suboptimal levels of available sulphur in the 0 to 10cm soil layer while 60 to 65 per cent of paddocks in mixed farming areas had phosphorus availability in excess of critical levels. The same survey found 93 per cent of paddocks had suboptimal legume nodulation (Hackney et al. 2019).

In Australia, the most common analysis used to determine available sulphur is the potassium chloride extraction method ('S KCl-40') and the critical concentration is 8mg/kg, with below 4 being extremely low. Sulphur deficiency presents as a general paleness of the leaves and when sulphur concentrations are extremely low, leaves will appear almost yellow.

POTASSIUM MEASUREMENT AND PLANT AVAILABILITY

Potassium plays a key role as an activator of enzymes in plants, particularly those involved in protein synthesis. It is also critical for the regulation of transpiration and for the development and function of root nodules. Potassium plays a critical role in determining seed yield.

In Australia, the Colwell extraction method (Colwell K) is the most commonly used analysis to determine soil potassium levels. Critical potassium levels required to support plant growth vary with soil texture (Table 3.4), increasing with clay content. Potassium deficiency is more common in sandy soils of WA and is less common in NSW except for lighter soils under high rainfall. Potassium deficiency is more common in paddocks where large quantities of herbage are removed, such as with silage or hay making. Potassium deficient plants have leaves with mottled pink leaf margins which become necrotic when severe. Red splotching can also appear when deficiency is severe.

MICRONUTRIENTS MEASUREMENT AND PLANT AVAILABILITY

A range of micronutrients are necessary for legume growth, rhizobia survival and the formation and maintenance of an effective symbiosis for nitrogen fixation. These nutrients are copper, cobalt, iron, nickel, zinc, boron, manganese, molybdenum and selenium. Selenium, while not an essential nutrient for plants is critical for enzyme function in rhizobia and for maintenance of the nitrogen fixing symbiosis in between legumes and rhizobia.

Molybdenum, which is an essential component of the nitrogenase enzyme that allows nitrogen fixation to proceed, is one of the most common deficiencies impacting legume performance encountered in Australian soils. Molybdenum deficiency is most commonly found in acidic, sandy soils particularly those that have high levels of aluminum and/or iron. As molybdenum is vital for nodule function, legumes deficient in this nutrient will present with older leaves pale green to yellow in colour. Inspection of the roots may also reveal very prolific nodulation on the root system (Figure 3.5), however, the nodules will be very small and white in colour indicating nodules are non-functional.

Zinc is the other micronutrient deficiency that can occur across a wide range of soils types from acidic sandy soils through to calcareous high clay content soils. Zinc is important for plant growth, rhizobia enzyme function and nitrogen fixation.

Other micronutrient issues can occur but are generally more localised and are associated with different soil types and soil chemical attributes. Some, such as boron and manganese can be problematic in terms of deficiency or toxicity. For example, manganese toxicity can occur in some low pH soils while deficiencies can be seen in soils with high pH.

Soil tests are generally unreliable for determining micronutrient availability with plant tissue tests preferred. Correcting micronutrient deficiencies is generally achieved through the use of fortified fertilisers (e.g. molybdenum-fortified superphosphate) or by the use of foliar sprays.

It is important to remember that applying micronutrients in excess of requirements can lead to unintended consequences. For example, excess application of molybdenum can result in development of copper deficiency in grazing animals.

SOIL ORGANIC CARBON MEASUREMENT AND ROLE IN PLANT GROWTH

Soil organic matter plays a vital role in increasing legume growth, rhizobia survival, nodule formation and nitrogen fixation. It contributes to increasing soil water-holding capacity by improving soil structure, aggregate stability, and infiltration. Additionally, soil organic matter is an important reservoir of nutrients that once mineralised can be available to plants and soil biota, including rhizobia. It also increases the soil's cation exchange capacity (i.e. the soil's ability to hold onto and exchange cations such as calcium, magnesium, and potassium) which is particularly important in lighter textured soils (such as sands and sandy loams). Soil organic matter can also buffer against the effects of soil acidity.

Carbon is the measurable component of soil organic matter. To test for soil organic carbon, the recommended method is the dry combustion method (sometimes referred to as the LECO method which is one of the instruments used to analyse carbon). Soils containing inorganic carbon need to be pretreated with

Table 3.4: The critical Colwell potassium value (mg K/kg soil) and range in critical value based on soil texture.

Soil texture	Critical value	Critical value range
Sand	126	109–142
Sandy loam	139	126–157
Sandy clay loam	143	127–173
Clay loam	161	151–182

Source: Gourley et al. (2007)

Figure 3.5: The root system of a molybdenum-deficient legume. Note the prolific number of small white ineffective nodules.

Photo: Belinda Hackney

GRDC

sulphurous acid prior to the dry combustion method, so be sure to mention this is if you have calcareous soils or soil with a high pH (>7.5 pH_{Ca}). Previously, soil organic carbon was measured using the Walkley-Black method however this only measures readily oxidisable organic carbon and is typically only 80 per cent of the total organic carbon in soil.

The amount of organic carbon in soil is largely driven by soil texture and climate. Soils with a higher clay content typically have a higher concentration of organic carbon, as do soils in higher rainfall environments due to increased plant growth.

3.2.6 Drainage

Most of the G_2HSLs discussed in this guide require good drainage for optimal performance. An exception to this is gland clover, which has the capacity to grow in soils that are both well-drained and those that have relatively poor drainage.

WATERLOGGING

Soils with poor drainage and subject to waterlogging provide poor conditions for legume growth, rhizobial survival and the capacity to develop and maintain an effective symbiosis. Where soils are waterlogged for extended periods, oxygen is limited and root growth in sensitive species is affected as is rhizobial survival. Further, waterlogged conditions can increase susceptibility to issues such as root rot and foliar disease. Legume species differ in terms of their adaptation to waterlogged soils. Within the G_2HSLs, gland clover is the most tolerant to waterlogging. Gland clover is less tolerant to waterlogging than balansa clover, but more tolerant than the *yanninicum* (white-seeded) subspecies of subterranean clover. Biserrula, bladder clover and the serradellas have poor tolerance to waterlogging.

3.2.7 Salinity

Legumes are very sensitive to salinity. Saline soil is often subject to a gradient of salt and waterlogging and can have high within-site variability. Legumes tend to find a niche in saline areas where they can persist. The most saline-tolerant annual pasture legume is *Melilotus siculus* (Messina); however, this is not hard-seeded. Mixtures of species may optimise the paddock coverage and legumes that tolerate waterlogging are often used in mixtures for saline plantings (for example, balansa clover or gland clover). Some legumes can avoid the worst of the salinity by germinating late (after salt is diluted with rainfall) and senescing early (before the soil dries out and salinity of the soil solution is too high). Burr medics, gland clover and early maturing cultivars of balansa clover fit this model.

Saline areas are often difficult to spray for weeds due to waterlogging, patchiness and perennial species that can become tall, clumpy and/or rank, and therefore successful legumes are likely to be those that grow where weeds cannot. Sensitivity to insects and the inability to compete with weeds should be considered when choosing legume species for saline areas.

When choosing the right G_2HSLs, it is critical to consider both the soil physical and chemical requirements for successful long-term productivity. In terms of consideration of the combined impacts of soil texture and soil chemical conditions, the flowcharts provided (Figures 3.6 to 3.8; pages 24–29) can help in selection of a G_2HSL, and also show where subterranean clover and annual medics are likely to be most suitable.

Table 3.5: The adaptation of hard-seeded legume species and cultivars to total annual rainfall (mm).

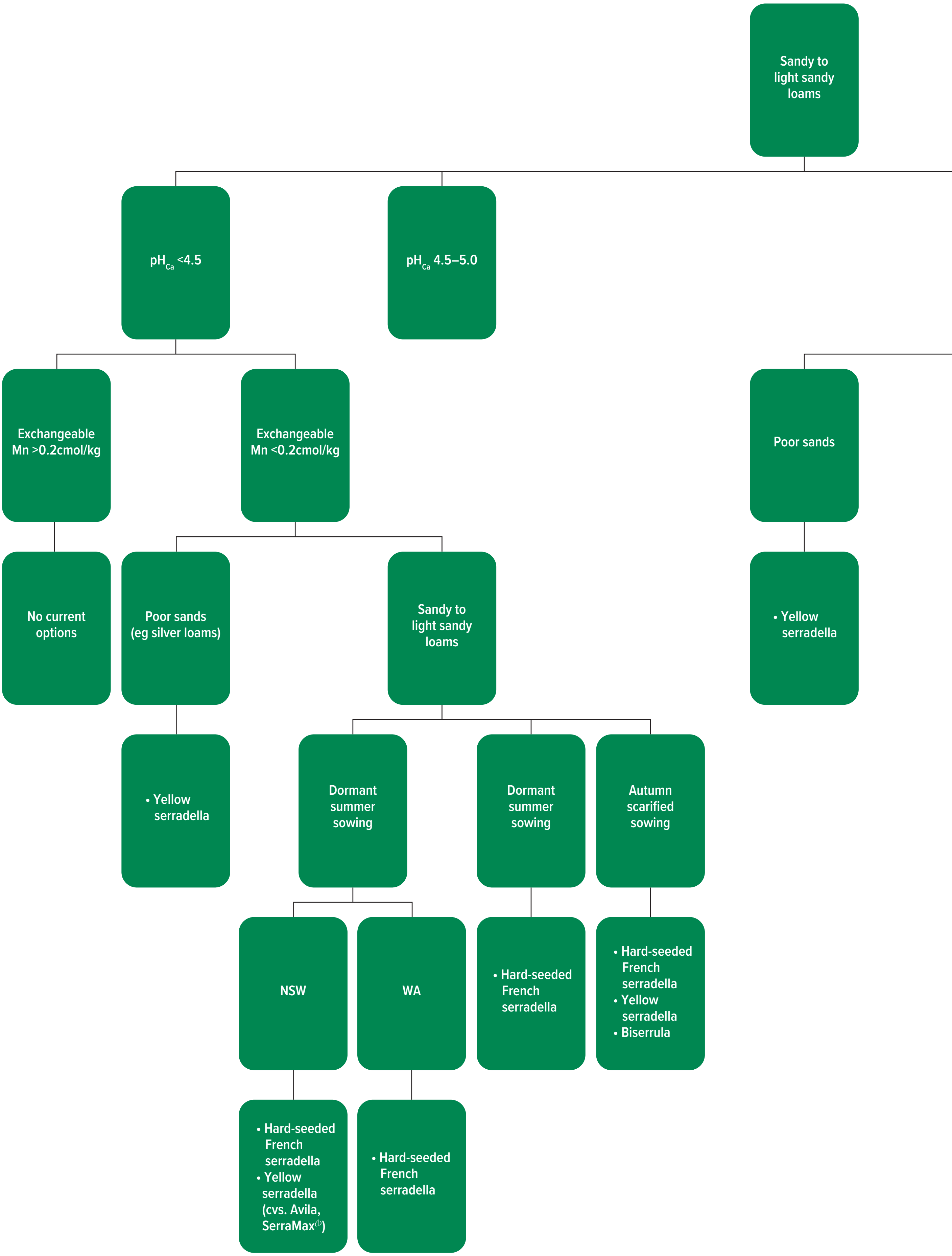
	300–325	325–350	350–375	375–400	400–425	425–450	450–475	475–500	500–550	550–600	600–750
Arrowleaf clover			Cefalu	Cefalu	Cefalu	Cefalu	Cefalu Zulu	Cefalu (NSW) Zulu	Cefalu (NSW) Zulu Arrotas (WA)	Cefalu (NSW) Zulu (NSW) Arrotas	Zulu (NSW) Arrotas
Biserrula	Casbah	Casbah Crown$_2$*	Casbah Crown$_2$	Casbah Crown$_2$	Casbah Mauro Crown$_2$	Casbah Mauro Crown$_2$	Casbah Mauro Crown$_2$	Casbah Crown$_2$ (NSW) Mauro	Casbah Crown$_2$ (NSW) Mauro	Casbah (NSW) Mauro	Mauro (NSW)
Bladder clover		Diaman$_2$ti	Diaman$_2$ti*	Bartolo Diaman$_2$ti	Bartolo Diaman$_2$ti	Bartolo Diaman$_2$ti	Bartolo Diaman$_2$ti	Bartolo Diaman$_2$ti (NSW)	Bartolo Diaman$_2$ti (NSW)	Bartolo Diaman$_2$ti (NSW)	Bartolo (NSW)
Gland clover		Prima	Prima	Prima	Prima	Prima	Prima	Prima	Prima	Prima	Prima (NSW)
French serradella	Fran$_2$o⌽	Fran$_2$o⌽	Fran$_2$o⌽	Fran$_2$o⌽ Margurita⌽	Fran$_2$o⌽ Margurita⌽	Fran$_2$o⌽ Margurita⌽	Fran$_2$o⌽ (NSW) Margurita⌽	Fran$_2$o⌽ (NSW) Margurita⌽	Fran$_2$o⌽ (NSW) Margurita⌽	Fran$_2$o⌽ (NSW) Margurita⌽	Margurita⌽ (NSW)
Yellow serradella	Yelbini⌽	Yelbini⌽	Yelbini⌽ Charano	Yelbini⌽ Charano Santorini⌽ SerraMax	Yelbini⌽ Charano Santorini⌽ SerraMax	Charano Santorini SerraMax⌽ (NSW)	Charano Santorini SerraMax⌽ (NSW)	Santorini SerraMax⌽ (NSW) King	SerraMax⌽ (NSW) King Avila	SerraMax⌽ (NSW) King Avila	Avila (NSW)
Trigonella	Carn$_2$ac	Carn$_2$ac	Carn$_2$ac	Carn$_2$ac	Carn$_2$ac	Carn$_2$ac	Carn$_2$ac	Carn$_2$ac	Carn$_2$ac (NSW)	Carn$_2$ac (NSW)	Carn$_2$ac (NSW)

■ Good adaptation ■ Marginal adaptation ■ Poor adaptation. It is important that appropriate cultivars are used for specific rainfall zones.

*cultivars scheduled for commercial release after 2023.

Where a cultivar name is shown alone, this indicates it is suitable for use in BOTH WA and NSW within a given rainfall range. Where the cultivar name is followed by a specific state in brackets, it indicates that the cultivar will suit that state within a given rainfall range.

Figure 3.6: G_2HSLs, subterranean clover and annual medic options for sandy to light sandy loam soils of varying pH.



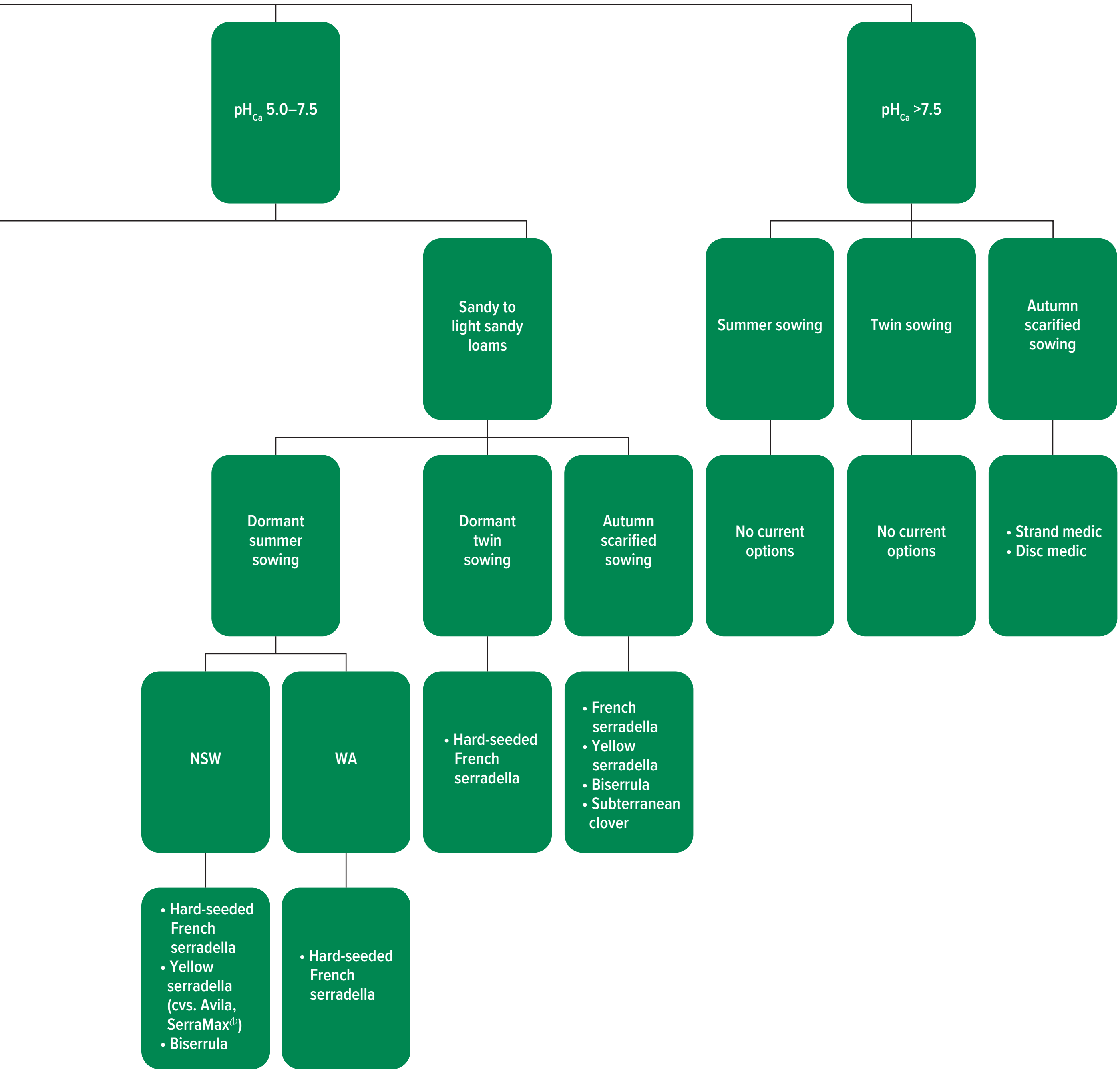
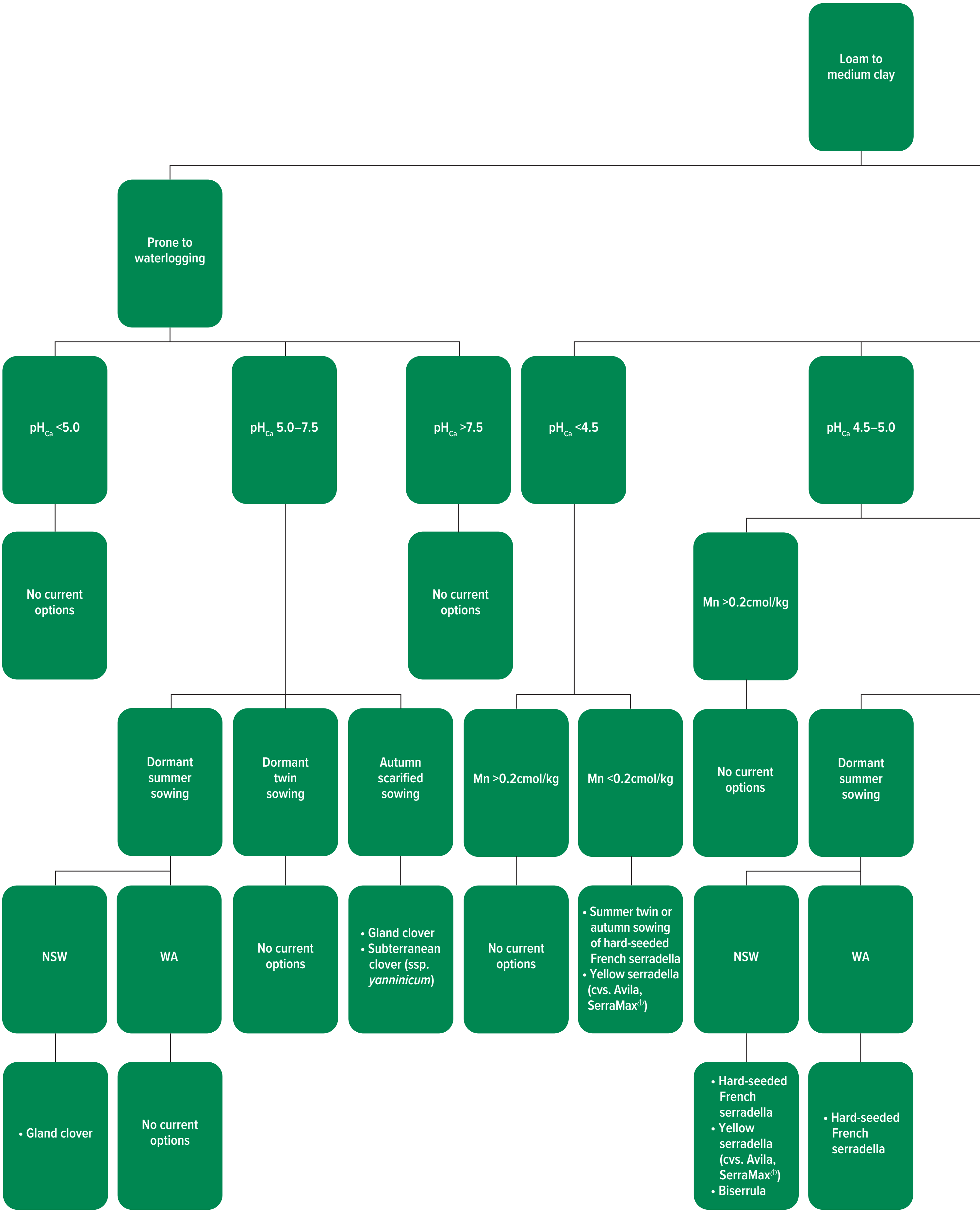

pHCa 5.0–7.5
pHCa >7.5
Sandy to light sandy loams
Summer sowing
Twin sowing
Autumn scarified sowing
Dormant summer sowing
Dormant twin sowing
Autumn scarified sowing
No current options
No current options
• Strand medic
• Disc medic
NSW
WA
• Hard-seeded French serradella
• French serradella
• Yellow serradella
• Biserrula
• Subterranean clover
• Hard-seeded French serradella
• Yellow serradella (cvs. Avila, SerraMax)
• Biserrula
• Hard-seeded French serradella

Figure 3.7: G_2HSLs, subterranean clover and annual medic options for loam to medium clay soils.



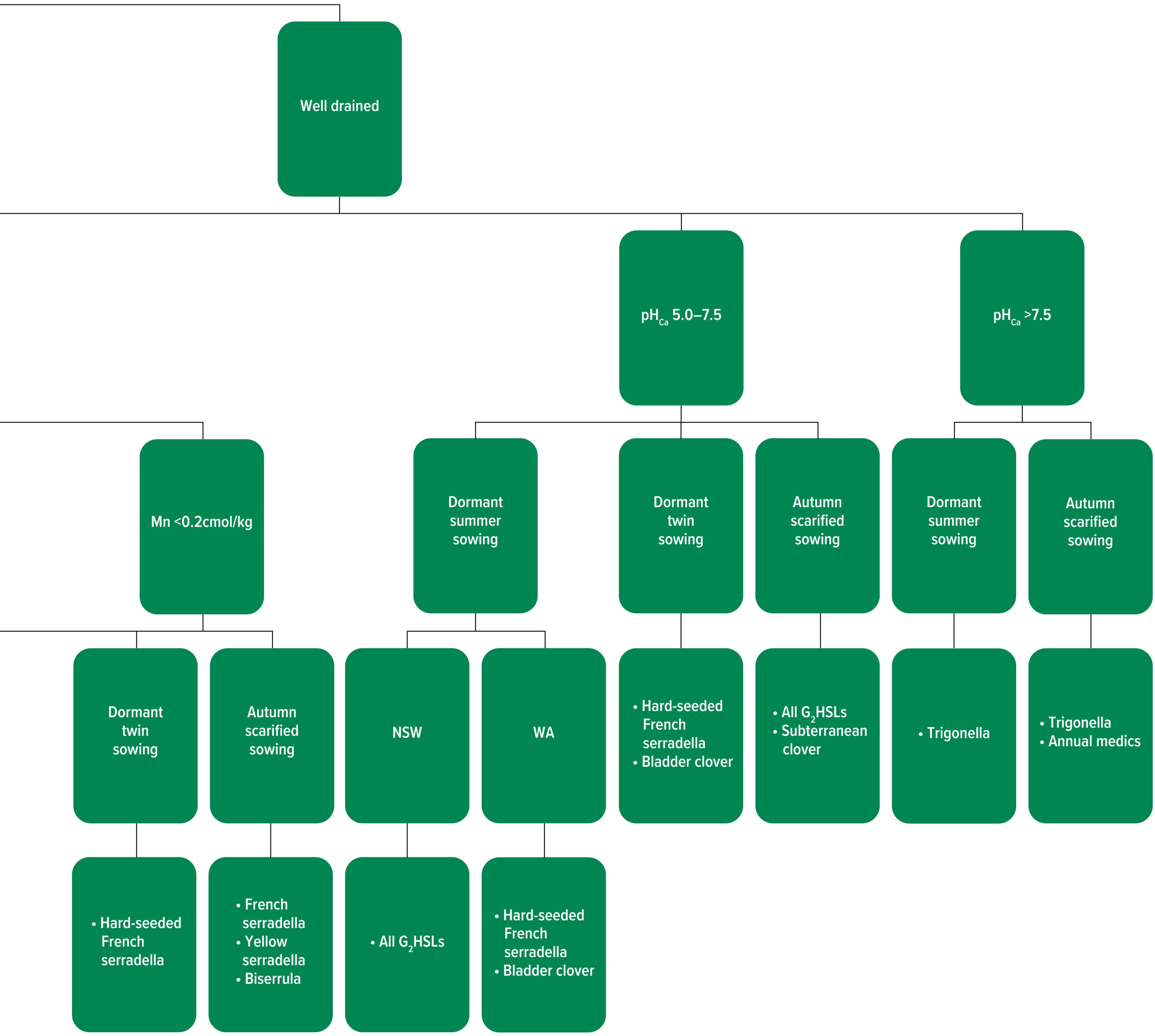
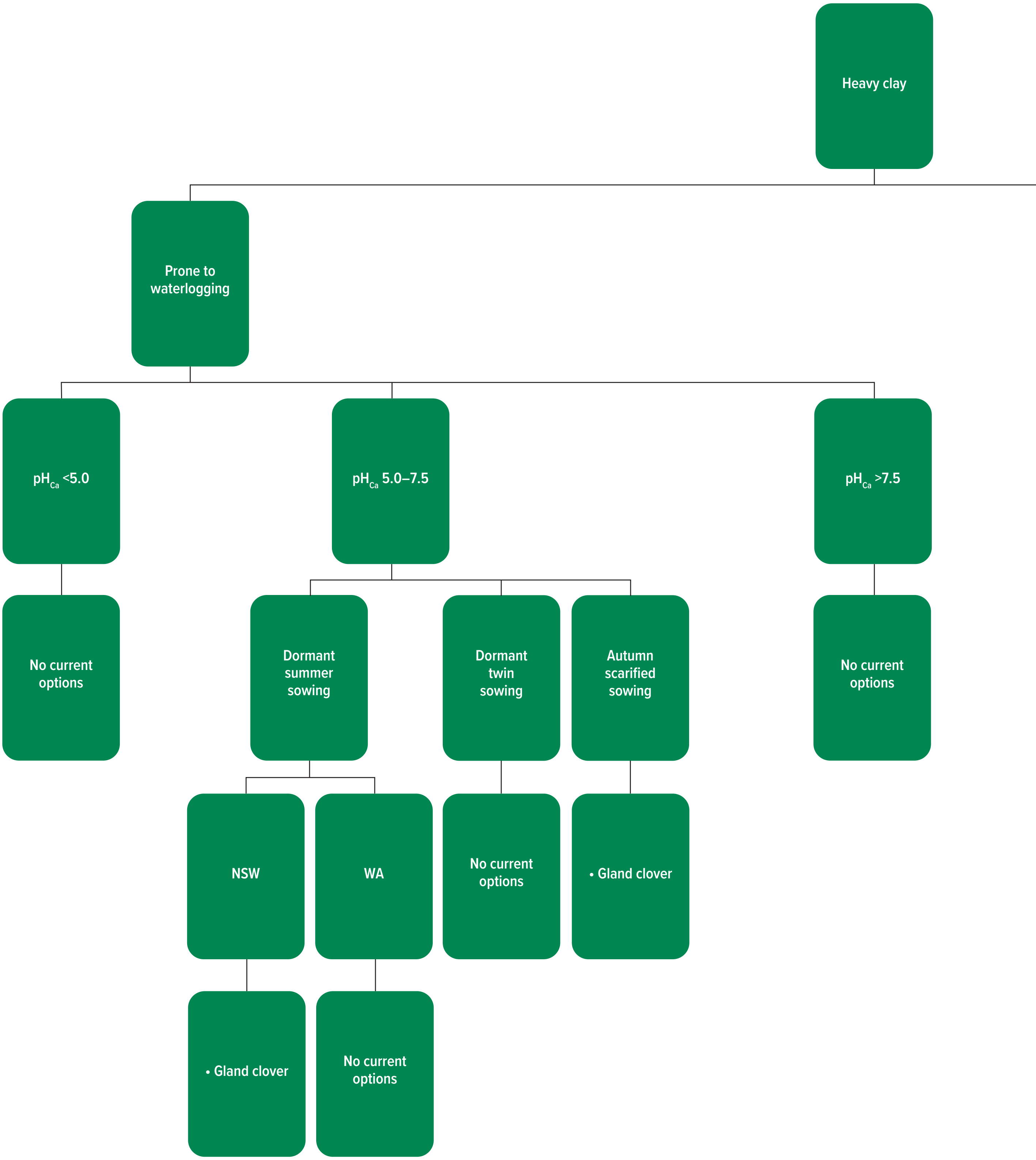

Well drained
pH_{Ca} 5.0–7.5
pH_{Ca} >7.5
Mn <0.2cmol/kg
Dormant summer sowing
Dormant twin sowing
Autumn scarified sowing
Dormant summer sowing
Autumn scarified sowing
Dormant twin sowing
Autumn scarified sowing
NSW
WA
• Hard-seeded French serradella
• Bladder clover
• All G_2HSLs
• Subterranean clover
• Trigonella
• Trigonella
• Annual medics
• Hard-seeded French serradella
• French serradella
• Yellow serradella
• Biserrula
• All G_2HSLs
• Hard-seeded French serradella
• Bladder clover

Figure 3.8: Legume and G_2HSL options for heavy clay soils.



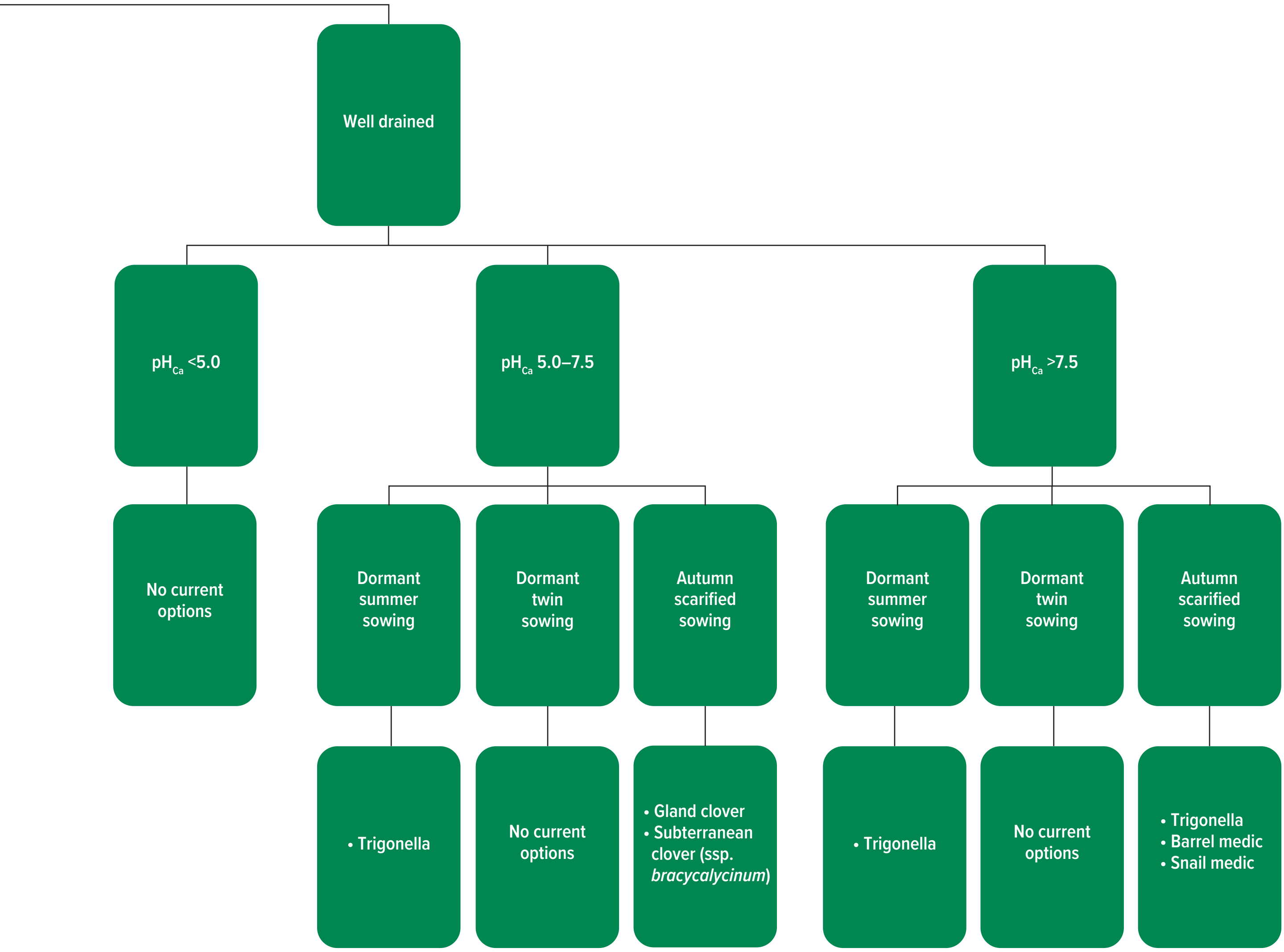

Well drained
pH_{Ca} <5.0
pH_{Ca} 5.0–7.5
pH_{Ca} >7.5
No current options
Dormant summer sowing
Dormant twin sowing
Autumn scarified sowing
Dormant summer sowing
Dormant twin sowing
Autumn scarified sowing
• Trigonella
No current options
• Gland clover
• Subterranean clover (ssp. *bracycalycinum*)
• Trigonella
No current options
• Trigonella
• Barrel medic
• Snail medic

Figure 3.9: A subterranean clover pasture (left) and biserrula pasture (right). Photos at top taken on 11 November 2015. A total of 55mm rainfall had been received at the start of November following very dry conditions (<20mm rainfall for both September and October). Photos at top show the pods that had been produced by biserrula prior to November rain and the green herbage that had grown since the rain. Photos at bottom (taken 26 November) show the additional pods produced by biserrula following November rain. Note also the differences in ground cover of the two pastures.

Subterranean clover 11/11/2015

Biserrula 11/11/2015

Subterranean clover 26/11/2015

Biserrula 26/11/2015

Photos: Belinda Hackney

3.3 Understanding rainfall and climatic requirements

The G_2HSLs discussed in this guide vary in their suitability to climatic conditions. There are differences between species' adaptation to rainfall (total and growing season). Within species, there are also considerable differences in adaptation due to maturity and flowering time. As an example, both biserrula and French and yellow serradella are capable of surviving and reproducing in arid environments when compared to clovers. Within cultivars of French and yellow serradellas, there are significant differences in adaptation to total and growing season rainfall conditions with cultivar maturity ranging from 75 to 140DTF. For biserrula, however, flowering times are more compressed, with less variation within the genus. A feature of biserrula over spring and early summer is its capacity to withstand prolonged dry periods, produce seed and then to recommence growth and seed production when rainfall occurs, which contrasts with traditional legumes such as subterranean clover (Figure 3.9). The indeterminate growth and deep rooting system of biserrula can help ensure the establishment of robust seedbanks even under adverse growing conditions (Figure 3.10).

Climatic conditions, particularly rainfall and temperature, can have a significant influence on the capacity of legumes to produce biomass and to reach nitrogen fixation targets. Prolonged dry periods, drought and extended periods of high temperatures limit plant growth for most annual legumes. Such conditions also limit rhizobial survival. Where unfavourable climatic conditions interact with limiting soil factors such as coarse-textured soils, then the impact on legume performance and rhizobial survival is exacerbated. Rhizobial populations generally decline over summer as a result of low moisture conditions but increase rapidly following opening season rainfall. However, where autumn breaks occur late or under extended drought periods, rhizobia populations may not recover sufficiently and re-inoculation may need to be considered.

When sowing new pasture legumes, climatic conditions need to be carefully considered (Table 3.5; page 23). Many G_2HSLs are suited to dormant summer sowing using hard seed harvested on-farm (Chapters 4 and 5). Although this can have many beneficial outcomes, sowing in summer usually means soil moisture conditions are suboptimal for rhizobial survival and wet inoculant delivery systems (peat, liquid injection, freeze-dried inoculants) are not recommended under such conditions. More robust inoculant delivery systems, such as low-moisture granules, should be used

GRDC™

for dormant summer sowing operations or in other situations where legumes may be sown where soils are dry and rainfall is not anticipated for some time. An alternative approach is to dormant summer sow G_2HSLs into soils where their specific rhizobia have previously been introduced (for example, for serradella via a lupin crop). Some producers have had success introducing the rhizobia for their G_2HSLs with the crop immediately preceding the legume (for example, by mixing inoculant granules with fertiliser drilled for the preceding crop; see Chapter 4).

3.4 Understanding the farming system and rotations to be implemented

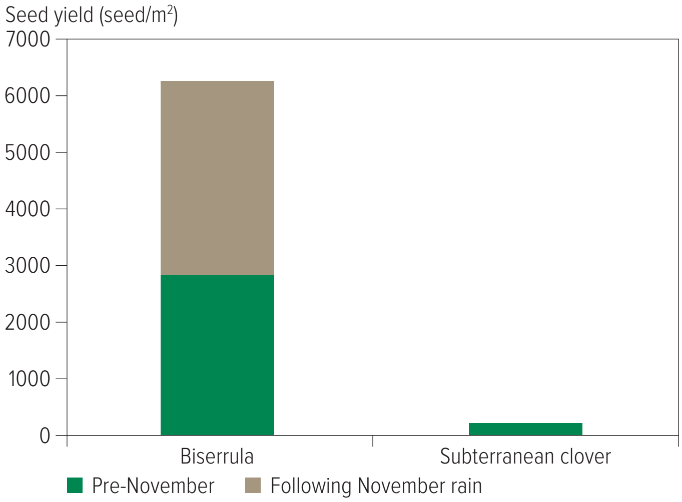
G_2HSLs offer the platform on which to build highly flexible pasture–crop rotation systems, and the choice of legume may depend on the rotational options intended. The G_2HSLs can persist through a cropping phase and regenerate without the need for resowing. This means that once a seedbank is established, it is possible to run medium to long-term rotations that better fit climatic and market conditions. The length of the cropping phase can be designed without exhausting an established seedbank; however, a number of factors should be carefully considered:

- the size of the seedbank formed;
- the hard seed level of the cultivar used; and
- climatic factors that affect hard-seed breakdown (for example, temperature and moisture conditions) and thereby influence residual hard seed level.

Results of field trials and hard seed breakdown studies over the past decade have provided insight into how long a cropping phase can be sustained and still allow for adequate regeneration post cropping (Figure 3.11). Long cropping phases require legumes that not only have high initial hard seed levels, but also those that maintain high levels of hard seed over a number of years. Using hard-seeded legumes in rotations will be discussed in detail in Chapter 7.

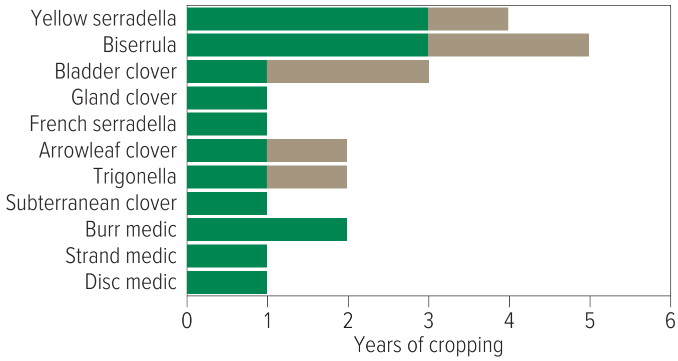
When comparing legume options for any given environment, it is important to make fair and parallel comparisons. For example, in promotional materials, it is often claimed that a particular cultivar of a certain species has a high level of hard seed, but the actual percentage of hard seed may not be quoted and therefore it is difficult to ascertain the relative hard-seededness and breakdown pattern for a given cultivar. The comparative attributes of a range of G_2HSLs and traditional legume species in terms of their tolerances to certain soil and climatic stresses, and the range in hard seed levels for cultivars within given species, are shown in Table 3.6.

Figure 3.10: The seed yield of biserrula and subterranean clover (seed/m^2) in a dry spring at Temora NSW showing the seed produced prior to November and seed produced after 55mm rainfall in early November 2015.



Source: Howieson and Hackney (2017)

Figure 3.11: The duration of cropping (years) that can be implemented over an established seedbank of a range of G_2HSLs, subterranean clover and annual medics that will facilitate adequate regeneration of the legume without the need for resowing after the cropping phase.



Green shading indicates the suggested maximum length of the cropping phase; brown shading indicates the length of the cropping phase that is possible in situations where the seedbank has had repeated opportunity for replenishment over a number of years preceding the cropping phase.

Source: The information presented here is the result of numerous field trials in WA and NSW over the past 10 years

Table 3.6: The rainfall requirements and tolerance to soil stresses for a range of annual pasture legumes and their rhizobia. Also included are the hard seed levels at the time of seed formation, and that remaining at the autumn following the initial seed-set. A comparison is provided with the traditional annual pasture legumes.

Second generation hard-seeded legumes (G_2HSLs)	Average annual rainfall requirements (mm)	Soil pH_{Ca} range host plant[1]	Soil pH_{Ca} range rhizobia[1]	Exchangeable aluminium tolerance range[1]	Soil texture where suited	Waterlogging tolerance	Hard seed level at formation (%)	Hard seed level in following autumn (%)	Header harvestable	Suitable for dormant summer sowing	Suitable for dormant twin sowing
Arrowleaf clover	>350	4.8–8.0	5.5–8.0	0–20	Sandy loam to medium clay	Poor	>85	40–60	Yes	Yes (NSW) No (WA)	Marginal
Biserrula	>300	4.2–8.0	4.5–8.5	0–20	Sand to loam	Poor	>95	70–90	Yes	Yes (NSW) No (WA)	Marginal
Bladder clover	>350	5.0–8.0	5.5–8.0	0–10	Sandy loam to medium clay	Poor	>95	40–60	Yes	Yes	Yes
Gland clover	>320	4.8–8.0	5.5–8.0	0–30	Sandy loam to heavy clay	Good	>80	40–60	Yes	Yes (NSW) No (WA)	No
French serradella[2]	>300	4.0–7.0	4.5–7.0	0–50	Sand to loam	Poor	>90	40–70	Yes	Yes	Yes
Yellow serradella	>300	4.0–7.0	4.5–7.0	0–60	Infertile sands to loams	Poor	>90	40–>85	Yes	Some cultivars (e.g. SerraMax, Avila)	Yes
Trigonella	>300	5.0–8.5	6.0–8.5	0–10	Sandy loam to medium clay	Moderate	>90	40–70	Yes	Yes	Untested
Traditional legume species											
Subterranean clover (ssp. *subterraneum*)	>350	4.8–7.0	5.5–8.0	0–15	Sandy loam to medium clay	Poor	60–80	Most <30	No	No	No
Subterranean clover (ssp. *yanninicum*)	>350	4.8–7.0	5.5–8.0	0–15	Sandy loam to medium clay	Moderate	60–80	Most <30	No	No	No
Subterranean clover (ssp. *brachycalycinum*	>350	5.0–8.0	5.5–8.0	0–5	Loam to clay	Poor to moderate	60–80	Most <30	No	No	No
Balansa clover	>350	4.8–7.0	5.5–8.0	0–20	Sandy loam to clay	High	>80	20–50	Yes	Marginal (NSW) No (WA)	No
Rose clover	>300 (>250?)	5.0–8.0	5.5–8.0	0–5	Sandy loam to medium clay	Poor	>85	50–60	Yes	No	No
Burr medic (*spineless*)	>300	>5.2	5.5–8.5	0–15	Sandy loam to medium clay, some salt tolerance	Poor	>90	60–80	No	No	No
Barrel medic	>200	>5.7	>5.7	0–5	Loam to clay	Poor	>95	90	No	No	No
Strand medic	>300	>5.8	>6.0	0–5	Sandy loam to clay	Poor	>90	80	No	No	No
Disc medic	>300	>5.8	>6.0	0–5	Sandy loam to medium clay	Poor	>90	80	No	No	No
Murex medic	>300	>4.5	>5.5	0–15	Sand-loam	Poor	>95	60	No	No	No
Snail medic	>300	>5.8	>6.0	0–5	Loam to clay	Poor	>90	85	No	No	No
Sphere medic	>350	>4.8	>5.5	0–5	Loam to clay	Poor	>90	70	No	No	No

[1] The range where performance of the host or the rhizobia is optimised.

[2] Refers to hard-seeded French serradella cultivars $Fran_2o$, Margurita and Erica. The cultivars Cadiz and Eliza are 100% soft-seeded and are not included here.

Chapter 4:
Getting started with G_2HSLs – setting up nursery paddocks

Having understood the general characteristics of the G_2HSLs and which of them fit the farming system and soil/climate niche of your farm, there are a range of decisions to be made around the best approach to establishing them. This chapter discusses the key decisions to be made when establishing G_2HSLs on your farm.

Some growers fail in their attempts to establish G_2HSLs the first time. The four main reasons for failure as reported to the authors of this guide over 20 years are:

- poor weed control;
- misunderstanding the niche of the selected legume;
- mishandling of small seeds at sowing (usually sowing too deep); and
- presence of herbicide residues.

For these reasons, we recommend starting with a small nursery paddock in which the above factors can be controlled and observed, and in which several different G_2HSLs are sown, and from which lessons learned can be implemented the following year with seed harvested from the nursery, at a very low cost. We recommend treating the nursery paddock with similar care and attention as for a high return cash crop.

This chapter deals with the setting up of nursery paddocks for the purpose of harvesting seed to enable a more widespread pasture renovation strategy to be undertaken on-farm (see Chapter 5). The principles of weed control in the lead-up to sowing, the set-up of machinery for sowing, the possible herbicide residue risks and the use of rhizobia inoculants can and should be applied to larger-scale sowing strategies discussed in Chapter 5.

4.1 The nursery paddock concept

Unlike subterranean clover, the G_2HSLs produce their seed above ground and hold it aerially, and the G_2HSLs discussed in this guide have good seed retention capabilities. Therefore, they can be harvested with a conventional cereal header harvester. Consequently, it is possible to bulk up these species in a relatively small area at low cost and use the seed (or pod) to sow larger areas of pasture on the farm (Figure 4.1). We call this the 'nursery paddock' approach and it is similar to the concept of bulking up a new variety of wheat. The authors have worked with many growers over a number of years who have evaluated four to five species they are considering sowing more broadly initially in nursery blocks of 5 to 20ha each. This process is also useful in confirming which species are best suited to the grower's region without committing excessively in outlay for seed. From here, growers can harvest seed of those species that best suit their situation or niche.

The G_2HSLs have been found to produce 200 to >1500kg seed/ha (but more commonly 200 to 800kg/ha) when harvested commercially using a cereal header, depending on species and growing conditions. As seeding rates for these species are in the range of six to 10kg/ha, a much smaller nursery area can be used to produce enough seed to begin a pasture paddock renovation program.

4.2 Pre-sowing requirements

Prior to growing G_2HSLs (or any legume), it is important to consider paddock selection and preparation. It is critical to pay attention to possible competition from weeds and the potential for damage from in-crop herbicide residues. As when seeding a cash crop, consider soil fertility and likely pests and diseases.

4.2.1 The clean-up phase

Competition from weeds is the leading cause of pasture renovation failure in southern Australia, regardless of the pasture species being sown. It is critical that management strategies are implemented in the years leading up to sowing of a new pasture to minimise the weed seedbank.

Weed species vary in terms of their persistence in the seedbank (Figure 4.2). Species such as barley grass are exhausted relatively quickly if no additional seed is allowed to enter the soil seedbank. However, for other species such as annual ryegrass, wild oats and wild radish, seed persists for longer and therefore it is important to understand that more effort will be required to reduce the seedbanks. It is important to consider the absolute number of weed seeds that may be present in the seedbank. As an example, in Figure 4.2, there were more than 9500 germinable weed seeds/m^2 present in a previously cropped paddock at the commencement of the experiment. To achieve an establishment of 300 to 500 plants/m^2, pasture legumes are generally sown at 10 to 15kg/ha. It is easy to predict that the newly sown species will be exposed to extreme competition from the large number of weeds present if no pre-sowing weed control measures are taken. Establishment and production of the legume will be adversely affected unless the weeds are controlled.

Figure 4.1: Seed nursery concept for increasing the area of pasture sown on-farm using G_2HSLs.

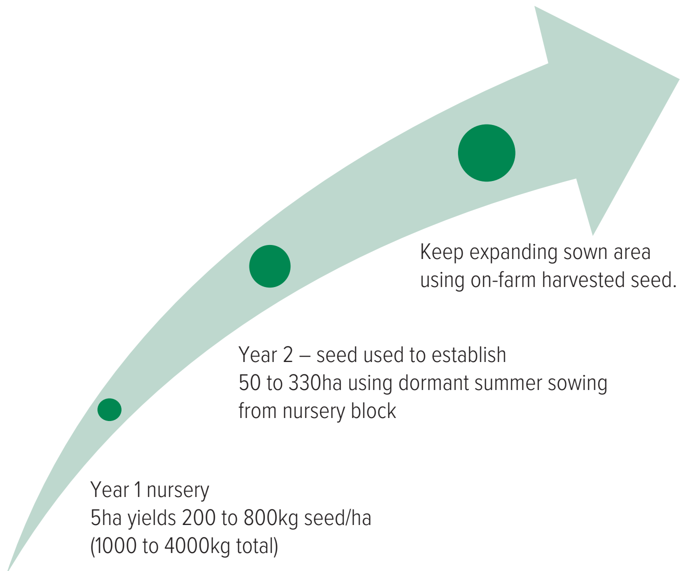
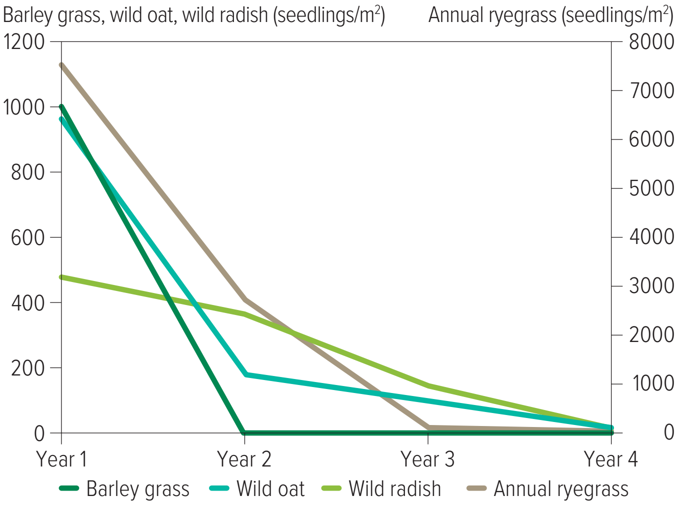


Figure 4.2: The number of seedlings (seedlings/m²) emerging from cropping paddocks over a four-year period where no additional seed was allowed to enter the seedbank.



Source: Cheam (1987); Dunbabin and Cocks (1999); Peltzer and Mason (1999).

There are many strategies to reduce the weed seedbank, including application of herbicides, strategic defoliation (silage or haymaking) and grazing. No single tactic will be universally successful in reducing weed seed levels, and an integrated approach is usually the most effective. It is also worth considering strategic tillage to stimulate weed seed germination followed by use of knockdown herbicides.

4.2.2 Weed control pre-planting

In the year of establishing a new pasture, it is important to take advantage of any pre-sowing opportunity to control weeds. It is important to ensure that herbicides used in this period will not cause residual damage. Carefully read all labels for details regarding plant-back requirements.

Pastures established via conventional sowing (after the autumn break) have the advantage of an additional opportunity for a non-selective herbicide prior to sowing. However, the advantage of this additional knockdown needs to be weighed against the distinct disadvantage of delayed emergence due to lower temperatures, reduced growth in the establishment year and, in many cases, reductions in seed production in the establishment year. Despite this, we recommend conventional sowing of a well-prepared nursery paddock as the safest option for increasing the supply of seed to be later spread more widely across the farm. The seed purchased should be of certified quality with a high germination count.

4.3 Understand herbicide residues and their effect on legume health

Herbicides vary in the time taken to breakdown and become inactive. Some require a specific time period to elapse until a potentially sensitive plant species can then be sown. Others require rainfall or specific soil moisture levels to be reached in addition to the passing of a minimum time period since application. Other herbicides may have differing persistence according to soil pH, soil moisture conditions or other soil characteristics.

Although herbicides are an essential tool in preparing a paddock for pasture renovation, it is critical to ensure that the herbicides chosen do not in themselves (or via their residues) impact on the capacity of the legumes to establish and set seed. It is critical to thoroughly read herbicide labels and understand the requirements that need to be met prior to sowing a potentially sensitive plant species. If in any doubt, seek professional advice.

The method you choose to establish your new legume pasture may influence the likelihood of herbicide residue damage. For example, dormant summer sowing (see Chapter 5) means sowing two to four months earlier than the conventional sowing date. If early autumn rains arrive, residues from previously applied herbicides can be higher than expected.

Herbicide residues can impact root hair formation (the primary point of rhizobia infection in most legumes), rhizobia survival, the growth and development of the host plant and the ability of the host plant and rhizobia to form and maintain an effective symbiosis (form nodules and fix nitrogen). It is critical to review herbicide usage in the preceding seasons and ensure that all parameters for residue breakdown have been met. Keep accurate records of the date and rate of herbicide application along with rainfall and soil moisture conditions between application and your intended sowing date. Always thoroughly read and abide by usage and plant-back periods specified on herbicide labels. Undertake a soil test to determine which species of legume is most suited to sow and to determine the nutrient status of the paddock. Such a test will include soil pH, which you should note in relation to the impact it may have on the persistence of herbicide residues.

4.4 Sowing rates for nursery paddocks

The sowing rate of seed required for establishing a nursery paddock varies with legume species (Table 4.1). Conventional sowing uses seed that has been scarified so that more than 90 per cent will germinate once in contact with moist soil. Sowing rates are very low relative to cereals, but closer to those for canola.

Table 4.1: Minimum seeding rates of scarified seed (kg/ha) for conventional sowing of pasture legumes to establish a nursery paddock.

Species	Seed form	Sowing rate as a monoculture (kg/ha)
Arrowleaf clover	Scarified	7
Biserrula	Scarified	5–7
Bladder clover	Scarified	10
Gland clover	Scarified	5–7
French serradella	Scarified	7–10
Yellow serradella	Scarified	7–10
Trigonella	Scarified	7–10

GRDC

4.5 Sowing equipment

The G_2HSLs have been successfully sown using a range of seeding equipment from airseeders to conventional disc and tyne seeders and combine seeders with a small seeds box. Whatever equipment is used for sowing, it is critical that sowing depth is accurately controlled. Sowing seed too deep can result in a significant reduction in emergence and is one of the leading causes of establishment failure for G_2HSLs. For growers who regularly sow canola, we recommend using a canola set-up, adjusted for the smaller seeds. For those who have access to a combine with a small seeds box, this can present an ideal set-up for seeding nursery paddocks.

4.6 Sowing depth

Sowing depth is critical as small seeds cannot emerge with vigour from deeper than 1.5cm. The seeds of most G_2HSLs are very small; much smaller than subterranean clover and canola, and require only shallow burial at sowing. The aim should be to sow at a depth of 1cm or less.

Burial of seed deeper than 1.5cm can result in a significant decline in emergence. Species such as arrowleaf clover, biserrula and gland clover are particularly susceptible to loss via deep burial as they have very small seeds (800,000 to 1,000,000 seeds/kg). Be aware that furrows can collapse on sandy soils and effectively bury seeds to depths in excess of 4cm. Take steps to avoid this by retaining stubble, setting furrow depth to 1cm, and using press wheels if possible. Testing the depth setting of sowing equipment by using a few kilograms of rice coloured with a food dye before seeding the legume is recommended. It is preferable to see seed on the surface after sowing than for it to be buried too deep.

4.7 Fertiliser requirements at sowing

Undertake a soil test prior to sowing a new pasture to determine possible nutrient deficiencies that may exist in the paddock. Soil testing also provides information that can be used to choose the most appropriate legume species to suit the paddock conditions. Ensuring there is sufficient phosphorus, sulfur and potassium is critical for legume growth. Check your soil test results and determine what fertilisers are needed at sowing (refer to Chapter 3).

Seed only carries sufficient nutrients to support the germinating legume for about 7 to 10 days, so there needs to be adequate nutrition within the seed placement zone to support the emerging legume. Generally, it can be useful to sow a new pasture using a 'starter'-type fertiliser that contains phosphorus, potassium and sulfur to ensure adequate nutrition for legume establishment. Avoid providing nitrogen as this can increase competition from weeds.

Many micronutrients are also important to support legume growth. However, soil testing to determine whether micronutrients are deficient is not generally useful as soil analyses are not sensitive enough for this purpose. Plant tissue tests are more accurate for determining where deficiencies or toxicities of micronutrients are suspected. In acidic soils, molybdenum can often be deficient. Molybdenum-deficient areas have generally been well defined in research, and in such areas the use of molybdenum-fortified fertiliser every four to seven years is often sufficient to overcome potential deficiencies.

4.8 Pest control pre-sowing

Some major pests of legume pastures include redlegged earth mite and aphids. Where possible, try to minimise the potential of carryover of these pests from previous years by undertaking management actions to reduce egg-laying. If this is not possible, spray immediately after sowing for control of redlegged earth mite and in spring for aphids. For serradella, control any budworm in spring as the larval stage can predate pods and reduce yield (see Chapter 6 for more detail on pests and diseases).

4.9 Inoculation with rhizobia and establishing a need to inoculate

Except for the serradellas grown in WA, it is recommended that all G_2HSLs are inoculated at sowing. This is due to the parallel rhizobia selection programs over the past three decades that have selected strains that are now available for all G_2HSLs. The exception for serradella in WA comes about as the lupin inoculant also nodulates serradella and fixes nitrogen optimally. This rhizobium is also very persistent and genetically stable, and therefore in paddocks where lupins have been well nodulated serradella will readily nodulate with suitable rhizobia that already inhabit the soil.

For the other G_2HSLs, specialised rhizobia are available for inoculation in the year of sowing. When the legume moves into a cropping rotation and the host is absent, rhizobia must be able to source sufficient nutrients and moisture in their free-living state to persist. In coarse-textured soils with low levels of organic matter, rhizobia numbers can decline sharply over the summer period. Added to this, in situations where crops are grown for a number of years between pasture phases, rhizobia numbers in coarse-textured soils can fall to suboptimal levels. Therefore, selection programs have been undertaken over the past 30 years to produce inoculant rhizobia capable of surviving extremes of soil conditions. These programs have generally been very successful in selecting resilient strains of rhizobia for tolerance to desiccation, acidity, salinity and absence of the host legume. For example, there has not been any recorded failure of nodulation in regenerating stands of biserrula, even after multiple crops. However, where rhizobia numbers have been driven to extreme lows, the response to re-inoculation in these soils is generally very good as there is little competition from background resident rhizobia. Therefore, the opportunity exists to replace or replenish the soil rhizobia if improved strains become available.

A simple 'need to inoculate' experiment can determine this. By seeding a short run of the legume uninoculated, then inoculating the next run, and by adding nitrogen to a third run, the grower can test whether it is time to re-inoculate their legumes. If the first run is poor in comparison to the second and third runs, then inoculation is required. If the first two runs are poor relative to the third, then other factors are compromising nodulation. This simple experiment can be done the year before seeding a large paddock, or indeed into a regenerating stand at the break of season, to determine if (re-) inoculation is required.

Inoculation should be viewed as an insurance policy. Inoculating legumes is a relatively small expense in the overall cost of pasture renovation. A legume that fails to nodulate or achieves suboptimal nodulation can use more nitrogen from the soil pool than it contributes via biological nitrogen fixation. To maximise nitrogen fixation potential, inoculate each time you sow.

4.9.1 Selecting the right inoculant group

If the grower is seeding a new stand of G_2HSLs or has determined a need to re-inoculate, then the inoculant choice is important, as is the right carrier of the inoculant. It must be suitable to the time of sowing and the soil moisture conditions during and after sowing.

It is critical that the correct inoculant group is supplied for legumes at sowing as the groups contain different species of rhizobia and, in general, rhizobia do not cross over between legumes. The legumes and their matching groups are shown in Table 4.2.

4.9.2 Forms of inoculant carrier and their application

Techniques of inoculation have substantially progressed since the rudimentary approach of transferring soil from paddocks containing well-nodulated legumes to recipient paddocks. There are two main modern approaches to inoculation: seed inoculation and soil inoculation.

- Seed inoculation is where the rhizobia are adhered to the seed before planting, by dusting, slurry, lime or phosphate pelleting, or vacuum impregnation.
- Soil inoculation refers to the addition of a rhizobial carrier directly to the soil, with the carrier being either liquid or granular.

Traditionally, peat has been the main form of inoculant carrier applied when sowing a new pasture. Peat supplies very high numbers of rhizobia, but numbers can decline very quickly during the sowing process if sown into dry soils. Freeze-dried inoculants and inoculants delivered by liquid injection similarly can provide very high numbers of rhizobia, but similar to peat the numbers decline very quickly in dry sowing situations. Therefore, any of the wet inoculant delivery options (seed applied or liquid injection) are suitable inoculant options to use where sowing will occur into a moist soil. If using these delivery systems, only mix enough inoculant with seed that will be sown within the next 24 hours, remembering that fresh is best.

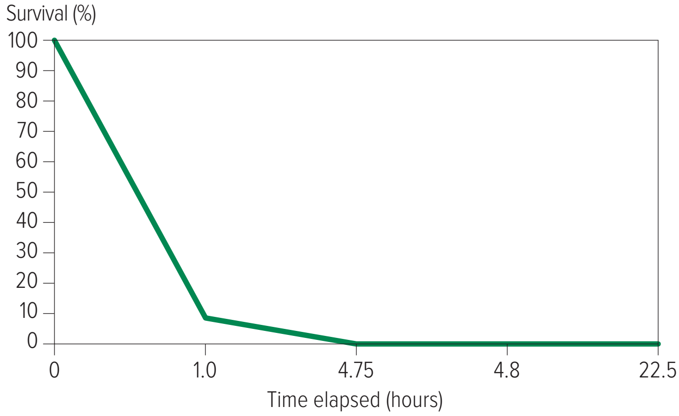
An example of how quickly rhizobia numbers can decline when delivered by wet inoculant delivery systems is shown in Figure 4.3. In this example, peat inoculant was mixed with seed and sown within five hours of inoculation into moist soil with the number of rhizobia surviving on the seed up to the point of sowing recorded and then a sample collected from the soil almost a day after initial inoculation. Importantly, more than 90 per cent of rhizobia had died within an hour of commencing the inoculation process. By the time the seed was sown, less than 1 per cent of rhizobia had survived, which was still enough (>6000 cell forming units/seed) to initiate nodulation, but these results emphasise how quickly rhizobia desiccate in wet delivery systems and the need to sow seed as soon as possible after treatment and into moist soil that optimises potential survival.

Sowing into dry soils, as in dormant summer sowing, requires inoculants that provide protection to the rhizobia from desiccation (Table 4.3). Low moisture granular products manufactured from bentonite clay and impregnated with rhizobia have proven to be very effective when sowing into dry soils and/or when there is an anticipated long delay between sowing and germination of the legume. These situations can arise when sowing pastures conventionally using scarified seed in autumn into dry soil or when establishing pasture using unprocessed seed such as when dormant summer or dormant twin sowing (see Chapter 5). Granular products generally contain a lower number of rhizobia,

Table 4.2: The inoculant group required for various G_2HSL species.

G_2HSL	Inoculant group
Arrowleaf clover, bladder clover, gland clover	Group C (WSM1325)
Biserrula	Biserrula Special (WSM1497)
French serradella, yellow serradella	Group G/S (WU425/WSM471)
Trigonella	Group AL (RRI128) for soil with pH_{Ca} >6.0 Group AM (WSM1115) for soil with pH_{Ca} <6.0

Figure 4.3: The percentage of rhizobia surviving after peat inoculation and sowing of legume seed. Sowing was completed within five hours of commencing seed inoculation as a peat slurry and the number of cells surviving recorded throughout the inoculation and sowing process and collected from the soil 22.5 hours after the commencement of the inoculation process.



Source: Roughley et al. 1993

but maintain a stable number over an extended period. Bentonite clay granules have also been used widely in dormant twin sowing, delayed dormant twin sowing and conventional sowing situations under moist and dry soil conditions. Other granular formulations exist and these vary in moisture content and suitability for use in dry sowing situations.

The cost, ease of application and effectiveness of various inoculation techniques varies and is information that growers may use to decide which is most applicable for their seeding operation (Table 4.3). The effectiveness of various inoculation techniques is consistent with the general opinion in Australian agriculture that the optimal application of rhizobia is 1011 colony forming units (CFU) per hectare, with the minimum standard in peat to be ≥109CFU.

PEAT SLURRY AND LIME PELLETING

The approach of mixing peat with a water solution and an adhesive, termed peat slurry inoculation, allows for more rhizobia to attach to the seed coat. This application process is as easy and as cost effective as dusting, yet it results in better nodulation outcomes. However, there can be problems with this inoculation technique. For example, when the slurry dries, the inoculum can dislodge from the seed and become stranded in the seed hopper, which can cause blockages.

Table 4.3: Some techniques of inoculation with their cost and effectiveness.				
Techniques	Application	Cost	Ease of application	Effectiveness
Peat slurry	Seed	Low	Easy	High
Soil dusting	Seed	Low	Easy	Low
Lime or phosphate pelleting	Seed/soil	Low	Difficult	Low
Vacuum impregnation	Seed	High	Very difficult	High
Freeze-dried powders	Seed	Medium	Moderately difficult	High
Pre-inoculated seed	Seed	High	Easy	Low*
Clay granules	Dry/wet soil	High	Medium	Medium
Peat granules	Wet soil	Very high	Easy	Medium
Liquid injection	Wet soil	Medium	Moderately difficult	High
Tea-bagging	Soil	Low	Easy	Low

*except for lucerne (*Medicago sativa*) and other medics.

Source: Harrison (2017)

Fine limestone ($CaCO_3$) coated on the outside of the peat slurry and allowed to dry and consolidate the pellet is termed 'lime-pelleting'. This technique allows for easier application in that it dries the peat slurry, allowing for a separation of individual pellets for precision sowing. For the best results, sowing must occur immediately after lime pelleting. Lime pelleting, through providing calcium, can also increase nodulation. Lime-pelleting of seed should not be used with serradella (both French and yellow) as these species do not tolerate alkalinity.

Some growers have had great success in delivering inoculant the year prior to sowing their intended pasture (Figure 4.4). To do this, they have placed inoculated seed of the final crop in the rotation. As the rhizobia contained in inoculants for all G_2HSLs have strong saprophytic competence, the rhizobia can survive and multiply within the soil rhizosphere in the absence of the host. Delivery with the final winter crop in the rotation ensures the peat is introduced into good moisture at sowing. If this technique is used, any seed treatments must be omitted from the crop seed that may interfere with rhizobia survival. This includes products such as fungicides and pesticides.

FREEZE-DRIED POWDERS

Freeze-dried powders can be applied to the soil using water injection or through slurry application to the seed; however, freeze-dried inoculants are a wet delivery system and should not be used when sowing into dry soils or where there is an anticipated delay between sowing and germination. Rhizobial cells desiccate rapidly in a dry environment and die. A protectant is usually supplied with the powder to aid with reabsorption of water.

LIQUID

Liquid injection refers to the peat culture (peat or freeze-dried formulations) being mixed with water and polymers and applied directly to the seedbed (usually into the furrow) at the time of sowing. This is a common technique for inoculating soybeans and works well in damp soils.

Figure 4.4: The root system of a biserrula plant showing excellent nodulation. Inoculant for this sowing of biserrula was applied to the wheat seed used to sow the final crop in the rotation with the biserrula established via summer sowing in the following February. No seed treatments were applied to the wheat seed prior to sowing.

Photo: Belinda Hackney

GRANULES

Another simple way of introducing rhizobia to the soil is with granular inoculants. These have been found to be superior to liquid inoculants in some settings, such as dry soils (Figure 4.5). Granular inoculants can be manufactured by adding peat slurry to moist clay and mixing it together, then allowing the granules to dry. In more recent innovations, clay-based granular inoculants have been successful when sown into dry soil, especially for dormant summer sowing of hard-seeded pasture legumes in the crop–pasture rotation. An advantage of dry granules is that they can be stored for up to six months without refrigeration.

Alternatively, granules can be made by suffusing liquid broth cultures onto ready-made granules, which absorb the inoculant. These granules have a higher moisture content than clay granules.

Granular products contain fewer rhizobia per gram than peat inoculants. Application rates vary depending on the granular product used and, for some, also with row spacing. The application rates can vary from 5 to 15kg/ha depending on these factors.

Granular inoculants offer capacity to separate rhizobia from other chemicals applied to the seeds and seed exudates, therefore increasing survival rates. Granular products differ in their suggested method of delivery. For example, some formulations can be mixed with fertiliser for delivery at sowing whereas others cannot. Be sure to read product labels thoroughly. Granules are an expensive form of rhizobia delivery, but formulations that are tolerant of sowing into dry soils can significantly open the sowing window for legume pastures.

4.9.3 Pre-inoculated seed

Pre-inoculated seed describes a pre-purchase inoculation procedure where the rhizobia is entrapped in a factory-applied seed-coating that may include insecticides, micronutrients and fungicides. It also allows for a range of plant growth and protection agents, polymers and dyes to be included in the formulation. It is a common method of inoculation for lucerne, subterranean clover and annual medics particularly in the eastern states of Australia. However, rhizobia survival on pre-coated seed can be highly variable due to differences in tolerance of some rhizobia strains to the coating products and processes. Testing has found poor survival of the rhizobia inoculant on many samples of clover, biserrula and serradella, raising doubts about the efficacy of the pre-inoculating system for these species (Hartley et al. 2012, Farquharson et al. 2022). For annual clovers, it is suggested that seed is used within six weeks of coating and more sensitive species are used within two weeks of coating. Rhizobia survival for pre-inoculated annual medics and lucerne has been generally acceptable if seed is used prior to label expiration date. Where the expiration date has elapsed, seed will need to be re-inoculated before sowing (Farquharson et al. 2022).

Figure 4.5: Bladder clover sown into dry soil in early May 2008 during the Millennium drought where there was nodulation failure due to low viability rhizobia delivery (left) compared to sowing with dry granular inoculant (right). Photos taken in early October 2008. There was an average of 0.8t DM/ha in sowing on the left and 2.4t DM/ha in sowing on the right. Nodulation was below adequate for the sowing on the left with nil occupancy of nodules present with commercial Group C inoculant (WSM1325) compared to above adequate nodulation and 85 per cent occupancy by WSM1325 for sowing on the right. All products were used in accordance with product recommendations and within expiry dates.

Photos: Belinda Hackney

Chapter 5:
Larger plantings and establishment options for G_2HSLs using dormant seed

Once harvested from the nursery paddock, the seed of the G_2HSLs can be used to establish pastures directly without further processing (assuming an absence of weed seeds) via innovative approaches that widen the window of the seeding operation. This is a distinct feature of the G_2HSLs that takes advantage of their hard (dormant) seed (or seed in pod).

There are several options for sowing G_2HSLs using unprocessed seed (or pod), and these include:

- dormant summer sowing;
- dormant twin sowing; and
- delayed dormant twin sowing.

These sowing options help overcome the initial barriers of seed cost and timing of pasture renovation within the farming calendar, which have created hesitancy to sow pastures. The G_2HSLs can also be established using scarified seed either by conventional late autumn–winter sowing or earlier in autumn using strategic dry sowing. The options available for sowing require different forms of seed (or pod), different levels of seed processing (unprocessed or scarified) and a rhizobial carrier to be available, together with other requirements for success, all of which are further discussed below.

5.1 Dormant summer sowing

Dormant summer sowing refers to the technique of sowing unprocessed seed or pod into dry soil in late summer and relying on the environment to break a sufficient proportion of the dormant hard seed by mid to late autumn, in time for the first germinating rains.

Dormant summer sowing makes use of seed that is harvested on-farm with conventional cereal machinery, without incurring the transport and processing costs of dehulling (for podded legumes such as serradella) and seed scarification (as for most hard-seeded legumes). When the G_2HSLs described in this guide are harvested on-farm, there is minimal scarification of seed and in the case of serradella, the pod breaks into segments that remain intact, thereby encasing the seed within the segment. If this seed is sown in mid to late summer, the hard seed coat of the pasture legume is then subjected to fluctuations in soil temperature and moisture. These diurnal fluctuations contract and expand the hard seed coat, which makes it permeable to water. Therefore, a proportion of the seed will breakdown and will become germinable at the break of the season in autumn.

Dormant summer sowing allows the pasture to be sown before the labour demand of the winter crop sowing program peaks, therefore better spreading on-farm labour and machinery requirements. Importantly it allows the legumes to germinate and commence growth earlier in the season when soil temperatures are higher. This contrasts with traditional sowing systems using scarified seed where the pasture is generally sown after the cropping program, resulting in legumes emerging when soil temperatures are low and growth is restricted.

Successful dormant summer sowing requires consideration of the following, and these points are discussed further in the subsequent sections:

- herbicide residues;
- understanding dormant hard seed and its breakdown;
- other factors affecting hard seed formation and breakdown rates;
- sowing rates;
- sowing timing;
- sowing depth;
- stubble management;
- inoculants;
- seedling survival; and
- the effect of dormant summer sowing on herbage and seed production.

5.1.1 Herbicide residues

Dormant summer sowing occurs three to four months prior to conventional autumn/winter pasture sowing. Therefore, there is an increased risk of herbicide residues being present at the time of sowing and at the time of seedlings emerging in late summer or early autumn. Keep accurate records of herbicides applied in the seasons leading up to pasture sowing and be sure to abide by ALL requirements to meet safe plant-back criteria.

5.1.2 Understanding dormant hard seed and its breakdown to select the best options for dormant summer sowing

There is frequently confusion over the terms 'initial hard seed level', 'hard seed breakdown' and 'residual hard seed' and the role each play in determining which species and cultivars are most suited to use in dormant summer sowing. Definitions for these terms are as follows.

- 'Initial hard seed level' refers to the percentage of seed that is resistant to germination immediately following seed formation. For the G_2HSLs and for traditional legumes such as subterranean clover and annual medics, all have high initial hard seed levels.
- 'Hard seed breakdown' refers to the processes of fluctuations in temperature and moisture that occur when legume seed is left in the paddock after formation (or when harvested seed is used in processes such as dormant summer sowing) that cause the impermeable seed coat of the legume to breakdown and become susceptible to germination. Hard seed breakdown rates can vary considerable between and within legume species.

- 'Residual hard seed' refers to the percentage of hard seed remaining after hard seed has been exposed to seed breakdown conditions over a specific time. In the context of dormant summer sowing, this refers to the amount of hard seed remaining after opening autumn rains have been received. For dormant summer sowing to be successful, a minimum of 30 to 50 per cent of hard seed (depending on species) needs to breakdown and become germinable in the period between sowing and opening autumn rains to provide sufficient germination to establish a vigorous pasture.

Research over the past 15 years has resulted in an understanding of the hard seed breakdown patterns of hard-seeded legumes across a range of environments. Not all species, or cultivars within species, of freshly harvested unprocessed seed are suitable for dormant summer sowing. Additionally, the suitability of species or cultivars to dormant summer sowing varies with environmental conditions, specifically temperature, rainfall and the capacity of soils to retain moisture.

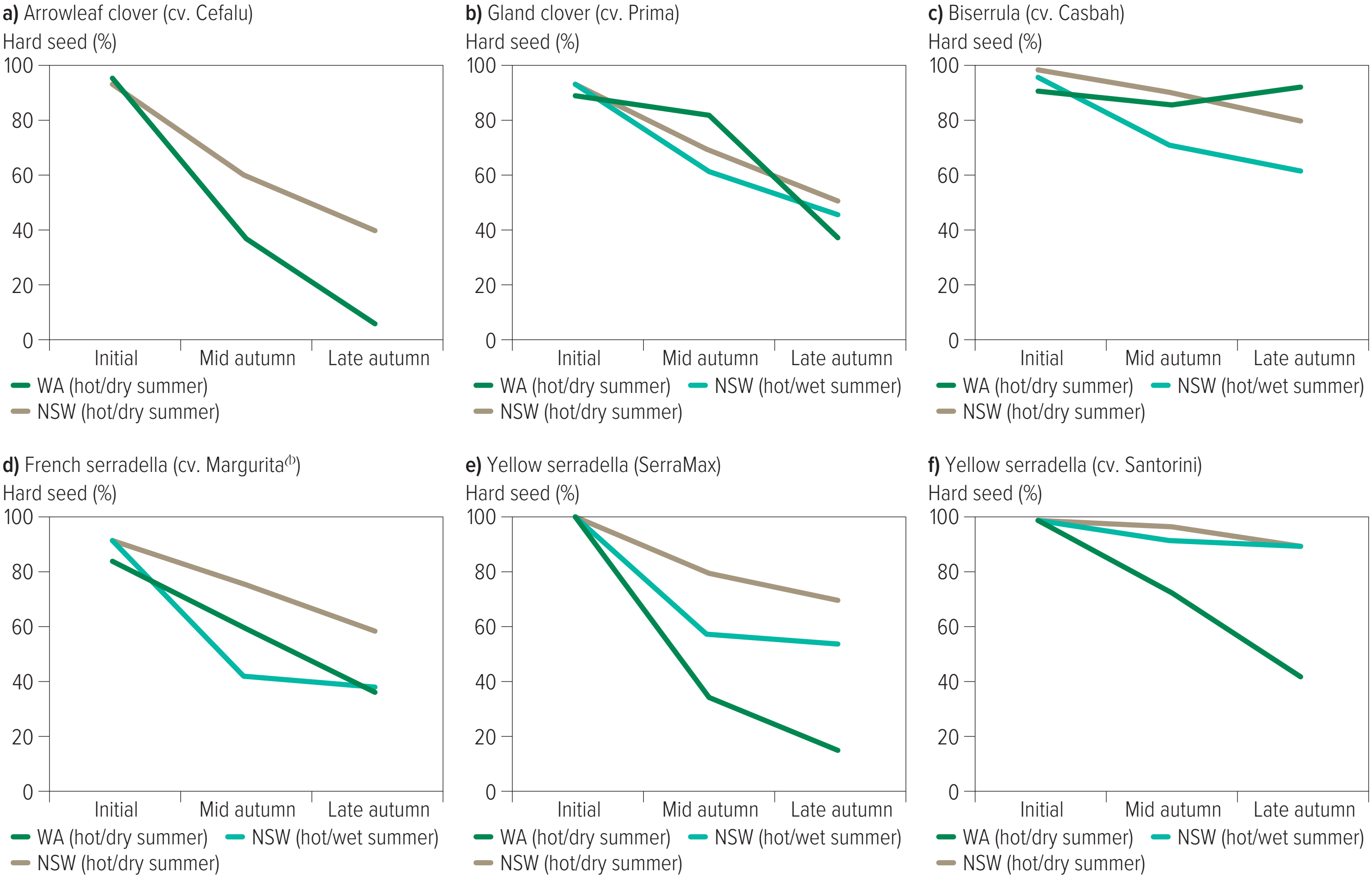
Research in WA and NSW has demonstrated the considerable differences in rates of hard seed breakdown attributable to the effects of climatic and soil conditions (Figure 5.1). In these experiments across both states, arrowleaf clover (cv. Cefalu), gland clover (cv. Prima), bladder clover (cv. Bartolo), French serradella (cvs. Fran$_2$o(b) and Margurita(b)), yellow serradella (cvs. Avila and SerraMax(b)) have all been shown to have hard seed breakdown attributes that could be used for dormant summer sowing. However, some species/cultivar combinations differ significantly in hard seed breakdown patterns across states and regions. For example, in WA, biserrula (cv. Casbah) has minimal hard-seed breakdown between February sowing and late autumn, whereas in central and southern NSW 30 per cent and 20 per cent of seed, respectively, typically softens and is capable of germination within the same timeframe. Conversely, yellow serradella (cvs. Santorini and SerraMax(b)) both break down more rapidly in WA than in NSW with Santorini having only 10 per cent of seeds softening between dormant summer sowing and late autumn in NSW. Although species/cultivar combinations may have hard seed breakdown patterns suitable for dormant summer sowing, it does not mean they are appropriate to use in all situations. Consideration needs to be given to the ability of seedlings to survive once germination occurs (see Section 5.1.9).

5.1.3 Other factors affecting hard seed formation and breakdown rates

Conditions during the formation of seed and those following sowing of seed in summer can have a considerable impact on the proportion of seed that breaks down over summer and into autumn. In terms of seed formation, seeds need to dry down to a moisture content of less than 14 per cent before the seed coat is fully formed. Therefore, where moisture conditions are high in the late reproductive stages of growth, full formation of the seed coat may occur later or a proportion of the seed may not have a fully formed seed coat. Such conditions can result in the seed having a lower hard seed content. Conversely, seed formed under lower moisture conditions is likely to have a higher hard seed content.

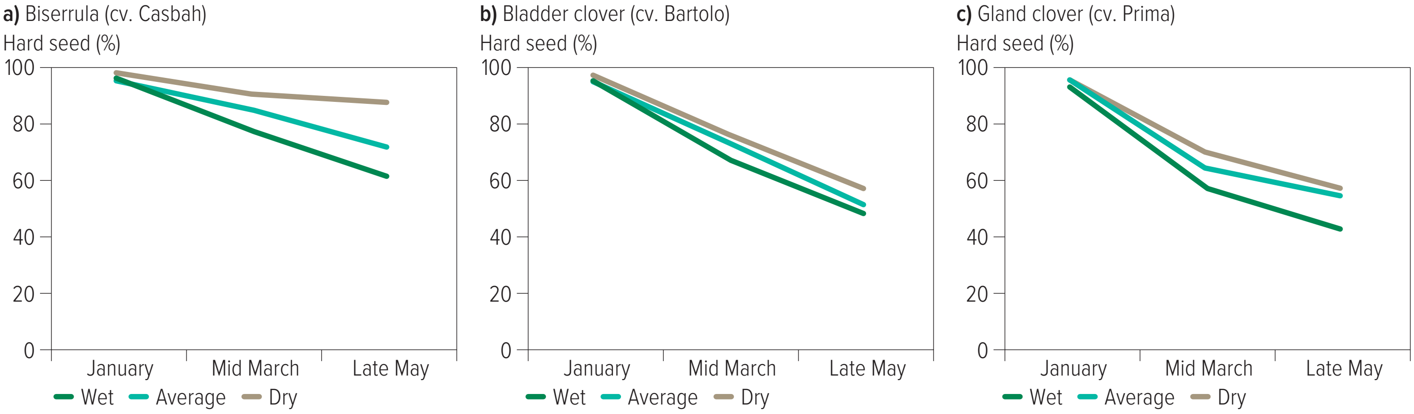
Seasonal conditions (temperature and moisture) between sowing and opening autumn rains can have a significant impact on seed softening patterns and therefore the success of dormant summer sowing (Figure 5.2). Seed softening patterns following dormant summer sowing have been studied over a number of years

Figure 5.1: The hard seed content (%) for a range of G$_2$HSLs buried in mesh pockets in January (initial) and retrieved in mid or late autumn under typical WA summer conditions (hot/dry) and under either hot/dry or hot/wet summer conditions in NSW.



Source: Adapted from Nutt et al. (2021)

Figure 5.2: The hard seed content (%) of seed buried in mesh pockets in January and retrieved either in mid-March or late May at Greenethorpe NSW in years of average, below average (dry) or above average (wet) summer rainfall conditions.



Source: Hackney, unpublished

and seasonal conditions in NSW. For biserrula, depending on summer–autumn moisture conditions, hard seed breakdown rates can vary from less than 10 per cent under summer/dry conditions to almost 40 per cent in above-average rainfall summers. This has led some growers in NSW to use a mixture of unprocessed and scarified seed in their dormant summer sowing mix for biserrula in the event that a very dry summer is encountered. Other species such as bladder clover and gland clover have similarly shown reduced hard seed breakdown rates under dry compared to wet summer conditions, but not to the degree of biserrula. In the case of bladder and gland clover, regardless of summer moisture conditions, sufficient hard seed has softened to facilitate formation of dense pastures.

The harvesting process can also have an impact on hard seed content. Where header settings cause abrasion/percussion, the hard seed content may be affected slightly by either scratching of the seed coat of bare-seeded species (for example, clovers) or cracking pod segments of serradella. However, the effect of harvesting is minimal and is only likely to result in less than a 5 per cent difference in initial hard seed content.

Storing harvested, unprocessed seed for extended periods (longer than one year) can also impact hard seed breakdown patterns without impacting initial hard-seed content with some species showing significantly quicker softening following storage (Figure 5.3). Storing on-farm harvested seed may be a useful mechanism to allow growers to successfully establish a wider range of species/cultivars using dormant summer sowing than could otherwise be achieved by sowing freshly harvested seed.

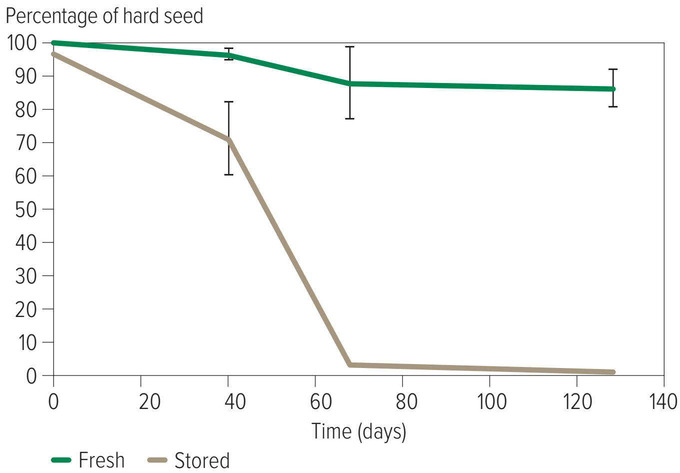
5.1.4 Sowing rates

The seed used for dormant summer sowing is in an unprocessed state. This means that higher sowing rates must be used to achieve adequate density. For serradella, the minimum recommended sowing rate is 20kg/ha (pods). For biserrula and the hard-seeded clovers, the minimum sowing rate should be 12kg/ha (seed). In practice, many growers who harvest their own seed often use much higher seeding rates than the minimum rates above (commonly >30kg/ha serradella pod and >20kg/ha biserrula and clover). Increasing seeding rates results in a higher number of germinable seeds and improved seedling density leading to earlier canopy closure and higher growth rates. With dormant summer sowing, it is possible to achieve very dense, vigorous and competitive pastures at a very low cost.

5.1.5 Sowing timing

Dormant summer sowing must be undertaken from late January to early March, with consideration of local climatic and soil conditions in choosing the optimum time. In areas that experience hot, dry summer–early autumn conditions, dormant summer sowing can occur anytime during the late January–early March period. Sowing earlier in this window will expose the seed to greater accumulated temperature fluctuations, which may result in greater hard seed breakdown and improved emergence. In areas where there may be higher rainfall or higher levels of soil moisture over summer and early autumn, hard-seed breakdown can occur very rapidly, particularly where there are also large diurnal fluctuations. In these areas, it is advisable to delay sowing until mid-February to lessen the risk of very early germination.

Figure 5.3: Hard seed breakdown of both fresh and stored seeds of *T. spumosum* (95GCN111) exposed to paddock conditions over 129 days. 95 per cent confidence intervals are presented at the intersected points to represent significant difference.



Source: Harrison et al. (2021)

5.1.6 Sowing depth

Seeds or pods should not be placed deeper than 1cm when sowing (use canola settings on seeder). Significant reductions in emergence can occur when seed is buried beyond this depth. Equally, seeds and pod segments should not be top-dressed on the soil surface as hard seed breakdown will be very slow without adequate seed–soil contact. An exception to this rule is yellow serradella cultivar SerraMax, which has a seed that can break down when on the soil surface. Best results with dormant summer sowing for most G$_2$HSLs are seen where the seed/pod is drilled into the soil at the correct depth.

5.1.7 Stubble management

Consideration may need to be given to stubble management depending on the available sowing equipment. It is important to remember that very high stubble burdens that create a thick crop residue layer on the surface may reduce temperature fluctuations that otherwise assist in breaking down hard seed. Think about harvest height, use of straw spreaders and management of stubble over early summer (for example, grazing stubbles) to reduce the potential for thick stubble and heavy crop residue loads that may interfere with sowing and hard seed breakdown. On the other hand, stubble can assist in reducing windblown sand that might fill seeding furrows. A balance is required.

5.1.8 Inoculants

As dormant summer sowing occurs under high temperatures and often under very low soil moisture conditions, it is critical to ensure that the form of inoculant delivery facilitates survival of rhizobia in adequate numbers until the seedlings emerge, which may be some months after sowing. Good results have been achieved using dry clay granules containing the appropriate inoculant group for a given species.

As temperatures are very high at sowing, using the peat inoculation technique is unlikely to result in survival of sufficient numbers of rhizobia by the time the seedling emerges to enable adequate nodulation. Some growers have had success in peat-treating seed of the preceding cereal crop with the inoculant group for the legume species (to be sown in the following summer). If this approach to inoculation is adopted, then the fungicide treatments on the cereal seed must be avoided as this can be highly toxic to rhizobia.

Establishing rhizobia in the soil before sowing of the legume is known as 'alternative host delivery'. This approach has seen success with rhizobia specific for clovers sown into infertile, acidic soil by inoculating wheat in the preceding season, and for biserrula by sowing granules with the preceding wheat crop. Rhizobia delivered to the soil in this approach must colonise the soil in the absence of their host. Fortunately, this has been a selection requirement in strains developed for the G$_2$HSLs. Alternative host delivery has been improved by the refinement of clay granules, which can be sown with the crop before for dormant summer or dormant twin sowing.

5.1.9 Seedling survival

Although several cultivars of G$_2$HSLs possess hard seed breakdown characteristics suitable for dormant summer sowing, not all cultivars can be successfully used in all situations (Table 5.1). In dormant summer sowing, seedlings will often emerge in late summer to mid-autumn, which is considerably earlier than emergence following conventional late autumn sowing. Seedlings emerging in late summer to mid-autumn will experience higher temperatures and may be exposed to greater moisture stress. Therefore, the species/cultivars used for dormant summer sowing must be capable of surviving such conditions either by rapid development of their root systems or the ability to better regulate moisture loss via transpiration.

Research in WA and NSW over several years has found that seedlings of French serradella (cvs. Margurita$^{\Phi}$ and Fran$_2$o$^{\Phi}$) and bladder clover (cv. Bartolo) emerging early have a high survival rate and subsequently produce dense, productive swards. In addition to these cultivars, in NSW arrowleaf clover (cv. Cefalu), biserrula (cv. Casbah), gland clover (cv. Prima) and yellow serradella (cvs. Avila and SerraMax$^{\Phi}$) have also proven to be very reliable options for dormant summer sowing. Within yellow serradella, Avila should only be used for dormant summer sowing in NSW in areas receiving more than 550mm rainfall.

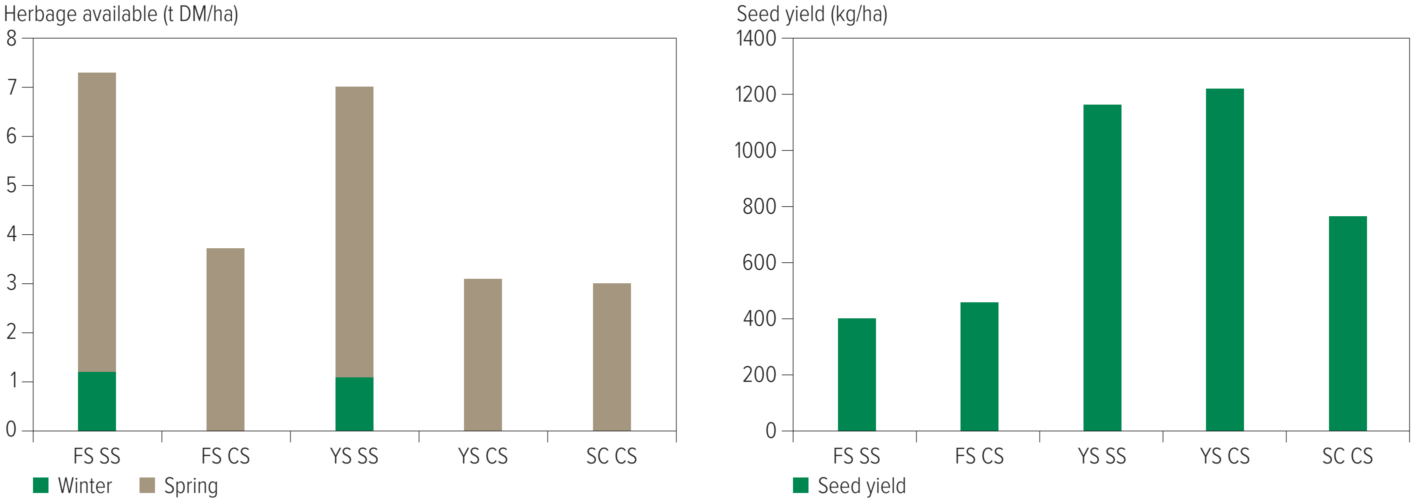
Table 5.1: Species and cultivar options for dormant summer sowing.

Western Australia (300 to 600mm)	New South Wales (350 to 650mm)	New South Wales (>550mm only)
French serradella (cvs. Margurita$^{\Phi}$ and Fran$_2$o$^{\Phi}$)	French serradella (cvs. Margurita$^{\Phi}$ and Fran$_2$o$^{\Phi}$)	French serradella (cv. Margurita$^{\Phi}$)
Bladder clover (cv. Bartolo and Diaman$_2$ti)	Bladder clover (cv. Bartolo and Diaman$_2$ti)	Arrowleaf clover (Cefalu)
Yellow serradella (cv. SerraMax$^{\Phi}$)	Arrowleaf clover (cv. Cefalu)	Yellow serradella (Avila)
Biserrula[2]	Gland clover (cv. Prima)	
Trigonella (cv. Carn$_2$ac)	Biserrula (cv. Casbah)[1, 2] Yellow serradella (cv. SerraMax$^{\Phi}$) Trigonella (cv. Carn$_2$ac)	

[1] It should be noted that unscarified biserrula may not breakdown sufficiently in very dry summer environments when summer sown. Use of a ratio of 70 per cent unscarified seed and 30 per cent scarified seed can enhance germination and establishment in such areas.

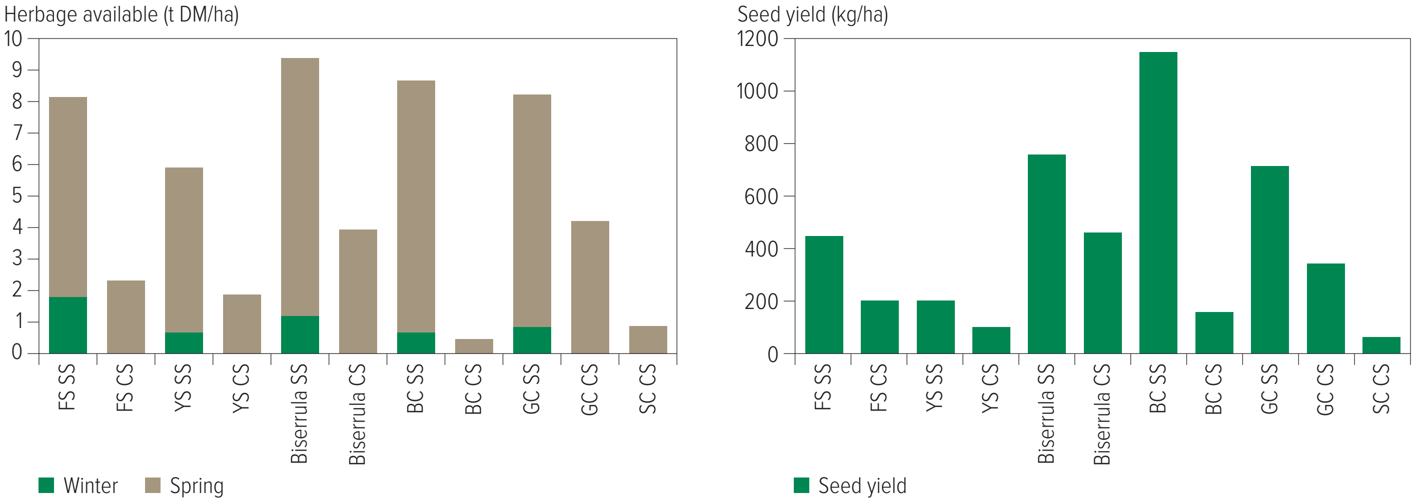
[2] Biserrula (cv. Crown$_2$) is under evaluation for dormant summer sowing.

Figure 5.4: Herbage availability (t DM/ha) at the end of winter and in peak spring and seed yield (kg/ha) for French serradella (FS) and yellow serradella (YS) established either via dormant summer sowing (SS) of unprocessed seed in February or conventional sowing (CS) of scarified seed in late May compared to conventionally sown subterranean clover (SC) at Mingenew, WA.



Source: Nutt et al. (2021)

Figure 5.5: Herbage availability (t DM/ha) at the end of winter and in peak spring and seed yield (kg/ha) for French serradella (FS) and yellow serradella (YS), biserrula, bladder clover (BC) and gland clover (GC) established either via dormant summer sowing (SS) of unprocessed seed in February or conventional sowing (CS) of scarified seed in late May compared to conventionally sown subterranean clover (SC) at Greenethorpe NSW.



Source: Nutt et al. (2021)

5.1.10 Effect on herbage and seed production

Dormant summer sowing using species/cultivars suitable to the region can significantly increase herbage production in the year of establishment (Figures 5.4 to 5.6; page 45). Dormant summer sowing allows seedlings to emerge earlier in the growing season when temperatures are higher, and plants can grow more rapidly. The rate of leaf expansion in any plant is related to accumulation of heat units (often referred to as growing degree days). Legumes generally have a higher heat accumulation need than grasses to produce a new leaf. Therefore, the earlier they can emerge and commence growth, the more heat units they can accumulate and the more leaves they can produce before the onset of winter. The more rapidly the canopy forms, the greater the light interception the sward has and the better able it is to continue to grow throughout winter and the more rapid it can accelerate growth as temperatures rise in spring. This contrasts with late autumn conventional sowing where the time for emergence is delayed by low temperatures, the seedling takes longer once emerged to reach heat accumulation targets to expand a new leaf, there are fewer leaves for light interception over winter and overall growing season herbage production potential is reduced.

Dormant summer sowing has not been found to have any negative consequences for seed production, with outcomes either similar to that of conventionally sown swards in WA (Figure 5.4) or significantly higher in NSW (Figure 5.5).

5.2 Dormant twin sowing

Dormant twin sowing involves sowing header-harvested seed or pod segments together with the seed of the crop to be established in the last year of the cropping phase at the conventional time for crop seeding. A proportion of the G_2HSL hard seed breaks down between sowing and the arrival of autumn rains in the following season, approximately 10 months later. Dormant twin sowing therefore represents an opportunity to sow the final crop while at the same time setting up conditions for the establishment of a new pasture in a one-pass operation. Unlike conventional undersowing, the seeding rate for the cereal used in dormant twin sowing does not have to be reduced. There are some key considerations to improve the success of dormant twin sowing, especially management of the depth of placement of the legume seed/pod and these are as follows:

- sowing depth;
- hard seed breakdown;
- suitable species for dormant twin sowing;
- sowing rates;
- herbicide residues;
- inoculants; and
- effects on herbage and seed production.

5.2.1 Deep burial-efficiency issues

The efficiency of dormant twin sowing, that is the number of seedlings emerging compared to the number of seeds sown, is lower than for dormant summer sowing. Much of this reduction in efficiency is due to seed losses caused by deep burial of seed in the soil over time. Larger-seeded species suited to dormant summer sowing (for example, bladder clover), or those sown using pods (serradella) tend to have better efficiency than smaller-seeded species (for example, biserrula), which are less capable of emerging if seeds become deeply buried.

In dormant twin sowing, it is critical that seed is delivered via a separate sowing tube to the cereal seed. Cereal sowing depth is much too deep for emergence of the G_2HSLs suited to dormant twin sowing. Ensure that the tube delivering legume pod or seed is set to a shallow depth (<1cm). If press wheels are following the cereal sowing tubes, then simply dropping the seed or pod into the furrow behind the press wheels may be sufficient to allow for soil coverage to occur over time. If seed is left exposed, then there is increased risk of ant theft. The preferred method of sowing is delivery of seed via a third tube that is set to a shallow depth.

It is important to consider soil type when deciding whether dormant twin sowing is an appropriate method for pasture establishment. Soils where furrows are prone to collapse following sowing, for example, some sandy soils or where soil may be moved by wind over summer, are less suitable for dormant twin sowing.

There are strategies that can be used at dormant twin sowing to help reduce excessively deep burial occurring over time. Sowing at a lower speed can reduce soil throw and results in a decreased chance of furrow collapse.

5.2.2 Hard seed breakdown following dormant twin sowing

The breakdown of the unprocessed pod segments or seed is influenced by soil moisture throughout the cereal growing season and by fluctuations in temperature during the growing season and over the next summer and early autumn. The longer the seed is in contact with soil, the greater the proportion of seed that softens and is capable of germination in the following year.

5.2.3 Species suitable for dormant twin sowing

Research in WA and NSW has identified a range of hard-seeded legume species suitable for use in dormant twin sowing (Table 5.2).

5.2.4 Sowing rates

When dormant twin sowing, the seed or pod segments will be in contact with the soil for a prolonged period between sowing and germination in the following year. In that time, the seed may become buried deeper in the soil due to soil settling or furrow collapse, particularly in sandy soils. It is important to ensure seeding rates take account of this potential issue. Minimum seeding rates should be 20kg/ha of pod segments if using serradella and 12kg/ha for bare-seeded species. However, it is advisable where possible to use seeding rates of 30kg/ha of pod segments and 15kg/ha bare seed to guard against seed losses due to deep burial.

As the sowing year is purely a seed-softening year for the sown legume, there is no requirement to reduce the normal sowing rate for the cereal crop. This contrasts greatly with conventional undersowing, which uses scarified pasture seed. For conventional undersowing, the cereal sowing rate is generally reduced by 50 to 75 per cent.

5.2.5 Herbicides and their residues

Where dormant twin sowing is used to establish a G_2HSL, consideration needs to be given to the herbicides used in the crop that is sown with the unprocessed pod segments or seed. Although there will be minimal germination of the unprocessed pod segments or seed when twin-sown, the legumes will germinate earlier in the following year than when pastures are conventionally sown. The emergence window for dormant twin-sown legumes is similar to when legumes are dormant summer sown; that is, germination is likely to commence from

Table 5.2: Species and cultivar options for dormant twin sowing.

Western Australia	New South Wales
French serradella (cvs. Margurita⁽ᵖ⁾ and Fran$_2$o⁽ᵖ⁾)	French serradella (cvs. Margurita⁽ᵖ⁾ and Fran$_2$o⁽ᵖ⁾)
Yellow serradella (cvs. Avila, SerraMax⁽ᵖ⁾)	Yellow serradella (cvs. Avila, SerraMax⁽ᵖ⁾)
Bladder clover (cv. Bartolo)	Bladder clover (cv. Bartolo)
	Biserrula (cv. Casbah)[1]

[1] Care must be taken when using biserrula for dormant twin sowing as seed may become buried too deeply between sowing and germination in the following year to achieve good emergence. The use of biserrula for twin sowing is considered marginal. Consideration of soil type is also critical as deep burial is more likely in sandy soils where furrows are prone to collapse.

Figure 5.6: Top photo shows (L to R) the herbage cut in late July from an area of $0.1m^2$ for swards of biserrula, arrowleaf clover, French serradella, yellow serradella, bladder clover and gland clover established via dormant summer sowing compared to conventionally sown (late May sowing) subterranean clover (circled). Bottom photo shows herbage in mid-August for (L to R) bladder clover established via dormant summer sowing, conventional late May sowing of arrowleaf clover (pitchfork) and summer sowing of arrowleaf clover at Condobolin NSW.

Photos: Belinda Hackney

late summer onwards. It is critical that herbicides that are likely to cause residual damage are avoided in the crop sown with the unprocessed legume seed or pod. When choosing herbicides for use in the crop, be mindful of plant-back requirements. Similarly, it is important to consider herbicides used in the period between crop harvest and likely germination of the dormant twin-sown legume.

5.2.6 Inoculants

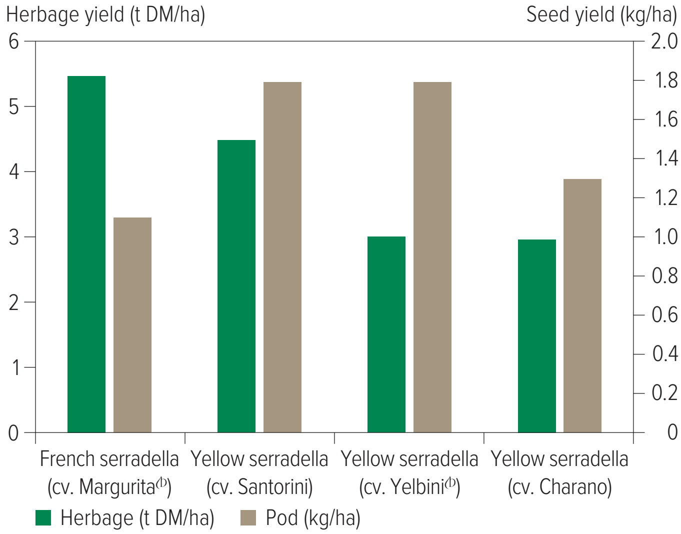
Where dormant twin sowing is used, there is a long period between sowing and emergence of the legume seedlings. This means there is a long period where rhizobia must survive in the absence of the host legume. Current rhizobia strains for each legume host species exhibit strong saprophytic competency, that is, the capacity to survive in the absence of the host legume. Dry clay inoculant granules have been successfully used with dormant twin sowing in research trials in WA and NSW. Additionally, growers have used peat inoculation of the legume seed and achieved adequate nodulation in the following year. If using peat or other wet inoculant delivery systems to treat the legume seed or pod segments, it is important that sowing occurs within 12 hours of treating the seed and that seed is sown into moist soils.

5.2.7 Effects on herbage and seed production

Foundational research in WA confirmed the potential of dormant twin sowing as a strategy for pasture establishment (Figure 5.7). The early focus of research involved assessing the suitability of French and yellow serradella cultivars for use in dormant twin sowing. French serradella (cv. Margurita⁽ᐩ⁾) and Yellow serradella (cv. Santorini) both produced in excess of 4t DM/ha when established by dormant twin sowing, and all cultivars evaluated produced more than 1t pod segments/ha, which would be more than sufficient for establishing a seedbank for future regeneration.

Further evaluation of other species occurred in NSW. The herbage and seed production achieved by dormant twin sowing was compared to that of pastures established via standalone sowing or undersowing (both using scarified seed) in the year prior (Figure 5.8a). A significant disadvantage of traditional undersowing, which uses scarified legume seed, is the intense competition for moisture, light and space between the crop and the undersown pasture, which can result in pasture legumes producing insufficient seed for subsequent regeneration. This was reflected in differences between herbage yields and seed production between the conventional standalone and undersown treatments. When sowing a new legume pasture, a minimum of 150kg seed/ha should be produced to establish a seedbank capable of achieving dense pasture swards in subsequent years.

Figure 5.7: Herbage yield (t DM/ha) and pod yield (kg/ha) for a range of French and yellow serradella cultivars in field-tests at Northam, Western Australia.



Source: Loi et al. (2008)

When undersown, biserrula, French serradella and bladder clover produced significantly less seed in the establishment year than their standalone counterparts. Neither biserrula nor French serradella met this benchmark when undersown (and subterranean clover did not achieve this regardless of sowing method). Twenty-five and 40 per cent of the seed formed in the biserrula and French serradella undersown treatments softened over summer, equating to 18 and 25kg/ha of germinable seed of biserrula and pod of the serradella, respectively. Although this would appear to be sufficient germinable seed to form a dense pasture in Year 2, seed size was also adversely impacted by undersowing with the biserrula and French serradella seed being 40 to 50 per cent smaller than the seed used for initial sowing (as was the subterranean clover established by undersowing; Figure 5.8a). Thus, undersowing affected not only seed yield, but also seed size resulting in smaller, less vigorous seedlings in the regenerating pastures. Bladder clover seed yield was significantly reduced by undersowing compared to standalone sowing, but seed size was only reduced by about 10 per cent.

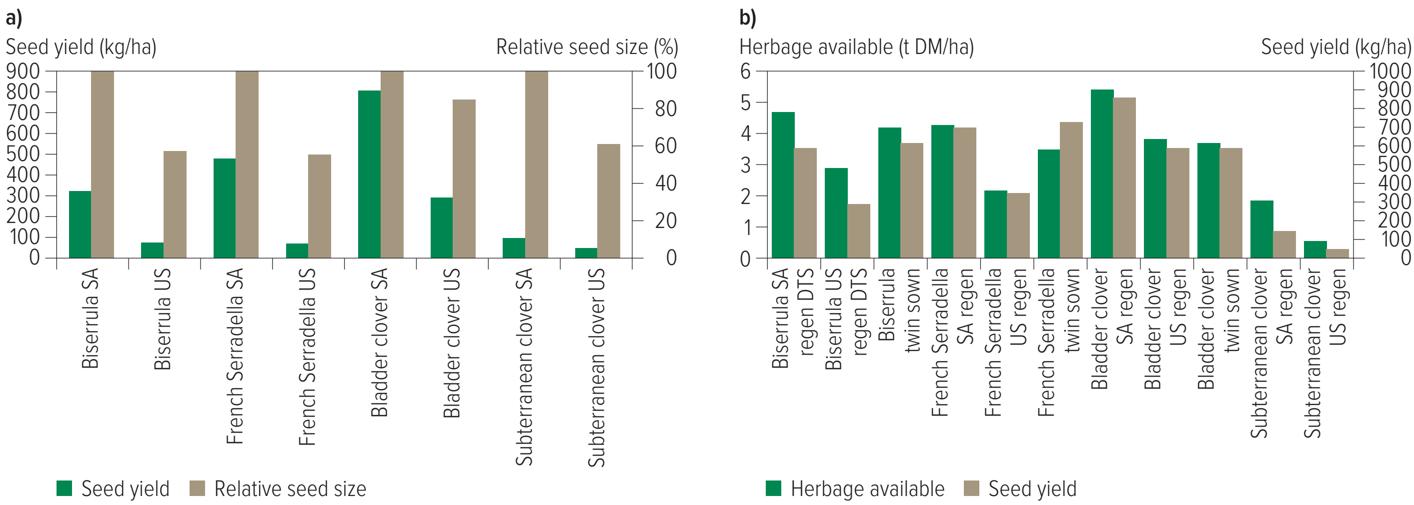
When comparing performance of the pasture regenerating from undersowing with that emerging from dormant twin sowing, the twin-sown biserrula and French serradella swards produced 1.5 times more herbage than that of the regenerating pasture that was initially established by undersowing (Figure 5.8b). Additionally, the maximum yield achieved by the pasture established by dormant twin sowing was 1.5 times greater than that achieved by the pasture originally established by undersowing for biserrula and French serradella. Both biserrula and French serradella seed yield achieved by dormant twin sowing was significantly higher than for their undersown equivalents. For biserrula and French serradella, the herbage production and seed yield achieved was equivalent to that of the regenerating standalone sowings.

5.3 Delayed dormant twin sowing

Delayed dormant twin sowing involves broadcasting unprocessed seed or pod segments of G_2HSLs in early winter, while the furrow is still partially open, following crop establishment. Delayed dormant twin sowing was developed to reduce seed losses due to deep burial over time, especially in sandy soils where the furrow can collapse, resulting in poor emergence of twin-sown legumes. Allowing the sowing furrow to settle and stabilise somewhat following sowing of the crop can reduce the depth to which legume seed is buried, resulting in improvements in emergence.

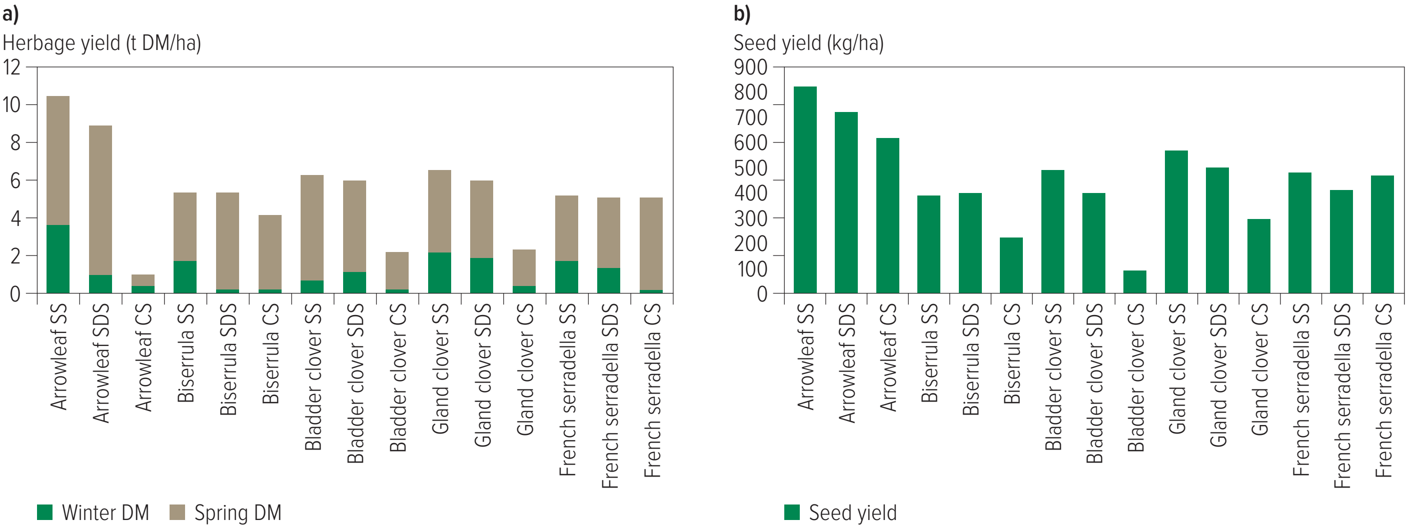
The species suitable and sowing rates for delayed dormant twin sowing are the same as for dormant twin sowing. It is preferable to drill inoculant granules with the cereal crop rather than spread them on the surface. Peat inoculation of the legume seed is less preferred for this sowing option as the seed is dropped on the surface and rhizobia are prone to desiccation. The same consideration needs to be given to in-crop herbicide use and the potential for herbicide residues to impact pasture establishment in the following year as for summer and dormant twin sowing.

Figure 5.8: a) The seed yield (kg/ha) and relative seed size of biserrula, French serradella, bladder clover and subterranean clover established via conventional sowing of scarified seed in 2009 and b) the herbage production (t DM/ha) and seed yield (kg/ha) from regenerating swards established via standalone (SA) or undersowing (US) in 2010 compared to herbage production and seed yield of pastures of these species emerging from dormant twin sowing (DTS) where seed was twin sown with the crop in 2009.



Source: Hackney et al. (2012)

Figure 5.9: a) Herbage yield (t DM/ha) in winter and spring and b) seed yield (kg/ha) for a range of annual legume species established via dormant summer sowing (SS) with unprocessed seed or pod segments in February or using scarified seed via strategic dry sowing (SDS) in early autumn or conventional sowing (CS) in late May at Collingullie, NSW, in 2016.



Source: Adapted from Hackney et al. (2023)

5.4 Strategic dry sowing

Strategic dry sowing involves the sowing of scarified seed of suitable G_2HSLs prior to the autumn break, so that they can emerge immediately following early to mid-autumn rainfall and while temperatures are still favourable for growth. It is critical to remember that species used in strategic dry sowing must be able to rapidly establish their root system and withstand moisture stress conditions that might cause a false break in traditional legume species such as subterranean clover.

Species that are suitable for strategic dry sowing include the deeper-rooted G_2HSLs such as biserrula, French serradella and yellow serradella. Where early to mid-autumn temperature conditions are less extreme and where rainfall is more reliable, arrowleaf clover, bladder clover and gland clover may also be suitable for strategic dry sowing. Sowing rates for strategic dry sowing are the same as for conventional late autumn sowing. Generally, for small-seeded species such as arrowleaf clover, biserrula and gland clover, rates of 5 to 7kg seed/ha will be sufficient. For larger-seeded species, such as bladder clover and serradella, seeding rates of 7 to 10kg/ha are suggested.

As strategic dry sowing occurs under conditions of low soil moisture, it is critical that the inoculant delivery system used is capable of supporting rhizobia survival until germination and nodulation. Low moisture granular inoculants have proved to produce adequate nodulation in pasture legumes established via strategic dry sowing.

5.4.1 Effect on herbage and seed yield

Strategic dry sowing has been shown to achieve similar herbage and seed yields to dormant summer sowing (Figure 5.9), although in years with dry spring conditions, dormant summer sown swards have generally produced more herbage than strategic dry sowing (Figure 5.10). Strategic dry sowing has generally resulted in significantly higher herbage production and seed yield compared to conventional late autumn/early winter sowing regardless of seasonal conditions.

Figure 5.10: Arrowleaf clover established by dormant summer sowing (left), strategic dry sowing of scarified seed in early April (middle) or conventional sowing of scarified seed in late May (right) at Greenethorpe NSW. Photo taken in late August 2017 at Greenethorpe NSW where winter and spring rainfall were below average.

Photos: Belinda Hackney

5.5. General comments on sowing rates

As we have discussed, rates of seed required for sowing vary with the form of sowing and species to be used (Table 5.3). Dormant summer, dormant twin and delayed dormant twin sowing all use unprocessed (or minimally processed) seed. Only a proportion of the seed softens and is capable of germination in the autumn following sowing. For that reason, sowing rates for dormant summer, dormant twin and delayed dormant twin sowing need to be higher than for conventional sowing.

Strategic dry and conventional sowing use seed that has been scarified so that more than 90 per cent will germinate once in contact with moist soil. For that reason, seeding rates are usually lower than for dormant summer, dormant twin and delayed dormant twin sowing. Due to additional processing to scarify seed, seed costs for conventional sowing are usually substantially higher than for dormant summer, dormant twin and delayed dormant twin sowing.

Frequently, when used as part of a cropping rotation, hard-seeded legumes are sown as a monoculture. This simplifies management in terms of weed control. However, growers often want to sow mixtures of legumes to increase feed supply over the growing season or in situations where soil types vary considerably across paddocks or if they intend to sow legumes with a non-legume (for example, perennial grass). If you are intending to sow mixtures, it is important to consider issues such as herbicide compatibility so that there is maximum scope for future weed control options. Additionally, if using dormant summer sowing, it is important to choose species with compatible hard seed breakdown characteristics to ensure parity in composition.

Table 5.3: Minimum seeding rates (kg/ha) for dormant summer sowing, dormant twin sowing, delayed dormant twin sowing, strategic dry and conventional sowing of pasture legumes when sown as a monoculture or as part of a mixture.

Sowing strategy	Species	Seed form	Sowing rate as a monoculture (kg/ha)	Sowing rate as a component of a mixture (kg/ha)
Dormant summer sowing	Arrowleaf clover	Unprocessed	12	3–6
	Biserrula[1]	Unprocessed	12	2–4
	Bladder clover	Unprocessed	12	3–6
	Gland clover	Unprocessed	12	2–4
	French serradella[2]	Seed in pod	20	8–12
	Yellow serradella[2]	Seed in pod	20	8–12
Dormant twin sowing	Biserrula[3]	Unprocessed	15	
	Bladder clover	Unprocessed	15	
	French serradella[2]	Seed in pod	30	
	Yellow serradella[2]	Seed in pod	30	
Delayed dormant twin sowing	Bladder clover	Unprocessed	15	
	French serradella[2]	Seed in pod	30	
	Yellow serradella[2]	Seed in pod	30	
Strategic dry sowing	Arrowleaf clover	Scarified	7	2–4
	Biserrula	Scarified	7	2–4
	Bladder clover	Scarified	10	4–6
	Gland clover	Scarified	7	2–4
	French serradella	Scarified	10	4–6
	Yellow serradella	Scarified	10	4–6
Conventional sowing	Arrowleaf clover	Scarified	7	2–4
	Biserrula	Scarified	7	2–4
	Bladder clover	Scarified	10	4–6
	Gland clover	Scarified	7	2–4
	French serradella	Scarified	10	4–6
	Yellow serradella	Scarified	10	4–6

[1] In some cases, better establishment of biserrula via dormant summer sowing has been achieved using a mixture of 9kg/ha unprocessed seed and 3kg/ha scarified seed especially in regions or seasons where summer rainfall is low.

[2] Ensure cultivars suitable for this method of sowing are used. Refer to Chapter 3 for details.

[3] Biserrula has only been evaluated for dormant twin sowing in NSW. Owing to very small seed size of biserrula, it can easily be buried too deeply in dormant twin sowing operations if adequate care is not taken at sowing or where soil may move and cause deep burial over time.

Chapter 6:
Maximising profit, growth and nitrogen fixation from G_2HSLs

This chapter outlines management decisions after seeding G_2HSLs that maximise nitrogen fixation, growth and the amount of seed-set, particularly in relation to:

- weed control post-sowing, including selective grazing;
- managing pests and diseases; and
- rotations to use fixed nitrogen.

This chapter also provides up-to-date modelling evidence on the profitability of including G_2HSLs in the rotation.

6.1 Profitability

The optimisation of regenerating pastures in low-medium rainfall agriculture involves a range of complex decisions by producers seeking to evaluate the costs and benefits. In these farming systems, cropping is the key profit driver and profit from pasture years is seen indirectly from how they fit in the system, usually enabled by a productive livestock enterprise. However, pasture years also provide value to the cropping enterprise through break crop effects, organic nitrogen supply to subsequent crops and reducing management costs. Bioeconomic and biophysical modelling by Monjardino et al. (2022) revealed the value of G_2HSLs as part of cropping rotations (see also Chapter 9, Figure 9.12; page 79).

Key findings were as follows:

- When established on 30 per cent of the farm, G_2HSLs trebled farm profit relative to continuous cropping rotations, assuming prior five-year average input costs and commodity prices, and a productive livestock system.
- G_2HSLs produced, on average, 50 per cent more profit than subclover pastures (due to higher nutritive value and nitrogen fixation).
- The most profitable novel legume options allowed growers to run up to 20 per cent more sheep on a similar pasture area (30 to 40 per cent) while maintaining cropping on 60 to 70 per cent of the farm.
- Profitability of rotations with pasture phases depended on a range of conditions being met. These conditions included reliable establishment of pastures for every pasture year, early establishment (first germination event) in the first year, reliable regeneration in successive pasture phases with a high proportion of legume, the opportunity for grazing in the establishment year, optimal levels of pasture use by the livestock enterprise and sufficient nitrogen fixation to meet the requirements of one subsequent cereal or canola crop.

Figure 6.1: An example of a weed wiper – a useful tool that can be used in an integrated weed management program. The herbicide is disseminated from a wettable 'blanket' that is set to the height of the target weeds.

Photo: Belinda Hackney

These conditions are all met by the innovative establishment methods developed for the new G$_2$HSLs in this guide.

On fine-textured soils, where it might be possible to carry fixed nitrogen into a second cropping season, farm profit increased by an extra $20/ha in the second crop by replacing fertiliser nitrogen with mineralised legume nitrogen.

6.2 Weed control following sowing

When deciding which G$_2$HSL to grow, it is critical that you consider which selective herbicide options are available in your establishment year should weed issues arise following sowing. It is also critical, if sowing a mixed legume pasture or a pasture containing legumes and non-legumes, that the herbicide compatibilities of the species you intend to sow are understood.

Monitor newly sown pastures regularly and check for weeds that may be emerging. If weed control is needed, it is best undertaken while the weeds are small. Generally, most selective herbicides require the sown species to be of a certain minimum size (often stated as a minimum number of leaves) prior to application. Check herbicide labels carefully for stage of growth requirements for safe application to the legumes you have sown, and for stage of growth where the herbicide is most effective on the target weed. Herbicides need to be registered for use in the pasture that you have sown.

Not all legumes have similar herbicide tolerances. Check herbicide labels and with industry advisers as to whether specific herbicides are safe to use.

There are some other weed management options that can be worth exploring. For example, weed wipers (Figure 6.1) can work well for control of some weeds where the weeds grow higher than the sown pasture. In situations where there is not a distinct difference between the target weed(s) and the legume, grazing prior to use of the weed wiper can reduce the legume height relative to the weed and allow wiping to occur without damaging the pasture. Use of grazing as a tactic prior to wiping needs to consider the relative palatability of the legume compared to the target weed(s).

Remember, it is preferable to reduce the weed seedbank as much as possible prior to sowing a new pasture. Ensure you use high seeding rates, the correct inoculant and that adequate nutrition is available for the establishing pasture.

Herbicides have direct effects on target weeds in the growing season, but they can also have indirect effects through their residues. The application of herbicides to crops can also adversely affect non-target agricultural crops, and legumes are no exception. The authors have gathered evidence of herbicide residues effecting nodulation. This section deals with:

- growing season herbicides;
- herbicide residues – Group 2, clopyralid (Group 4), SUs; and
- observing labels – plant-back period, rainfall requirements, soil moisture requirements for specified periods.

Table 6.1: Herbage biomass (kg DM/ha) in mid-spring for a range on annual legumes sown in May using scarified seed and treated with early post-emergent applied grass-selective herbicides (haloxyfop or clethodim) or one of nine selective broadleaf weed herbicides compared with an unsprayed (nil) control where herbicides were applied when legumes had between three and seven true leaves. Herbicides were applied via vehicle-mounted boomspray where water was applied at 100L/ha.

Product	Rate	Yellow serradella (cv. Avila)	French serradella (cv. Margurita[PBR])	Biserrula (cv. Casbah)	Bladder clover (cv. Bartolo)	Arrowleaf clover (cv. Cefalu)	Gland clover (cv. Prima)	Subclover (cv. Seaton Park)	Burr medic (cv. Cavalier)
		Herbage biomass (kg DM/ha)							
Nil		2192	3600	4752	3216	4624	4752	2960	4496
Haloxyfop (520g/L)	100mL/ha	2320	3216	3984	3088	4368	4752	2832	4112
Clethodim (240g/L)	330mL/ha	2192	3728	4496	3088	4368	5008	2704	4752
Flumetsulam (800g/kg)	25g/ha	2064	3472	400	3088	3984	4752	2320	4112
Imazamox (700g/kg)	50g/ha	1936	3600	3088	1680	2832	4496	2064	2704
Terbutryn (500g/L)	700mL/ha	1936	3344	3984	3088	3984	4496	2064	–
Diflufenican (500g/L)	200mL/ha	–	3088	4496	3088	4240	4624	2832	–
2.4-D (625g/L)	1.7L/ha	1424	2576	–	2192	1424	2576	2192	1296
2.4-DB (500g/L)	3.2L/ha	2576	3472	–	3344	4368	4496	2960	4368
MCPA (750g/L)	960mL/ha	2064	3344	3984	2832	3728	4112	2448	3600
Diflufenican (25g/L) +bromoxynil (250g/L)	1L/ha	–	–	–	2832	3472	4368	2448	–
Difluenican (25g/L) +MCPA (250g/L)	1L/ha	–	–	–	1296	3088	4496	1680	–

■ no significant reduction in herbage production.
■ indicates a statistically significant but acceptable reduction in herbage biomass (<30 per cent).
■ indicates a statistically significant and severe reduction (>30 per cent) in herbage biomass.
– no registration for the species and/or label specifically states product should not be used.
Crosshatched cells – indicate label supports use on a legume-based pasture, however the label does not provide guidance on safety for that species and use is at the user's own risk.

Figure 6.2: The effect of a range of commonly used selective broadleaf weed herbicides on (top to bottom) arrowleaf clover (cv. Cefalu), biserrula (cv. Casbah), bladder clover (cv. Bartolo), gland clover (cv. Prima), French serradella (cv. Fran2o[Φ]) and yellow serradella (cv. SerraMax[Φ]) where the herbicides were applied between three and seven true leaf stage of growth at rates and concentrations reported in Table 6.1. Photos taken four weeks after application.

Photos: Belinda Hackney

6.2.1 Growing season herbicides

Removing grass and broadleaf weeds from legume pastures is common practice whether the pasture is recently sown or regenerating from the seedbank. Studies have been undertaken by the authors to determine the impact a range of commonly used selective herbicides have on the herbage production, nodulation and seed yield of a range of G_2HSLs where the herbicides were applied early in the growing season, when legumes had three to seven true leaves (Tables 6.1, 6.2 and 6.3; pages 50–53).

EFFECTS OF HERBICIDES ON LEGUME BIOMASS

In general, grass-selective herbicides containing the active ingredients haloxyfop or clethodim did not cause a significant reduction in the herbage production of G_2HSLs (the exception was haloxyfop used on biserrula, where there was a statistically significant but acceptable reduction in herbage biomass; Table 6.1).

For herbage production, the tolerance of G_2HSLs to selective broadleaf weed herbicides varied (Table 6.1, Figure 6.2; page 51). For example, all G_2HSLs had good tolerance to flumetsulam (except biserrula), terbutryn, 2,4-DB and MCPA-amine at the rates used in field-tests. The use of 2,4-D caused an unacceptable reduction in herbage biomass for all species. Imazamox was very damaging to arrowleaf and bladder clover, whereas diflufenican and bromoxynil caused unacceptable damage to arrowleaf clover. The use of diflufenican and MCPA caused unacceptable damage to herbage production in all G_2HSLs, apart from gland clover.

EFFECTS OF HERBICIDES ON LEGUME NODULATION

The effect of broadleaf weed herbicide application on nodulation was variable (Table 6.2). Bladder clover nodulation was only adversely impacted by application of diflufenican and MCPA, whereas arrowleaf clover nodulation was adversely impacted by all herbicides except 2,4-D. Of the broadleaf weed herbicides that could legally be applied to biserrula, only imazamox and diflufenican did not impact nodulation. French serradella nodulation was impacted by fewer herbicides than yellow serradella.

EFFECTS OF HERBICIDES ON LEGUME SEED PRODUCTION

Overall, the G_2HSLs generally had good recovery from herbicide application in terms of seed yield. After herbicide application, no significant reductions in seed yield were recorded in French serradella, bladder clover and gland clover (Table 6.3). Arrowleaf clover also exhibited strong recovery from herbicides applied in the field-tests with only 2,4-D causing a significant reduction in seed yield. Biserrula seed yield was only significantly reduced by flumetsulam and imazamox. Imazamox, terbutryn and 2,4-D caused significant seed yield reduction in yellow serradella.

Ultimately, the level of damage to the G_2HSLs that can be tolerated will depend on the intended use of the pasture. For example, if the pasture is to be primarily used for grazing, then herbicides that cause less reduction in herbage production may be required to maximise herbage availability for livestock. If the paddock is to be used for seed production, then a greater reduction in herbage biomass may be acceptable given most

Table 6.2: The effect of a range of grass-selective (haloxyfop and clethodim) or selective broadleaf weed herbicides on the nodulation score of a range of annual legumes. The scoring system of Yates et al. (2016) was used where a score of 4 (20 to 40 nodules of <5mm diameter and/or 3 to 4 nodules >5mm diameter) indicates adequate nodulation. All shaded squares indicate a significant reduction in nodulation compared with the unsprayed control. Legumes were sown using scarified seed in May, herbicides were applied when legumes had between four and seven true leaves and nodulation scoring was undertaken 10 to 12 weeks after sowing. Herbicides were applied via vehicle-mounted boomspray with water applied at 100L/ha.

Product	Rate	Yellow serradella (cv. Avila)	French serradella (cv. Margurita(D))	Biserrula (cv. Casbah)	Bladder clover (cv. Bartolo)	Arrowleaf clover (cv. Cefalu)	Gland clover (cv. Prima)	Subclover (cv. Seaton Park)	Burr medic (cv. Cavalier)
		Herbage biomass (kg DM/ha)							
Nil		3.31	3.33	3.53	3.68	4.31	3.73	5.29	3.97
Haloxyfop (520g/L)	100mL/ha	3.13	3.05	2.80	4.97	3.84	3.35	5.46	3.65
Clethodim (240g/L)	330mL/ha	3.09	3.38	3.04	3.69	3.92	3.33	6.01	3.55
Flumetsulam (800g/kg)	25g/ha	3.29	3.25	1.96	3.73	3.72	3.72	5.98	3.92
Imazamox (700g/kg)	50g/ha	2.87	3.21	3.53	3.50	3.77	3.63	5.44	3.94
Terbutryn (500g/L)	700mL/ha	2.88	3.05	3.03	3.40	3.90	3.37	5.53	–
Diflufenican (500g/L)	200mL/ha	–	3.09	3.60	3.66	3.23	3.30	6.00	–
2.4-D (625g/L)	1.7L/ha	2.37	2.94	–	3.89	4.09	3.82	5.80	3.98
2.4-DB (500g/L)	3.2L/ha	3.26	3.21	–	3.58	3.83	3.98	6.05	3.64
MCPA (750g/L)	960mL/ha	2.77	3.00	2.90	3.40	3.36	3.73	5.44	3.16
Diflufenican (25g/L) +bromoxynil (250g/L)	1L/ha	–	–	–	3.56	3.44	3.56	5.22	–
Difluenican (25g/L) +MCPA (250g/L)	1L/ha	–	–	–	3.31	3.47	3.30	5.41	–

■ no significant reduction in legume nodulation.
■ indicates a statistically significant reduction in legume nodulation.
– no registration for the species and/or label specifically states product should not be used.
Crosshatched cells – indicate label supports use on a legume-based pasture, however the label does not provide guidance on safety for that species and use is at the user's own risk.
Results apply to the cultivar of the species tested and like any crop or pasture species there can be cultivar variation in response to herbicide application.

species showed excellent recovery in terms of seed yield from the majority of herbicides applied. A primary purpose for using legumes in farming systems is to build soil nitrogen and therefore consideration should be given to the impact herbicide use may have on legume nodulation. When considering growing a pasture containing multiple legumes, choosing species that have at least some compatibility in herbicide tolerance should be considered for ease of management and to maximise herbage production, nodulation and seed yield of the sward.

6.2.2 Herbicide mixtures

It is common practice to apply a combination of herbicides in a single pass for the purposes of controlling problem weeds. Applying mixtures of herbicides can increase the spectrum of weeds controlled and/or the combination of herbicides may have a synergistic impact on the control of particular target weeds. When contemplating use of herbicide mixtures, it is critical to consider whether their application may have undesirable impacts on the non-target crop or pasture over and above where the herbicides may be applied singularly. It is also important to consider whether a combination of herbicide products is covered by registration and whether the herbicides are compatible when mixed together. Therefore, the labels of any individual herbicides intended to be used in a mixture should be read thoroughly. Where growers are unsure of potential impacts of application of mixtures to G_2HSLs, they should seek professional advice.

6.2.3 Residual effects of herbicides and plant-back periods

Sulfonylurea (acetolactate synthase; ALS), pyroxasulfone, triasulfuron and clopyralid are pre and post-emergent herbicides that are commonly applied to crops and that possess residual soil activity. Through residual action, these herbicides may continue to control weeds, but they can also have unintended consequences on legume crops and pastures. Sulfonylurea and clopyralid also have registration for use in pastures, but they are very damaging to legumes. Pasture legumes most commonly encounter the residual effects of sulfonylurea and clopyralid when they are sown after a cropping phase.

The effect of some residual herbicides on legume nodulation was examined in field-tests in WA where the herbicides had been applied in the previous year (Table 6.4). Plots that had been treated with clopyralid had lower nodulation than the control plots for all cultivars planted. Chlorsulfuron-treated plots were significantly lower in nodule counts for all cultivars apart from Prima. Where pyroxasulfone was applied, the nodule count was significantly lower for Casbah, whereas triasulfuron produced a lower nodule count for Dalkeith, Casbah and Prima than for unsprayed treatments.

Table 6.3: The effect of a range of grass-selective (haloxyfop and clethodim) or selective broadleaf weed herbicides on seed yield (expressed as a percentage of the unsprayed (nil) control) for a range of G_2HSLs established using scarified seed sown in May. Herbicides were applied when plants had four to seven true leaves using a water rate of 100L/ha. Shaded cells indicate a significant reduction in seed yield. Herbicides were applied via vehicle-mounted boomspray.

Product	Rate	Yellow serradella (Avila)	French serradella (Margurita)	Biserrula (Casbah)	Bladder clover (Bartolo)	Arrowleaf clover (Cefalu)	Gland clover (Prima)
		Herbage biomass (kg DM/ha)					
Nil		100	100	100	100	100	100
Haloxyfop (520g/L)	100mL/ha	85	100	93	100	100	100
Clethodim (240g/L)	330mL/ha	92	108	100	108	100	82
Flumetsulam (800g/kg)	25g/ha	92	100	21	108	100	100
Imazamox (700g/kg)	50g/ha	69	100	71	83	83	118
Terbutryn (500g/L)	700mL/ha	69	83	86	100	100	100
Diflufenican (500g/L)	200mL/ha	–	100	86	100	100	82
2, 4-D (625g/L)	1.7L/ha	62	92	–	83	67	82
2, 4-DB (500g/L)	3.2L/ha	92	100	–	100	100	109
MCPA (750g/L)	960mL/ha	92	92	93	108	100	118
Diflufenican (25g/L) +bromoxynil (250g/L)	1L/ha	–	–	–	83	100	109
Diflufenican (25g/L) +MCPA (250g/L)	1L/ha	–	–	–	92	83	82

■ no significant reduction in seed yield.
■ indicates a statistically significant reduction in herbage biomass.
– no registration for the species and/or label specifically states product should not be used.
Crosshatched cells – indicate label supports use on a legume-based pasture, however, the label does not provide guidance on safety for that species and use is at the user's own risk.
Results apply to the cultivar of the species tested and like any crop or pasture species there can be cultivar variation in response to herbicide application.

Table 6.4: The effect of several residual herbicides on the nodulation of a range of G_2HSLs and subterranean clover when the legumes were sown in May and the herbicides had been applied to a cereal in July (of the previous year).

	Biserrula (cv. Casbah)	Bladder clover (cv. Bartolo)	Gland clover (cv. Prima)	French serradella (cv. Margurita[PBR])	Subterranean clover (cv. Dalkeith)
Chlorsulfuron	red	red	green	red	red
Triasulfuron	red	green	red	green	red
Clopyralid	red	red	red	red	red
Pyroxasulfone	red	green	green	green	green

green: no significant reduction in nodulation.
red: indicates a statistically significant reduction in nodulation.
Results apply to the cultivar of the species tested and like any crop or pasture species there can be cultivar variation in response to herbicide application.

When intact cores were sampled over time, the herbicides were shown to have residual effects for up to 10 months in glasshouse studies, and consistently produced lower nodule numbers for up to 12 months after application in the paddock (Figure 6.3). Clopyralid was particularly damaging, reducing the number of subterranean clover nodules by at least 80 per cent after four and seven months, and by 50 per cent after 10 months. Chlorsulfuron and triasulfuron were less damaging but caused as much as 60 per cent reduction in nodule number. Pyroxasulfone caused less damage to subterranean clover, but effects were seen towards the end of the growing season.

In a related experiment, triasulfuron significantly decreased nodulation in subclover in comparison to the control at a concentration of 0.000225 gram of active ingredient per hectare (gai/ha) (Figure 6.4).

The data highlights the need for growers to adhere to plant-back recommendations. Carefully read herbicide labels as the requirements for herbicide breakdown can be complex and can include, but are not limited to, factors such as time elapsed since application, rainfall received and its timing since application, specific requirements for maintenance of soil moisture levels for specified periods of time, soil texture and organic matter levels, soil pH and the initial herbicide application rate. All the plant-back requirements for a specific herbicide must be followed to reduce the probability of unintended damage to legumes.

Although usually accurate for the health of the plant above the ground, the plant-back recommendations do not seem to consider damage to the root system, particularly nodulation on legumes. Biserrula is particularly sensitive to herbicide applications, with all residual herbicides evaluated significantly reducing nodulation and biomass production in comparison to the unsprayed control.

If the opening growing season rains are delayed (for example, from mid-April to mid-May), applied chemicals can have prolonged residual effects. Further, dry and/or cool conditions reduce microbial degradation of herbicides (that is, a longer period of residual activity), whereas warm and moist conditions will increase this microbial activity (that is, a shorter period of residual activity).

6.2.4 Controlling weeds by grazing

Grazing offers the opportunity to control weeds through consumption by livestock. The degree to which livestock will graze certain weeds depends on factors including the nutritional requirements of the animals, the differences in relative palatability between the weeds and legumes, and the stocking rate. Higher stocking rates reduce the capacity for livestock to graze selectively, which may increase weed consumption. For example, biserrula (especially the cultivar Casbah) is not highly palatable to grazing animals, although it has high feeding value. When introduced to

Figure 6.3: The residual effect of a range of herbicides applied the year prior on the above-ground biomass of clover at 28 days of growth where intact soil cores were extracted from the paddock in summer and transferred to the glasshouse for sowing and germination.

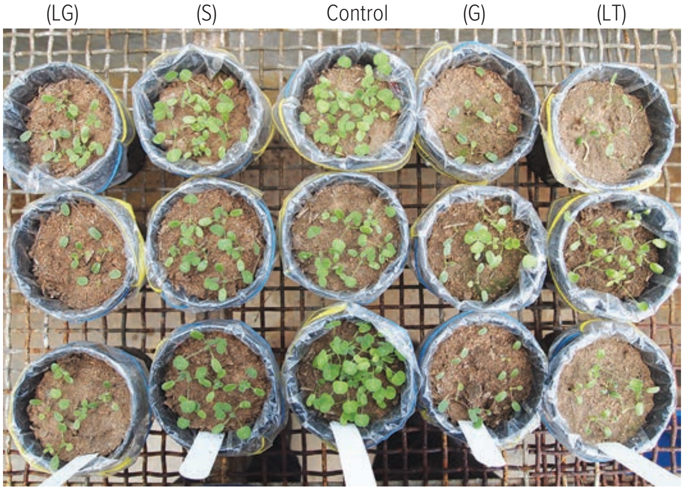
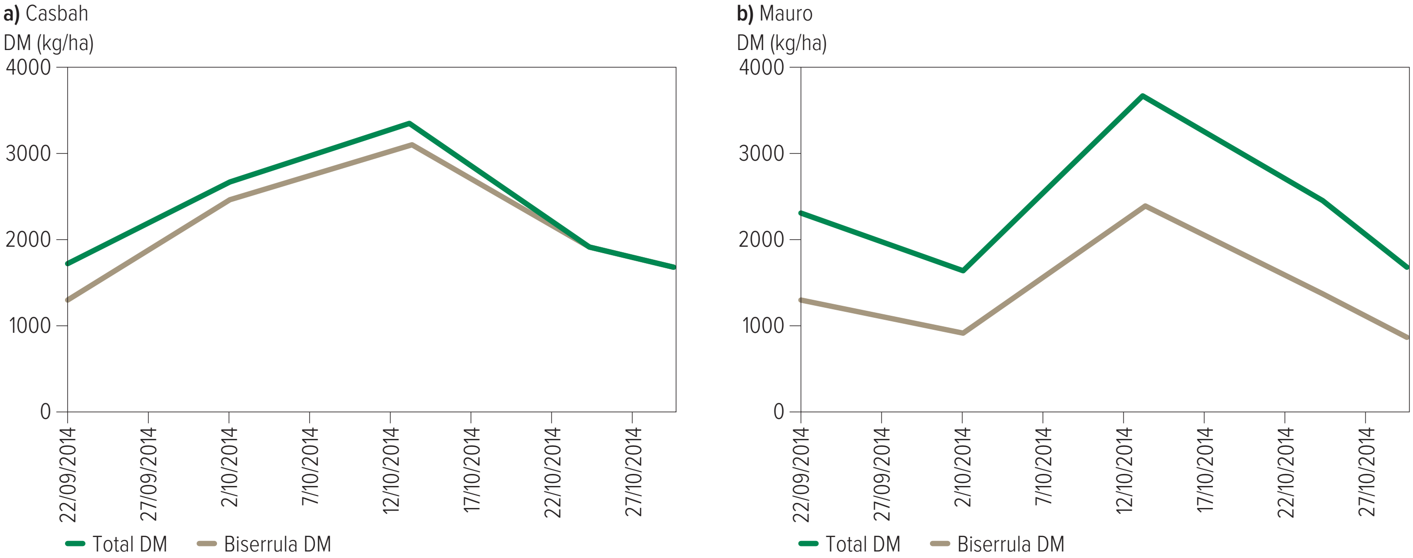


Photo: Ron Yates, DAFWA

Figure 6.4: *T. subterraneum* (cv. Dalkeith) grown for 25 days in the presence of triasulfuron applied to soil at different concentrations. Note that even at the lowest level of residue, no nodules are present on the plant.

Photo: Ron Yates, DAFWA

Figure 6.5: The herbage availability of biserrula (Casbah versus Mauro) and annual ryegrass when sheep were introduced to established pasture in late September up until their removal in late October 2014 at Wagga Wagga NSW.



Source: Howieson and Hackney (2017)

biserrula pasture, livestock will tend to graze weeds in preference to the biserrula. Problem weeds such as annual ryegrass can be effectively reduced in density within such pastures. Exploiting livestock selective preferences such as this can assist in preserving the useful life of grass-selective herbicides. It is important to be aware that differences exist in palatability of the biserrula cultivars (Figure 6.5). Studies at Wagga Wagga in NSW found that grazing was a very effective method to remove annual ryegrass from the cultivar Casbah, but not necessarily from the cultivar Mauro. Therefore, it is important to know which cultivar you are growing for this method of weed control to be effective.

6.2.5 Using grazing and herbicides

For arrowleaf clover and gland clover, options also exist for integrating grazing and herbicide applications to increase weed consumption. For example, spray grazing may be possible for smaller paddocks where sufficient livestock, preferably sheep (as cattle cannot graze low enough to be effective), can be used to intensively graze a pasture that has been treated with a sublethal dose of a phenoxy herbicide such as MCPA seven days prior. The phenoxy herbicide increases the palatability and accessibility (by causing the leaves to stand up) of weeds such as capeweed, Paterson's curse and some thistles. Stock are grazed at intensities 10 to 20 times higher than usual for a short duration, causing damage to the growing points of the weeds. Care needs to be taken as to which legumes this technique is applied to. Additionally, consider potential adverse animal health implications ensuring observation of all herbicide label grazing withholding periods for the spray-graze technique. It is generally preferable to use older animals in spray grazing operations and to ensure that high stocking rates minimise per head intake of weeds. Some weeds, such as thistles, when consumed in excess, may cause nitrate poisoning.

6.3 Making a profit from grazing G_2HSLs

An integral component of ensuring profitability from the inclusion of G_2HSLs in the farming system is capacity to graze in the establishment year. The potential for profitability in grazing systems arises from:

- Using dormant summer sowing and the other alternative establishment strategies outlined in the previous chapter, to increase biomass for grazing in the establishment year.
- Due to their higher plant nutritive value, the G_2HSLs offer improved animal nutrition. An increase in dry matter digestibility of 5 per cent is equivalent to an increase in pasture biomass production of about 1000kg/ha (Thomas et al., 2021).

In contrast, it is very unlikely that pastures established via conventional sowing will produce sufficient green herbage to consider grazing (due to late establishment) in the establishment year. Grazing of conventionally sown pastures in the establishment year is likely to result in poor seed production. Thus, pastures established via conventional sowing are generally best left ungrazed during the establishment year, unless there is a protracted wet spring.

6.4 Seasonal grazing management of G_2HSLs

The main objective of the establishment year for newly sown G_2HSLs (or any pasture legume) is to establish a large, robust seedbank.

6.4.1 Grazing following out-of-season sowing

For pastures established via dormant summer sowing, strategic dry sowing, previous year dormant twin or delayed dormant twin sowing, seasonal conditions will dictate whether grazing in the establishment year is a feasible option. In above-average rainfall conditions and where the autumn break occurs early, pastures established by these four methods can often be carrying very high levels of biomass by late winter and early spring (sometimes >4t DM/ha). Under such circumstances, grazing can be beneficial to reduce biomass load and increase seed production potential. This can be particularly important for species such as biserrula, which can be very susceptible to Botrytis (grey mould) when the canopy is dense in late winter and early spring and where rainfall continues to be high through spring.

However, in below-average rainfall years or years where the autumn break occurs late, it is generally advisable to minimise grazing to optimise seed production.

6.4.2 Grazing and seed production

Optimising seed production in the establishment year is the key to establishing a robust seedbank for future regeneration of G_2HSLs. If management has been optimised during the growing season, and a strong dense pasture has been achieved, some decisions might need to be made towards the end of the season regarding how to maximise seed-set.

This primarily revolves around strategic grazing to manage canopy loads. If left under-grazed, a well-grown G_2HSL is at risk of growing too tall and then lodging, or becoming too moist and consequently rotting, creating a haven for insects and, in some cases, disease. Under these circumstances, seed production (and harvesting) can be problematic. Alternatively, if spring rains are sparse, then using too much moisture in the growth phase through accumulation of abundant biomass can leave insufficient soil moisture for seed-set. Under these circumstances, the seed yield is reduced.

Expert seed producers endeavour to keep relatively dense pastures at a height of approximately 15cm through until early spring, then lower the grazing pressure to allow seed heads to form and mature.

Studies were undertaken on four farms (six sites) in the Katanning, Mingenew and Kojonup areas of WA in yellow serradella pastures to determine the effect of defoliation severity and timing on seed yields (Table 6.5). Swards were defoliated to heights of 3 or 6 cm above ground using a mower every three to four weeks from 6 weeks after the autumn break. Defoliating to 3 cm left approximately 300 kg residual DM/ha while defoliating to 6 cm left approximately 700 kg residual DM/ha. Defoliation ceased either three weeks prior to the commencement of flowering, at the commencement of flowering or three weeks after the commencement of flowering. For all treatments, the quantity of herbage present three weeks post flowering was measured. Across six sites, defoliation three weeks prior to flowering to 3 or 6cm had no significant effect on seed production, but seed production was reduced when the more severe defoliation occurred at flowering. Defoliation three weeks after grazing reduced seed production to less than 50kg/ha. Approximately 80 per cent of the variation in serradella seed production between sites and grazing treatments was explained by herbage present at the end of flowering. Minimal serradella seed was produced when herbage at the end of flowering was 1000kg DM/ ha or less, but at higher herbage levels seed production increased by about 250kg/ha for each additional 1000kg DM/ha.

Further studies in NSW (Figure 6.6) have investigated the relationship between residual herbage mass left after grazing in spring with the regeneration of various G_2HSLs in the following autumn. Biserrula was able to be grazed to lower levels (800kg DM/ha) than both French serradella or bladder clover (1600kg DM/ha) in spring and still meet the benchmark set in that experiment for regeneration in the following autumn (500 seedlings/m^2). Similarly, an additional study investigating the effect of use of residual biomass of biserrula over summer found that it could similarly be grazed to about 800kg DM/ha and still have sufficient seedbank resources to meet minimum experimental benchmarks for regeneration in the following year.

In general, all species showed increasing seedling density in the following autumn where higher residual spring had been retained.

Ultimately, the decision on grazing intensity will involve consideration of the growth stage of the plant at grazing, its maturity pattern and its capacity for recovery and seed-set following grazing. For example, early maturing species such as gland clover and bladder clover will have reduced capacity for recovery and seed-set compared to a later maturing species if grazed after they commence reproductive growth in spring. In contrast, indeterminate species such as biserrula and French serradella will have greater capacity for post-grazing recovery as flowering can be protracted through spring into summer.

In general, in the establishment year, it is advisable to adopt a more conservative approach to grazing intensity and aim to achieve establishment of a seedbank of >200kg/ha, which for most G_2HSLs will be achieved if the sward is managed to have a minimum biomass of 1800 to 2000kg DM/ha in late spring. Once a seedbank is established, more intense grazing practices can be adopted.

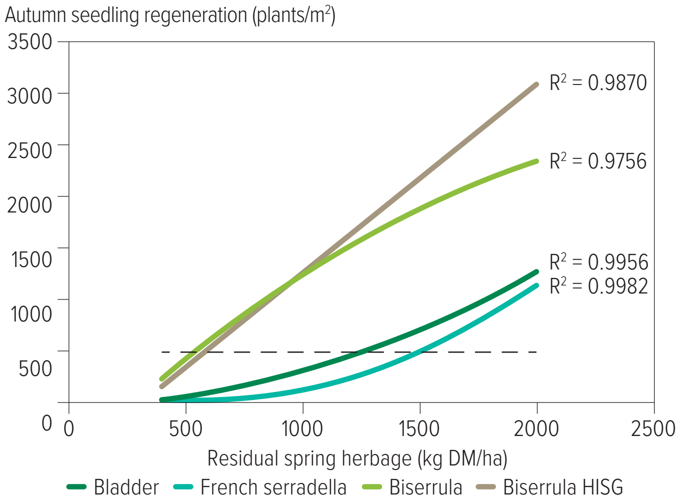
Table 6.5: The effect of defoliating yellow serradella swards to heights of 3 cm or 6 cm from six weeks after the break of season three (3) weeks pre-flowering, flowering or three weeks post-flowering on herbage available (kg DM/ha) three weeks post flowering and seed production (kg/ha).

Defoliation height above ground (cm)	Defoliation cessation timing	Herbage available three weeks post flowering (kg DM/ha)	Seed production (kg/ha)[1]
Control (uncut)		2830	529[a]
3cm	3 weeks pre-flowering	2290	565[a]
	until flowering	1480	296[b]
	3 weeks post-flowering	1170	45[c]
6cm	3 weeks pre-flowering	2560	457[a]
	until flowering	2400	549[a]
	3 weeks post-flowering	1390	53[c]

[1]Only the effect of defoliation height was found to be significant in affecting seed yield with numbers followed by the same letter within this column not significantly different from each other.

Source: Yates et al. (2022)

Figure 6.6: The relationship between residual spring herbage mass (kg DM/ha) and following autumn seedling regeneration for bladder clover, French serradella and biserrula at sites in NSW. For biserrula, the study included a treatment where biserrula was grazed at high intensity over the summer period (HISG).



* Note: The dashed line indicates the minimum target for autumn seedling regeneration for development of a robust pasture.

Source: Howieson and Hackney (2017)

6.4.3 Consumption of residues

Consumption of residues (including mature seed) needs to be managed more carefully for some G_2HSLs compared to others. Some species are more likely to be eaten, depending on the ability of sheep to find and take up the seed head or pod. After consumption, a general rule is that the larger the seed, the more likely a sheep will masticate it and remove it from the seedbank. Table 6.6, generated from animal house feeding experiments with full faecal collection Figure 6.7, gives information about the rates of seed passage assuming that sheep can scavenge all the seeds. The seed of small-seeded species such as biserrula (about 1.3mg) can be consumed by sheep with 88 per cent remaining viable post-ingestion. Other small-seeded species such as arrowleaf clover and gland clover have high rates of passage as the seeds are difficult to chew. For the large-seeded species, only 20 per cent of subclover and 40 per cent of medic seeds pass through sheep after consumption. Bladder clover has 43 per cent passage through sheep and French serradella ranges from 16 to 28 per cent passage. There are some exceptions to the seed size and passage rule, with yellow serradella seeds held tightly in woody pods, which leads to higher rates of mastication than would be predicted by seed size alone (8 to 14 per cent pass through intact into faeces).

Hard seededness at maturity is another factor to consider as small seeds that are soft may avoid mastication, but will imbibe (absorb moisture and start to germinate) in the gut and are therefore unlikely to survive passage. This is evidenced by the higher rates of hard-seededness in seeds recovered from faeces than the hard-seededness of the seed that was fed to sheep (Table 6.6).

Seed has a much higher energy content than the pod structures and senesced plant material. Although high rates of passage are beneficial for the seedbank, it comes at a cost of valuable nutrients for livestock production during summer.

Figure 6.7: A pellet of sheep manure containing undigested biserrula seed. Note, seed in faeces tends to be very hard-seeded so this seed may not soften in time for germination in the next season.

Photo: Belinda Hackney

Consideration must also be given to management of summer residues from the perspective of ensuring seed:soil contact. It is important that the seeds or pods have contact with the soil for the hard seed breakdown process to begin, so grazing (or mulching if grazing is not possible) is recommended.

Table 6.6: Seed size, proportion that pass through sheep intact after consumption and hard-seededness as fed and as recovered from faeces.

		Seed mass	Seed passage after consumption	Seed dormancy (hard-seed)	
Species	Cultivar	(mg)	(%)	As fed (%)	In faeces (%)
Biserrula	Casbah	1.3	88	99	98
Rose clover	SARDI Rose	3.5	41	23	97
Bladder clover	Bartolo	2.7	43	96	98
Subclover	Dalkeith	4.7	20	11	83
Medic	Cavalier	3.6	40	96	98
	Toreador	2.0	43	42	91
Messina	Neptune	7.2	25	61	87
Yellow serradella	Avila	2.1	14	42	87
	Santorini	2.4	8	91	81
French serradella	Margurita⍉	2.3	28	79	84
	Cadiz	2.1	23	84	84
	$Fran_2o$⍉	2.3	16	80	83
Trigonella	$Carn_2ac$	2.0	27	94	93

Data collected in an experiment where seeds in pods or heads were added to a ration and fed to sheep in metabolism crates.

Source: Norman unpublished

Figure 6.8: Native budworm larvae (*Helicoverpa* spp.) can be a serious pest of French serradella causing significant reductions in seed production (left). The photo on the right shows French serradella pod segments that have been attacked by budworm larvae.

Photos: Belinda Hackney

6.5 Pests of G_2HSLs

Pests can be problematic in the establishment and ongoing production of G_2HSLs. Redlegged earth mites will affect all G_2HSLs except gland clover and high numbers can cause serious damage in autumn. Byrobia mite, blue oat mite, aphids and native budworm (Figure 6.8) are other pests that can cause damage to some of the legumes (Table 6.7).

For mites, undertaking strategic control practices to reduce egg laying in the years leading up to pasture sowing can be an effective strategy to reduce the impact of these pests on susceptible newly established legumes. Mites tend to be most damaging to legumes early in establishment (cotyledon stage). Aphids tend to cause damage to susceptible species later in the growing season. Native budworm, to which French serradella is susceptible, can cause extensive damage to seed pods and a reduction in seed production.

Gland clover is resistant to all pasture pests. Gland clover contains a small amount of coumarin, which is an insect deterrent.

It is good practice to monitor newly sown or re-emerging legumes for pest damage and undertake management actions for control, if needed. The key objective of the establishment year is to optimise seed production to establish a large, resilient seedbank for future regeneration. It is critical to ensure pests do not impact on this objective.

6.6 Diseases of G_2HSLs

G_2HSLs have good tolerance to diseases that in the past have affected legume-based pastures (Table 6.8). Generally, if G_2HSLs are grown in soils to which they are suited, few diseases are observed. As an example, arrowleaf clover can be affected by Phytopthora root rot but this has only been observed when growing in poorly drained soils to which it is not suited.

Table 6.7: The susceptibility of G_2HSLs to a range of pests.

	Redlegged earth mite[1]	Byrobia mite[1]	Blue oat mite[1]	Blue-green aphid	Cowpea aphid	Spotted alfalfa aphid	Lucerne flea	Thrips	Native budworm
Arrowleaf clover	Highly susceptible	Highly susceptible	Highly susceptible	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant
Biserrula	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Highly susceptible	Highly susceptible	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant
Bladder clover	Highly susceptible	Highly susceptible	Highly susceptible	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant
Gland clover	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Moderately susceptible	Moderately susceptible	Tolerant or resistant	Tolerant or resistant
French serradella	Highly susceptible	Highly susceptible	Moderately susceptible	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Moderately susceptible	Highly susceptible	Highly susceptible
Yellow serradella	Highly susceptible	Highly susceptible	Highly susceptible	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Moderately susceptible	Moderately susceptible
Trigonella	Tolerant or resistant	Tolerant or resistant	Moderately susceptible	Moderately susceptible	Moderately susceptible	Moderately susceptible	Highly susceptible	Moderately susceptible	Tolerant or resistant
Subterranean clover	Highly susceptible	Highly susceptible	Highly susceptible	Highly susceptible	Highly susceptible	Moderately susceptible	Tolerant or resistant	Highly susceptible	Tolerant or resistant

Tolerant or resistant. Moderately susceptible. Highly susceptible.

[1] Plants are most susceptible to attack at the cotyledon stage of development.

[2] Some subterranean clover cultivars have been bred to provide resistance against insect pests; however, the average for the species is assessed here.

Botrytis can be a serious disease in biserrula but it generally only occurs in stands with extremely dense canopies where pasture is not well used and where airflow is poor (Figure 6.9). Botrytis is rarely observed in pastures that are grazed and not allowed to grow unchecked. If Botrytis is anticipated in an under utilised biserrula pasture, take steps to reduce available biomass via grazing if possible. Otherwise, fungal sprays or mowing can be effective as a preventive action.

6.7 Making a profit from fixed nitrogen via rotational cropping

A well-nodulated and successfully managed G_2HSL pasture will fix approximately 20 to 30 units of nitrogen for every tonne of above-ground biomass. Typically, G_2HSLs grown as monocultures will produce 4 to 12t DM/ha/year depending on growing conditions. This means they can contribute 80 to 300kg N/ha via nitrogen fixation to the soil. About 30 to 50 per cent of this nitrogen can become available for the next growing season, with the remainder available over the following two growing seasons. Under optimal conditions for legume production (the right legume, good weed control, good nutrition, appropriate grazing intensity, good rainfall, low pest and disease pressure), this nitrogen is sufficient to support a following non-legume crop without the addition of nitrogen fertiliser. In this way, the profits from G_2HSLs are manifested. Further, the fixed nitrogen must be exploited, otherwise the resource will lead to an incursion of weeds. Rotational options to use fixed nitrogen are discussed in the following chapter.

Where growers want to use the paddock for livestock grazing over several years, or where regeneration in year two is known to be reliable (for example, NSW), consider sod seeding a cereal or ryegrass into the paddock in the year following establishment to assist in using the fixed nitrogen. This strategy will also be beneficial to livestock production with the higher metabolisable energy of the cereal or grass balancing the high protein content of the legume.

However, where G_2HSLs are to be used in rotations, it is important to use the fixed nitrogen in a productive way. Without consideration of nitrogen use, weed invasion can rapidly become problematic.

Figure 6.9: Botrytis can be a problem in biserrula swards that are allowed to become overgrown and it can rapidly reduce herbage yield and seed production.

Photo: Belinda Hackney

Table 6.8: The tolerance of G_2HSLs to a range of diseases.

	Clover scorch	Phytopthora root rot	Rhizoctonia root rot	Bean yellow mosaic virus	Botrytis	Pseudopeziza leaf spot	Brown leaf spot	Anthracnose
Arrowleaf clover	Tolerant or resistant	Moderately susceptible	Tolerant or resistant	Moderately susceptible	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant
Biserrula	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Highly susceptible *	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant
Bladder clover	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Moderately susceptible	Tolerant or resistant	Tolerant or resistant
Gland clover	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant
French serradella	Tolerant or resistant	Tolerant or resistant	Moderately susceptible	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Moderately susceptible	Tolerant or resistant
Yellow serradella	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Moderately susceptible	Tolerant or resistant	Moderately susceptible	Moderately susceptible
Trigonella	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Tolerant or resistant	Moderately susceptible	Tolerant or resistant	Moderately susceptible	Moderately susceptible
Subterranean clover	Moderately susceptible	Highly susceptible	Highly susceptible	Moderately susceptible	Moderately susceptible	Moderately susceptible	Moderately susceptible	Tolerant or resistant

■ Tolerant or resistant. ■ Moderately susceptible. ■ Highly susceptible.

There can be variation in disease susceptibility between cultivars of a given species.

* Botrytis is generally only a problem in under utilised pastures that are permitted to grow unchecked through winter and spring.

Chapter 7:
Rotation options following first year's seed-set

The G_2HSLs discussed in this guide offer great flexibility within pasture–crop rotations. Many produce high levels of hard seed, meaning there is capacity (once a seedbank has been established) to crop over them and have the legumes regenerate after the cropping phase without the need for resowing. This provides flexibility in terms of making decisions on the rotation sequence based on predicted weather conditions or commodity prices. Once a seedbank is established, the legumes can be used in an 'on-demand' way to regenerate whenever a crop is not in the paddock. Such a system allows growers to rapidly alter their crop-to-pasture ratio and therefore crop-to-livestock ratios on-farm.

7.1 Understanding hard seed and hard seed breakdown patterns

The G_2HSLs discussed in this guide generally have hard seed levels in excess of 90 per cent at the end of their first growing season. The proportion of hard seed that breaks down over summer and autumn depends on the effects of temperature and moisture over that time as well as specific cultivar hard seed characteristics. As an example, Avila yellow serradella typically has a much lower hard seed content in late autumn (50 to 60 per cent) compared to Santorini (70 to 90 per cent). Additionally, research has shown that hard seed breakdown varies considerably between western and eastern Australia (Table 7.1), which is attributable to differences in temperature and rainfall characteristics and the capacity of soil to hold moisture.

In terms of suitability for use in on-demand rotations, it is advisable to choose species and cultivars that retain a higher proportion of hard seed where longer cropping rotations are used. Generally, biserrula and yellow serradella cultivars such as Santorini, Yelbini$^{\phi}$ and Charano can be successfully used in rotations where crops may be grown for three or more years following initial seed-set. Arrowleaf clover, bladder clover, gland clover and the hard-seeded French serradella cultivars (Margurita$^{\phi}$ and Fran$_2$o$^{\phi}$) are generally better suited to one year pasture, one year crop (1:1) rotations. Once a legume seedbank has been allowed to seed down multiple times, these species may tolerate longer cropping phases.

Due to their ability for high nitrogen input, it is advisable to crop over the G_2HSLs in the second season. Cropping the paddock uses the nitrogen and allows time for the hard seed to breakdown in readiness to regenerate the following year. For some species such as biserrula and some cultivars of yellow serradella (for example, Santorini, Yelbini$^{\phi}$, Charano), regeneration is generally poor in the year following sowing (Year 2), and cropping in that year leads to good regeneration in Year 3. This is particularly relevant in WA where hard seed breakdown is slow.

7.2 Flexible rotations

A key benefit of G_2HSLs is the ability to establish flexible pasture–crop rotations with the hard-seeded legumes capable of operating in an on-demand role once the seedbank is established. This means that growers can alter the crop-to-pasture ratio of their farm quickly in response to climatic or commodity prices and therefore also quickly alter crop-to-livestock ratios.

If a poor rainfall year is predicted with a high risk of a reduction in crop yield, then where a hard-seeded legume seedbank exists the grower can make the choice to pull out of cropping for the year and allow the pasture to regenerate. As an example, in the poor rainfall years of 2017–2020 in NSW, G_2HSL pastures produced an average of 4t DM/ha, which was used as a grazing resource for livestock and contributed nitrogen for the following crop. As a comparison, in those years, subterranean clover and medic typically produced less than 750kg DM/ha.

In addition to growing G_2HSLs as a resource of nitrogen and grazed fodder, growers are also capitalising on the productive potential of G_2HSLs by using them for fodder conservation, as silage or hay. This can help with weed control strategies. Additionally, many growers will sod seed oats or ryegrass into a

Table 7.1: Typical hard seed levels (%) immediately following seed set (initial) and in late autumn in Western Australia and New South Wales.

	Initial hard seed	Late autumn hard seed – Western Australia	Late autumn hard seed – NSW
Arrowleaf clover	>90	20–40	40–60
Biserrula	>95	85–95	60–80
Bladder clover	>90	40–60	40–60
French serradella[1]	>90	40–60	30–60
Gland clover	>90	40–60	40–60
Yellow serradella	>90	50–80	50–80
Trigonella	>90	30–50	30–50

[1] For hard-seeded French serradella cultivars Margurita$^{\phi}$ and Fran$_2$o$^{\phi}$. Note soft-seeded cultivars Cadiz and Eliza contain no hard seed.

paddock with an existing hard-seeded legume seedbank in late summer or early autumn. The addition of a cereal or grass to the legume provides a better balance of energy (cereal or grass) and protein (legume) for livestock. Growers then use such paddocks for direct grazing or fodder conservation.

7.3 Using the nitrogen fixed in pasture years in cropping rotations

Nitrogen fertiliser is the highest input cost in most cropping systems in southern Australia and its pricing can be highly volatile. Further, it contributes to >50 per cent of the carbon footprint in cropping. Several experiments have shown that when wheat is grown after G_2HSLs, there can be a significant reduction in the requirements for nitrogen fertiliser to support grain production.

Research in WA (Table 7.2) across several sites and growing seasons has shown wheat grown after G_2HSLs attains the same yield with no nitrogen application compared to where up to 92kg N/ha was applied to the wheat crop. At two sites, there was an increase in grain protein in response to nitrogen fertiliser but the increase would not have resulted in a change to wheat grading. Further, recent data from WA has found that no matter how much nitrogen fertiliser is administered, the continuous cereal rotation consistently produced lower wheat proteins than when pasture legumes were in rotation (up to four years) (Harrison et al. 2023).

In NSW, experiments have also been undertaken to test the yield response of cereal crops to nitrogen application when grown after G_2HSLs (Table 7.3, Figure 7.1). At a site near Ungarie in 2019, a range of G_2HSLs were grown under severe drought conditions. Subterranean clover was also grown as a control, with a continuous cropping treatment also included. In 2020, wheat was sown over the site with a range of nitrogen fertiliser rates applied (Figure 7.1). For the G_2HSLs, grain yields of 3.8 to 4.5t/ha were recorded without addition of nitrogen fertiliser with no response found from application of nitrogen up to 150kg N/ha over the growing season. In contrast, both the wheat grown after the subterranean clover and wheat in the continuous cropping treatment showed significant increases in grain yield with application of nitrogen. Grain protein similarly showed no response to nitrogen application when grown after the G_2HSLs, but significant responses were recorded in the subterranean clover and continuous cropping treatments.

In NSW, a similar experiment was undertaken over the 2020 and 2021 growing seasons where rainfall in both years was well above average (Figure 7.2). Again, the wheat grown as part of the continuous cropping treatment or after subterranean clover showed incremental increases in yield in response to application of nitrogen fertiliser whereas for wheat grown after either arrowleaf clover or biserrula, there was no significant difference in yield in response to nitrogen application.

The results of the WA and NSW experiments indicate that G_2HSLs in the crop rotation have the potential to significantly reduce nitrogen fertiliser requirements for subsequent crops without compromising yield. Decisions regarding nitrogen fertiliser application need to consider the growth (and associated nitrogen fixation) of the legume in the year preceding the crop and therefore the likely nitrogen carryover, seasonal growing conditions and potential crop yields as well as grain protein targets.

Table 7.2: Wheat grain yield (t/ha) and protein (%) when grown after one year of a range of G_2HSLs in the year preceding the wheat crop. Nitrogen fertiliser (t N/ha) was applied to the wheat crop at rates shown.

Legume	Location	Year	Nil N		46kg N/ha		92kg N/ha	
			Wheat yield (t/ha)	Wheat protein (%)	Wheat yield (t/ha)	Wheat protein (%)	Wheat yield (t/ha)	Wheat protein (%)
French serradella	Brookton	2013	5.0	9.6	4.7	10.3	4.8	10.3
French serradella	Cascade	2013	4.3	11.2	4.4	12.8	4.2	13.3
Bladder clover	Babakin	2015	2.3	11.0	2.0	13.5	1.9	16.2
Biserrula	Chapman Valley	2016	5.1	10.1	4.7	11.2	5.1	11.2
Biserrula	Ardath	2019	3.4	13.9	2.9	13.8	2.8	15.9

Source: Loi et al. (2022)

Table 7.3: The grain yield (t/ha) and protein content (%) for wheat grown as part of a continuous cropping treatment, after subterranean clover or after a range of G_2HSLs where nitrogen fertiliser was either withheld (nil) or applied at 15kg N/ha at sowing, or at sowing and again at growth stage 31 and 51 (total nitrogen application 150kg/ha) at a site near Ungarie in 2020.

Legume	Nil N		N at sowing only (15kg N/ha)		N at sowing plus top-dressed (150kg N/ha)	
	Wheat yield (t/ha)	Wheat protein (%)	Wheat yield (t/ha)	Wheat protein (%)	Wheat yield (t/ha)	Wheat protein (%)
Continuous crop	1.7	8.0	2.9	8.5	4.0	11.0
Subterranean clover	1.8	9.0	2.7	9.3	3.8	11.2
Arrowleaf clover	3.8	11.0	3.4	11.8	4.0	11.5
Biserrula	3.8	13.0	3.8	12.8	3.3	13.0
French serradella	4.5	12.9	4.4	13.4	4.2	13.2

Source: Hackney et al. (2022)

Figure 7.1: Wheat grown near Ungarie in 2020 following either wheat (left) or biserrula (right) grown in 2019. In 2020, nitrogen was either not applied, applied at sowing only (15kg N/ha) or at sowing plus top-dressed (a total of 150kg N/ha).

a) Wheat on wheat — **b)** Wheat on biserrula

a) L–R: N at sowing, nil N, N at sowing+topdress

b) L–R: Nil N, N at sowing+topdress, N at sowing

Photos: Belinda Hackney

7.4 Weed control benefits for crops

Growing G_2HSLs in rotation with crops offers alternative tools to assist in the control of weeds. An integrated approach to weed control has numerous benefits, including controlling problem weeds while prolonging the life of herbicide options for weed control.

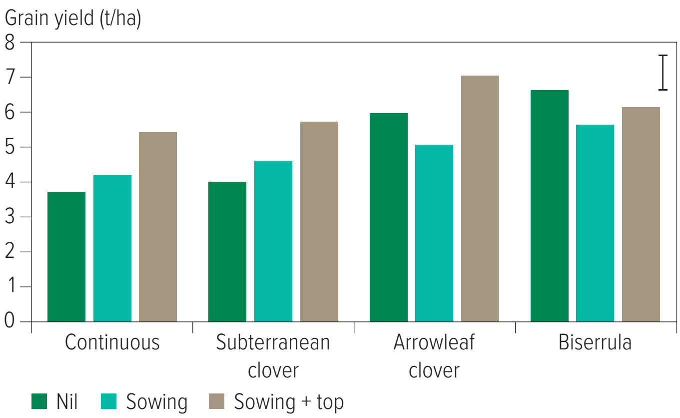
7.4.1 Direct competition

Dormant summer sowing G_2HSLs increases herbage production early in the growing season. Where pastures emerge early, they achieve canopy closure relatively quickly, which then provides considerable competition against weeds (Figure 7.3). In the example for a site in NSW, 90 per cent ground cover was achieved by July in the summer-sown biserrula treatment, leaving limited opportunity for weed establishment. Conversely, for the conventionally sown subterranean clover (sown in late May), measurable quantities of herbage of the sown legume were not present until August. Consequently, even though an additional knockdown had been applied prior to sowing the subterranean clover, its slow emergence (due to colder temperatures) and slower development of the canopy allowed for weed invasion. This resulted in a proportionally higher weed content in the late-sown pasture, thereby compromising legume herbage production and nitrogen fixation.

Regenerating G_2HSL pastures also have significant potential to compete against weeds, as they can survive earlier emergence due to their more rapidly developing root system, and (for some) improved capacity to regulate transpiration losses.

Although G_2HSLs have attributes that enable them to compete well against weeds, it is important to have a vigilant clean-up program for a number of years prior to sowing a new pasture, regardless of the species to be sown or the sowing method. Weed invasion remains the number one cause of pasture establishment failure. It is far better to clean up weeds as much as possible prior to sowing a new pasture than to try and fix up a weed problem in a newly established one.

Figure 7.2: The grain yield (t/ha) of wheat grown as part of a continuous cropping treatment, after subterranean clover or after the G_2HSLs arrowleaf clover or biserrula, and the effect of withholding nitrogen fertiliser (nil) or application of nitrogen at sowing (15kg N/ha) or at sowing and top-dressed at growth stage 31 and 51 (total 150kg N/ha) at a site near Condobolin, NSW, in 2021.



Source: Hackney et al. (2022)

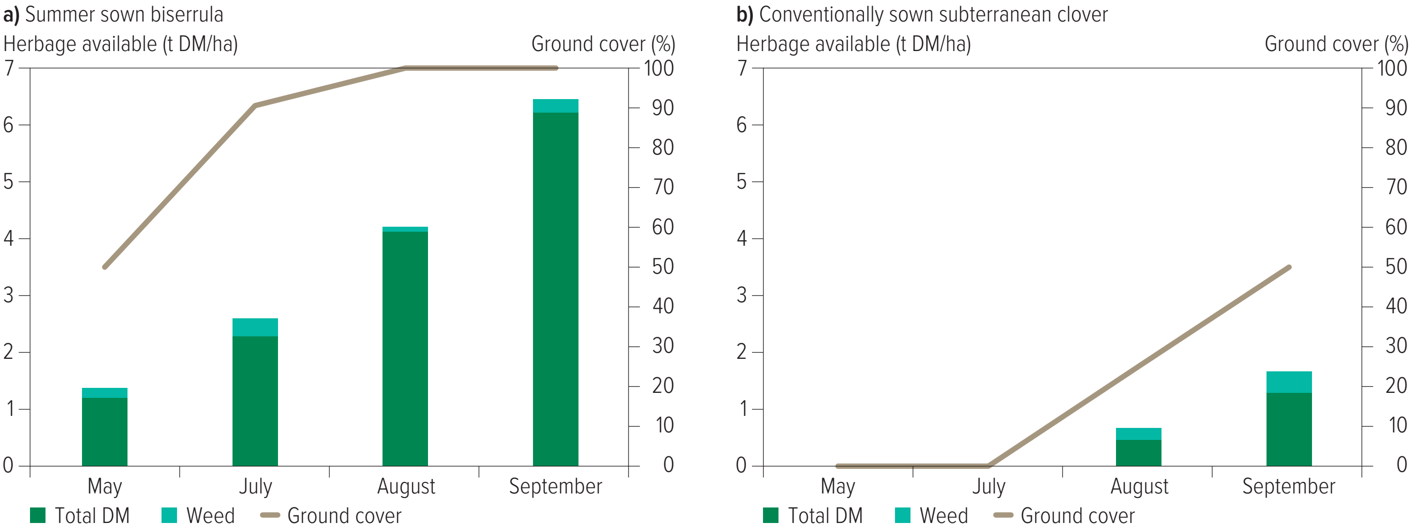
7.4.2 Reducing weeds via fodder conservation

G_2HSLs can regenerate early in the growing season and they can survive conditions that would result in a false break in traditional legumes such as subterranean clover or annual medic. Therefore, they can produce very high levels of biomass by late winter and early spring. In such situations, converting excess pasture growth to silage or hay can be considered, and such strategies can be used as an integrated weed control tactic.

If you are considering fodder conservation as a tactic for weed control, consider the stage of maturity of the target weeds at the time of cutting. Silage making generally occurs three to four weeks prior to cutting hay. As such, weeds are likely to be cut prior to (or early in) the reproductive stage of growth when making silage, which has the potential to have the greatest impact on potential weed seed-set. Additionally, making silage can improve the palatability (but not the quality) of weeds in the silage. The fermentation of silage has also been shown to significantly reduce the germinability of any weed seed (Table 7.4). Additionally, ingestion of the silage by livestock offers another opportunity to further reduce the germination of any weed seeds that remain

GRDC

Figure 7.3: Sown legume herbage and weed availability (t DM/ha) from May to September for a) biserrula established via dormant summer sowing or b) subterranean clover established via conventional sowing in May. Ground cover (%) of the sown legume is also shown for each treatment for a site near Condobolin in NSW.



Source: Hackney unpublished

viable after ensiling. The potential for regrowth of weeds in pasture following cutting from silage must also be considered, as in good seasons there may still be potential for such weeds to set a significant quantity of seed. Follow-up grazing or herbicide control may be necessary depending on weed species and growing season conditions.

Cutting legume pasture for hay also offers an opportunity to control weeds. In contrast to cutting for silage, haymaking offers a reduced timeframe for regrowth of weeds; however, depending on weed species, this may still occur. A disadvantage of cutting for hay is that some weed species may have already produced viable seed at the time of cutting, which may shatter out and return to the weed seedbank or become a contaminant of the hay. Additionally, as weeds are more mature at the time of cutting, they may be less readily consumed by livestock than in silage and the opportunity for digestion and reducing germination of any viable seeds may be reduced.

Ultimately, the decision about whether to cut for silage or hay as a method of weed control needs to consider the weeds involved, their stage of growth, the likely end use of the conserved fodder (that is, the class of livestock likely to be fed), the need for additional weed control tactics post-cutting to control regrowth and perhaps most importantly, the trade-off in quality and quantity that occurs between possible silage and hay cutting times as well as the capacity for the legume to recover and produce seed to either establish a seedbank (newly sown pasture) or replenish a seedbank.

Grazing senesced pastures may have a different impact on weed seed-set compared to G_2HSLs seed-set. In the same experiment that was reported in Table 6.6 (page 57), researchers also offered sheep in metabolism crates annual ryegrass, wild radish and wild turnip seeds. Ingestion by sheep effectively removed 94 per cent, 70 per cent and 85 per cent of the turnip, wild radish and annual ryegrass seeds. Heavy crash grazing of senesced pastures may offer an additional opportunity to reduce weed populations. However, it is important to consider the species of G_2HSL in the pasture as their susceptibility to ruminant digestion can vary (see Table 6.6; page 57).

Table 7.4: The germination of a range of weed seeds that were ensiled or subject to digestion by cattle or to both ensilage and digestion compared to non-ensiled, non-ingested seed.

Weed species	Common name	Germinability (%)				Control seed viability (%)
		Control	Ensiled	Digestion	Both	
Avena fatua L.	Wild oats	88.7 (±4.67)	20.7(±11.10)	0	0	91.3 (±2.40)
Bromus diandrus Roth.	Great brome	94.0 (±3.46)	0	0	0	96.0 (±2.00)
Bromus hordeaceum L.	Soft brome	100 (±0)	5.3 (±3.53)	9.3 (±9.30)	0	100 (±0)
Echium spp.	Paterson's curse	24.0 (±10.58)	0	11.1 (±4.88)	0	45.3 (±7.42)
Hordeum spp.	Barley grass	69.3 (±6.57)	0	11.6 (±6.38)	0	70.7 (±6.36)
Lollum rigidum Gaud	Annual ryegrass	82.7 (±.3.71)	12.7 (±3.53)	63.6 (±7.87)	0	85.3 (±3.33)
Raphanus raphanistrum L.	Wild radish	34.0 (±5.9)	0.7 (±0.67)	3.6 (±2.57)	0	82.7 (±3.71)
Vulpia spp.	Silvergrass	63.3 (±31.80)	24.0 (±8.08)	19.9 (±10.00)	0	64.0 (±32.08)

Values in parentheses are standard errors of the mean. Ensiled more than 3 months in unchopped subterranean clover dominant pasture with a dry matter content of 587.9g/kg. Digestion: 48h *in sacco* in the rumen of mature Red Poll steers. There were n = 3 replicate bags/treatment and n = 50 seeds per bag. Viability includes the proportion of germinated plus viable ungerminated seeds.

Source: Piltz et al. (2021)

7.4.3 Alternative mode-of-action herbicides

Weed herbicide resistance is becoming an increasing problem worldwide. Herbicide resistance within a weed population accelerates where there is an over-dependence on a herbicide with a particular mode-of-action. Rotation of herbicide groups and the integrated use of herbicides with other weed control tactics such as grazing, fodder conservation and/or cultivation can be beneficial in slowing the development of resistance and prolonging the useful working life of herbicides. Use of G_2HSLs in cropping rotations offers the opportunity to not only rotate to herbicides with a different mode-of-action to those used in a continuous cropping scenario, but also to use other tactics such as grazing and fodder conservation to help control weeds and delay resistance development.

7.5 Pest and disease benefits for crops

Similar to most break crops, G_2HSLs provide a pest and disease break in cropping rotations. The G_2HSLs do not carryover the root or foliar diseases that typically compromise cereal production such as take-all, cereal cyst nematode (CCN) and Rhizoctonia, or fungal diseases carried over by spores on cereal stubble such as yellow leaf spot and white grain.

Root lesion nematode can cause significant losses in susceptible crops. Some G_2HSLs have good resistance to this important pest and research has shown that their inclusion in the crop rotation can reduce pest populations. Glasshouse studies in WA (Table 7.5) have shown that serradella, and particularly French serradella, is resistant to root lesion nematode. Biserrula appears to vary in susceptibility from susceptible to resistant, indicating more research is required. Other species such as gland clover and arrowleaf clover are susceptible to this pest and therefore should not be grown prior to a crop if nematodes are likely to be an issue.

The impact of serradella on nematode populations has subsequently been confirmed in field-tests (Table 7.6), where root lesion nematode populations were significantly reduced after growing serradella.

7.6 Will germinating G_2HSLs be a problem in following crops?

Between the end of the G_2HSL growing season and sowing of the following season's crop, there are generally multiple fallow sprays that remove any legumes that germinate. Once the crop is sown, it generally outcompetes any legumes that may emerge. Additionally, many of the broadleaf weed herbicides used in crops are lethal to G_2HSLs. Thus, the risk of legumes impacting following crops is minimal.

Table 7.5: Root lesion nematode (*Pratylenchus neglectus*) resistance profiles for pasture species in glasshouse experiments in WA.

Species	Cultivar	2017	2008	2007
French serradella	Margurita(b)	R	R	R
Yellow serradella	Santorini	R	MR	MR
Biserrula	Casbah	R	MR	S
Arrowleaf clover	Cefalu	S	S	S
Gland clover	Prima	SVS	–	SVS
Subterranean clover	Dalkeith	MR	MR	S
Wheat	Susceptible control	SVS	S	S

R = Resistant, MR = Moderately resistant, S = Susceptible, SVS = Susceptible to very susceptible.

Source: Collins et al. (2021)

Table 7.6: Root lesion nematode (*Pratylenchus quasitereoides*) levels (RLN/g soil) in paddocks before and after a French serradella pasture.

Location	Season	Before serradella (RLN/g soil)	After serradella (RLN/g soil)
Pingelly	2015	21	4
Pingelly	2015-16	45	1
Gibson	2013	4	1

Source: Collins et al. (2021)

Chapter 8:
Harvesting seed on-farm

A distinctive feature and major advantage of the G_2HSLs is the ability to harvest seed on-farm using a conventional header. This means that growers can start with a relatively small area and increase the amount of seed at a relatively low cost on-farm. Another advantage of this model is that it allows growers to evaluate several species without a large economic outlay and determine which species best suit their soils, climate and prospective farming systems. This system contrasts sharply with those based on traditional annual legumes such as subterranean clover or annual medics where growers need to buy sufficient seed to cover the full area they intend to sow.

8.1 Arrowleaf clover

There are two main strategies for harvesting arrowleaf clover: direct heading or windrowing followed by header harvesting (Figure 8.1). Although direct heading is a feasible option, in some areas arrowleaf clover will retain green material and relatively high moisture content in the stems late into the season. Green stems can cause blockages when direct heading and therefore spraying with a desiccant may assist the drying process. Many growers choose to windrow arrowleaf clover to reduce moisture content in the stems. Windrowing also assists in maintaining consistency of bulk flow of herbage through the header. Another advantage of windrowing is that there is less chance of seed shattering while waiting for stems to dry down. Follow timing guidelines for windrowing canola to match maturity of the seed.

Regardless of whether arrowleaf clover is to be harvested directly or following windrowing, excellent results are achieved using a conventional open-front cereal harvester. Use similar settings as for harvesting wheat but windspeed may need to be reduced to 50 to 70 per cent of that used for wheat.

8.2 Biserrula

Biserrula can be harvested with a header, although yields can vary considerably. If harvesting with a header, do so as soon as possible after senescence, as that is when the pods are easiest to thrash (Figure 8.2). The longer they are exposed to the sun, the tougher the pods become. Generally, for Casbah and Mauro, best results are achieved by windrowing the senesced plants prior to harvest. Ensure that the sward has fully senesced prior to windrowing. Once windrowed, harvesting is then best undertaken in the heat of the day as the pods are more brittle and more seed is likely to be extracted. Do not harvest on cool or high humidity days as the pods will be more inclined to pass straight through the header. Be prepared to lose a little bit of seed over the riddles, rather than have a very chaffy sample, as this can sometimes be difficult to get out of the header box. The new release cultivar $Crown_2$ has a more papery pod held aloft above the canopy and appears to offer greater suitability for direct heading, but more research is needed to quantify this.

The header concave needs to be closed as much as possible with high rotor speed with the fan setting similar to canola. Adjust sieves to balance the sample without too many repeats. A significant proportion of the pod fed into the header may pass through without seed being extracted. Seed harvest yields using a well-set up conventional header commonly range from 100 to 400kg/ha. Pod that passes through the header without seed extraction will contribute to regeneration in subsequent years, so make sure the straw chopping spreader function is on.

Some growers have improved the efficiency of seed harvesting by undertaking header modifications. This has included modifying the concave to expose the plant material to threshing and adding extra rub bars to make the threshing more complete.

Figure 8.1: Direct heading arrowleaf clover (left) near Uranquinty NSW and windrows of arrowleaf clover awaiting harvest near Greenethorpe NSW (right).

Photos: Craig Rodham (left), Belinda Hackney (right)

Figure 8.2: Harvesting windrowed, fully senesced biserrula near Beckom NSW (left) and a header sample of harvested seed near Condobolin NSW (right).

Photos: Mike O'Hare (left), Paul Sinderberry (right)

If higher seed yields are required, then biserrula can be harvested using a clover suction harvester with yields of 500 to 800kg/ha. Suction harvesters need to be slightly altered to harvest biserrula. Four-foot ducts are much better, as seven-foot ducts suck up too much pod for the capacity of the drum.

The drive cog on the drum needs to be changed to a 29-tooth cog, the same one used for medic. The cog on the cleaning fan should be changed to a 20-tooth, to slow the fan down, to enable you to open the fan shutters wider and to give you more air, but less blast. Again, do not be afraid to lose a little bit of seed rather than get a chaffy sample. The sand screens need to be changed to a much finer mesh, as too much good seed will be lost through subclover screens or medic screens. The mesh is 0.89mm aperture and 0.37mm wire diameter. This can be purchased from Locker Group at their online store (Meshstore). All other settings are the same as for subclover.

The best way to prepare the biserrula for suction harvest is with a set of harrows made from car tyres. To make these, you need about 18 to 30 car tyres about the same size. You then cut one side of each tyre with a sharp knife, half way between the shoulder of the thread and the bead and lay that tyre with the cut side down. Make a row of five tyres side by side, then the next row of four tyres, a row of five again then four on the back row. Bolt them together where they touch. On the front row, use a hole saw about one-inch size and drill a line of holes along the front row at about 4 o'clock and 8 o'clock, but do not drill through the outside of the tyres on either end. Press the outside edge down and put a piece of ¾-inch pipe through the row of holes. You will need a sledgehammer to drive the pipe through. This will make the draw bar to pull with and the pipe cannot come out. Attach some chain to the pipe, between the first and second tyre on each end, and attach to the towing vehicle. The 5/4 rows are suitable for smaller farm utes or you can make the rows bigger for bigger utes. Tow these at about 25km/h and it will smash up the leaves and vine, leaving all the pod sitting on top of the ground with virtually no soil disturbance. These harrows are also very good for harvesting yellow serradella and medic.

8.3 Bladder clover

Bladder clover is commonly harvested by direct heading using an open-front header with a tyned reel (Figure 8.3). Crop lifters may be useful on lodged or low growing stands and should be spaced about 30cm apart. Very short stands may be raked prior to harvesting with a header fitted with crop lifters or a pick-up front. Settings are similar to those used for wheat but windspeed generally needs to be reduced to 50 to 70 per cent of that used for wheat.

Figure 8.3: Harvesting bladder clover (left) and harvested seed (middle and right).

Photos: Trenton Browne (left and middle), Angelo Loi (right)

Figure 8.4: A paddock of gland clover being harvested in WA (left) and a sample of direct-headed gland clover seed at Parkes in NSW (right).

Photos: Angelo Loi (left), Richard Rice (right)

8.4 Gland clover

Gland clover is probably the easiest of all G_2HSLs to harvest with a harvest index exceeding 90 per cent. It is usually harvested using an open-front header with a tyned reel but bat or air reels also work well (Figure 8.4). The fan speed usually needs to be set to 50 to 60 per cent that of wheat. Concave settings are not critical and use of canola screens can improve the proportion of seed captured. Gland clover matures quite early in the growing season. It can be successfully harvested while there is still a small proportion of green material at the base of the stems and this is preferable to leaving the stand too long and risking losses due to seed being shed.

8.5 French serradella

French serradella can be harvested with a header fitted with an open-front, finger tyne reel (Figure 8.5). It is important to note that harvesting using a header yields pod segments, not naked seed. On average, about two-thirds by weight of the harvested pod is seed. Use minimum drum speed and a fan speed about 50 per cent of that used for wheat. If the pods do not break up into segments, increase the drum speed. If too much naked (dehulled seed) is in the sample, reduce the drum speed and/or increase the concave gap. The top sieve should be set as for lupins and the bottom sieve as for wheat. Crop lifters (fitted 30cm apart) may be needed if the sward has lodged. The ideal result is a box sample of serradella pods broken into one to two pod segments to make it easier for auguring.

8.6 Yellow serradella

As with French serradella, harvesting yellow serradella using a header results in the collection of pod segments with each segment containing a seed. On average, about half of the weight of harvested pod is seed. Yellow serradella is ready to harvest when the pods snap when bent. Yellow serradella can be harvested with an open front header, preferably with a finger tyne reel (Figure 8.6). Crop lifters (fitted 30cm apart) may be required if the sward has lodged. The cultivars Santorini and Charano can be raked and harvested with a pick-up front but this should not be attempted for cultivars Yelbini$^{\phi}$ and Avila.

Header settings used are similar to those for wheat. Quite aggressive drum and rotor settings may be needed. It is best to harvest on hot, low humidity days as this results in higher breakage of the pods into segments. It is critical to empty the header when the box is no more than one-third full. Yellow

Figure 8.5: Harvesting French serradella (left) and harvested pod segments (right) at Uranquinty NSW.

Photos: Craig Rodham

serradella pods become entangled and bridge in the box, meaning that emptying a full box is very difficult. It is also important to consider where you store harvested pod. Generally, it is best to store harvested pod in a bunker or in a shed with a concrete slab. Yellow serradella pod should not be stored in silos or field bins as it can be extremely difficult and dangerous to empty as the pods could become entangled and create bridges.

8.7 Trigonella

Trigonella is well suited to direct-header harvesting (Figure 8.7). Seed threshes out of the pods easily. Header settings for harvesting of trigonella should be similar to those used for gland clover.

Trials are ongoing in larger harvesters to understand the process-ability of this new legume.

Figure 8.6: Harvesting yellow serradella in Western Australia.

Photo: Angelo Loi

Figure 8.7: A header harvesting trigonella (left) and harvested seed (right) in Western Australia.

Photos: Rob Harrison

Flowering Trigonella. Photo: Hayley Norman

Chapter 9:

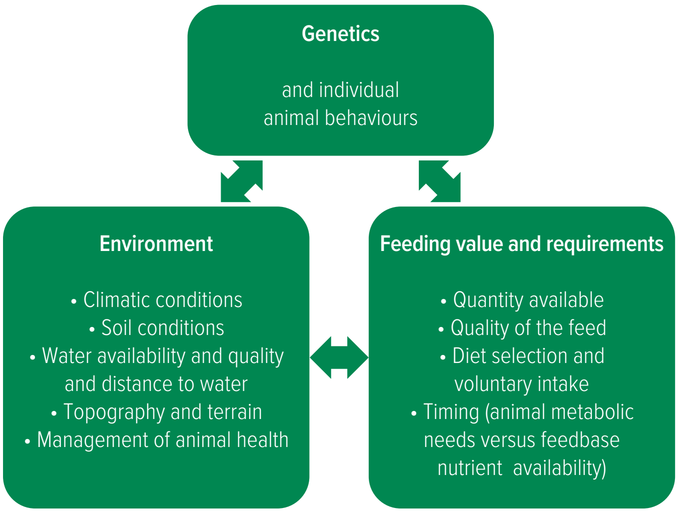
Livestock production from G_2HSLs

Whole-farm stocking rates are a key driver of profitability. Despite this, growers often maintain conservative stock numbers to reduce the risk associated with seasonal variability and the cost of supplementary feeding. The G_2HSLs selected for southern Australian farming systems contribute significantly to livestock production through direct grazing, conservation of excess herbage as silage or hay, and through consumption of senesced pasture over the summer period. In longer-term pastures, the nitrogen fixed by G_2HSLs can be used by non-leguminous components of such pastures (for example, grasses or forbs), thereby increasing production potential. Additionally, the nitrogen that G_2HSLs fix can increase production in subsequent crops used for supplementary grain, grazing or fodder conservation.

Livestock production potential is impacted by genetic, behavioural, environmental and nutritional factors (Figure 9.1). Feeding value is the value of forage in terms of animal production, that is, it is a function of both how much of the forage is eaten (voluntary feed intake) and the use of that forage. Nutritive value is defined by the nutrient content or animal response per unit of feed intake. An animal can only express its full genetic potential if it is not constrained by environmental conditions, factors impacting voluntary intake and nutritional value of the ingested feed.

In terms of environmental factors, soil characteristics can affect the supply of nutrients to plants (for example, soil acidity can result in the reduction in availability of key macro and micronutrients). This can constrain plant growth and the nutrient content of the plant, which impacts the quantity, quality and timing of feed supply for livestock. Climatic conditions influence the nutritional demands of livestock and impact the growth rate of plants and can also affect nutrient uptake and the nutrition profile of plants. Other factors such as topography can create microclimates that influence plant growth and how animals use the landscape for grazing. Management factors such as the distance animals must travel to water impact the feed requirements, and water quality and availability are critical in optimising livestock production. Control of internal and external parasites also affects how effectively animals use feed available to them.

Figure 9.1: Factors affecting animal production.



Where traditional annual pastures are used in southern Australian farming systems, feed shortages are often experienced in late summer to mid-winter (Figure 9.2). By late summer, dry feed residues (crop stubbles and pasture) have declined in terms of availability and quality, and traditional legumes have not yet

Figure 9.2: The conceptual growth curves over a year for G_2HSLs and first-generation hard-seeded annual legumes (G_1ALs) such as subterranean clover and annual medics.

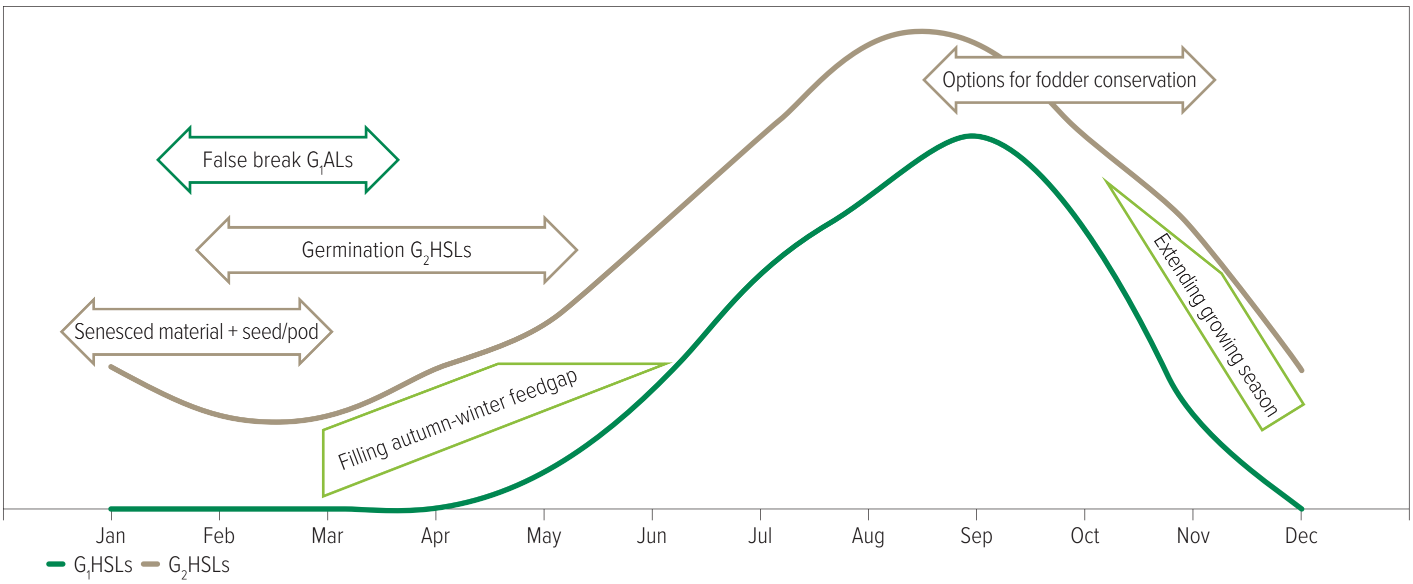


Figure 9.3: The G_2HSLs differ in their capacity to extend the growing season. Left shows a comparison of gland clover (L) and arrowleaf clover (R). Right shows a comparison of arrowleaf clover (L) and biserrula (R). Photos taken in December 2016 near Eugowra, NSW.

Photos: Belinda Hackney

regenerated, or if a germination event occurs, both subterranean clover and annual medics are very susceptible to seedling loss due to false breaks. For traditional legumes, feed quality issues (and to a lesser extent, feed availability) can be a problem in late spring and early summer as dry spring conditions can severely constrain production potential and feed quality declines as plants move from vegetative growth to reproduction and seed-set. At the break of season, germinating plants have high nutritional value but quantity of biomass restricts intake. The G_2HSLs can fill these feedgaps as they are able to regenerate on late summer and early autumn rain, grow rapidly and provide high-quality feed from mid-autumn onwards. The deep root systems enable more reliable production later into spring and summer, assisting to prolong the growing season (Figure 9.3). The bulk of feed that G_2HSLs produce over spring provides valuable senesced forage that can be grazed over summer. Overall, the inclusion of G_2HSLs in southern Australian farming systems has the potential to reduce the need for supplementary feeding. This can significantly reduce economic and labour costs associated with supplementary feeding.

Whereas the previous chapters of this guide have shown the productive potential of G_2HSLs, it is equally important to consider their impact on the production of meat and wool. Higher quality is a goal for reproducing, lactating and rapidly growing livestock. The needs of the system must be considered and often quality is more important than quantity produced, especially where energy supplementation is challenging.

9.1 Factors that determine the value of feed sources for livestock production

9.1.1 Feeding value

Feeding value is defined as the animal production achieved when grazing under unrestricted herbage availability conditions. All animals have a basic nutritional requirement for maintenance and thermal regulation that must be met before any feed ingested can be available for reproduction, building muscle, laying down fat or growing fibre. In extensive systems where animals choose how much and what to eat, feeding value is a function of voluntary intake and the nutritive value of the ingested feed.

Herbage availability can constrain voluntary intake during pasture establishment, under conditions that restrict pasture growth such as drought or cold conditions or if paddocks are over-stocked. Excess herbage allows an individual animal to select a diet that optimises their needs through selection of plant species or parts of plants that have a higher feeding value. Sheep and goats, with their smaller mouths, are much better at selecting the high nutritional parts of plants than cattle.

Assessing nutritive value can provide an indication of the overall feeding value of a forage. Nutritive value provides a guide as to how much forage will be eaten; higher fibre in forage constrains intake as the material takes longer to breakdown and pass out of the rumen. Relative palatability of feed is a function of nutritional value, secondary plant compounds and the animals' nutritional requirements. Animals may therefore choose to eat a particular feed based on factors other than its nutritive value. Nevertheless, assessing nutritive value is the most useful tool available to determine how a given feed may influence livestock production. The following section discusses the key parameters that are tested when undertaking an analysis of the nutritive value of a feed.

9.1.2 Nutritive value

This term refers to the efficiency with which the nutrients are used for animal maintenance or production. Animal production is a function of the nutritional value of feed that is eaten. Assessing nutritive value is complicated and involves predicting what happens in both the digestive tract and body. A range of characteristics that collectively contribute to nutritive value are listed here and further discussed below:

- digestibility;
- metabolisable energy;
- protein;
- fibre content;
- ash;
- vitamins;
- minerals; and
- secondary compounds.

DIGESTIBILITY

Digestibility is the proportion of the feed ingested by an animal that can be used for supporting maintenance and production. Digestibility on a laboratory analysis report can be reported in one of two ways:

- DMD (dry matter digestibility) is the proportion of the dry matter ingested by the animal that is digested.
- DOMD (digestible organic matter in the dry matter) is the proportion of the organic matter in the ingested feed that can be digested by the animal. This measurement is corrected to account for inorganic matter. As DOMD is a measure of digestibility of the organic matter in the dry matter, it will be a lower value than DMD. This is more appropriate for plants with a high salt content.

The digestibility of a feed will affect voluntary intake. Feeds with a higher digestibility move through the digestive tract more rapidly and allow the animal to consume more. As digestibility declines, the feed remains in the digestive tract for longer and limits intake. It is very rare for the digestibility of a forage to exceed 85 per cent; exceptions may occur with very young ryegrass or clover. However, in general, most plants require at least 15 per cent indigestible components to maintain structural integrity.

The nutritive value required for maintenance and production depends on the physiological state of the animal. That is, whether the animal is growing, mature, pregnant or lactating. An example of this is shown in Table 9.1, which compares the digestibility required to either maintain various classes of sheep in their current state or to achieve a very modest change in liveweight (a gain of 50g/head/day) assuming that herbage availability is not limited. When animals are exposed to poor weather or are pregnant or lactating, feeds with higher nutritive value are required for maintenance and growth. For animals with high physiological demand, such as a lactating ewe with twins, it is not possible for her to eat enough, even if nutritive value of a forage exceeds 80%, for her to maintain her weight and body condition. Such an animal will lose weight regardless of the forage she is fed.

Table 9.1: The approximate matter digestibility (DMD%) assuming feed availability is not limited required for maintenance of current body weight or to support a liveweight gain of 50g/day.

	DMD% required for maintenance	DMD% required to increase liveweight by 50g/day
Dry ewe (50kg), good weather conditions	60	70
Dry ewe (50kg), poor weather conditions	63	72
Pregnant ewe (100 days' gestation), good weather conditions	67	76
Lactating ewe with 25-day old twins, good weather conditions	Not possible on forages alone	Not possible on forages alone

Source: Grazfeed Version 5.0.8 (from Freer et al. 1997)

METABOLISABLE ENERGY (ME)

Metabolisable energy refers to the energy density of a feed and is reported as megajoules per kilogram of dry matter (MJ/kg DM). The ME of a feed is calculated from the digestibility. The calculation used to determine ME varies depending on whether digestibility has been determined as DMD or DOMD (from Standing Committee on Agriculture 2007). The two different formulas are as follows:

- ME (MJ/kg DM) = (0.172 x DMD%) – 1.707
- ME (MJ/kg DM) = (0.194 x DOMD%) – 2.577

Given that ME is calculated from digestibility, it follows that higher digestibility feeds will have a higher metabolisable energy.

Summer sown gland, conventional sown biserrula (with dog), summer sown biserrula. Photo taken in August.

Photo: Belinda Hackney

Table 9.2: The crude protein (%) content of feedstuffs required for various classes of sheep.

	Minimum crude protein requirement (%)
Weaner lambs, pregnant or lactating ewes	15
Adult sheep	12
Minimum for survival	9

Source: Roberts (2022)

PROTEIN

The true protein content of feeds is difficult to measure, and ruminants can convert non-protein nitrogen to protein via the rumen microbes, given sufficient energy. Therefore, feed tests generally report the crude protein (CP) of a feed, which is calculated from the total nitrogen content of a feed. Crude protein is calculated as:

- Crude protein (CP) = total nitrogen (N) x 6.25

The multiplication factor of 6.25 is used as protein contains about 16 per cent nitrogen. Animals have differing dietary CP requirements depending on maintenance, growth and production requirements (Table 9.2). It is important to note that crude protein is not always the same as true protein.

FIBRE CONTENT

Sheep, cattle and goats require long fibre for healthy rumen function but too much fibre restricts intake and provides low levels of energy. Fibre fractions differ in their relative digestibility. There are different fibre fractions reported on a feed test report:

- lignin is the structural fibre that is largely indigestible;
- ADF (acid detergent fibre) consists of cellulose, which ruminants can partially digest, and lignin;
- NDF (neutral detergent fibre) is the most digestible fibre fraction. It is an estimate of the total cell wall content of a feed, which is composed of hemicellulose plus the fibre remaining in the ADF fraction.

Fibre content is an indicator of feed quality. High-quality, high-digestibility feeds will have a lower fibre content (Table 9.3). Low-fibre feeds will enable higher animal intake as feed moves through the intestinal tract more quickly than higher-fibre feeds.

ASH

Ash is a measure of the inorganic materials such as sand, soil or salt in a feed. Such materials may be digested (e.g. salt) but have no energy value for animals. Where the ash content of a feed exceeds 12 per cent, it can indicate that significant quantities of sand or soil have contaminated the sample or the plant has accumulated salt.

MINERALS

There are 14 essential dietary minerals:

- calcium;
- phosphorus;
- chlorine;
- magnesium;
- potassium;
- sodium;
- sulfur;
- cobalt;
- copper;
- iodine;
- iron;
- manganese;
- selenium; and
- zinc.

Currently, a significant proportion of pasture plants contain less calcium, phosphorus, magnesium, sodium, sulfur, copper, iodine, zinc, selenium or cobalt than is required for growth and reproduction, with significant genetic variation among and within legumes (Masters et al 2019).

The mineral content of a feed will be influenced by the soils in which it is grown. Not all minerals required by animals are essential for plants. For example, selenium is essential for livestock, but it is not an essential nutrient for plants, although plants will assimilate this nutrient. There are some acidic soils in southern Australia where selenium is deficient, and plants growing in these soils can often be deficient in selenium. Other common mineral deficiencies in Australia include cobalt, copper,

Table 9.3: The dry matter digestibility (DMD%) and crude protein (%) of a range of G_2HSLs, subterranean clover and wheat stubble from early summer to early autumn.

	Senesced residue (vegetative + reproductive material)						Seed or pod segments	
	December		Mid-January		Early March			
	DMD%	CP%	DMD%	CP%	DMD%	CP%	DMD%	CP%
Arrowleaf clover	50–54	12–14	43–46	8–10	31–34	4–6		
Biserrula	54–58	11–15	41–48	7–10	29–33	4–5	76 (60)	30 (22)
Bladder clover	48–65	10–14	35–44	8–10	25–28	3–4	53	20
Gland clover	38–42	7–10	31–35	6–8	24–29	4–5		
French serradella	49–55	10–13	40–44	7–9	28–35	4–5	60	23
Subterranean clover	48–55	9–11	34–42	6–9	ns	ns	44	15
Wheat stubble	40–45	4–7	28–34	2–4	20–25	2–3		

For biserrula, the DMD and CP of both the seed and the pod plus seed (in parentheses) is shown. The DMD and CP shown for serradella is for the pod segment, which contains the seed.

iodine, calcium, phosphorus and magnesium. Most of these are managed through fertilising plants or directly supplementing animals. Calcium and magnesium deficiencies are more difficult to manage as they are associated with metabolic changes in the animal usually during pregnancy or lactation.

VITAMINS

Vitamin E deficiency can be a problem for sheep grazing dry pastures and grain supplements over an extended time. Vitamin E is associated with antioxidant pathways and is important for the health of young and reproducing animals, and during heat stress events. Ruminants generally synthesise sufficient vitamin C, vitamin D and vitamin B complexes. Vitamin A deficiency is rarely a problem for animals grazing pastures, although there may be a benefit from supplementation for rams, bulls and young animals. Vitamin K is rarely deficient unless there are issues with vitamin K antagonists such as dicoumarol (see gland clover). Cobalt is required for the synthesis of vitamin B_{12}, and it is not uncommon to give young animals vitamin B_{12} injections.

SECONDARY COMPOUNDS

Secondary compounds can also impact nutritional value. There are many secondary compounds found in plants, some of which can enhance or detract from the nutritional value. Some of the better-known secondary compounds found in some legumes are condensed tannins. Tannins bind to protein in the plant, which reduces breakdown of proteins in the rumen. The impact this has on feeding value depends on the tannin content of the forage. Legumes that contain low to moderate levels of tannins can be useful in reducing bloat and increase the quantity of protein reaching the lower levels of the gastrointestinal tract (bypass proteins). High levels of tannins can depress growth rates as the protein cannot be digested and can also reduce intake due to the bitter taste of tannins. Of the G_2HSLs, serradellas are tought to contain sufficient quantities of tannins to reduce bloat incidence.

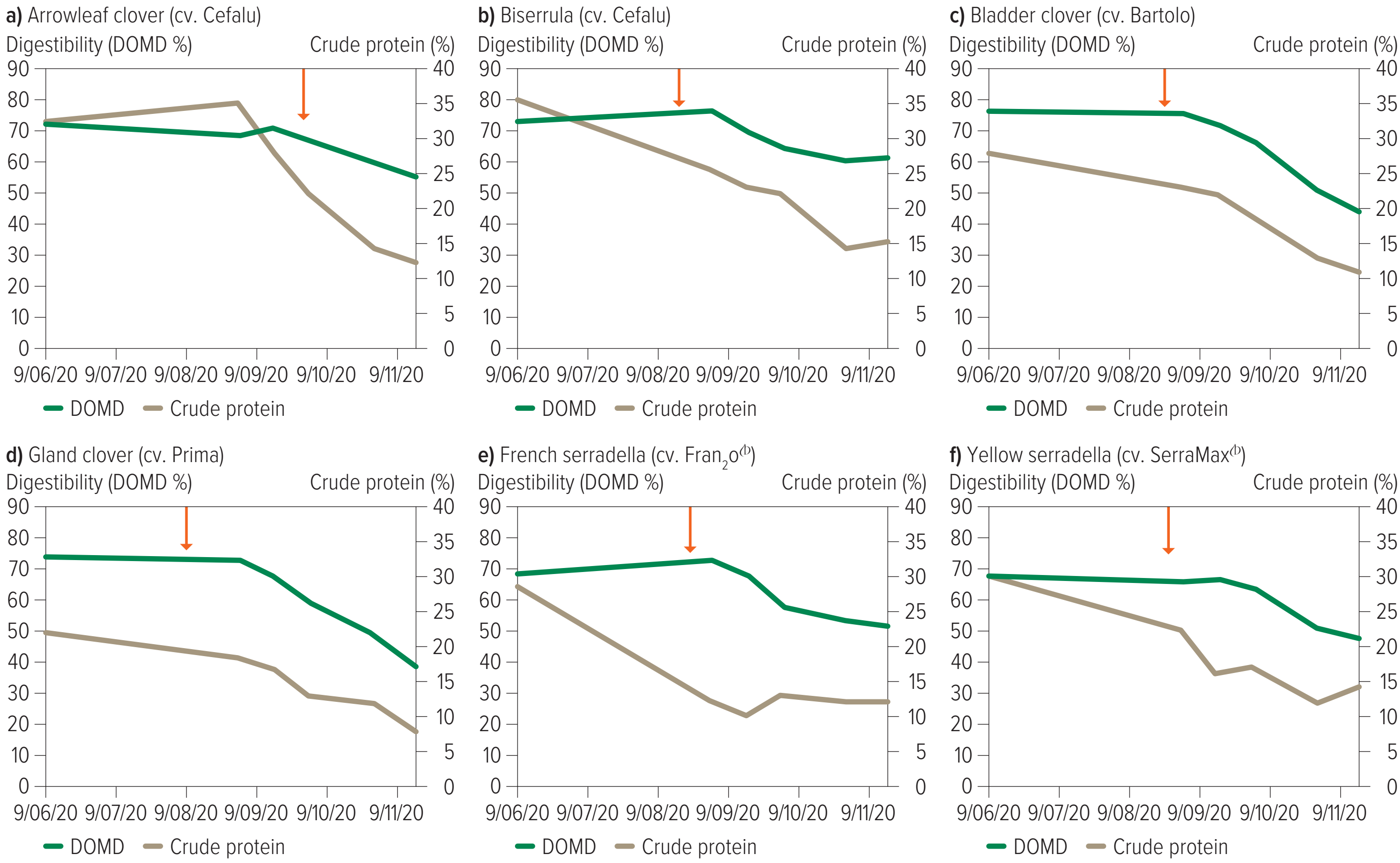
MEASURING NUTRITIVE VALUE

There are many methods used to estimate nutritive value, with variable cost and accuracy. These methods range from animal house metabolism crate nutrient balance experiments ('gold standard') to chemical analysis in a laboratory and near infrared spectroscopy (NIRS) prediction of the traits.

The NIRS method involves the development of statistical relationships between measured traits and light absorbance in the near infrared region of the electromagnetic spectrum. The same method is used to predict protein content of grains at receival bins. For most forages, the NIRS method is reasonably accurate, fast (within minutes) and inexpensive. Some traits are easier to predict by NIRS than others, and the quality of the reference data used to develop the calibration is critical.

In vitro measurement (often called wet chemistry) is the step between animal house and NIRS methods, where the nutritional trait is measured in a laboratory using a range of methods. For example, digestibility (or energy) can be measured using enzymes, rumen fluid or a combination of both. This is generally more accurate than NIRS but more time-consuming (more than five days) and expensive. It is important when getting forage tested that you select the measurement methods that meet your needs in terms of speed and accuracy.

Figure 9.4: The digestibility (DOMD, %) and crude protein (%) from early winter to late spring for a range of G_2HSLs established via dormant summer sowing at Condobolin, NSW. The arrows indicate the commencement of flowering for each species–cultivar combination shown.



Source: Hackney et al. (unpublished)

GENERAL NUTRITIVE VALUE PRINCIPLES

Legumes have the highest nutritional value in the vegetative phase and this declines as the plant flowers, makes pods, sets seed and senesces. Although herbage availability is often a constraint to livestock production in winter, especially for traditional legumes (as small plants grow slowly), herbage quality will limit intake and productivity in late spring and summer. Legumes that flower relatively late, are more indeterminate (extend reproduction over a longer time) or like G_2HSLs have deeper roots (to access moisture for longer), generally maintain higher nutritional value for longer.

Once senesced, pasture plants have low digestibility (low energy value), low to moderate crude protein and high indigestible fibre. The high fibre constrains voluntary feed intake and low nutrient density constrains production. In summer and autumn, consumption of seed and dead leaves from annual legumes can allow animals to maintain liveweight, providing the seeds are easy to pick up and a portion are able to be chewed and digested. French serradella is an example of a pasture species that can provide high feeding value in summer. It has deep roots and an indeterminate growth habit so can stay greener (and maintain nutritional value) for longer. It also produces large high-energy seeds in thin pods that are relatively easy for sheep to find, eat and chew. Although this is advantageous from a livestock production perspective, it can impact the seedbank.

9.1.3 Nutritive value and livestock production during the growing season

The G_2HSLs differ in terms of the forage quality throughout the growing season, which can impact livestock production (Figures 9.3, page 70; 9.4 and 9.5). Generally, all G_2HSLs will have a digestibility of 70 per cent or higher through autumn and winter and into early spring. Through this period, most species will be in the vegetative stage of growth. As plants enter the reproductive stages of growth, forage quality will begin to decline. The rate of decrease varies between species and within species, with significant variation between cultivars depending on their maturity time. In general, species or cultivars that mature earlier (for example, gland clover) or rapidly increase stem-to-leaf ratio (for example, arrowleaf clover) tend to decline in quality more rapidly. Exceptions to this general rule include serradella and biserrula, both of which have an indeterminate growth habit so that they continue to produce significant quantities of herbage late into the season in response to soil moisture availability and/or late spring rainfall.

Many grazing studies have been undertaken comparing G_2HSLs to traditional legumes. For example, studies in WA have shown similar liveweight gain and meat quality when comparing sheep grazing bladder clover, French serradella and trigonella to those grazing subterranean clover (Figure 9.6). These studies also found that sheep health (as indicated by assessment of blood plasma) did not differ significantly between the legume species grazed. Studies in NSW have reported similar sheep growth rates in sheep grazing arrowleaf clover, biserrula, bladder clover and lucerne in spring. All grazing studies completed to date have not considered the differences that exist in feed availability due to the capacity of G_2HSLs to be established earlier (by dormant summer sowing) or regenerate earlier (due to reduced susceptibility to false breaks) or their capacity to extend the growing season. Research has also shown that sheep grazing biserrula produce significantly less methane than those grazing other legumes.

Figure 9.5: The contribution of stem, leaf and reproductive components of annual legumes change throughout the growing season, which impacts nutritive value. Images show (L to R) biserrula (cv. Casbah), bladder clover (cv. Bartolo) and arrowleaf clover (cv. Cefalu) stem, leaf and reproductive components in mid-August (top images) and early October (bottom images).

a) Biserrula (cv. Casbah) **b)** Bladder clover (cv. Bartolo) **c)** Arrowleaf clover (cv. Cefalu)

Photos: Belinda Hackney

9.1.4 Nutritive value and livestock production from late spring through to autumn

The G_2HSLs can provide the bulk of the feed for use by grazing livestock from late spring through to autumn. Livestock can obtain nutrition from the senesced vegetative material as well as the reproductive components of the plant, whereas the residue provides protection to the soil against wind and water erosion (Figure 9.7). As with grazing in the growing season, livestock, particularly sheep, have the capacity to select different components of the dry residue when grazing and therefore the actual digestibility and crude protein they obtain from material they ingest may be considerably different to the raw values that nutrient analysis show for the residue as a whole. That is, animals are generally able to select a diet that is higher in quality than indicated by analysis of a whole feed sample. The nutritive value of the seed and pod segments will also be influenced by the amount of seed ingested that the animal can digest as opposed to the proportion that flows through the digestive tract undigested. As much as 88 per cent of biserrula seed can pass through the animal undigested and therefore does not contribute to livestock production, whereas a high percentage of French serradella pod is digested by the grazing animal (see Table 6.6, page 57).

The nutritive value of the senesced residue can vary considerably depending on seasonal conditions over summer and autumn (Table 9.3, page 72; Figures 9.7 and 9.8). The amount of rainfall received over summer can have a significant impact on the nutritive value of the senesced residue. Where summer conditions are drier, the nutritive value of the senesced residue will stay higher for longer. The capacity of dry residues of G_2HSLs to maintain stock liveweight over summer varies between species, cultivars within species and seasonal climatic conditions. However, G_2HSLs provide the bulk of the feed that can provide necessary roughage for rumen function and addition of other supplements (for example, grain) can be used to bridge the quality gap in the diet.

9.1.5 G_2HSLs for silage and hay production

As shown in previous chapters, G_2HSLs can produce large quantities of herbage, frequently in excess of that which can be used by grazing in spring. There is significant potential to use G_2HSLs for silage or hay production and then provide this conserved fodder for feeding in times of feedgaps (Figure 9.9). Making the decision of whether to conserve the forage as silage or hay requires consideration of the class of animal (for example,

Figure 9.6: Sheep grazing French serradella in a commercial paddock near Brookton, WA, in spring (left) and trigonella in a duty of care grazing study (right).

Photos: Anna Butcher (left) and Hayley Norman (right)

Figure 9.7: Gland clover residue lying on the soil surface in December near Parkes, NSW (left), and showing the soil being protected by the residue (right).

Photos: Belinda Hackney

Figure 9.8: Top photo shows ewes and lambs grazing serradella residue in February 2020 at Brookton, WA. Bottom photos show Mike O'Hare in a paddock of biserrula in late February 2014 that had been grazed throughout summer, with close-up showing residue remaining. Note in all photos the plant residue providing soil surface protection from erosion.

Photos: Anna Butcher (top), Belinda Hackney (bottom left and right)

young growing animal, mature animal, lactating animal) that the forage will be fed to. Silage is cut earlier in the growing season when the plants are in vegetative or early reproductive stages of growth and therefore the feed quality is generally higher. Cutting for hay can provide a greater bulk of conserved forage, but as cutting occurs later in the growing cycle of the plant, the nutritive quality is generally lower than for silage. It is also important to consider weather conditions and the impact this has on the capacity to make silage or hay. Silage is a higher moisture product and requires less wilting time than hay and there are potentially reduced losses (in both quantity and quality) of silage between cutting and making of silage compared to hay, where losses due to inclement weather and multiple raking events may reduce the quality and quantity of herbage that is conserved.

It is also important to consider the plant structure when deciding between making silage or hay. Species such as arrowleaf clover have thick stems that will take longer to dry down to the target moisture content for making silage or hay. Achieving the desired moisture content quicker may be improved by use of a mower conditioner that crimps the stems, increasing their rate of moisture loss. This can reduce the amount of leaf material that is shattered due to the discrepancy in dry-down rates if the stems are unconditioned. Conditioning may also be useful for species such as serradella or biserrula where the leaflets are quite small and delicate relative to the stems.

Figure 9.9: A biserrula–balansa clover-grazing wheat paddock near Manildra, NSW, prior to cutting for fodder conservation (left). Arrowleaf clover (middle) windrowed awaiting baling at Uranquinty, NSW and biserrula hay at Beckom, NSW (right).

Photos: Belinda Hackney

Table 9.4: Some examples of plant species that have been reported to cause various categories of photosensitisation.

Photosensitisation type	Plant species reported to have caused photosensitisation
Primary	Biserrula, lucerne[1], subterranean clover, annual medics[1], grazing cereals, St John's wort, buckwheat, canola[2], ryegrass, vetch
Secondary	Caltrop, *Panicum* spp., *Brachiaria* spp., various algae, canola[2], Paterson's curse, heliotrope, fireweed, lupins
Contact	Parthenium weed, giant hogweed

[1] Severe outbreaks often associated with infestation of lucerne and medics by cowpea aphids.

[2] Canola has been implicated in both primary and more rarely secondary photosensitisation.

If making silage, it is important to remember that legumes generally have a much lower sugar content (reported as water soluble carbohydrate level, WSC, in a feed analysis) compared to grasses. For silages that have a dry matter content of <35 per cent, the target pH to achieve fermentation conditions to produce a high-quality silage should be in the range of 3.5 to 4.2. The amount of WSC in plant material used to make silage will determine the ultimate pH achieved by the silage and how quickly the drop in pH occurs. The closer silage pH gets to the target range and the more rapidly this drop occurs, the higher the quality the silage will be. As legumes have a lower WSC level than grasses, it may be worth considering using an additive in the silage-making process that will allow a lower pH to be achieved in a shorter timeframe to optimise silage quality.

Gland clover is a very early maturing species and would not be well suited to fodder conservation. Additionally, gland clover contains low levels of coumarin, which is valuable in protecting the plant from insect attack. However, under conditions where spoilage may occur, it is possible for coumarin to be converted to dicoumarol. Dicoumarol is an anti-coagulant (often used in rodent poisons), which can deplete vitamin K in the body resulting in intestinal bleeding. For this reason, gland clover should not be used for fodder conservation.

9.2 Are the G_2HSLs safe for livestock?

Introduction of new plant species to farming systems may present risks to livestock. This includes poor nutritive value (leading to suboptimal growth rates), secondary plant compounds (that may have a negative impact on the health, performance and product quality of livestock) and physical structures such as spines or burrs that injure animals or contaminate wool.

Laboratory assessment of nutritional value may not accurately represent voluntary feed intake – a trait that is notoriously hard to measure in paddock grazing studies. Addressing the risk of new introductions is difficult due to the large number of potential compounds that impact intake and nutrient digestion, and their possible interactions. It is common practice to conduct a replicated grazing study (often called a duty of care study) to compare the feeding value of novel species with widely adopted and commercially successful cultivars prior to commercial release (see Figure 9.6). These experiments have been executed for gland clover, bladder clover, eastern star clover and trigonella. In all cases, wethers grazing the new legume had similar productivity, health and meat quality (flavour, aroma and texture) to flockmates grazing Dalkeith subterranean clover during a less than 50 day grazing window from winter to late spring. In these experiments, there must be sufficient forage that voluntary intake is not constrained. These experiments are therefore good at comparing feeding value but do not account for differences in pasture productivity associated with different growth rates and responses to grazing.

9.2.1 Photosensitisation

Photosensitisation affects domestic livestock with numerous underlying causes. Many plant species including domesticated grasses, legumes and crops as well as grass and broadleaf weeds can cause photosensitisation. It is important to recognise the three different types of photosensitisation that can occur in grazing animals and are triggered by different plant species. The three types of photosensitisation are as follows:

- Primary photosensitisation is triggered when animals ingest plants that contain photoreactive compounds that cause damage to unpigmented skin when the animal is exposed to sunlight. Animals affected by primary photosensitisation recover following removal from the inciting cause.
- Secondary photosensitisation has longer-term consequences for the animal. Plants that cause secondary photosensitisation contain compounds that when ingested affect liver function as well as skin. Recovery from secondary photosensitisation can be highly variable depending on the degree of liver damage that has occurred.
- Contact photosensitisation can occur due to direct contact with some plants with the exudates of the plant causing a reaction with sunlight.

Some examples of plant species known to cause different categories of photosensitisation are shown in Table 9.4.

The onset of primary photosensitisation can be rapid, affecting unpigmented skin within hours to days of ingestion of the offending plant. Contact photosensitisation onset can occur within minutes to hours of exposure. Secondary photosensitisation onset is usually longer as liver damage occurs before the symptoms of photosensitisation are seen.

Outbreaks of primary photosensitisation have been reported in unpigmented sheep in both WA and NSW grazing biserrula-dominant pastures. Cattle breeds that have unpigmented udders or sections of skin have also occasionally been reported. Outbreaks have occurred in autumn, winter and spring while the plant is in the vegetative and early reproductive stages of growth. No outbreaks have been reported when the plant is in the later stages of reproductive growth, or when the plant is fully senesced. Similarly, there have been no reports of biserrula silage or hay causing photosensitisation when fed to sheep or cattle. Although the biochemistry of photosensitisation arising from ingestion of biserrula is not well understood, growers are advised that the likelihood of an outbreak increases as pasture swards become biserrula-dominant. Thus, close inspection of stock and frequent rotation of paddocks is recommended, together with providing an alternative source of forage, such as hay or straw. Impacted animals will often seek to dilute intake of the forage causing photosensitisation and will eat weeds or straw. Growers have also reported that drilling of cereals into paddocks containing a biserrula seedbank has assisted in reducing photosensitisation outbreaks (Figure 9.10). Other growers running meat sheep have used pigmented rams over unpigmented ewes and have reported this has lessened the incidence of photosensitisation in lambs. Similarly, growers grazing fully pigmented cattle breeds (for example, Angus) have not reported evidence of photosensitisation when grazing biserrula (Figure 9.11).

Figure 9.10: A biserrula seedbank that has had a cereal sown into it north-west of Condobolin, NSW, in 2020. The photo was taken five weeks after the paddock had been grazed at a stocking rate of 31 dry sheep equivalents per hectare (DSE/ha) for six weeks in early to mid-winter.

Photo: Belinda Hackney

Figure 9.11: First calving heifers grazing a regenerating biserrula pasture north-west of Condobolin, NSW.

Photo: Paul Sinderberry

Many plants can cause photosensitisation. A well-documented extensive outbreak of photosensitisation in sheep was observed across SA's Eyre Peninsula and Northern Adelaide Plains from late September through October 2017. Large numbers of growers reported lambs and older sheep with swollen ears and faces, some with visibly sunburnt facial skin. These sheep had been grazing a variety of pasture types, but predominantly pastures with a high content of legumes such as medic and vetch species. Some flocks grazing cereals were also affected. Similarly, very large numbers of sheep were affected by photosensitisation in the Monaro region of NSW in 2020 and 2021 when grazing pastures containing lucerne with cowpea aphid infestations.

9.2.2 Bloat

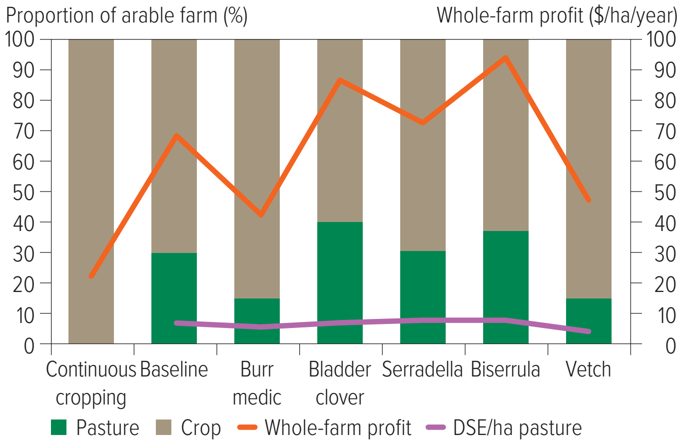
Bloat in cattle is a severe animal welfare and economic issue for livestock industries. It can occur when animals are grazing young, lush, highly digestible pasture, particularly pastures that contain a high proportion of lucerne, clover or annual medics. During digestion, rumen microbes ferment feed and produce large quantities of gas, which is normally belched (eructated). Many legumes contain foaming agents when fermented in the rumen and this foam can trap the gas and prevent its release from the upper gastrointestinal tract. As bloating progresses, the animal's lungs become compressed resulting in death if not treated promptly.

French Serradella, WA. Photo: John Howieson

Some legumes contain tannins that bind to protein in legumes and reduce its degradation in the rumen, which reduces susceptibility of animals to bloat. Of the G_2HSLs, serradella is thought to contain a sufficient level of tannins to reduce bloat risk, but not so much as to reduce protein availability for growth or to limit intake (high tannin levels can reduce palatability and bind protein). Growers report that biserrula also has lower bloat potential than many other legumes, although the authors are unaware of research to quantify the existence of tannins in this species. Other research has shown that biserrula produces significantly lower levels of methane than other legumes. Arrowleaf clover is also anecdotally reported to have lower bloat potential; however, there have also been reports of bloat in cattle grazing young, lush arrowleaf clover pastures. Arrowleaf clover increases its stem-to-leaf ratio rapidly during maturity and it is likely that this results in a reduction in bloat potential as the plant ages.

In terms of bloat, animals should always be monitored closely when introduced to high legume content pastures, particularly if those pastures are in a lush, vegetative state of growth. It is also important to consider access of animals to roughages such as hay or straw, which may assist in reducing the incidence of bloat.

Figure 9.12: Whole-farm profit (orange line) and proportion of arable farm under crop (brown area) and pasture (green area) for the six legume pasture scenarios evaluated on a typical 3750ha mixed farm in the Central Wheatbelt region of Western Australia (continuous cropping included for reference). Baseline represents a subclover pasture.



Source: Monjardino et al. (2021)

9.2.3 Red gut

Red gut is a disorder affecting sheep and is usually seen where animals are grazing young, lush pastures. It is often associated with sheep grazing pasture swards containing very high proportions of lucerne. On these pastures, rather than the majority of fermentation occurring in the rumen, the lush ingested feed passes rapidly into the intestines and fermentation there causes excessive distention resulting in shifting of the organs and allows space for the intestines to twist, cutting off blood supply. Twisting of the intestines is irreversible and the animal rapidly deteriorates and dies. To the authors' knowledge, there have been no reports of sheep being affected by red gut when grazing G_2HSLs. However, care should always be taken when grazing animals on green, lush pastures with provision of a roughage source where possible, ensuring vaccinations are up-to-date and regular monitoring.

9.3 Profit from grazing

The feeding value of pastures drives whole farm stocking rates and profitability. The results of bioeconomic modelling shown in Figure 9.12 suggest that replacing a baseline subclover-based pasture with G_2HSLs has the potential to boost whole-farm profitability by an average of 24 per cent (8 per cent serradella, 27 per cent bladder clover and 37 per cent biserrula). However, vetch (higher establishment costs) and burr medic (lower overall feeding value) reduced profitability. The most profitable G_2HSL options allowed growers to run up to 20 per cent more sheep on similar pasture areas (30 to 40 per cent) while maintaining cropping on 60 to 70 per cent of the farm. Provision of forage with higher digestibility and energy levels allowed livestock to attain market liveweight earlier and reduced emissions intensity, which is consistent with other studies of pasture intensification.

The high value of the improved pastures in these systems is driven by the high feeding value of pastures and the nitrogen supply to subsequent crops. This assumes reliable establishment of productive annual legume pastures and high representation in pasture composition, enabling a high-quality feed source for livestock and good levels of nitrogen fixation, which are strong profit drivers in these modelling studies. Economically optimal stocking rates were used, which may be higher than more conservative stocking rates typically chosen to reduce risk and better match availability of labour. Growers who run sheep at low stocking rates will need to look to generate alternative benefits from growing pasture phases to ensure profitability. The analyses assume that the legume-based pastures fix substantial quantities of nitrogen, which is then available to crops in at least the subsequent season. Therefore, any problems with inoculation or establishment of pastures, would challenge this assumption given the analyses are based on well-established and productive annual legume-based pastures. Additional costs for establishing under difficult conditions (for example, late break, high weed burdens, low winter temperatures) and the risk of establishment failure may need to be considered in further analyses of these systems, although the flexibility in establishment time for G_2HSLs may mitigate some of this risk. The modelling was sensitive to any additional nitrogen applied; for example, a requirement for starter nitrogen in crops following annual legumes pastures will reduce the profitability of pastures. Growers are often reluctant to grow crops without some applied nitrogen, even after productive legume pastures, to ensure risk of yield loss from nitrogen deficiency is mitigated. Adding to this is the difficulty in measuring the organic nitrogen in the soil that may mineralise and become available to crops during the growing season.

References

Blake B (2000) *Understanding Soil pH*. New South Wales, Acid Soil Action Program, NSW Agriculture.

Bromfield SM, Cumming RW, David DJ and Williams CH (1983) Change in soil pH, manganese and aluminium under subterranean clover pasture. *Australian Journal of Experimental Agriculture*, vol 23, p181–191.

Bromfield SM (1987) Simple tests for the assessment of aluminium and manganese levels in acid soils. *Australian Journal of Experimental Agriculture* vol 27, p399–404.

Cheam AH (1987) Emergence and survival of buried doublegee (Emex australis Steinh.) seeds. *Australian Journal of Experimental Agriculture*, vol 27, p101–106.

Collins S, Wilkinson C and Huberli D (2018) Oats, pastures and other legumes. Are rotations offering breaks for root lesion nematodes or crown rot? GRDC Grains Research Updates, Perth, Western Australia.

Dunbabin MT and Cocks PS (1999) Ecotypic variation for seed dormancy contributes to the success of capeweed (Arctotheca calendula) in Western Australia. *Australian Journal of Agricultural Research*, vol 50, p1451–1458.

Farquharson EA, Ballard RA, Herridge DF, Ryder MH, Denton MD, Webster A, Yates RJ, Seymour NP, Deaker RJ, Hartley E, Gemmel LG, Hackney B and O'Hara GW (2022) *Inoculating Legumes: Practice and Science*. Grains Research and Development Corporation

Gazey C and Azam G (2018) Effects of soil acidity. DPIRD agric.wa.gov.au/soil-acidity/effects-soil-acidity

Gourley CJP, Melland AR, Waller RA, Awty IM, Smith AP, Peverill KI and Hannah MC (2007) *Making better fertiliser decisions for grazed pastures in Australia*. Department of Primary Industries, Victoria. Available at: asris.csiro.au

Freer M, Moore AD and Donnelly JR (1997) GRAZPLAN: Decision support systems for Australian grazing enterprises—II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural Systems*, vol 54, p77–126.

Hackney, B, Dear, B, Li, G, Rodham C and Tidd J (2008). *Current and future use of pasture legumes in central and southern NSW – results of a farmer and advisor survey*. Proceedings of the 14th Australian Agronomy Conference (M. Unkovich, ed.), 21–25 September 2008, Adelaide, South Australia.

Hackney B. F., Jenkins J., Powells J., Edwards C. E., De Meyer S., Howieson J. G., Yates R. J., Orgill S. E. (2019) Soil acidity and nutrient deficiency cause poor legume nodulation in the permanent pasture and mixed farming zones of south-eastern Australia. *Crop and Pasture Science* 70, 1128-1140.

Hackney B, Rodham C and Piltz J (2012). *Potential use of new generation annual pasture legumes in crop–pasture rotations in central and southern NSW*. Proceedings of the 16th Australian Agronomy Conference, Armidale.

Harrison RJ, Howieson JG, Edwards TJ, Steel EJ, Poole CM, Yates RJ (2023) Increasing wheat proteins sustainably by rotation with forage legumes. Agronomy for Sustainable Development 43 (5):56. doi:10.1007/s13593-023-00913-9

Hackney B, Wicks T, Hart J and Piltz J (2022) *Cranking up crop yields and livestock production using summer sown pasture legumes*. GRDC Updates Wagga Wagga.

Harrison R (2017) *Domesticating Lebeckia ambigua – Solving the Rhizobia Issue*. Honours Thesis. Murdoch University.

Harrison RJ, Howieson JG, Yates RJ and Nutt BJ (2021) Long-term storage of forage legumes greatly alters the hard seed breakdown pattern in situ. *Grass Forage Science*, vol 76, p72–81.

Harrison RJ, Howieson JG, Edwards TJ, Steel EJ, Poole CM, Yates RJ (2023) Increasing wheat proteins sustainably by rotation with forage legumes. Agronomy for Sustainable Development 43 (5):56.

Hartley EJ, Gemell LG and Deaker R (2012) Some factors that contribute to poor survival of rhizobia on preinoculated legume seed. *Crop and Pasture Science* vol 63, p858–865.

Howieson J, Hackney B (2017) Pasture legumes in the mixed farming zone of WA and NSW: Shifting the baseline. Final Report B.PSP.0013 Meat and Livestock Australia.

Loi A, Nutt BJ, Revell CK and Flower K (2008). *Twin Sowing: a new technique to reduce the costs of pasture establishment.* In Proceedings of the 14th Australian Agronomy Conference. 21-25 September 2008, Adelaide, South Australia. M Unkovich, ed. Australian Society of Agronomy,

Loi A, Thomas D, Yates R, Harrison R, D'Antuono M, Re G, Norman H and Howieson J (2022) Cereal and oil seed crops response to organic nitrogen when grown in rotation with annual aerial-seeded pasture legumes. *The Journal of Agricultural Science*, vol 160, p207–2019.

Masters D G, Norman H C, Thomas D T (2019) Minerals in pastures—are we meeting the needs of livestock? Crop and Pasture Science 70, 1184-1195.

Monjardino M, Loi A, Thomas DT, Revell CK, Flohr BM, Llewellyn RS, Norman HC (2022). Improved legume pastures increase economic value, resilience and sustainability of crop-livestock systems. *Agricultural Systems,* vol 203, 103519.

Nutt BJ, Loi A, Hackney B, Yates R, Harrison R and Howieson J (2021) "Summer sowing": A successful innovation to increase the adoption of key species of annual forage legumes for agriculture in Mediterranean and temperate environments. *Grass Forage Science,* vol 76, p93–104.

Peltzer SC, Matson PT (2002) *How fast do the seedbanks of five annual cropping weeds deplete in the absence of weed seed input.* In Proceedings of the 13th Australian Weeds Conference. Perth, W. Aust. (Eds H Spafford Jacob, J Dodd, JH Moore) pp. 553–555.

Piltz JW, Bailes KL, Boschma SP and Weston LA (2021) The impact of ensiling at different moisture contents on germinability and viability of selected weed species' seeds. *Agronomy,* vol 11, 1639.

Roberts D (2022) *Supplementary feeding and feed budgeting for sheep*. DPIRD https://www.agric.wa.gov.au/feeding-nutrition/supplementary-feeding-and-feed-budgeting-sheep

Roughley RJ, Gemell LG, Thompson JA and Brockwell J (1993) The number of Bradyrhizobium (*Lupinus*) applied to seed and its effect on rhizosphere colonization, nodulation and yield of lupin. *Soil Biology and Biochemistry*, vol 25, p 1453–1458

Thomas DT, Flohr BM, Monjardino M, Loi A, Llewellyn RS, Lawes RA, Norman HC (2021) Selecting higher nutritive value annual pasture legumes increases the profitability of sheep production. Agricultural Systems 194, 103272.

Yates RJ, Abaidoo R, Howieson JG (2016) *Field experiments with rhizobia*. In *Working with rhizobia*. (Dilworth MJ and Howieson JG, eds.) pp. 145–166. Australian Centre for International Agricultural Research: Canberra, ACT.

Yates R, Harrison R, Steel E, Loi A, Norman H, Thomas D, Thompson A, Poole C, Lawes R, Nutt B, Monjardino M, Flohr B, Llewellyn R, Howieson J (2022). Dryland Legume Pasture Systems (DLPS-West) GRDC Milestone 190 Final Report (UMU1805-001RMX).

Arrowleaf clover. Photo: Belinda Hackney

Notes

P Level 4, 4 National Circuit, Barton ACT 2600 | PO Box 5367, Kingston ACT 2604
T 02 6166 4500 **F** 02 6166 4599 **E** grdc@grdc.com.au