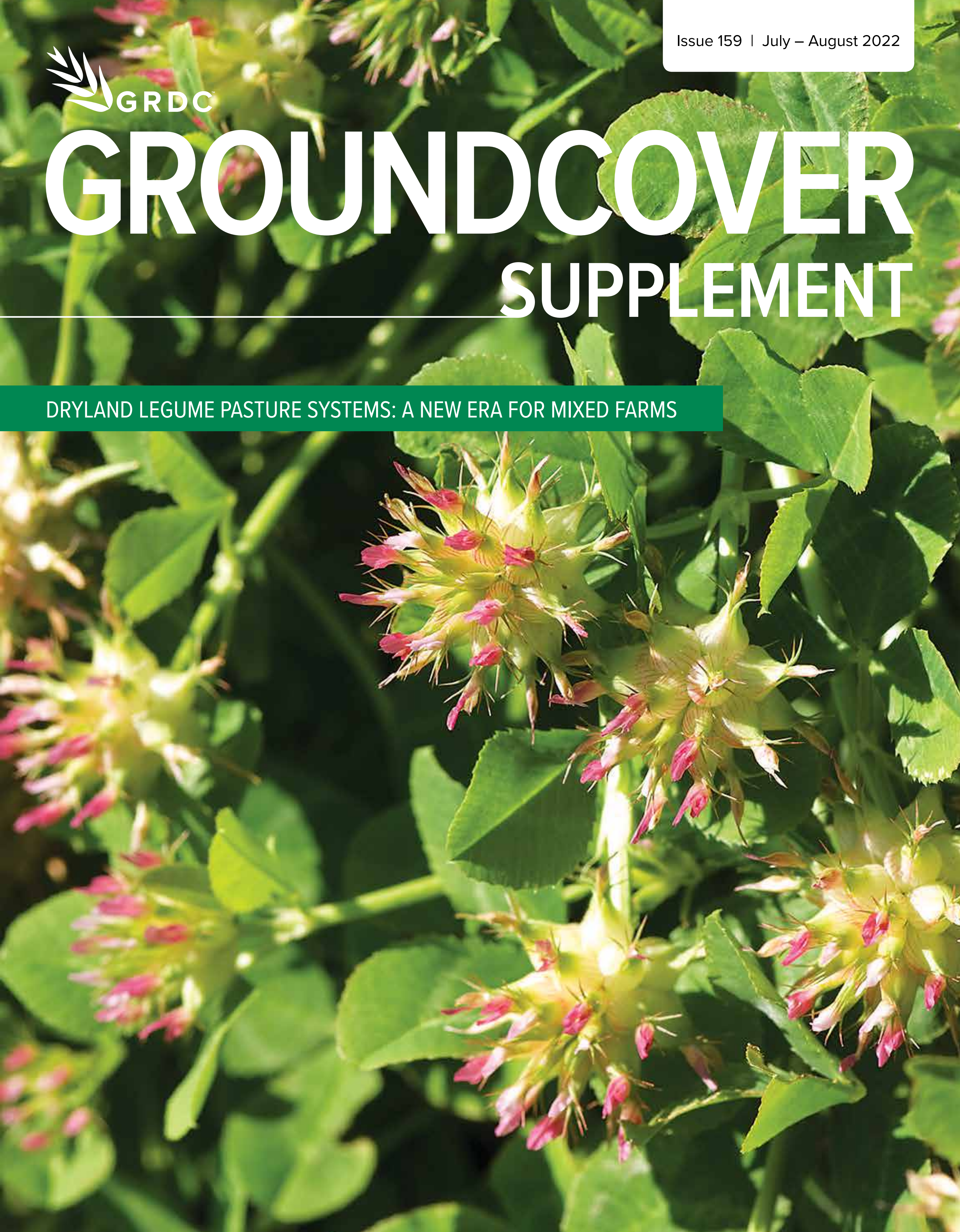

Issue 159 | July – August 2022

GRDC

GROUNDCOVER SUPPLEMENT

DRYLAND LEGUME PASTURE SYSTEMS: A NEW ERA FOR MIXED FARMS

NOVEL LEGUMES BOOST MIXED FARM PROFITS

Photo: MIG

Extensive field sites evaluating novel species as part of the Dryland Legume Pasture Systems project – such as this one hosted at the Wasley property at Canna in WA, 2020, by Mingenew Irwin Group – have formed important grower engagement bases.

By Dr Stephen Loss

■ High returns from stock and the benefits of pastures in rotations – through nitrogen fixing, weed and disease breaks and building organic matter – are encouraging growers to rethink the inclusion of pastures in mixed farms in medium to low-rainfall zones.

For the past five years, the $18 million national Dryland Legume Pasture Systems (DLPS) project has been supporting growers in making this change. It aimed to develop innovative legume pastures on mixed farms in low to medium-rainfall areas of western and southern Australia. These have been shown to boost average farm profit by 10 per cent and halve the risk of financial losses compared with intensively cropped farms.

Given competing priorities, pasture research often 'falls through the cracks' between RDCs, while commercial pasture breeding and seed companies focus on the high-rainfall zone, where grazing makes up a significant proportion of land use.

The DLPS was operational from 2017 to 2022 across four states with investment from the Australian Government Department of Agriculture, Water and the Environment as part of its Rural R&D for Profit program, GRDC, Meat & Livestock Australia (MLA) and Australian Wool Innovation (AWI).

Despite COVID-19 restrictions limiting face-to-face meetings in the final two years, national collaboration was excellent between the research partners – Murdoch University, the South Australian Research and Development Institute, CSIRO, the Western Australian Department of Primary Industries and Regional Development and the New South Wales Department of Primary Industry.

Grower groups were also integral to the operations of the DLPS – namely, Mingenew Irwin Group, Corrigin Farm Improvement Group, ASHEEP Esperance, Agricultural Innovation and Research Eyre Peninsula, Upper North Farming Systems, Mallee Sustainable Farming, Birchip Cropping Group and and Central West Farming Systems.

The project included four programs of R&D:

1 legume development and nitrogen fixation;
2 pasture benefits to cropping systems;
3 pasture benefits to livestock systems; and
4 whole-farm economics and modelling of legume pastures.

The work successfully developed and promoted low-cost legume pasture options, including serradella, biserrula, bladder clover, gland clover and medic. Together with reliable establishment techniques and management packages, research has shown the benefit they bring to both crops and livestock production on a range of soil types.

Most of the novel legumes have unique hard-seeded features and are aerial seeders, enabling them to be easily harvested and multiplied on-farm. Summer sowing of the species enables hard seed breakdown and exploitation of early breaks to the season in many areas. Twin-sowing techniques with grain crops can also reduce costs.

Results from the four R&D programs are included in this *GroundCover*™ *Supplement*, while grower case studies and outcomes from the fifth extension program are included in articles within the July–August 2022 *GroundCover*™. □

GRDC Codes UMU1805-001RMX, DAS1805-003RMX

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CONTENT CREATION AND PRODUCTION: Coretext Pty Ltd, www.coretext.com.au

GROUNDCOVER*™ *SUPPLEMENT edited by Dr Sue Knights

COVER IMAGE: Bartolo bladder clover, *Trifolium spumosum*.

PHOTO: Department of Primary Industries and Regional Development, Western Australia

PRINTING: IVE Group

CIRCULATION: Ms Maureen Cribb, 02 6166 4500

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ISSN 1039-6217 Registered by Australia Post Publication No. NAD 3994

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Spotlight on the next hard-seeded generation

By Dr Ron Yates, Ross Ballard, Dr Belinda Hackney, Robert Harrison, David Peck and Professor John Howieson

The Dryland Legume Pasture Systems (DLPS) project has built on decades of work by Murdoch University and the Western Australian Department of Primary Industries and Regional Development to develop novel hard-seeded legume pasture species, together with South Australian Research and Development Institute's continued efforts in developing medics for low to medium-rainfall regions.

These new hard-seeded species have several beneficial features: aerial seed production, seed dormancy and seeds that lack burrs and spines that could otherwise contaminate fleeces. Novel establishment methods such as summer sowing encourage seed dormancy breakdown during late summer, and germination on opening autumn rains.

Vigorous legume pastures create large, robust seedbanks, giving growers the flexibility to switch paddocks between crop and pasture production quickly – a useful attribute for growers seeking to capitalise on commodity prices or seasonal conditions. The aerial-seeding legumes can also be harvested with conventional harvesters, eliminating the need for extra machinery. The end result is a comparatively low-cost seed source for pasture renovation.

These new species have been evaluated through the DLPS project for their adaptation across southern Australian low to medium-rainfall environments and matched to their appropriate inoculant (rhizobia) group. Examples are shown in Table 1, together with new variety releases. □

GRDC Code DAS1805-003RMX

More information: Stephen Loss, stephen.loss@grdc.com.au
www.youtube.com/watch?v=rTPZBi9N9fo

Table 1: Soil requirements for optimal performance for a selection of new-generation legume species and their inoculants (rhizobia) evaluated in the Dryland Legume Pasture Systems project, together with other plant attributes. Subterranean clover is included for comparison. Varieties and accessions shown in red text were released or are near release as a result of the DLPS project.

Species, botanical name and recent variety releases	Region	pH_{Ca} (plant)	pH_{Ca} (rhizobia)	Inoculant group	Soil texture	Soil drainage requirements	Drought tolerance	Rooting depth (m)	Initial hard seed (%)	Hard seed in autumn following seed-set (%)
Arrowleaf clover (*Trifolium vesiculosum*) Cefalu	WA/c&s NSW[1]/SA/Vic	4.8–8.0	5.5–8.0	C	Sandy loam to medium clay	Well to moderately well drained	Good	1.3	>90	45-60
Biserrula (*Biserrula pelecinus*) Casbah	WA/c&s NSW Not suited for summer sowing WA	4.5–8.0	4.8–7.5	Biserrula special	Sandy loam to loam	Well drained	Excellent	1.8	>90	70-90
Bladder clover (*Trifolium spumosum*) Bartolo acc. CYP43.6.1	WA/c&s NSW/SA/Vic	5.0–8.0	5.5–8.0	C	Sandy loam to loam	Well drained	Very good	1.4	>90	45-60
Gland clover (*Trifolium glanduliferum*)	WA/c&s NSW	4.8–8.0	5.5–8.0	C	Sandy loam to clay	Well to poorly drained	Very good	1.4	90	50-60
French serradella (*Ornithopus sativus*) Margurita⁽ᵈ⁾, $Fran_2o$⁽ᵈ⁾	WA/c&s NSW/SA/Vic	4.0–7.0	4.5–7.0	G/S	Sand to loam	Well drained	Very good to excellent	1.8	>85	45-60
Yellow serradella (*Ornithopus compressus*) Avila 87GEH72.1a	WA/s NSW See note	4.0–7.0	4.5–7.0	G/S	Sand to loam	Well drained	Very good to excellent	1.8	>90	50->80
Strand medic (*Medicago littoralis*) Seraph⁽ᵈ⁾	SA/Vic	>5.8	6.0–9.0	AL	Loam to loamy clay	Well drained	Excellent	0.9	>95	75-85
Trigonella *Trigonella balansae* acc.5045early	WA/SA/Vic/c&s NSW	5.0–9.0	6.0–9.0	AM	Sandy loam to heavy clay	Good to poor drained	Very good to excellent	1.4	>90	30-50
Subterranean clover	–	4.8–8.0	5.5–8.0	C	Loam to medium clay	Well to moderately drained	Moderate	0.9	>80	5-30[2]

[1]c&s NSW refers to central and southern NSW [2]majority of cultivars
Note: Avila suited to summer sowing in reliable medium and high-rainfall regions of c&s NSW only

Hard-seeded legumes promote system agility

Flexibility is necessary in mixed-farming systems to respond to changing input costs, market opportunities and variable climatic conditions

By Dr Ron Yates, Robert Harrison, Dr Belinda Hackney and Professor John Howieson

KEY POINTS

- Productive new hard-seeded pasture legumes can bring flexibility and reduce establishment costs in low to medium rainfall zones but need to be matched to soil type and climatic conditions
- Summer sowing of unprocessed bladder clover seed and pod segments of hard-seeded French serradella cultivars has proved successful in acidic soils in WA and NSW
- Climatic and soil conditions in central and southern NSW mean other species, including arrowleaf clover, biserrula, gland clover and some cultivars of yellow serradella, are also suitable for summer sowing
- A new legume, trigonella, has performed well on both alkaline fine-textured soils in WA and acidic soils in NSW and is suitable for summer sowing – a new release is expected in a few years
- Another new legume, *Scorpiurus muricatus*, has performed well in both regions
- Matching the right inoculant to the host legume is critical to maximising nitrogen fixation potential

Photo: Dr Belinda Hackney, NSW DPI

Hard-seeded pasture legumes have unique features that can benefit farming systems. This biserrula stand photographed in 2020 was sown during the drought in 2018 at Tallimba, NSW.

■ A suite of novel pasture legumes and innovative establishment options has been under evaluation to give growers in low to medium-rainfall zones the ability to move more easily between pasture and crop sequences.

As part of the Dryland Legume Pasture Systems (DLPS) project, Murdoch University led the pasture improvement program in WA, together with researchers from CSIRO and the Department of Primary Industries and Regional Development (DPIRD). The central and southern NSW component was led by the NSW Department of Primary Industries. Similarities in the agro-ecological regions has allowed much of the learning from the western node to be transferred and adapted to NSW.

Murdoch University and DPIRD have a history of developing robust pasture legume species, including bladder clover (*Trifolium spumosum*), biserrula (*Biserrula pelecinus*) and other annual clovers such as gland clover (*Trifolium glanduliferum*). They also developed the first cultivars of hard-seeded French serradella (*Ornithopus sativus*) and new cultivars of arrowleaf clover (*Trifolium vesiculosum*) and yellow serradella (*O. compressus*).

These species have hard-seeded cultivars and produce their seed aerially. This means they can be conventionally harvested and the seed grown on-farm at comparatively lower cost. This is a clear benefit when compared with the cost and complexity of harvesting subclovers that bury their seeds and medics that drop their pods.

These pasture legumes all have unique hard-seed breakdown and germination patterns, which are affected by local environmental conditions. These include the intensity of temperature variation and soil moisture over summer and autumn.

Identifying cultivars with appropriate hard-seed breakdown patterns for the target sowing environment is key to successful establishment and ongoing persistence in the rotation.

The most progressive hard-seeded breakdown feature is the suitability for sowing in late summer. The uniform dormancy release enables unprocessed seed (or pod segments in the case of serradella) to be sown in February or March, avoiding any clash with autumn cropping operations.

Once the seedbank has been established, hard-seeded pasture legumes can regenerate on demand between crops, meaning they will grow in subsequent years without needing to be resown.

This develops a nitrogen bank for subsequent crops and also gives growers the flexibility to move from crops to pastures to meet seasonal or market opportunities that arise. During the pasture phase, the legumes provide high-quality forage.

MATCHING TO REGIONAL SOIL TYPES AND CLIMATIC CONDITIONS

Selecting hard-seeded pasture species that are widely adapted to climate and regional soil types and a range of farming systems is a challenge in a vast state such as WA. Traditionally, subclovers and medics have been used, but these species are falling behind in production and their suitability to evolving farming systems and changing climatic conditions.

However, hard-seeded varieties of species such as French serradella and biserrula have performed successfully on acid, coarse-textured soils in WA over several years. The serradella varieties Margurita⊕ and Fran$_2$o⊕, released in 2004 and 2020 respectively, have continued to be evaluated in the DLPS project.

With newly developed summer sowing practices, the new legume species have shown they can establish successfully on early autumn rains, producing more biomass, animal feed and nitrogen for following crops. They are also more competitive with weeds than current varieties.

The project has moved on to identifying new species that are adapted to WA's alkaline, fine-textured soils. Trigonella (*Trigonella balansae*), bladder clover, a couple of medic species and *Scorpiurus muricatus* have been evaluated with grower groups at Esperance, Mingenew and Narembeen.

In contrast, the temperate environments of central and southern NSW usually receive more summer rainfall than most parts of WA. The higher clay content and good soil moisture retention generally mean faster seed breakdown and more opportunities for summer sowing across a wider range of legume species.

Additional species successfully established by summer sowing in NSW include arrowleaf clover, biserrula and gland clover. Trigonella has also performed well on acidic soils (pH_{Ca} 4.8 to 5.2) in NSW, indicating it may be a useful species across a range of soil conditions.

The hard-seeded legumes have shown tremendous adaptation to variable climatic conditions, partly attributed to root systems that significantly extend past the average depth of the older medic cultivars.

In NSW, under severe drought conditions in 2019 where some sites received less than 70mm growing season rainfall, hard-seeded legumes such as biserrula set sufficient seed (>150kg/ha) for ongoing regeneration. However, subterranean clover and annual medics died before producing seed. Under the wetter-than-average seasons of 2020 and 2021, summer-sown hard-seeded legumes produced four to 10 times more herbage than conventionally sown traditional legumes.

In commercial settings, hard-seeded legumes established in the drought of 2017–19 have regenerated strongly following the break of the drought and traditional legumes have had to be resown.

Leading species or accessions for probable release and suitable for use in summer sowing include bladder clover (acc. CYP43.6.1) and trigonella (acc. APG5045 early). Additionally, the recent French serradella release (cv. Fran$_2$o⊕) from the WA node of the project showed consistent performance on acid soils in NSW and WA.

Arrowleaf clover (cv. Cefalu) continues to perform well in summer sowing situations in NSW, while the addition of a proportion of scarified seed of biserrula (cv. Casbah) to unprocessed seed has resulted in greater early vigour of summer-sown stands in NSW.

CARE WITH PAIRING RHIZOBIA

Certain pasture legumes such as French serradella are obligate nitrogen-fixing plants, which means they fix nitrogen much more efficiently than plants such as medics even when soil nitrogen levels are high.

It is vital that hard-seeded pasture species are matched with the appropriate rhizobia species to optimise production and increase soil nitrogen reserves for subsequent crops. Hard-seeded annual clovers require Group C inoculant, French serradella requires Group G/S, and biserrula requires the Biserrula Special inoculant.

Nearly all of the nitrogen-fixing strains of rhizobia are introduced to Australia from the Mediterranean region. Working with the Centre for Rhizobium Studies based at Murdoch University and supported by GRDC, the team has access to the world's largest rhizobia genebank to match appropriate elite nitrogen-fixing species and strains to the hard-seeded pasture legume species.

Photo: BPaul Sinderberry, Condobolin

Rhizobia need to be carefully matched to legume species and soil type. Pictured here is the French serradella Fran$_2$o⊕, which was inoculated with Group G/S rhizobia.

Rhizobiologists and geneticists identify stable rhizobia populations that fix nitrogen efficiently, are tolerant to desiccation and hostile soil conditions, and are suited to the inoculant manufacturing process.

The correct matching of rhizobial strain with the legume host ensures efficient nitrogen fixation for increased pasture production and benefits to following crops. Improvements in rhizobial inoculant can benefit current and new legume species. For instance, research is underway to find a better match for *Scorpiurus muricatus*, with germplasm from Morocco and Greece being assessed for both the legume and rhizobia. □

GRDC Codes DAS1805-003RMX, UMU1805-001RMX

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https://www.youtube.com/watch?v=Iq5jKkQ_qxA (Guydon Boyle case study)
https://www.youtube.com/watch?v=SM-zKtpTLwg&t=1s

Pasture legume improvement for alkaline soils in SA and Victoria

Trigonella balansae is a new pasture legume showing promise on alkaline soils in low to medium-rainfall regions of South Australia. It is related to the medics but holds its seed, allowing for harvest and cheap multiplication on-farm.

Photo: SARDI

By Ross Ballard, Fiona Tomney, Michael Moodie and David Peck

KEY POINTS

- New pasture legume species for neutral to alkaline soils in the low to medium-rainfall zones of Australia have proved challenging to find
- Annual medics continue to be the best performers in this zone, with new varieties coming on-stream
- New hard-seeded species are showing potential but must be matched to specific soil types

Annual medics have a long history of performing well across millions of hectares of neutral to alkaline soils in the low to medium-rainfall areas of South Australia and Victoria, but the adoption of new varieties is sometimes limited by the cost and supply of seed.

In recent decades, several alternative ley pasture species have been developed that produce seed or pods that can be harvested with a grain harvester. Some also have an unusual seed softening process that makes them suitable for summer sowing in February or March.

Annual medics (*Medicago* spp.) are well adapted to neutral to alkaline soils that are widespread in SA and Victoria.

The main medic species are barrel medics for loamy clays, strand medics for sandy loams and spineless burr medics for mildly acidic soils.

Medics have high levels of hard-seededness that allow them to regenerate after two to four crops, but they can also be grown in consecutive pasture years – which provides flexibility on mixed farms and benefits for following crops.

For example, at Lameroo in 2020, a single year of medic pasture increased yield of the following wheat by 1.8 tonnes per hectare, while two years of medic pasture increased wheat yield by 2.9t/ha.

As part of the national Dryland Legume Pasture Systems (DLPS) project, impressive crop benefits have been measured on soils where alternative legume species have grown well. These include French serradella (*Ornithopus sativus*), biserrula (*Biserrula pelecinus*), rose clover (*Trifolium hirtum*) and bladder clover (*Trifolium spumosum*).

But medics have been more consistent in their growth and especially in their regeneration after crops on neutral and alkaline soils (Figure 1).

The success of the annual medics has been underpinned by many decades of breeding for a range of important traits. These include aphid resistance, tolerance of sulfonylurea herbicide and Intervix® herbicide residues, tolerance of high levels of soil boron, suitable hard-seeded levels and resistance to powdery mildew.

Medics also have many registered herbicide options and are well understood by growers.

A shortfall of medics is that they drop their pods at maturity, so seeds need to be harvested with a specialised vacuum harvester. This is where some alternative legume species have an advantage, as they hold their pods and can be harvested using conventional headers.

In WA and NSW, MarguritaΦ and Fran$_2$oΦ French serradellas and Bartolo bladder clover are suitable to summer sowing, where an increased rate of hard seed or pod is sown in February. Key to the successful use of these species and summer sowing method is identifying the soil types where the alternative species perform well.

An example is provided in Figure 2, in which French serradella outperformed medic on neutral sand, whereas medic performed best on the two alkaline soils.

If interested in alternative species, we recommend initially sowing on small test areas. Sowing up and down a slope in dune/swale paddocks will allow the alternative species to experience a range of soil textures and pH, indicating which part of the landscape they best perform.

While it is necessary to inoculate the seed of all legume species, the alternative species have specific rhizobia requirements and you need to ensure that a suitable inoculum is applied.

Efforts to improve the harvestabilty of annual medics were also instigated. In preliminary work, with early desiccation of the medic sward, up to 900 kilograms of pods/ha was able to be harvested. Further work is planned for harvesting and sowing of medic pods.

NEW VARIETY DEVELOPMENT

The strand medic variety SeraphΦ (Figure 3) was released in 2021 and has 15 per cent higher production than prior varieties.

It is resistant to powdery mildew and tolerant of sulfonylurea and Intervix®

herbicide residues. Along with other contemporary medic cultivars, it has hard-seeded levels that allow it to persist and regenerate after crop, and it is soft enough to allow consecutive pastures to be grown.

Two new spineless burr medic cohorts are being evaluated for potential release: one tolerant of soil boron, another tolerant to red-legged earth mites.

A lack of pasture options for deep alkaline sands has been identified by growers as a gap, with no disc medic varieties commercially available. A cohort of disc medics is being evaluated, focusing on the release of a variety with increased ability to form more effective symbiotic relationships with rhizobia, fixing more nitrogen (Figure 4).

Trigonella balansae is a new species showing promise as an alternative to medic on alkaline soils. It is closely related to annual medic but is aerial seeded and can be conventionally harvested.

In historic work, the line APG5045 was identified as having the best agronomic performance, but its hard-seed levels have proven too low for use as a ley legume pasture.

Lines with higher levels of hard-seed have been developed. By the end of autumn 2022, hard-seededness and regeneration studies will be completed to determine whether they are suitable as a variety. Release will also depend on a favourable outcome from animal studies being completed by CSIRO to ensure this new legume is suitable for grazing.

Arrowleaf clover (*Trifolium vesiculosum*) is another aerial-seeded species showing promise on alkaline soils. The DLPS project has selected an early flowering line for the low-rainfall zone, with a 30 per cent increase in dry matter compared with Cefalu arrowleaf clover. Further evaluation is needed to determine whether it is suited for release. ☐

GRDC Code DAS1805-003RMX

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https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/02/resilient-pastures-for-low-rainfall-mixed-farms-crop-and-system-benefits-provided-by-legumes

https://grdc.com.au/events/past-events/2022/february/grdc-grains-research-update-adelaide

Figure 1: Legume production in 2019 and plant number regenerating in 2021, after a cereal crop sown in 2020. Values expressed as a percentage of medic. Values are means from four sites.

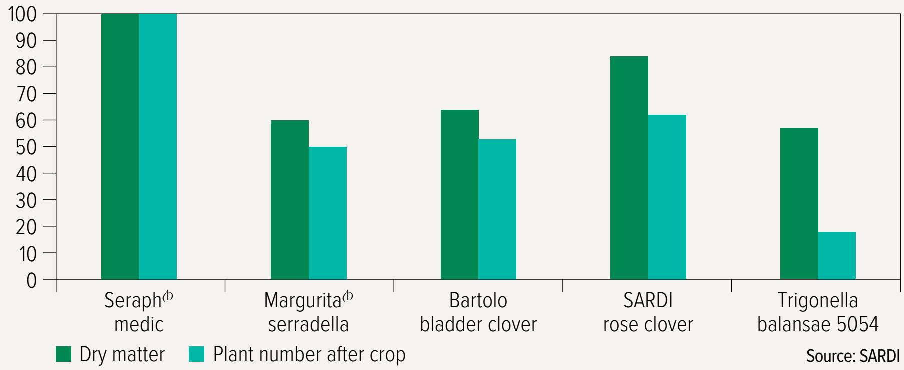


Figure 2: French serradella outperformed medics on a neutral sand at Speed (Vic) but underperformed on alkaline sites at Ungarra (SA) and Piangil (Vic).

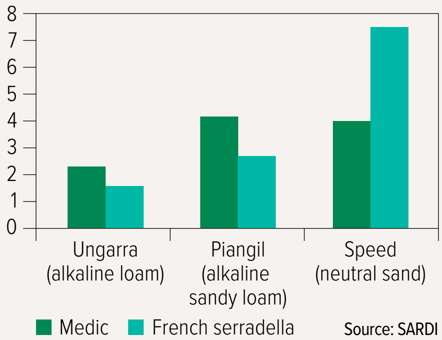


Figure 3: Seraph strand medic growing at Minnipa, SA.

Photo: Ross Ballard, SARDI

Figure 4: Variation in nitrogen fixation and growth of different medic varieties grown in hydroponics with the AL inoculant RRI-128 rhizobia (top) and a less effective strain (SRDI-148, bottom). The three disc medics on the right fix nitrogen well with both strains of rhizobia.

Photo: Ross Ballard, SARDI

Pastures that can supercharge crop sequences

Better-adapted legumes that reliably boost soil nitrogen are an answer to both higher nitrogen prices and low grain protein

By Robert Harrison and Dr Ron Yates

Photo: Robert Harrison, CSIRO

Hard-seeded pasture legumes such as this new bladder clover are proving beneficial in crop/pasture sequences in low to medium-rainfall regions.

KEY POINTS

- Better-adapted legumes in pasture phases boost yield and protein levels of following cereal crops
- It is important to use pasture legumes that are proven and efficient nitrogen fixers

Global market projections are indicating that low-protein grain will be increasingly difficult to sell, ultimately leading to greater disparity between premium and feed grain prices. Together with escalating fertiliser prices in recent years, this is driving the search for alternative means of boosting cereal protein levels. Elite legume pastures grown within crop sequences could help achieve this.

Large quantities of WA's cereal crops are not achieving grain protein levels preferred by markets due to several interacting factors. These include WA soils being highly weathered and generally low in organic matter and nutrients, a decline in forage legume density where pastures are used in cropping sequences, and growers producing more canola as a profitable break crop. This seems to be resulting in a decline in soil fertility, particularly organic matter content and nitrogen.

Continuous cropping systems, which are common in low-rainfall areas of WA, are highly dependent on synthetic nitrogen fertiliser. Its application is usually matched to crop type, soil characteristics, prevailing rainfall and crop yield potential. Improved crop varieties and agronomic management have increased yield potential considerably, but increased nitrogen fertiliser is needed to achieve these yields without compromising protein content.

Biologically fixed nitrogen from legumes in sequence with crops can significantly increase the sustainability of cropping systems and offer an alternative nitrogen source. With elite pasture varieties being developed together with new establishment techniques, a significant boost in the yield and protein levels of following cereal crops is possible – in some cases without the need to apply any nitrogen fertiliser.

As part of the national Dryland Legume Pasture Systems project, the impact of these new pasture species on subsequent cereal crops grown in dryland systems of WA has been quantified.

REGIONAL TRIALS

Rotational trials were conducted over four years at Ardath, Narembeen and Canna in WA. Soil types varied from coarse-textured acidic sands at Ardath to fine-textured loams at the other two sites.

The legumes sown differed between sites depending on the soil type and expected rainfall (Table 1). Common vetch was included as a comparison and sown on the first early rain. It does not have hard seed and needs to be resown each year.

Wheat and some barley were grown after several different pasture legumes, either sown in summer or late autumn or naturally regenerating from the established seedbank.

Soil was sampled at the start of every growing season and analysed for nutrient levels and moisture. There was no significant difference in the soil total nitrogen between plots within sites, except for the fallow plots which were significantly higher.

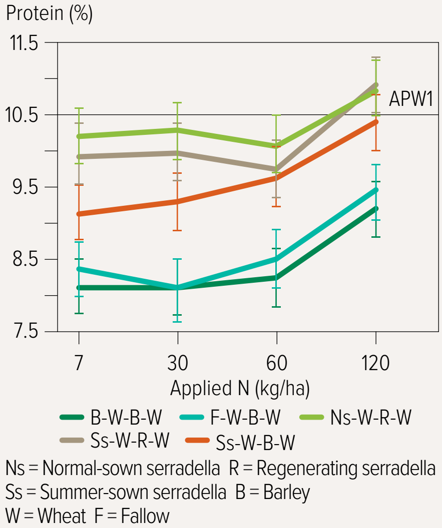
Plots in Ardath were 20 metres long, while plots in Canna and Narembeen were 10m long. Each cereal plot received fertiliser nitrogen (rates varied from four to 120 kilograms of nitrogen per hectare), applied as urea at the early tillering stage (Zadoks 20 to 25), 24 hours before a significant rainfall event (more than five millimetres).

WHEAT PROTEIN BENEFITS

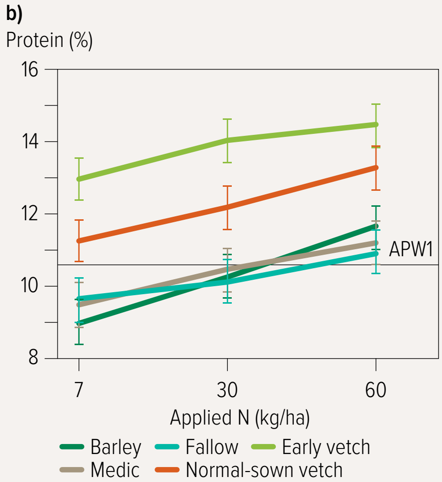
Protein levels for Scepter⦶ wheat are shown for all three sites in Figures 1a, 1b and 1c.

Figure 1: (a) Scepter⁽ᵈ⁾ wheat protein percentage in the fourth year of rotation at Ardath, where wheat yields ranged from 2.9t/ha to 4.0t/ha (b) second year at both Narembeen (wheat yields 3.2t/ha to 4.3t/ha) and (c) Canna (wheat yields 2.4t/ha to 4.2t/ha).

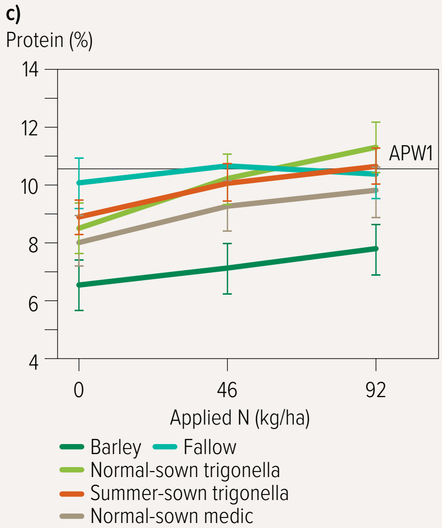
a)



b)



c)



Source: Murdoch University and CSIRO

These results demonstrate how pasture legumes, grown across three markedly different districts in dryland WA, increased grain protein levels in following wheat crops. The horizontal line in each graph indicates APW1 wheat classification.

Wheat grown in a continuous cereal rotation failed to reach the protein levels of wheat after a pasture legume, in many cases even when 120kg of fertiliser nitrogen was applied per hectare to the continuous wheat.

Efficient nitrogen-fixing pasture legumes (such as serradella, vetch and trigonella) used in rotation with cereals can allow growers to hedge on undersupplying nitrogen without significantly compromising yield and protein in high-demand wet years, while reducing the chance of oversupply in years of low demand.

OTHER BENEFITS AND CONSIDERATIONS

In general, there were small differences between the nitrogen benefits of the different pasture legume species. However, pasture species selection needs to be carefully considered. For example, medics can be poor nodulators and fix small amounts of nitrogen when the nitrogen content of the soil type is already large, compared with other pasture legumes. Therefore, the wheat crops studied had lower yield and protein levels at Narembeen and Canna when grown after medic, compared with other legume species.

But there are other rotational effects to consider. For example, deep-rooted legumes that produce large amounts of biomass tend to deplete soil moisture, unlike traditional pastures that sometimes leave moisture that benefits following crops.

Some of the hard-seeded varieties used as pasture legumes (such as serradella and bladder clover) are tolerant to the herbicide imidazoline and provide another tool for weed management within a crop/pasture rotation, especially for problem weeds such as barley grass.

An important note is that the pasture legumes in this study were not grazed by sheep. It is likely that heavy grazing will redistribute nitrogen from the systems studied but may improve the economic returns and potentially offset risk within the system, as seen in related economic modelling of pasture legume effects in rotations.

Further work will continue with crop rotation trials for trigonella to evaluate its capacity to regenerate, its water-use efficiency and ongoing benefits to subsequent crops. ☐

GRDC Code UMU1805-001RMX

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https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2022/03/cereals-after-pasture-legumes-have-higher-grain-protein-levels

Table 1: Site characteristics, annual rainfall (spring rainfall in brackets) and the pasture legumes examined at four locations in WA.

Location	pH $CaCl_2$ 0–30cm	Organic carbon %	Pasture legume	2018 rainfall (spring) mm	2019 rainfall (spring) mm	2020 rainfall (spring) mm	2021 rainfall (spring) mm
Ardath	4.9–5.6	1.0	*French serradella* (cv. Margurita)	313.6 (49.0)	179.4 (20.4)	270.4 (47.4)	423.4 (46.8)
Narembeen	5.8–7.9	0.6	*Vetch* (cv. RM4) and *medic* (cv. Scimitar)	–	253.2 (38.0)	145.0 (48.2)	511.6 (70.6)
Canna	6.0–6.5	0.5	*Trigonella* (acc. APG5045E) and *medic* (cv. Scimitar)	–	–	200.4 (14.8)	402.0 (62.0)

Source: CSIRO

Rotational benefits from resilient pastures

By Dr Bonnie Flohr, Ross Ballard and Dr Rick Llewellyn

KEY POINTS

- **Substantial increases in cereal yield and grain protein were measured after pasture or brown-manured vetch, compared with continuous cereal, in South Australia and Victoria**
- **While there were only modest differences between the effects of different pasture legumes on cereal yield, greater benefits are expected in the longer term as differences in legume regeneration and production accrue**
- **On neutral/alkaline sandy loam soils in the low-rainfall regions in SA and Victoria, vetch remains the best option to boost subsequent wheat performance where a sown legume ley of one-year duration is preferred. Medic is consistently the best option where a self-regenerating pasture is required**

■ To inform decisions about adopting new legume pasture species, a national project has been quantifying the benefits provided by these pasture species in regional mixed farm contexts in the low-rainfall zones of South Australia and Victoria.

The Dryland Legume Pasture Systems project southern component, led by the South Australian Research and Development Institute and CSIRO, has evaluated the rotational benefit of legume pasture species traditionally grown in the region. These have included medic (*Medicago littoralis*, cv. Seraph$^{\Phi}$) and vetch (*Vicia sativa*, cv. Studenica$^{\Phi}$). A number of alternative legume species were also investigated, including *Trigonella balansae* (acc. APG5045), bladder clover (*Trifolium spumosum*, cv. Bartolo), rose clover (*Trifolium hirtum*, cv. SARDI Rose) and French serradella (*Ornithopus sativus*, cv. Margurita$^{\Phi}$).

Substantial increases in cereal yield and grain protein were measured after medic pasture or brown-manured vetch, compared with continuous cereal crops.

Despite the costs of establishment, gains in subsequent crop yields alone can provide substantial return on investment, which are increased when accounting for grazing value and in the case of medic, the set-up of a pasture seedbank.

On neutral/alkaline sandy loam soils, vetch remains the best option where a sown legume ley of one-year duration is preferred. Where a self-regenerating pasture is preferred, annual medics are most commonly the best option.

ABOUT THE TRIALS

Four pasture/crop rotation trials were established from 2018 to 2021, targeting neutral and alkaline sandy loams receiving less than 400 millimetres of rainfall across SA and Victoria (Table 1). Sites were cropped with wheat in 2020 (and 2021 in Lameroo), following vetch, or one year of sown pasture, or two years of pasture sown in 2018 and regenerated in 2019.

Two-year regenerated pasture treatments were only included at Lameroo and Minnipa. The Minnipa site included large plots that were grazed by sheep. Legume break effects on following wheat grain yield, protein and available soil nitrogen were determined.

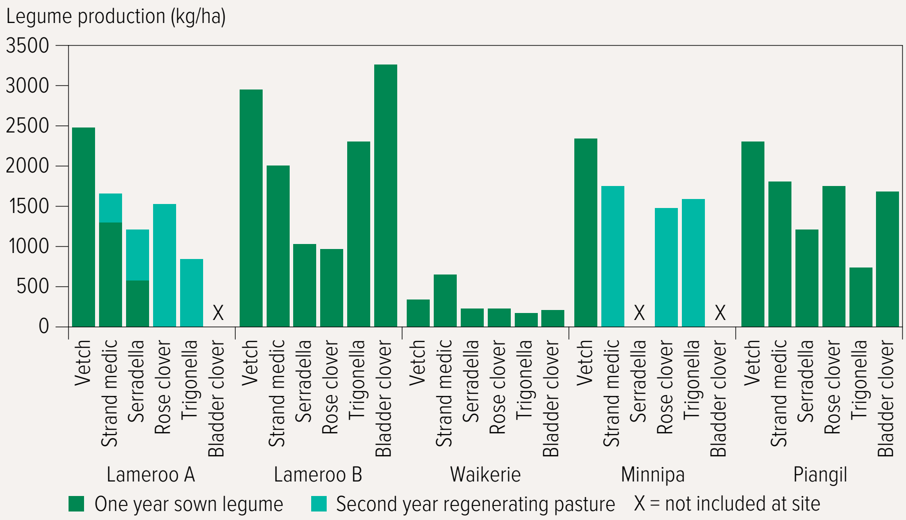
The amount of dry matter produced by the various legumes at each site is shown in Figure 1. Vetch consistently produced high dry matter over all sites, while legume production at the Waikerie site was curtailed by low rainfall in the 2019 establishment year.

The mean break effect from a one-year pasture was substantial, producing an additional 0.65 tonnes per hectare of grain yield. Wheat yield response was positive for all legumes, in the range of +24 per cent for bladder clover to +53 per cent for vetch (Figure 2).

Wheat grain protein levels also increased following a one-year legume phase, on average from 10.5 to 11.7 per cent, for all legume species.

Results following the two-year pasture phase at Lameroo and Minnipa varied. At Lameroo, benefits were greater than Minnipa. Wheat yield after two years of medic increased by 2.9t/ha, compared with the continuous cereal

Figure 1: Dry matter production by legume species in 2019 over five sites in South Australia and Victoria.



Source: SARDI

Table 1: Soil type, rainfall and rotation sequence at the four sites in the southern DLPS study.

Location	Site information	Rotation sequence and legumes
Lameroo SA A	Sand over loam pH (0–10 cm) = 7 Mean annual rainfall 381mm 2019 annual rainfall 254mm 2020 annual rainfall 457mm	Pasture/pasture/wheat/pasture Wheat/pasture/wheat/pasture Pasture/wheat Studenica^{Φ} vetch (BM), Seraph^{Φ} medic, SARDI rose clover, trigonella, Margurita^{Φ} serradella
Lameroo SA B	As above	Pasture/wheat Studenica^{Φ} vetch (BM), Seraph^{Φ} medic, SARDI rose clover, trigonella, Margurita^{Φ} serradella
Waikerie SA	Red sand pH (0–10 cm) = 8 Mean annual rainfall 253mm 2019 annual rainfall 119mm 2020 annual rainfall 326mm	Pasture/wheat/pasture Studenica^{Φ} vetch (BM), Seraph^{Φ} medic, SARDI rose clover, trigonella, Margurita^{Φ} serradella, bladder clover
Minnipa SA	Red sandy loam pH (0–10 cm) = 8.4 Mean annual rainfall 324mm 2019 annual rainfall 254mm 2020 annual rainfall 315mm	Pasture/grazed pasture/wheat/grazed pasture Volga vetch, Seraph^{Φ} medic, SARDI rose clover, trigonella, Harbinger medic
Piangil Vic	Red loamy sand pH (0–10 cm) = 7.4 Mean annual rainfall 330mm 2019 annual rainfall 211mm 2020 annual rainfall 315mm	Pasture/wheat/pasture Studenica^{Φ} vetch (BM), Seraph^{Φ} medic, SARDI rose clover, trigonella, Margurita^{Φ} serradella, Bartolo bladder clover

Source: SARDI

Table 2: Nitrogen fixation from one and two-year legume phases in Lameroo, SA.

2019 treatment	N fixation in 2018 (kg/ha)	N fixation in 2019 (kg/ha)
Rose clover – 2 years	20	25
Medic		29
Medic – 2 years	24	44
Serradella		7
Serradella – 2 years	6	25
Trigonella – 2 years	14	17
Vetch		46
P-value	<0.001	0.004
LSD	5	20

Source: CSIRO

treatment. At Minnipa, wheat yield did not increase; however, grain protein increased from 10.2 to 12 per cent.

After a one-year legume phase, available soil nitrogen preceding the wheat crop was increased on average by 36kg/ha.

Cereal yield responses at Lameroo in 2020 were attributed to increased nitrogen supply (including nitrogen fixation, Table 2) in the legume treatments that contributed to greater head number per square metre, harvest index and grain weight, along with reduced disease pressure.

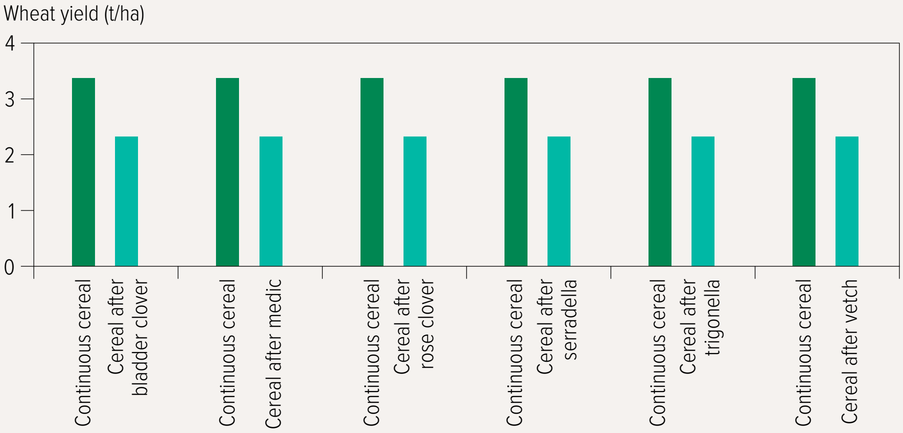
Vetch remains the best option on neutral alkaline soils in SA and Victoria, where a sown legume ley of one-year duration is preferred.

Among the pasture legume options, Seraph^{Φ} medic was the most productive overall, producing 1423kg/ha in the year of establishment and 1680kg/ha in regenerating swards. But, just as important, it has been the only treatment to consistently regenerate after the cereal crop, averaging about 500 plants per square metre.

There was not a large difference between the newly established pasture legumes in terms of the yield and protein boosts to the subsequent cereal crop. However, greater differences will likely accrue after future pasture phases due to varying ability to regenerate from a seedbank.

In the typically nitrogen-hungry Mallee cropping environment, it is possible for the yield gains in the crops that follow a pasture legume establishment phase to drive a substantial return on investment. With successful new seedbank establishment there is then the major additional value of low-cost legume establishment and livestock production from future pasture phases. □

Figure 2: Mean wheat yield response in 2020 following different single year legume phases across four sites in South Australia (excluding Minnipa) and Victoria. The two Lameroo sites received a total (sowing + in crop N) of 35 N kg/ha, Piangil (sowing + in crop N) 30 N, while Waikerie only 5kg/ha of N at sowing, with no topdress.



Source: SARDI

GRDC Code DAS1805-003RMX
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Crop/pasture flexibility lifts system agility

Growers' ability to switch between pasture and crop phases has been given a boost by hard-seeded legumes

By Dr Belinda Hackney and Tyson Wicks

■ Hard-seeded legume pastures are providing a step change in sustainability, flexibility and risk management for many mixed farmers in medium to low-rainfall zones across Australia.

To further inform growers, the capacity of these comparatively new legume species to support following crop production has been under evaluation at several sites in NSW as part of the national Dryland Legume Pasture Systems project.

In 2019, near Ungarie, several annual legumes were grown under severe drought conditions in a replicated experiment, with wheat included as a control check treatment. In 2020 the site was sown to wheat with the plots split for nitrogen treatment.

Fertiliser nitrogen treatments were either nil, applied at sowing only (as MAP) or applied at sowing plus topdressing with urea at Zadoks growth stage (GS) 31.

Despite the severe drought in 2019, all hard-seeded legumes established well and produced a moderate amount of biomass and seed, exceeding the performance of subterranean clover. They provided sufficient nitrogen to support wheat yields in 2020 of 3.8 tonnes per hectare, or more, without the addition of nitrogen (Figure 1).

Application of nitrogen at sowing, or at sowing and again at GS31 did not increase the grain yield above that achieved by the nitrogen provided by the legumes alone.

In contrast, both the continuous cereal and subterranean clover treatments showed significant response to the addition of nitrogen at sowing, with a further significant increase if nitrogen was also applied again at GS31.

With the continuous cereal and subterranean clover treatments, application of nitrogen at sowing and at GS31 was required to produce an equivalent grain yield to crops that followed the hard-seeded legumes with no applied nitrogen.

Results for grain protein followed a similar pattern. Wheat grown after hard-seeded legumes achieved 12 to 14 per cent protein without addition of any nitrogen, compared with eight to nine per cent protein when wheat was grown in the continuous cereal rotation, or after subterranean clover. Application of nitrogen at sowing and GS31 was required to lift grain protein to 11 per cent in the continuous cereal rotation.

SYSTEM AGILITY

Once a seedbank of hard-seeded legumes is established, pasture/crop rotations can be managed flexibly in response to seasonal conditions, commodity prices and farm logistics.

With an on-demand legume seedbank in place, growers can be flexible and change their livestock-to-crop ratios reasonably quickly.

For example, if seasonal conditions are predicted to be poor and high risk for cropping, then paddocks with a seedbank of hard-seeded legumes can be allowed to regenerate for grazing, to build soil nitrogen for subsequent crops, or both.

Alternatively, if returns from cropping are high, then paddocks can be cropped and the legume seedbank left to regenerate after the crop.

With increasing fertiliser costs, the hard-seeded legumes provide a way to reduce input costs and minimise risk by allowing a flexible switch between crop and pasture production in low to medium-rainfall environments, such as southern NSW. □

Photo: Paul Sinderberry, Condobolin

A stand of regenerating biserrula in early winter, north of Condobolin, NSW, in 2021. Hard-seeded legume species such as biserrula enable growers to easily switch between crop and pasture phases.

GRDC Code DAS1805-003RMX

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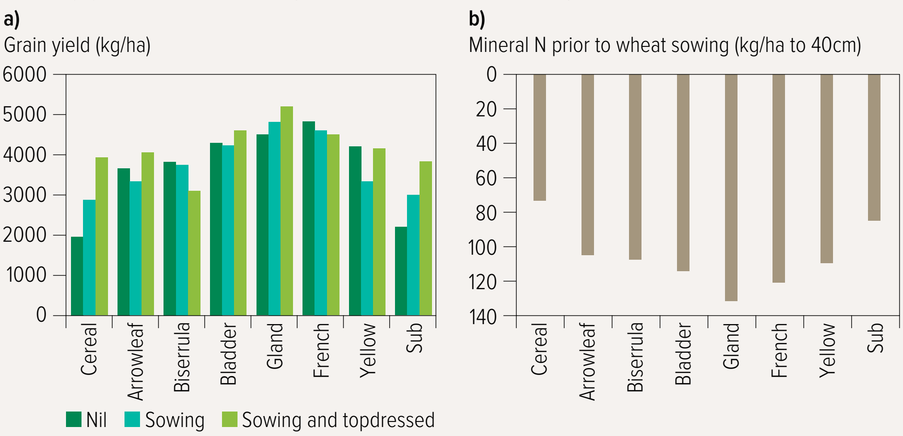
Figure 1: (a) The grain yield of wheat (kg/ha) where no nitrogen, nitrogen at sowing only or nitrogen at sowing and at GS31 was applied in 2020 following a range of hard-seeded annual legumes, wheat or subterranean clover sown in 2019. (b) Soil mineral nitrogen prior to wheat sowing in 2020.



Source: NSW DPI

The hard-seeded nature of novel pasture legumes

By Dr Ron Yates, Robert Harrison, Dr Belinda Hackney and Professor John Howieson

New summer sowing strategies have been developed through the national Dryland Legume Pasture Systems project and customised for medium to low-rainfall zones where pastures are grown in rotation with crops.

It is critical to check local trial results and grower experience to decide which species and variety are suited to summer sowing in your area. This is because it is essential to match the patterns of hard-seed breakdown to the climatic and soil conditions that drive breakdown over summer and early autumn.

Initial field trials in WA suggested bladder clover (*Trifolium spumosum*) and the hard-seeded French serradella cultivars (*Ornithopus sativus*) were suitable for summer sowing in WA's hot, dry conditions during February and March.

However, a broader range of hard-seeded legume species proved suitable for summer sowing in southern NSW, including arrowleaf clover (*Trifolium vesiculosum*), gland clover (*Trifolium glanduliferum*), biserrula (*Biserrula pelecinus*) and some cultivars of yellow serradella (*Ornithopus compressus*).

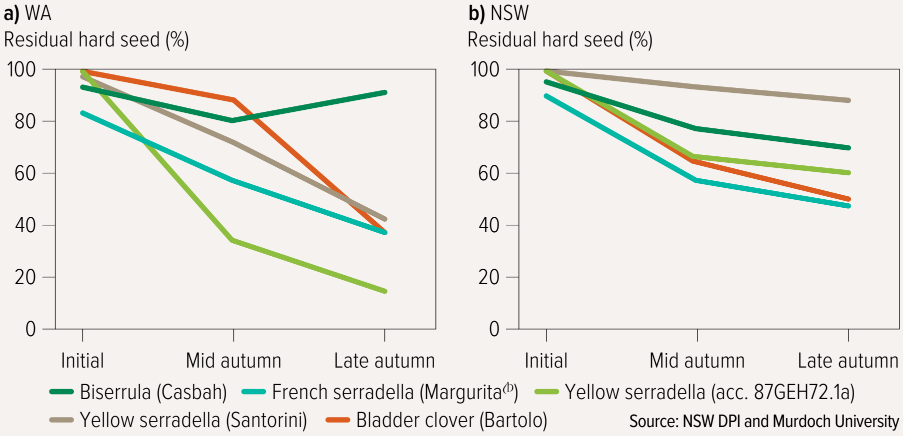
BREAKDOWN PATTERNS

Hard-seededness is a form of dormancy, an evolutionary trait that ensures seeds do not germinate even in seemingly optimal conditions, or may germinate in a staggered fashion to spread the odds of survival.

Seed dormancy traits and their breakdown patterns can be genetically diverse and interact with local environments. The challenge has been to find species and varieties with optimum breakdown patterns to enable summer sowing in low to medium-rainfall zones of Australia.

Figure 1 shows the patterns of hard-seed breakdown of several pasture legumes in WA and NSW. The pattern displayed by biserrula in WA is clearly unsuitable for summer sowing, with less than 10 per cent of seed softening by late autumn, whereas more than 30 per cent softened in NSW.

Figure 1: The hard-seed breakdown of five hard-seeded annual forage legumes for numerous sites across WA and central and southern NSW.



Source: NSW DPI and Murdoch University

In comparison, bladder clover, French serradella and yellow serradella (acc. 87GEH72.1a) had enough hard-seed breakdown over summer and into autumn in WA and NSW to be suitable for use in summer sowing.

It appears that hard-seed breakdown in many pasture legumes is faster in NSW compared with WA because of higher humidity, more frequent summer rain and soils with greater clay content, which help retain soil moisture for longer.

RESIDUAL HARD-SEED LEVELS

The residual hard-seed levels are an important consideration when selecting species and variety for inclusion in crop rotations. This is a measure of how much of the seed produced in a given season will remain dormant by the following autumn and winter.

High levels of residual hard-seed mean the legume seedbank will be more persistent within a cropping rotation and will be able to regenerate after one or more crops without the need for resowing.

Generally, legume varieties with residual hard seed of 40 to 60 per cent are well-suited to alternating years of pasture and crop. Given a couple of years of good legume growth and seed-set, a sufficient seedbank will be established to regenerate the legumes after two years of crop. For legumes with even higher hard-seed levels (more than 70 per cent), cropping phases of two to four years are feasible.

Photo: Dr Belinda Hackney, NSW DPI

Being aware of the breakdown pattern of the hard-seeded feature of novel pasture legumes such as biserrula can help match the best species to soil type and climatic conditions. This biserrula paddock has regenerated after three years of crop in NSW.

This sort of knowledge informs growers' selection of appropriate species for their environment and their management, and guides plant breeders in the development of future varieties suitable for changing climates. □

GRDC Code UMU1805-001RMX

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Twin and summer sowing pasture revolution

Demonstrating the benefits of summer sowing hard-seeded legumes. Left to right: Summer-sown Bartolo bladder clover, conventionally sown arrowleaf clover and summer-sown arrowleaf clover. Photo taken 16 August 2021 at Condobolin, NSW.

Photo: Dr Belinda Hackney, NSW DPI

By Dr Ron Yates, Robert Harrison, Dr Belinda Hackney and Professor John Howieson

KEY POINTS

- Novel sowing techniques such as twin and summer sowing are proving an economical strategy to establish hard-seeded legume pastures in low to medium-rainfall areas
- Be aware of genetic-by-environment effects on species performance and select species and variety accordingly
- Paddock preparation is the key for pasture legume success

■ Twin and summer sowing are two establishment techniques transforming pasture renovation in Australia's low to medium-rainfall mixed-farming regions.

The innovative techniques were developed to establish pastures without interfering with the busy autumn and winter sowing period for crops. Traditionally, pasture paddocks are sown after the cropping program, often in June or July, but these pastures suffer from slow germination and poor early growth.

Pasture seed is often scarified to break down hard-seededness and ensure good establishment when sown in autumn or winter. However, the novel establishment techniques are suited to using unprocessed seeds or pods, which then have their dormancy broken down naturally over the summer and early autumn period.

These innovative methods, developed through the Dryland Legume Pasture Systems project, lower the cost and risk of failure of pasture establishment. Additionally, as these legumes are aerial seeders, the seed can be produced on-farm using conventional equipment, which further reduces its cost.

SUMMER SOWING

For some legumes varieties, unscarified hard seeds or pods can be sown in February to March. After sowing, summer temperature and humidity fluctuations aid the breakdown of the hard seed to provide 30 to 50 per cent of seed ready for germination at the break of the season.

Summer sowing enables pastures to establish immediately after favourable rainfall in February or March, which provides a significant advantage over winter-sown pastures. Not all of the seed loses its dormancy; the remaining hard seeds are an 'insurance policy' against a false break. The seed dormancy breaks down during winter and spring and over the subsequent seasons.

Figures 1 and 2 show the performance of hard-seeded legumes at Canna, WA, and Condobolin, NSW, using summer sowing or conventional sowing with scarified seed in late autumn. There are subtle differences in the summer and autumn conditions between these regions that influence the breakdown of hard-seededness and the choice of legume variety.

Studies in WA and southern NSW showed that the seed dormancy can be sufficiently broken down over a four-to-six-week period to produce about 150 seedlings per square metre following opening season rains. A 1.5 to tenfold increase in herbage production was achieved relative to subterranean clover sown conventionally in winter.

TWIN SOWING

Twin sowing entails sowing pod or unscarified seed with high levels of hard-seededness (more than 90 per cent) together with grain crops in May/June the year prior to a pasture phase. This reduces establishment costs, as the pasture legumes and crop are sown in one operation.

With this method of sowing, the legume seed is lightly buried in the soil for an entire cropping season. It does not germinate in the crop due to its dormancy, but softens over the summer following harvest of the winter grain crop and is ready to germinate at the break of the next season in the autumn.

While twin sowing has been successful, its efficiency in terms of emergence of seedlings per kilogram of seed sown is generally lower than for summer sowing. However, twin sowing can be a more effective way to establish pasture than conventional cover cropping.

COVER CROPPING

Cover cropping involves sowing scarified seed at a reduced rate with the previous crop, so that the pasture germinates and grows under the crop. In many cases the pasture has difficulty competing for light and moisture with the crop, causing poor growth and seed production. Reducing the crop density can help address this. Cover cropping also reduces in-crop herbicide flexibility.

Twin sowing has many advantages over cover cropping. It removes the need to scarify the legume seeds and the competition with the crop, as the year within crop simply acts as a period for seed softening. There is no requirement to cut back the sowing rate of the final crop in the rotation and it does not reduce herbicide options.

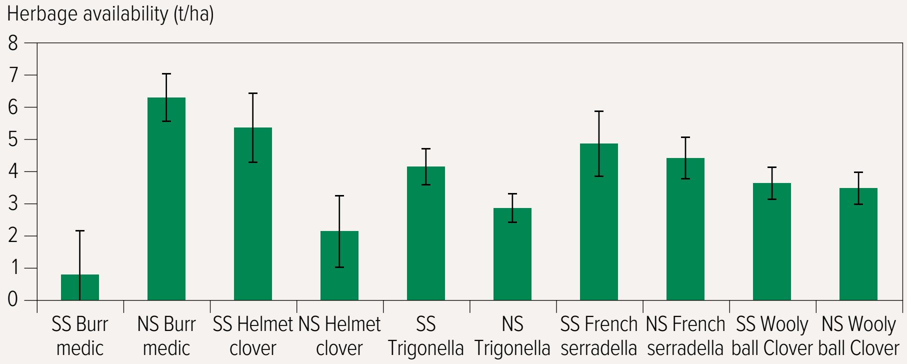
CONSIDERATIONS

Paddock preparation for summer and twin sowing

1 Good weed management prior to sowing is paramount. Excessive weed competition is the leading cause of pasture establishment failure with the novel techniques. A minimum of two, but preferably three, years of stringent weed management leading into pasture sowing is recommended.

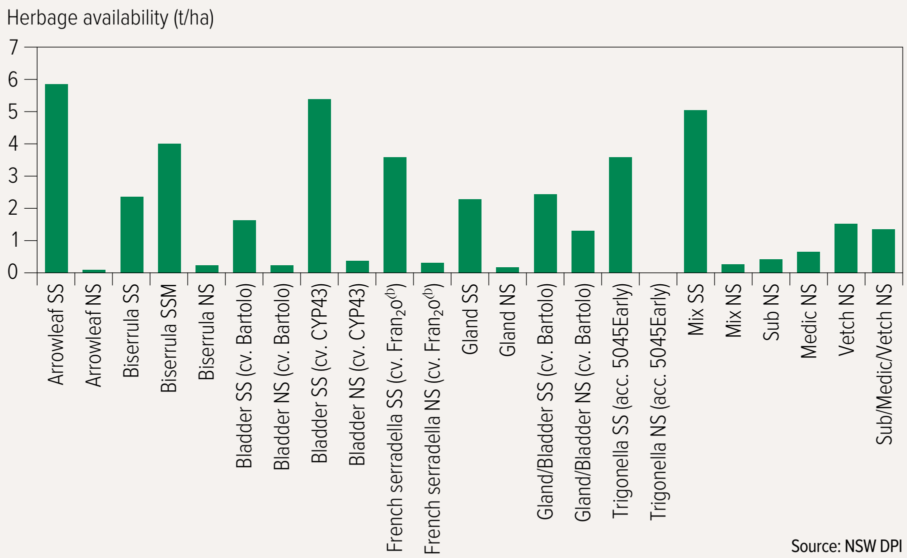
Check for potential herbicide carryover prior to sowing a new pasture. Factors that can influence herbicide breakdown and hence plant-back requirements include time elapsed since application, rainfall received since application, soil moisture conditions, soil pH, soil texture and the application rate. Make sure to abide by all label requirements and, if in any doubt, seek advice.

Figure 1: Herbage availability (t/ha) of summer-sown (SS) and normal-sown (NS) pasture legumes at Canna, WA, harvested 2 September 2020. Error bars represent standard error.



Source: Murdoch University and CSIRO

Figure 2: Herbage availability (t/ha) in mid-August 2021 for a range of annual legumes sown as unprocessed seed in summer (SS) or as scarified seed in late May (NS) at Condobolin, NSW. Four conventional species sown as scarified seed in late May are shown on the right-hand side. Note that the treatment 'Biserrula SSM' contained a mixture of 75 per cent unprocessed and 25 per cent scarified seed sown in summer; the treatment 'Mix SS' contained a mixture of all species used in summer sowing.



Source: NSW DPI

Sowing rate and depth

2 Ensure the pasture seed is sown at one to two centimetres. Deeper placement will reduce emergence and is a common cause of establishment failure, especially with twin sowing. For twin sowing, some growers have successfully dropped the seed or pods on the soil surface in front of the cereal sowing tynes and relied upon soil scatter at seeding to give sufficient burial.

Inoculants

3 It is critical when sowing any legume that an inoculant is used containing the correct rhizobia for that particular legume species, especially if the legume has not been grown in the paddock for the past three or four years. Granular inoculants are convenient to use and can provide superior rhizobial survival and nodulation over peat when sowing into dry soil. If using a peat inoculant, make sure treated seed is sown within 12 hours and kept out of direct sunlight.

Management in the establishment year

4 The main goal in the pasture establishment year is to achieve adequate growth and seed-set for future regenerations. Careful monitoring is required for signs of insect pests such as budworm, red-legged earth mite and aphids.

Where a high weed population occurs, it is important to start management early while the weeds are small. The tolerances of hard-seeded legumes to herbicides can vary considerably and it is important to seek advice on registered options.

In some situations, other options might be appropriate. For example, biserrula is somewhat unpalatable to grazing animals – which prefer annual ryegrass, wild radish and capeweed – so grazing will often reduce weed numbers. Weed wipers have also proven effective in killing weeds that sit above the pasture canopy later in the growing season, or where grazing has been used to reduce pasture height below that of the target weeds. □

GRDC Code UMU1805-001RMX

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Sowing strategies in SA and Victoria

By Dr Bonnie Flohr, Ross Ballard, Michael Moodie, Dr Therese McBeath and Dr Rick Llewellyn

KEY POINTS

- Summer and twin sowing benefits are greatest with an early break
- Summer sowing is possible with medic pods but provides limited production advantages over conventional sowing techniques
- Some legume species are suitable for summer and twin sowing but are less well-adapted or productive on a neutral pH sand
- Sowing depth is important for twin and summer sowing into dry soils
- Novel establishment methods are only suitable for weed-free paddocks

■ A shift towards early sowing, combined with a drying trend in autumn across southern Australia, means growers need adapted varieties and sowing strategies that provide more flexible plant establishment around the seasonal break.

On mixed livestock/cropping farms, sowing of pastures can clash with cropping programs and is often left to the end of the sowing program. Novel pasture establishment techniques include the use of unscarified 'hard seed' of adapted pasture varieties, sown either in late summer (summer sowing) or with the previous crop (twin sowing, Figure 1).

Novel pasture sowing practices avoid peak crop sowing times, reduce establishment costs and increase early season feed supply for animals. But they have had limited evaluation in low to medium-rainfall environments of South Australia and Victoria until more recently within the Dryland Legume Pasture Systems project.

This has been addressed more recently within the Dryland Legume Pasture Systems project.

SEASONAL BREAK ANALYSIS

The potential for production benefits associated with summer and twin sowing is moderated by the date of the seasonal break.

The seasonal break across the southern Australia was defined as seven-day period when mean rainfall exceeded evaporation between 1 March and 30 July. This was derived from long-term (1971–2018) climate data for the southern cropping belt.

In environments with a greater probability of an early seasonal break (for example, south-eastern Victoria, NSW), summer sowing will likely be more advantageous as the warm soil conditions support rapid germination and early growth for the autumn feed gap, and an extended growing season can be exploited more often (Figure 2).

ESTABLISHMENT AT LAMEROO

Three pasture sowing methods were evaluated in field experiments at Lameroo in the above-average 2020 growing season (457 millimetres, average 381mm) and included legume pasture species traditionally grown in the region – medic (*Medicago littoralis* cv. Seraph⁽ᴾ⁾) and vetch (*Vicia sativa* cv. Studenica⁽ᴾ⁾), as well as several alternative legume species. These were *Trigonella balansae* (acc. 5045), bladder clover (*Trifolium spumosum* cv. Bartolo), rose clover (*Trifolium hirtum* cv. SARDI Rose) and French serradella (*Ornithopus compressus* cv. Margurita⁽ᴾ⁾). The soil type at Lameroo is sand over loam (zero to 10cm pH in $CaCl_2$ is 7.0).

The sowing methods evaluated were:

- twin sowing (20 May 2019), where hard pasture seed/pod was sown with wheat seed in 2019 for 2020 pasture establishment;
- summer sowing (18 February 2020), where hard seed/pod was sown to germinate on the autumn break; and
- autumn sowing (28 April 2020), representing grower practice, where scarified germinable seed was sown on the break of the season.

An early break in the first week of March 2020 enabled early establishment of pasture species from summer sowing. This resulted in higher winter biomass

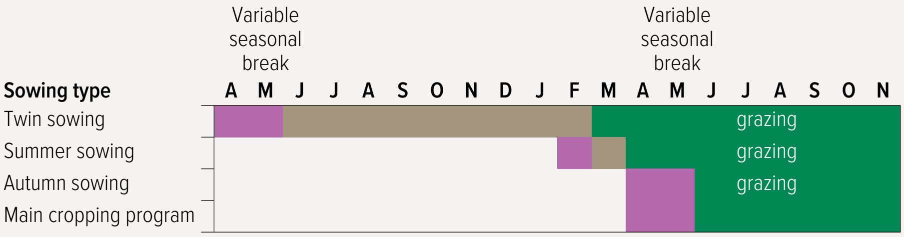
Table 1: Summary of novel establishment methods with pasture species at the three sites.

Location	Species (cultivar)	Sowing method*		
		Twin	Summer	Autumn
Lameroo	Bladder clover (Bartolo)	Red	Green	Green
	Strand medic (Seraph⁽ᴾ⁾)	Orange	Green	Green
	Rose clover (SARDI Rose)	Red	Red	Orange #
	French serradella (Margurita⁽ᴾ⁾)	Red	Red	Orange #
	Trigonella balansae (5045)	Red	Orange #	Orange #
Waikerie	Bladder clover (Bartolo)	Red	Orange +	Orange +
	Strand medic (Seraph⁽ᴾ⁾)	Orange	Green	Green
	Rose clover (SARDI Rose)	Red	Orange +	Orange +
	French serradella (Margurita⁽ᴾ⁾)	Orange +	Orange +	Orange +
	Trigonella balansae (5045)	Red	Orange +	Orange +
Piangil	Bladder clover (Bartolo)	Green	Orange	Green
	Strand medic (Seraph⁽ᴾ⁾)	Green	Green	Green
	Rose clover (SARDI Rose)	Green	Orange	Green
	French serradella (Margurita⁽ᴾ⁾)	Green	Green	Green
	Trigonella balansae (5045)	Red	Orange +	Orange +

Green = good establishment and production, **orange** = uncertain of suitability to environment and method, **red** = poor establishment and production. **+** indicates that establishment was adequate (>80 plants/m²) but production was low at the site, and **#** indicates inconsistent production results between experiments at the same location. *Single year experiments only.

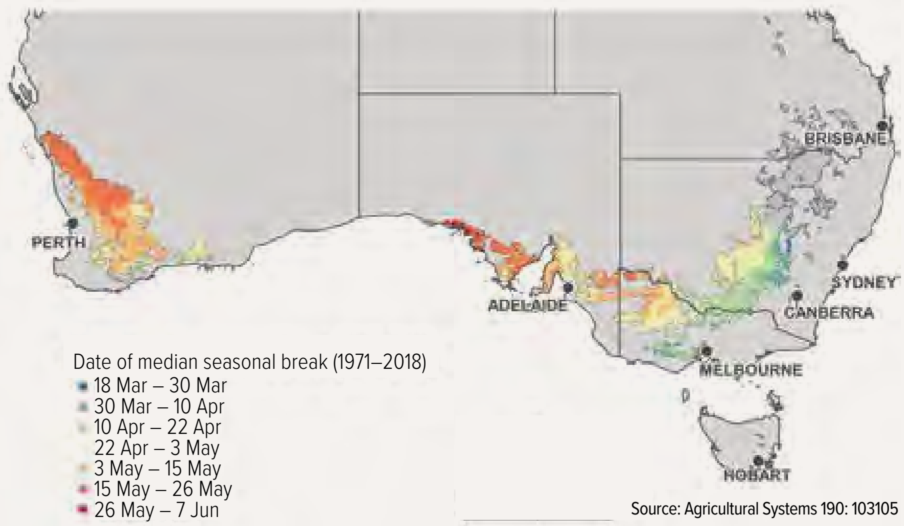
Source: CSIRO

Figure 1: Timeline of sowing date (purple), hard-seeded breakdown (brown) and plant growth period (green) of pasture sowing methods tested.



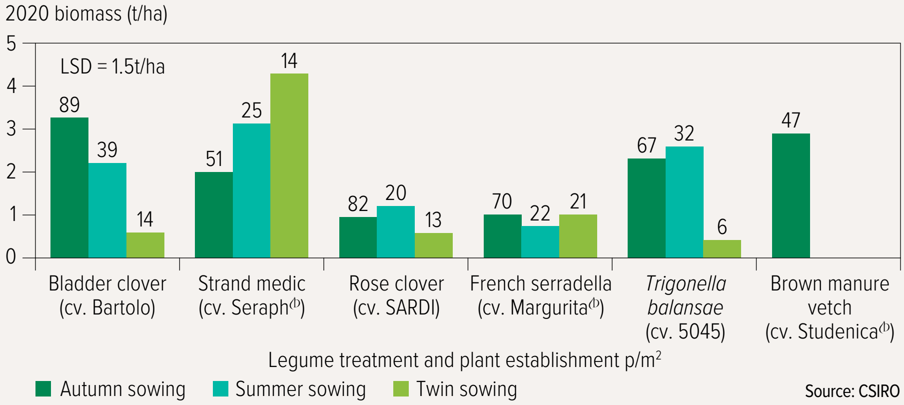
Source: CSIRO

Figure 2: Median seasonal break (1971–2018) in cropping regions throughout southern and western Australia based on the seven-day rolling sum of the rainfall to evaporation ratio.



Source: Agricultural Systems 190: 103105

Figure 3: September biomass* production of legume pasture species via autumn, summer and twin-sowing methods at Lameroo in 2020, LSD (5%) 1.5t/ha, P-value <0.001. The number above each column is plant number per m², LSD (5%) 14, P-value <0.001. *biomass includes background medic in twin sowing.



Source: CSIRO

production for summer-sown trigonella and medic compared with autumn-sown (Figure 3). However, summer-sown bladder clover had low plant density and growth compared with the autumn-sown plots.

Rose clover and serradella established adequate plant numbers from autumn sowing, but overall biomass production was low on the neutral pH sandy soil. Weed density was greatest in summer-sown (13 weeds per square metre) and twin-sown (eight weeds/m²), compared with autumn-sown (three weeds/m²).

Pasture establishment and production were generally low for all species when twin sowing was implemented, presumably due to furrow in-fill post-seeding resulting in excessive seed burial. Sowing depth needs to be addressed before twin sowing can be recommended for pasture establishment in these environments.

At Lameroo, bladder clover and trigonella production were competitive with medic when sown in autumn and were the best novel pasture options for this site.

The same sowing practices were also evaluated at Waikerie (SA, red alkaline sand 0–10cm pH $CaCl_2$ = 8) and Piangil (Victoria, red loamy sand 0–10cm pH $CaCl_2$ = 7.4) in the 2019 season. Both sites had below-average rainfall with a dry summer and autumn, and all treatments were established within two weeks of each other. Under the dry conditions twin and summer sowing produced no advantage over autumn sowing (Table 1).

At Waikerie, bladder clover, rose clover, serradella and trigonella established adequately from twin, summer and autumn-sown treatments (more than 80 plants/m²). However, biomass production was significantly less than medic, suggesting that these species were suitable for the novel sowing methods but were not well-adapted to the Waikerie soil type and environment.

At Piangil, all species established well with twin or summer sowing and had biomass production competitive with autumn-sown medic, except for trigonella, and summer-sown bladder and rose clover. In this environment, summer and twin-sown serradella production was competitive with medic.

Table 1 summarises the performance of the novel pasture legume species under various sowing methods for one year of experiments across three Mallee sites. The performance of species may depend on the environment and the frequency of seasons that offer early establishment opportunities, which are typically infrequent in low-rainfall southern environments compared with high-rainfall zones or southern NSW. ☐

GRDC Code DAS1805-003RMX

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https://grdc.com.au/events/past-events/2022/february/grdc-grains-research-update-adelaide

Novel hard-seeded and aerial-seeded legume pastures are providing a step change for pasture/crop sequences. The ability to be harvested on-farm with conventional machinery, such as this biserrula at Beckom in NSW, significantly reduces costs for growers.

Photo: Dr Belinda Hackney, NSW DPI

Harvest tips for hard-seeded pasture legumes

The aerial-seeded feature of many novel pasture legumes enables them to be direct-headed with conventional machinery – but they have their own individual considerations

By Dr Ron Yates, Dr Belinda Hackney and Professor John Howieson

■ Novel hard-seeded pasture legumes provide flexibility and reduce risk through alternative methods for pasture establishment, such as summer sowing, and create more flexible crop/pasture rotations. Additionally, seed costs can be reduced by harvesting these legumes on-farm with a conventional header, but each has their own individual characteristics to consider.

We recommend buying a small quantity of seed that can be grown in a nursery paddock and then using that seed to initiate a summer sowing program. The seed purchased for the nursery paddock, if coming from a reseller, will be scarified and a high percentage (usually more than 90 per cent) will germinate soon after sowing.

For that reason, sow your nursery paddock as you would a traditional legume such as subterranean clover or annual medic; that is, from mid-autumn onwards. Sowing rates for scarified legumes range from five to 10 kilograms per hectare depending on species, regional climatic conditions and machinery spacing.

When starting out with new hard-seeded legumes, many growers try three to five species in individual nursery blocks of five to 10 hectares each. This approach enables growers to evaluate the performance of various species on their farm without committing to a large financial outlay. They can then harvest the seed from species that performed best and use it to sow other areas of the farm.

The pods of hard-seeded pasture legumes are varied in shape, size and fibrous nature and this has implications for harvest (Figure 1 and Table 1).

From our work with growers in NSW over the past decade and more recently with the Dryland Legume Pasture Systems project, the typical quantity of seed of annual legume species harvested with a header is shown in Table 1. The range in seed yields achieved reflects differences between regions (that is, low versus medium-rainfall) and seasonal conditions.

While these seed yields might appear low compared with yields achieved by winter crops, it needs to be remembered that the seeding rates for pasture sowing are much lower. For example, when using the unprocessed seed harvested on-farm for summer sowing, the rates required are 10 to 12kg/ha for arrowleaf clover, biserrula, bladder clover or gland clover, and 20 to 30kg/ha for serradella pods. Therefore, a small nursery paddock can yield enough seed to sow large areas.

It is important to note that some cultivars of hard-seeded legumes, such as the French serradellas Margurita$^{\Phi}$ and Fran$_2$o$^{\Phi}$, are protected by Plant Breeder's Rights. This means growers are able to harvest seed of these cultivars for their own use, but it is illegal to sell off-farm without a licence. ☐

GRDC Code UMU1805-001RMX

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Photo: Dr Ron Yates, Murdoch University

Bladder clover is a prolific aerial seeder that can be direct-headed.

Figure 1: Pods and seed of a range of hard-seeded legume pasture species.

Photo: Dr Belinda Hackney, NSW DPI

Table 1: Typical seed yield and harvest considerations for a range of hard-seeded pasture legumes in NSW.

Species	Seed yield and comments on harvest
Arrowleaf clover (*Trifolium vesiculosum*)	300 to 800kg/ha. Many growers windrow arrowleaf clover for harvesting as the cultivars are relatively long-season and this prevents green stalks blocking the header.
Biserrula (*Biserrula pelecinus*)	100 to 350kg/ha. Best harvested under hot, dry conditions. Raking into windrows generally results in higher yields. Total seed available for harvest ranged from 500 to 1000kg/ha, but as the pod is papery, a lot passed through the header which will contribute to regeneration in subsequent years.
Bladder clover (*Trifolium spumosum*)	300 to 1200kg/ha. Bladder clover is a prolific seeder and is relatively easy to harvest.
Gland clover (*Trifolium glanduliferum*)	250 to 600kg/ha. Gland clover has a very high harvest index and harvests very well.
French serradella (*Ornithopus sativus*)	300 to 1000kg pod segments/ha. French serradella harvests well via direct heading.
Yellow serradella (*Ornithopus compressus*)	200 to 500kg pod segments/ha. Some of the old cultivars have hooked pods that can become entangled in the box, and growers recommend only filling the box to one-third to one-half to prevent problems augering out the pods.

Source: Dr Belinda Hackney, NSW DPI

Novel pasture legumes pass the livestock test

For mixed growers, novel pasture legumes provide improved nutritional value for livestock – and new research shows some have high survival after ingestion by sheep

By Dr Hayley Norman, Andrew Thompson, Ross Ballard, Jessica Gunn and Dr Belinda Hackney

Photo: Anvil Media

Large replicated grazing trials of trigonella, French serradella and subclover at Mokine, WA.

■ Livestock weight gain while grazing novel legume species in spring was similar in research trials to subterranean clovers and medics, but offers additional, unique agronomic advantages and some variation in nutritional value.

Research by CSIRO, the South Australian Research and Development Institute (SARDI) and the New South Wales Department of Primary Industries has been identifying the benefits of novel pasture legumes for livestock production as part of the national Dryland Legume Pasture Systems (DLPS) project.

The ability of a pasture to produce animal liveweight gains is a function of the amount of herbage present, the stocking density applied to the pasture, the quantity consumed by the animals and the quality of the herbage.

Hard-seeded legumes such as French serradella and bladder clover (and biserrula in NSW) can be summer-sown and, if there is sufficient moisture, they can produce high quantities of biomass early in the growing season.

Their deep root systems mean they tolerate dry conditions and produce plenty of seed. In Western Australia and NSW, their superior growth compared with other species and good nutritional value means they can carry more stock and produce more meat and wool per hectare.

The research also found that some of the novel legumes have improved capacity to survive ingestion by livestock, leading to lower depletion of the seedbank during summer grazing.

More than 80 per cent of biserrula seeds pass through sheep and remain viable. For French serradella and bladder clover, the feed quality of pods suggests they might contribute to improved liveweight gain for sheep grazing these residues over summer compared with other species.

The goals of the DLPS livestock research component were to:

1 quantify the on-farm production gains that could be achieved on high-quality legume pastures;

2 ensure novel species being considered for commercial release are safe for livestock and do not cause any taint flavour to meat;

3 understand the potential impact of grazing mature, aerial-seeding legumes on livestock productivity and seedbank dynamics; and

4 conduct plant analysis across DLPS trials in all states to optimise understanding of nutritional value across species, sites and seasons.

GRAZING STUDIES

Based on grazing experiments in WA and South Australia and associated meat quality tests, *Trigonella balansae* has proven its worth for further development for new crop/pasture sequences.

As part of a duty-of-care assessment in WA in 2020, a replicated large-scale grazing experiment was undertaken near Mokine comparing the liveweight gain, condition score and wool production of 14-month-old Merino wethers grazing subterranean clover (cv. Dalkeith), French serradella (cv. Erica) and trigonella at a stocking density of 12 dry sheep equivalents per hectare over a 50-day grazing period.

All three legume pastures produced comparable animal performance. After grazing, the sheep had similar liveweight gain, condition, wool growth and yield, hot carcass weight, cold carcass weight, carcass fat score, crude fat in muscle and ultimate pH of muscle.

At conclusion of the field trial, eight

animals from each legume treatment were processed at a commercial abattoir and the backstrap muscle was vacuum-sealed and aged at 4°C for four days before freezing. Meat sensory evaluation was then conducted by 48 consumer panellists. The eating quality of the lamb grown on the trigonella pasture did not differ from the other pastures, with panellists reporting similar tenderness, juiciness and flavour to other lamb evaluated.

Trigonella is a relative to fenugreek and its leaves have a curry-like aroma and taste; however, clearly this did not impact the flavour of the meat.

In another grazing study, at Minnipa in SA, the sheep feed value of trigonella was compared with legume species adapted to alkaline sandy loam soils commonly found in Mallee regions. The newly released powdery mildew tolerant strand medic (cv. Seraph$^{\Phi}$) was included with the widely naturalised strand medic variety Harbinger, common vetch (cv. Volga$^{\Phi}$) and rose clover (cv. SARDI rose). The 36ha trial was sown in 2019 and grazed by one-year-old Merino ewes, cropped in 2020 and allowed to regenerate in 2021. Wheat stubbles were also grazed in early 2021.

In 2019, trigonella pasture digestibility and crude protein levels were similar to other species and it produced comparable liveweight gains per head in sheep.

Table 1: Seed size, survival after ingestion by sheep and potential nutritional value (dry matter digestibility DMD, crude protein CP) of the pods.

		Seed size	Survival	Dormancy (%)		Nutritional value (*in vitro*)	
Common name	Accession	(mg)	(%)	(as fed)	(faecal)	DMD (%)	CP (%DM)
Biserrula	Casbah (seed)	1.05	78.2	73.8	98.5	76	30.3
	Casbah (pod)	1.25	88.0	99.0	98.3	59.6	21.9
Rose clover	SARDI Rose	3.54	41.3	22.8	97.2	52.7	20.3
Bladder clover	Bartolo	2.69	42.8	95.8	97.9	63.2	17.6
Subclover	Dalkeith	4.72	20.3	11.5	83.4	44.1	14.7
Medic	Cavalier$^{\Phi}$	3.64	39.5	96.5	97.8	54.7	23.5
	Toreador	2.04	43.1	41.8	91.4	53.0	18.0
Yellow serradella	Avila	2.10	14.5	42.0	86.6	36.3	15.2
	Santorini	2.37	7.7	91.5	81.3	50.5	14.8
French serradella	Margarita$^{\Phi}$	2.28	28.0	79.0	84.1	60.3	22.7
	Cadiz	2.12	23.2	84.3	84.1	62.1	23.0
	Fran$_2$o$^{\Phi}$	2.34	16.5	80.0	83.4	61.8	24.5
Trigonella	SA 5045	1.04	27.5	94.0	93.5	56.9	16.7
Radish	naturalised	1.41	29.2	76.8			
Turnip	naturalised	1.30	6.1	81.0	26.0	40.3	13.9
Annual ryegrass	naturalised	2.50	13.3	38.8	81.1	68.4	14.3

Source: CSIRO

BANKING SEED

Compared with subterranean clover, aerial-seeded legumes require more careful grazing management as the seed can be consumed by livestock, especially in the establishment year. The high feeding value of mature stands of some pasture species provides an opportunity to extend grazing, but it is important to ensure that enough seed enters the seedbank for future regeneration.

This component of the project used field and animal house studies to get a better understanding of trade-offs between late-season grazing, seed-set and seed survival after ingestion.

In field studies with French serradella, stands were mowed at a height of three centimetres to simulate heavy grazing at three weeks prior to flowering, at the start of flowering, or three weeks after flowering. Mowing three weeks prior to flowering had no significant effect on seed-set, while mowing at flowering reduced seed production.

As expected, defoliation three weeks after flowering had a massive impact on seed production and is not recommended if seed production is important.

The other critical parameter measured was how ingestion of the seeds by sheep affected seed viability post-ingestion. Pod and seed heads containing mature seed samples from 16 legume and four weed species were fed to Merino sheep in metabolism crates to determine seed survival and germinability after ingestion, and the mature legume seed digestibility (Table 1).

As a general rule, bigger seeds were more likely to be digested, but there was some variability within and between species. Seed survival after passage through the sheep ranged from eight per cent (yellow serradella) to 88 per cent (biserrula).

Within the serradellas, there was no relationship between seed size and survival after passage, as the structure of the pod is likely to affect how easily the sheep can chew the seed.

French serradella pod samples had much higher nutritional value for dry matter digestibility (DMD) and crude protein (CP) than yellow serradella (Table 1). In theory, for sheep grazing a mature French serradella pasture, only 16 to 28 per cent of ingested seed returns to the seedbank in a viable form, so care should be taken not to overgraze the residues.

Mature bladder clover seed heads had moderate nutritional value, while subterranean clover in burr was relatively poor quality (Table 1). Trigonella pods had 57 per cent DMD, 17 per cent CP and 27 per cent of seeds survived passage through sheep.

Of the weeds tested, 94, 70 and 85 per cent of the turnip, wild radish and annual ryegrass seeds, respectively, were unviable after ingestion by sheep. Hence, heavy grazing of legume pasture residues with established seedbanks may contribute to reductions in weed populations. This is particularly useful if herbicide-resistant weeds are an issue. □

GRDC Code DAS1803-003RMX

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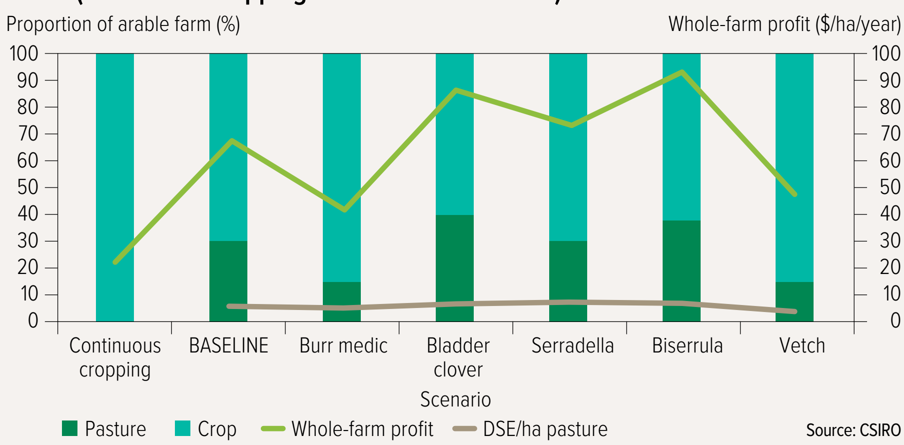
https://www.youtube.com/watch?v=SM-zKtpTLwg

Modelling underscores hard-seeded legume prospects

Modelling studies have demonstrated the potential profitability gains of including novel hard-seeded legumes in crop/pasture systems

Figure 1: Whole-farm profit (light green line) and proportion of arable farm under crop (aqua area) and pasture (green area) for the six legume pasture scenarios evaluated on a typical 3750-hectare mixed farm in the central wheatbelt region of WA (continuous cropping included for reference).



Source: CSIRO

By Dr Dean Thomas, Robert Harrison, Chris Herrmann, Dr Bonnie Flohr, Dr Marta Monjardino, Dr Rick Llewellyn and Dr Roger Lawes

■ Two economic modelling studies by CSIRO as part of the Dryland Legume Pasture Systems (DLPS) project have demonstrated productive legume-based pastures are profitable options in mixed-farming rotations in low to medium-rainfall regions. Results showed that rotations including novel hard-seeded pasture legumes were profitable and had multiple roles in business diversification and reducing risk and costs. This comes from supporting a livestock enterprise and reducing year-to-year biotic stress and nitrogen input costs for subsequent crops.

MODELLING COMPONENTS

The Land Use Sequence Optimiser (LUSO) and Model of an Integrated Dryland Agricultural System (MIDAS) bioeconomic models were used to investigate the economic performance of crop and pasture rotations, focusing on break crop effects that may persist across multiple years.

Considering crop and pasture phases in whole-farm economic analyses requires a deep understanding of value drivers and biological effects generated from both cropping and pasture sequences within a mixed-farming enterprise.

To gather this information as input data for the LUSO model, simulation modelling of crop (using the Agricultural Production Systems sIMulator, APSIM) and pasture production (using GrassGro) was conducted at Corrigin, in the Western Australian central wheatbelt. This dataset covered 30 years (1991–2020) and included inter and intra-seasonal variability.

MIDAS modelling scenarios were built for the WA central wheatbelt and southern Mallee of SA, applying linear programming to maximise whole-farm profit of a representative production system, subject to resource, environmental and managerial constraints.

The central wheatbelt MIDAS was parameterised for six pasture legume scenarios considering establishment and maintenance costs, initial germination rates, average legume proportion in the sward, nitrogen content, dry matter digestibility and biomass produced.

Traditional legume species such as subclovers and medics were included in modelling scenarios together with DLPS hard-seeded legumes, such as French serradella, biserrula and bladder clover.

LUSO model simulations were conducted over six seasons to evaluate the economic returns of particular crop and pasture sequences. The model represents how each crop or pasture within a simulated sequence affects nitrogen, disease population dynamics and weed population dynamics, which then affect yield and economic return of subsequent crops.

RESULTS

The LUSO-modelled profitability of different crop and pasture rotation sequences is shown (by phase) in Table 1. Results are for five-year average costs and prices and current prices averaged across high and low biotic stress scenarios for 1000 annual weather combinations. These were randomly generated from crop and livestock production simulated using 30 years of weather data.

Phases of novel pastures that were grazed (supporting a Merino sheep enterprise) were found to be more profitable than cropping phases for scenarios where five-year average costs and prices were used.

The most profitable rotation including pastures (PnWPnCWW highlighted in light green in Table 1) was $117 per hectare per year higher than the most profitable crop-only rotation (CWWCWW). The large loss from establishing novel pastures not grazed in the first season meant profitability was similar to the rotation with grazed volunteer pastures.

Higher profit from rotations with productive novel pastures was maintained in the sensitivity analysis conducted using current (higher) prices for wheat and canola and current nitrogen costs, with $88/ha/year higher profit in the rotation that included grazed novel pastures.

However, under these conditions, wheat and canola phases following novel pastures were most profitable. The profitability of rotations with unimproved pastures was similar to continuous cropping rotations, except for continuous wheat, which was less profitable.

Further, we identified benefits in reducing risk, where rotations that included an annual pasture phase returned higher profit under the least profitable 20 per cent of seasonal conditions, compared with cropping-only phases. Where scenarios had low biotic stress and used current (historically high) prices for wheat, canola and nitrogen fertiliser, there was no downside risk benefit from annual legume-dominant pastures.

MIDAS MODELLING

Whole-farm modelling results using MIDAS show significant profit potential when improved pastures become part of new optimised crop/livestock systems.

This was driven primarily by higher livestock production, reduced supplementary feeding and nitrogen fertiliser costs, but relatively little change in land use (that is, about 10 per cent more pasture area and 5 per cent less canola area).

In WA's central wheatbelt medium-rainfall region, biserrula, bladder clover and French serradella outperformed other options in economic value, resilience and sustainability.

Relative to the subclover baseline pasture, these three species increased whole-farm profit (37, 27 and 8 per cent respectively), increased sheep carrying capacity (50, 40 and 20 per cent), reduced fertiliser nitrogen inputs (-25, -20 and -9 per cent) and reduced methane intensity in terms of kilograms CO2-equivalents per dry sheep equivalent (-11, -8 and -2 per cent).

In the South Australian and Victorian Mallee low to medium-rainfall region analysis, results suggest including a baseline medic pasture led to profit gains of more than 20 per cent compared with continuous cropping.

Replacing the baseline medic with an improved strand medic, Seraph⁽ᵖ⁾, released through DLPS, increased potential whole-farm profit by a further 26 per cent.

Overall, the whole-farm crop/livestock analyses showed major profit gains are possible by using improved regenerating legume options achieved through greater pasture land utilisation, with higher stocking rates, while still maintaining a similar cropping program.

Alternative management tactics to reduce biotic stress and maximise profit were not considered, nor were any effects of conserved soil water in the prior season.

Structural changes to the enterprise mix of the baseline mixed farm were not overly important, with increased profit being driven by higher stock numbers, reduced supplementary feeding costs and reduced nitrogen fertiliser cost.

This research supports a greater role for novel annual pasture legumes to enhance sheep production and benefits to following crops in low to medium-rainfall regions. However, to achieve the benefits of higher profit and reduced risk, continued agronomic support is needed as growers implement complex management systems required to integrate new pasture legume species. □

GRDC Codes UMU1805-001RMX, DAS1805-003RMX

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MODELLING PRACTICE

Economic modelling can be a valuable tool to inform decision-making when it comes to adopting a new cropping practice. Modelling of crop and pasture sequences brings together new research findings on benefits and challenges of new farming systems, together with enterprise costs and revenue.

The LUSO and MIDAS modelling pointed to key management practices to achieve the high levels of profitability from annual legume-dominant pastures:

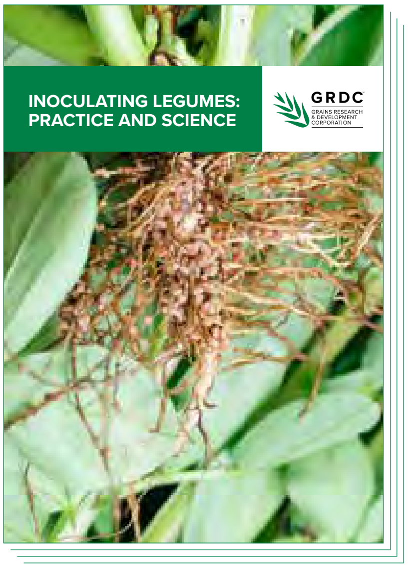
- **Pasture legume establishment is highly successful, resulting in legume-dominant pastures. Effective control of weeds is key.**
- **Pastures are well utilised, including during the year of establishment, by livestock run at optimal farm stocking rates for the region. Stocking rates in the mixed-farming region are typically conservative.**
- **There is successful nodulation and high levels of nitrogen fixed during pasture legume phases.**
- **If pastures are ungrazed in the establishment year, or all years, there is a large reduction in profit from income loss from the livestock enterprise.**

Table 1: Profit ($/ha) of five simulated rotation sequences of six years, with combinations of wheat (W), canola (C) and volunteer (Pv), novel (Pn) and ungrazed novel (Pnug) pasture phases. Simulations were conducted using either five-year average prices or current prices for wheat, canola and nitrogen fertiliser.

Rotation	1	2	3	4	5	6	Average
5-yr average $							
CWWCWW	71	146	112	56	107	82	96
PnugWPnCWW	-215	212	341	136	120	93	114
PnWPnCWW	382	212	341	134	120	92	213
PvCWPvCW	142	76	136	122	66	111	109
WWWWWW	136	108	88	65	43	15	76
Current $							
CWWCWW	375	265	211	324	209	170	259
PnugWPnCWW	-215	435	340	522	223	183	248
PnWPnCWW	381	434	340	518	225	183	347
PvCWPvCW	143	382	243	124	328	209	238
WWWWWW	263	216	178	156	119	77	168

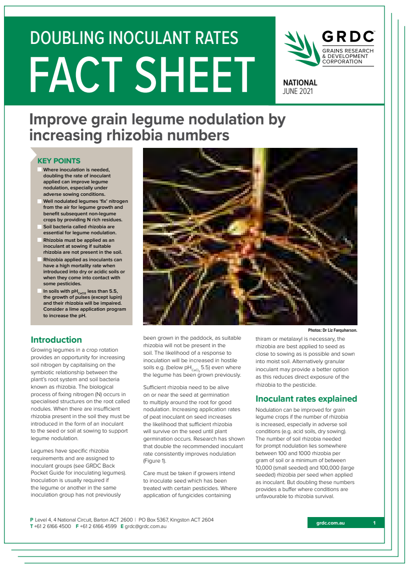
Source: CSIRO

Growing legumes in a rotation increases soil nitrogen and reduces fertiliser requirements for following crops



GRDC has published the following resources (currently in digital format only) with the aim of:

- increasing grower knowledge of legumes, rhizobia, nodulation and nitrogen fixation;
- improving the cost-effectiveness of inoculation as a key farm practice; and
- enabling growers to boost farm profits through improved legume nodulation and nitrogen supplies.



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Inoculating Legumes: Practice and Science https://grdc.com.au/inoculating-legumes

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