Cranking up crop yields and livestock production using summer sown pasture legumes – revisiting fundamental soil and agronomy with new technologies to increase production and rotation flexibility

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Take home message

- Summer sowing of hardseeded legumes is a robust and effective way to establish pastures well adapted to climatic variability and acidic soils
- Once a seedbank is established, hardseeded legumes can add flexibility to pasture-crop rotation systems enabling growers to capitalise on crop and livestock market opportunities
- Hardseeded legumes can support high yields in following grain crops even when they were grown in a poor season. Considerable savings in nitrogen fertiliser are possible
- Growers should focus on what they should grow, considering soil, climatic and pasture-crop rotation systems used in order to maximise the potential of hardseeded legumes in their farming systems.

Introduction

Maintaining crop areas and profitability is facing considerable pressure as a result of rising input costs, particularly fertilisers, and competition from currently lucrative livestock enterprises. Increasingly, this is leading growers to explore opportunities to better integrate crop and livestock production in a way that allows for more fluid transition between enterprises in response to market opportunities, input cost pressures and climatic conditions. A component of building flexibility in to mixed farming systems is via consideration of the pasture component of the farming unit.

Pastures in mixed farming systems of eastern Australia have generally been used as phases of 3-10 years in a cropping rotation. While such pastures systems can provide stability in terms of productivity, they are also relatively inflexible in terms of allowing for rapid transition of total farming land area between crop and livestock production enterprises. Additionally, these pastures often require relatively lengthy periods to adequately establish (i.e. lenient grazing in the first 12 months) and require resowing after each cropping phase. For traditional pastures, sowing also coincides with peak labour demand, with ideal sowing time generally coinciding with the winter crop sowing window. Labour competition frequently results in pasture sowing occurring after the winter cropping program is completed, which can lead to poor pasture growth and seed production with impacts on long term persistence and performance.

However, astute pasture legume breeding programs and development of intuitive pasture establishment techniques such as summer sowing, have resulted in the development of highly productive and flexible legume-based pastures. Such pastures can be integrated into farming systems to increase productivity of crop and livestock systems. Legume species used in these pastures have also proven to be very tolerant of highly variable seasonal conditions, including extreme drought.

What is summer sowing and what legume species is it applicable to?

Summer sowing was developed by Dr Brad Nutt and colleagues at Murdoch University and the Department of Primary Industries and Regional Development in Western Australia (see Nutt et al. 2021). Summer sowing eventuated after the same team had previously developed range of robust pasture legume species including bladder clover, biserrula and gland clover, along with the first cultivars of hardseeded French serradella and new cultivars of arrowleaf clover and yellow serradella. All of these species produce their seed aerially, as opposed to subterranean clover which buries a proportion of its seed. Aerial seed production meant that it was possible to harvest seed of the legumes using conventional headers. This alone was a significant achievement as it allowed seed to be harvested quickly, efficiently and at relatively low cost.

When the aerial seeded legumes are harvested with a header, very minimal damage is caused to the seed coat (or the pod in the case of serradella), meaning that the seed retains a very high hard seed level. Such seed could be sent for further processing (i.e. scarification) and then subsequently sown in mid to late autumn like a traditional pasture sowing. However, early experiments showed that if the unprocessed seed was sown in mid to late summer, then a proportion of it would soften due to fluctuations in temperature and moisture and be capable of germinating on opening autumn rainfall. This meant that pasture sowing could be completed well ahead of the winter crop sowing program. The legume species suited to summer sowing also had attributes such as deep root systems and/or capacity for improved control of transpiration losses, which meant they could survive periods of high temperature and/or moisture stress that would normally result in high mortality of early sown traditional pasture legumes such as subterranean clover and annual medics. Additionally, as the pasture emerged early while temperatures were warm, more biomass could be produced than for conventionally sown pastures.

The early experiments in Western Australia found that bladder clover and hardseeded cultivars of French serradella were reliable for summer sowing in that environment. Later experiments found that arrowleaf clover, biserrula and gland clover in addition to bladder clover, hardseeded French serradella cultivars and some cultivars of yellow serradella were options for summer sowing in the central and southern regions of NSW. Higher soil moisture throughout summer and its interaction with temperature fluctuations appears to have increased hard seed breakdown rates in NSW (Nutt *et al.,* 2021).

How effective is summer sowing?

To date, in NSW, we have completed 18 replicated field trials (2012-2021) comparing summer sowing to conventional sowing across areas receiving long-term average annual rainfall of 380- 650 mm. Average annual rainfall over that period has ranged from 70% below to 50% above average across sites, with growing season rainfall varying by a similar magnitude. Across year and seasonal conditions, summer sowing has resulted in production of 4-10 t dry matter (DM)/ha, considerably higher than that achieved when pastures were conventionally sown (Table 1). Under drought conditions summer sowing maintained a similar level of production to the overall average and showed capacity for elasticity in response to improved conditions in wetter than average years.

Table 1. Total herbage production for annual legumes established via summer sowing (t DM/ha) as unprocessed seed in February or via conventional sowing of scarified seed in late May averaged over all years, in drought years or in higher than average rainfall years for 18 experimental sites between 2012 and 2021 in central and southern NSW. The herbage production for subterranean clover established via conventional sowing is also shown.

	Overall average (t DM/ha)	Drought year (t DM/ha)	Wet year (t DM/ha)
Summer sowing[1]	4-10 (av 4.8)	4-6 (av 4.1)	4-20 (av 8.6)
Conventional sowing[1]	0.3-4 (av 0.9)	0.3-1.8 (av 0.6)	2-5.5 (av 2.4)
Subterranean clover	0.8	0.3	2.0

[1] Species included were arrowleaf clover, biserrula, bladder clover, gland clover, French serradella and yellow serradella

With the exception of arrowleaf clover, all hardseeded legumes when established via summer sowing in extreme drought (2019), produced at least 80% of average herbage yield for all years (Figure 1). Capacity to maintain high levels of productivity in drought provides useful feed for livestock as well as building soil nitrogen for following crops. All species except bladder clover were also highly responsive to improvements in seasonal conditions producing 20-30% more herbage than the average across all years.

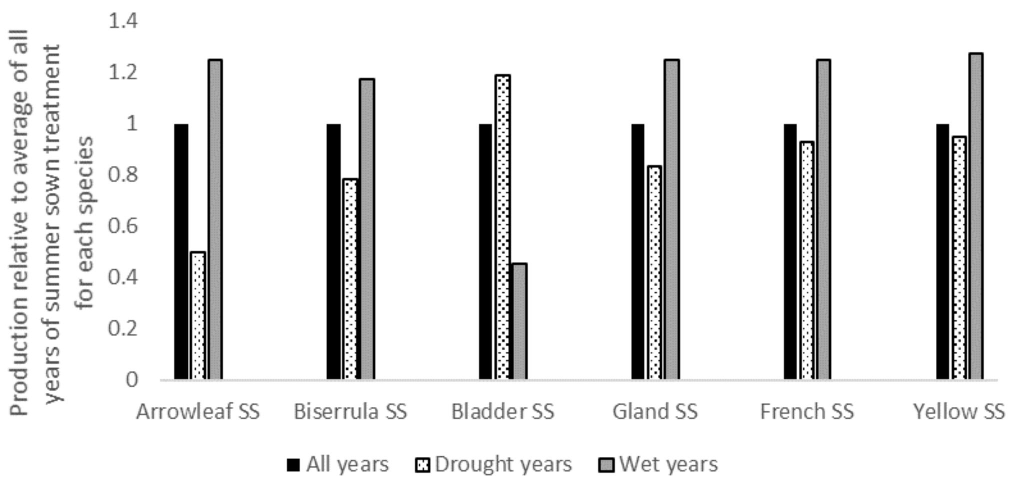

Figure 1. The herbage production of a range of hardseeded annual pasture legumes established via summer sowing relative to the overall average herbage production within each species averaged over 18 sites in NSW in the period 2012-2021.

N supply for following crops

The capacity of hardseeded legumes to support following crop production has been under evaluation at a number of sites in NSW. Near Ungarie in 2019, a number of annual legumes were grown under severe drought conditions in a replicated experiment with wheat included as a control. In 2020, the site was sown to wheat with the plots split for nitrogen treatment. Nitrogen treatments were either nil nitrogen, nitrogen applied at sowing only (as MAP) or nitrogen applied at sowing plus topdressing with urea at GS31.

Despite the severe drought of 2019, all hardseeded legumes provided sufficient nitrogen to support grain yields in 2020 of >3.8 t/ha without addition of nitrogen (Figure 2). Application of nitrogen at sowing or at sowing and then 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 addition of nitrogen at sowing with a further significant increase if nitrogen was also applied again at GS31. Further, the continuous cereal and subterranean clover treatments, application of nitrogen at sowing and at GS31 was required to produce an equivalent grain yield to the hardseeded legumes where no nitrogen was applied. Results for grain protein followed a similar pattern with wheat grown after hardseeded legumes achieving 12-14% protein without addition of any nitrogen compared to 8-9% wheat grown in the continuous cereal rotation or after subterranean clover. Application of nitrogen as sowing and GS31 was required to lift grain protein to 11% in the continuous cereal rotation.

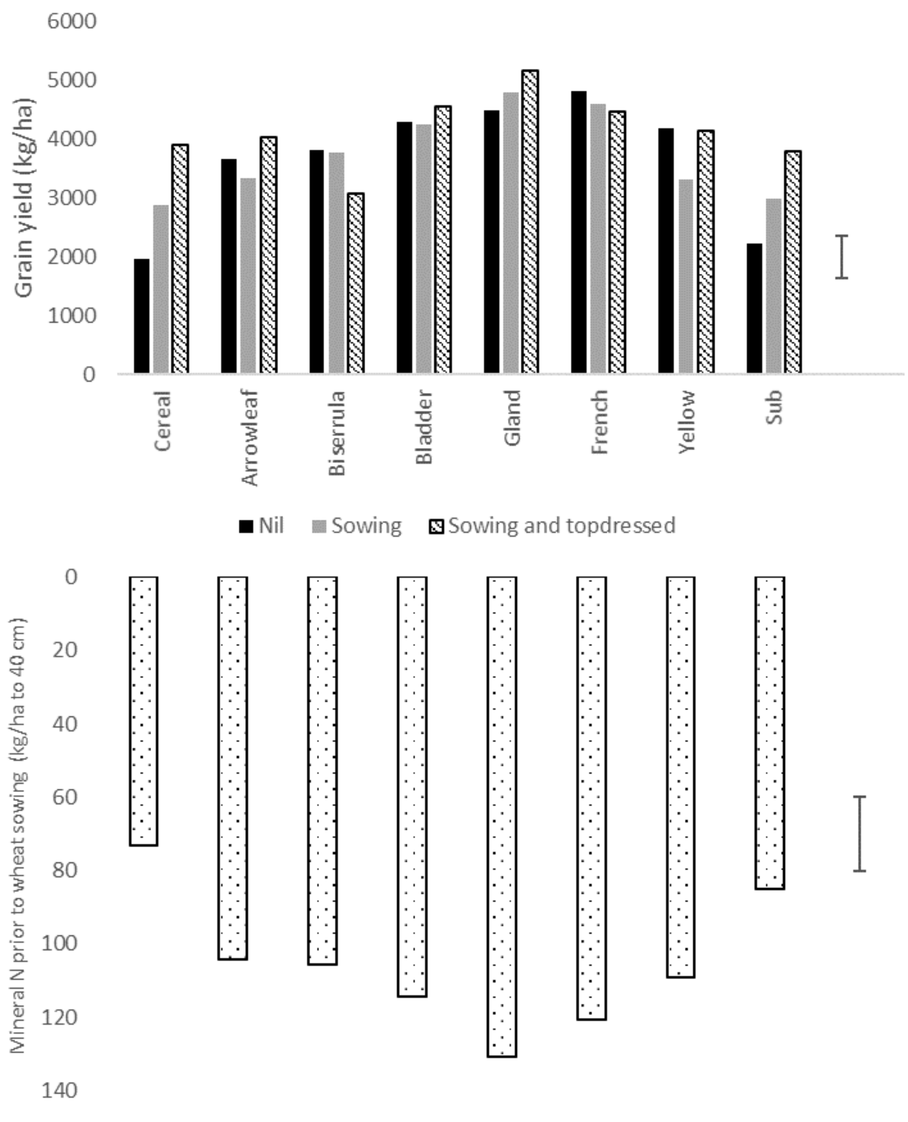

Figure 2. The grain yield of wheat (kg/ha) where no nitrogen, nitrogen at sowing only or nitrogen at sowing and at GS31 was applied in 2020 grown after a range of hardseeded annual legumes, wheat or subterranean clover in 2019. Soil mineral nitrogen prior to wheat sowing in 2020 is also shown.

Feed quality for livestock

Previous research has shown that at the same stage of growth, the feed quality of hardseeded legumes is similar to that of traditional legumes such as subterranean clover (Hackney *et al.*, 2021a). Therefore, when utilised directly via grazing, it would be expected that similar liveweight gains would be achieved if intake is not restricted by herbage availability.

However, capacity for increased production from hardseeded legumes due to better tolerance of variable growing conditions or because of suitability to summer sowing, means that there is potential for greater levels of livestock production to be achieved. Such increases in livestock production may be achieved through utilising the forage produced directly by grazing (i.e. increasing stocking rate) or via strategic fodder conservation when seasonal conditions allow.

In terms of fodder conservation, it is important to consider the timing of cutting. The quantity of herbage available and its quality can change rapidly throughout spring, which has a significant impact on the potential liveweight gain that might be achieved later in feeding the conserved fodder. At a site near Condobolin in 2021, the quantity of herbage available for fodder conservation from hardseeded legumes established via summer sowing was monitored over the growing season (Figure 3). If we consider the probable times for making silage (15 September) and hay (16 October), it can be seen that the quantity of herbage available at each time was reasonably stable, but the stem, leaf and reproductive plant material ratio varied considerably. We are still awaiting plant quality analysis for these data. However, based on our previous research, we know that in mid-September at the late vegetative-early reproductive stage of growth, the digestibility and protein of the herbage of hardseeded legumes would range between 65-69% and 21-29%, respectively. By mid-October, given the plants stage of growth, digestibility would be in the order of 59-62% and protein 13-20% (Hackney *et al.*, 2021a). From a livestock production perspective, delaying harvest from mid-September to mid-October, the likely decline in feed quality would see the potential liveweight gain of weaner steers decline from 2.5 kg/hd/d to 1.6 kg/hd/d (Grazfeed version 32). In this scenario, the potential liveweight gain declines from 1.1-3.1 t/harvested ha as silage to 0.75-2.3 t/harvested ha for hay, depending on legume species. In some situations there may be an increase in herbage availability between probable silage and hay cutting times, however, the inevitable decline in plant quality over that time almost always means that there will be a reduction in potential liveweight gain on a per head basis (Note: these calculations include factoring in of 20% loss due to residual herbage below cutting height and losses during the fodder conservation process).

Whether the increase in herbage availability makes up for the decline in feed quality will determine what the absolute livestock production per harvested hectare will be. Clearly, however, summer sowing of suitable species offers scope for increasing livestock production either directly via grazing or indirectly via conservation as compared to the conventional sowing of traditional legume species such as subterranean clover or annual medics (Figure 3).

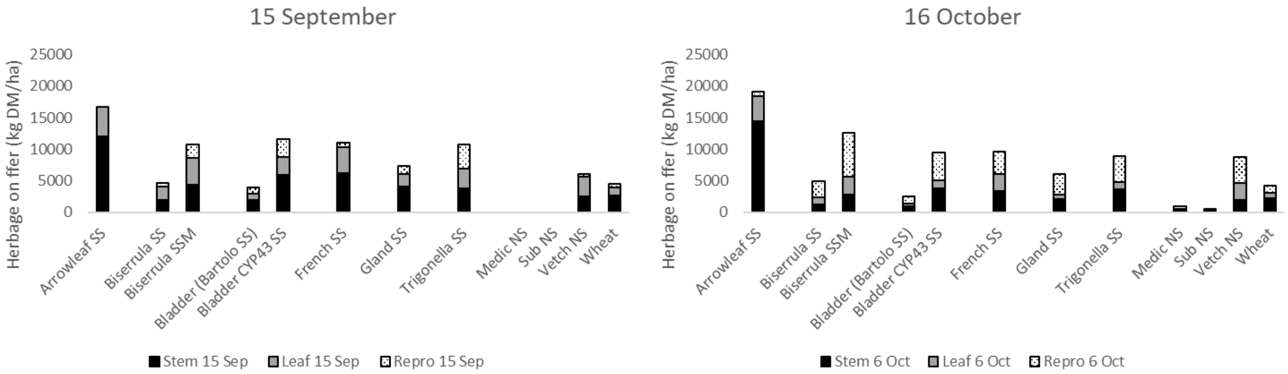

Figure 3. Herbage on offer (kg DM/ha) of stem, leaf or reproductive plant components for a range of hardseeded legumes established via summer sowing (SS) or for annual medic, subterranean clover and vetch established via conventional sowing and wheat at probable silage (15 September) or hay (16 October) cutting times at Condobolin in 2021.

Considerations when using hardseeded legumes in rotations and specific considerations for summer sowing

Hardseeded annual legumes can be highly successful when used in rotation with crops. However, there are certain fundamental management requirements that must be satisfied in order to ensure success in growing them. Many of these principles are common to traditional legumes but some are specific to the hardseeded legumes.

Paddock preparation

All plants have four fundamental requirements for growth; space, light, moisture and nutrients. Paddock preparation is key in setting a foundation for satisfying these requirements when sowing any new pasture. Running down the weed seedbank in the years leading up to sowing a new pasture is critical to establishment success. Competition from weeds is the leading cause of establishment failure in newly sown pastures. A minimum of two, but preferably three years of absolute weed control leading up to pasture sowing are essential to minimise weed competition in newly established pastures. For many weed species providing there is no topping up of the seedbank (e.g. wind borne seed, seed from weed escapes, seed transported by water, machinery or livestock), populations within the weed seed bank can be drastically reduced in a two to three year period (Figure 4). However, it is important to consider the absolute number of weed seeds that main remain in the seedbank rather than just the percentage. For example, a 3% survival of a weed seed after three years with an initial seedbank population of 300 seeds/m^2 gives a vastly different competition scenario to 3% survival from an initial seedbank population of 10 000 seeds/m^2. Populations of the same weed can also exhibit differences in how quickly seed will decline in number within the seedbank with locality. Local climate and soil conditions (e.g. temperature, temperature variation, moisture) can influence factors such as germination, dormancy and emergence of weed seeds. Similarly, management can influence population dynamics of a weed population. For example, development of herbicide resistance can result in changes in seed behaviour of resistant weed populations within the seedbank or regular use of specific herbicides may see plants develop escape mechanisms such as later emergence. Such factors can result in changes in the weed competition risk profile when sowing new pastures. The key point is to plan well ahead when considering sowing any new pasture to minimise potential weed competition.

Some weeds such as wild radish and spiny emex can persist at low levels in the seedbank over an extended period of time and for species such as these, survival of the seed is aided if the seed is buried at depth. The population density of these species can rapidly rebound from low levels due to their ability to produce large quantities of seed per plant. However, significant reductions in seedbank populations can still be achieved over a three-year period. As with any weed, strategies for selective control once a pasture is established must be considered in advance to prevent weeds rapidly increasing in density. Carefully considering herbicide tolerances of pasture species to be sown is an important in the planning process to maximise options for selective weed control. Similarly, thought should be given to other tactical options that can be used to control weed seed set leading up and following pasture sowing. This may include use of tactical grazing, spray-grazing or strategic fodder conservation. Research in Victoria demonstrated an 80% reduction in the wild radish seedbank population through instigating silage cutting in one year (Henne and Sale 2014).

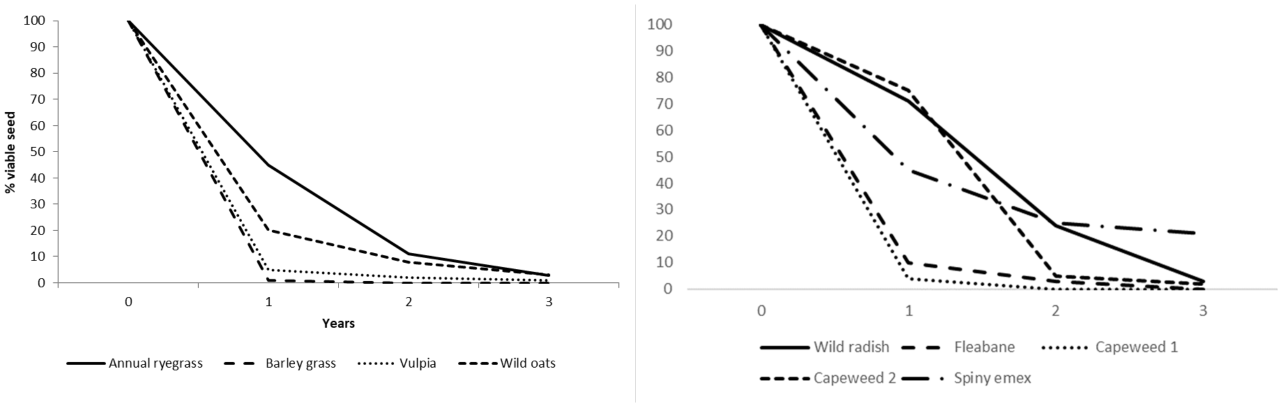

Figure 4. The percentage of seed in the soil seedbank remaining viable over a three year period for a range of grass and broadleaf weed species. Source: Cheam (1987), Dowling (1996), Peltzer et al. (2002), Dunbabbin and Cocks (1999), Green et al. (2010).

Herbicide residues

Ensure, when sowing new pastures, that all plant back requirements have been met prior to sowing. Carefully check the herbicide label. Herbicides can have time, rainfall and/or specific soil moisture requirements for breakdown. Additionally, some herbicides present different risks for residues associated with soil pH or texture. The rate of application also needs to be considered for some herbicides. It is critical to have accurate records of what herbicides have been used in previous crops and to make sure all requirements for safe plant back have been met. Remember, if you are undertaking summer sowing, this will occur some 3-4 months earlier than traditional pasture sowing meaning that plant back requirements need to have been satisfied at the time of sowing so that seed, inoculant and early germinating pastures are not exposed to residues.

It is also critical to be mindful of herbicides used in the maintenance of summer fallow following harvest of the previous years crop. It is not uncommon to see poor establishment in newly sown pastures due to a forgotten herbicide used in the summer fallow. A recent survey (n=155 farming businesses) found that more than half had used at least one herbicide in the fallow that would present a risk for pasture legumes they intended to sow that year, either via summer or conventional sowing (Hackney et al. 2021b)

Species selection

When choosing which hardseeded legume(s) to grow, it is important to determine if what you want to grow aligns with what you should grow. What you should grow is determined by your climate, soils and the type of pasture-crop rotation system you intend to run.

Most of the hardseeded legumes will grow well in soils with good drainage where soil pHCa is in the range of 5.0-7.0 (Table 2). Species such as serradella and biserrula have good tolerance to more acidic soils. All species in Table 2 have good tolerance to drought conditions. However, arrowleaf clover tends to produce seed later in the season than other hardseeded legume species and so under severe drought conditions, its seed production may be compromised.

Residual hard seed levels are an important consideration in species selection for inclusion in crop rotations. Residual hard seed is a measure of how much of the seed produced in a given season that remains hard by the following autumn. Higher levels of residual hard seed mean that the legume will be more persistent in the seed bank over time and has the capacity to withstand a longer cropping interval and regenerate without the need for resowing.

Generally, cultivars of legume species with residual hard seed of 40-60% are well suited to 1:1 rotations (that is alternating years of pasture and crop). Occasional two-year crop intervals may also work well with such cultivars once a couple of years of legume seed set have occurred. For cultivars of legume species that have higher hard seed levels (>70%), cropping phases of 2-4 years are feasible.

Table 2. Preferred soil pH_{Ca} for hardseeded annual legumes and their rhizobia, suitable soil texture and soil drainage characteristics, drought tolerance and residual hard seed percentage in the autumn following seed set.

	pH_{Ca} (Plant)	**pH_{Ca} (Rhizobia)**	**Soil texture**	**Soil drainage**	**Drought tolerance**	**Residual hard seed[2] (%)**
Arrowleaf clover	4.8-8.0	5.5-7.5	Sandy loam to medium clay	Good drainage	Good	40-60
Biserrula	4.2-7.5	4.8-7.0	Sandy loam to loam	Good drainage	Excellent	70-90
Bladder clover	5.0-8.0	5.5-7.5	Sandy loam to loam	Good drainage	Very good	40-60
Gland clover	4.8-8.0	5.5-7.5	Sandy loam to clay	Good to poorly drained	Very good	40-60
French serradella[1]	4.0-7.0	4.5-7.0	Sand to loam	Good drainage	Very good to excellent	40-60
Yellow serradella	4.0-7.0	4.5-7.0	Sand to loam	Good drainage	Very good to excellent	40-80

[1]This information refers to the hardseeded French serradella cultivars Fran2o, Margurita and Erica.
[2]The hard seed remaining in the autumn following seed set

Which cultivars of the hardseeded legume species are suitable for summer sowing?

There are a limited number of commercially available cultivars of most of the hardseeded legume species. As an example, there is only one cultivar each of gland clover and bladder clover and these have proven to be successful for use in summer sowing. For both French and yellow serradella, a number of cultivars are available. For French serradella, the cultivars $Fran_2o$, Margurita and Erica are suitable for summer sowing. For yellow serradella, we have had success with Avila and a soon to be released cultivar. It should be noted that Avila is not well suited to areas receiving less than 500 mm average annual rainfall.

For biserrula, we have had good success in sowing unprocessed seed for summer sowing. However, in cases where summer is extremely dry, hard seed breakdown can be restricted and therefore plant density may be lower than desirable. In the past two years we have been experimenting with seed that has been lightly scarified (25% germination). Use of partially processed biserrula seed in summer sowing has resulted in a significant increase in plant density and biomass production (Figure 5).

It is critical to check local trial results in determining which species/cultivars are suited to summer sowing in your area. As stated earlier in this paper, initial field trials in WA suggested bladder clover and the hardseeded French serradella cultivars were suitable for summer sowing in their hot, summer-dry conditions. However, in NSW, where many areas receive more summer rain and/or retain higher levels of soil moisture due to the higher clay content of soils, use of other species/cultivars are possible. Remember to carefully assess your particular situation with regard to summer rainfall, soil and temperature conditions and seek advice if you are unsure.

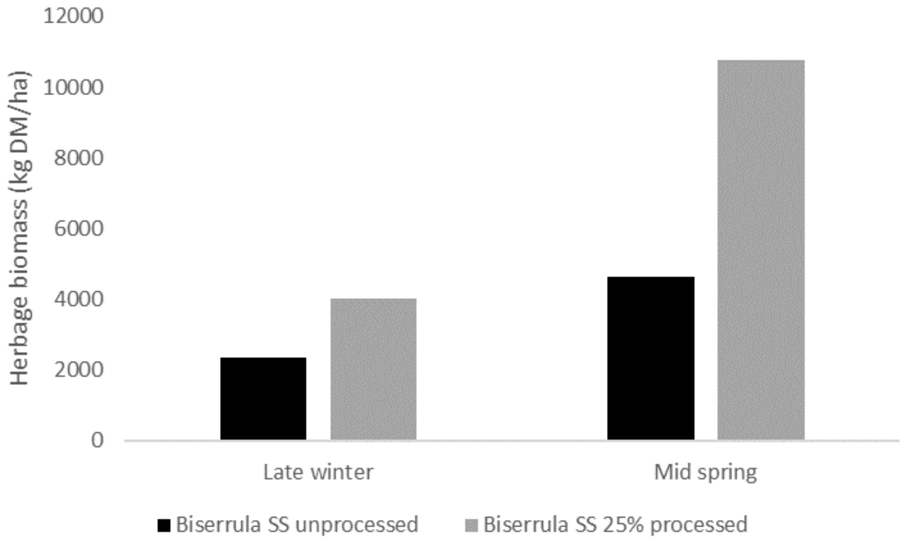

Figure 5. Herbage biomass (kg DM/ha) of summer sown biserrula where seed was either unprocessed or where a mix of 75% unprocessed and 25% scarified seed was sown.

Sowing time

For summer sowing, unprocessed seed is used. For the clover species and biserrula, this means seed that has not been scarified, while for serradella, pod segments are used. Adequate time is required for a proportion of the hard seed to break down for germination. Summer sowing is generally best undertaken from mid January to late February. However, successful establishment has occurred where sowing has occurred as early as December or as late as mid March. However, it is important to note that sowing beyond late February may result in reduced hard seed breakdown and lower plant density.

Sowing rate

Summer sowing requires a source of unprocessed seed. Generally, growers will have a nursery paddock from which they harvest seed and then use this to sow other areas of the farm. Use of nurseries can be a useful way to evaluate which species might work best for your farm. We frequently advise growers who have not previously grown hardseeded legumes to grow nursery blocks of 5-20 ha of a range of species (using purchased scarified seed sown in autumn). Growers can then harvest species that work best for them and use this unprocessed seed in summer sowing operations.

When summer sowing the hardseeded clovers or biserrula, the minimum suggested sowing rate is 12 kg unprocessed seed/ha. For serradella pod segments, a minimum rate of 20 kg/ha is used.

Inoculants

It is critical to ensure the correct inoculant group is used for each legume sown. Additionally, sowing in summer presents additional challenges of high temperature and often limited soil moisture, both of which can adversely impact rhizobia survival. Low moisture clay granular inoculant has proven to be an effective form of inoculant delivery in our summer sown field trials since 2012.

Fertiliser at sowing

Adequate nutrition is critical for both the legume plant and for rhizobia. Recent surveys have shown that phosphorus deficiency prevalence is relatively low (<30%) compared to sulphur deficiency (>75%) in soils of central and southern NSW (Hackney et al. 2021b). However, most growers (70%) use MAP or DAP when sowing new pastures. Ensure that soils are analysed from paddocks to be sown to new pastures and that appropriate fertilisers are used to address deficiencies that may be present.

Management following the establishment year

Our field trials have shown that hardseeded legumes produce 4-10 t DM/ha within the growing season. This represents potential nitrogen fixation of 80-250 kg N/ha (Table 1). We often find that growers want to allow legume pastures to regenerate in the second year. However, growers need to consider the value of nitrogen for supporting production of following crops. As shown in Figure 2, the use of hardseeded legumes in rotation with crops can significantly reduce the expenditure required on N-fertiliser to support crop production. Further, large quantities of unutilised nitrogen present an opportunity for weed proliferation.

Flexible rotations

Once a seedbank of hardseeded legumes is established, there is opportunity to alter how pasture-crop rotations are managed in response to seasonal conditions and commodity prices. With an on-demand seedbank in place, growers have the opportunity to flex and change their pasture to crop ratios and hence livestock to crop ratios within short timeframes. As an example, if seasonal conditions are predicted to be poor and high risk for cropping, then paddocks with a seedbank of hardseeded legumes can be allowed to regenerate and the herbage utilised for livestock and/or to build soil nitrogen for subsequent crops. Alternatively, if returns from cropping are high, then paddocks can be put to crop knowing that there is sufficient seed in the seedbank to allow for regeneration after the crop.

The crop phase length that can be imposed without needing to resow depends on residual hard seed levels of the legumes. For species with very high residual hard seed levels such as biserrula and some cultivars of yellow serradella, it is possible to crop over paddocks where there has been high initial seed set for 3-5 years and have strong regeneration of the legume. For species such as arrowleaf clover, bladder clover, gland clover and hardseeded cultivars of French serradella, rotations of one year crop, one year pasture are suggested, although once the legume has set seed a number of times, the seedbank will support occasional two-year cropping phases without needing to be resown.

Ultimately, the length of the crop phase imposed over the legumes will involve balancing out nitrogen supply provided by the legumes relative to requirements of the crop as well as considering the relative value of cropping and livestock to the overall farming system within and between years.

Conclusions

Over the last decade, summer sowing of hardseeded legumes has proven to be an effective means of establishing highly productive pastures. Summer sowing has been robust in the face of seasonal variation including extreme drought providing feed for livestock and nitrogen for subsequent crops. From a cropping perspective, hardseeded legumes have supported high levels of grain production in the year following their growth without requiring additional N-fertiliser; a significant cost and risk mitigation strategy that can be incorporated into contemporary farming systems. The ability of hardseeded legumes to maintain productivity in drought conditions, yet exhibit elasticity in response to improved seasonal conditions and provide additional options for use such as fodder conservation can only be beneficial in achievement of crop and livestock production goals. Perhaps though, one of the greatest advantages of hardseeded legumes is the capacity for growers to flex and change their crop and pasture ratios over short time periods once a seedbank is established in response to seasonal and commodity price conditions.

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