Final report

Not enough nodules: impact of herbicides, pesticides and other farm management tactics

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Abstract

Recent surveys of paddocks in southern Australia revealed more than 90% had legumes that were inadequately nodulated. Without sufficient and effective nodulation, legumes are unlikely to meet expected nitrogen fixation targets which then have the capacity to affect pasture production, pasture quality and ultimately livestock production. There are many factors that can affect nodulation and nitrogen fixation in legumes which include processes that impede host legume and rhizobia function and the formation of an effective symbiosis. Herbicides are a key tool in managing weeds in established pastures and in crops prior to the sowing of pastures. However, herbicides can impact the host legume, rhizobia and the process of symbiosis formation. Similarly, other pesticides such as insecticides and fungicides while also important tools to support pasture productivity, can nonetheless impact the capacity for nitrogen fixation. Additionally, other farm management practices such as initial sowing rates of legumes when establishing pastures, inoculant delivery forms used, the duration of weed control practised prior to sowing new pastures, fertilisers used at sowing (type and rate) and soil moisture conditions at sowing can also impact short and long-term legume function and persistence in pastures. Further, grazing management and fertiliser application (type and frequency) can impact legume function and persistence. The aim of this review was to examine the literature to ascertain what is known about management factors impacting legume performance and particularly capacity for fulfilling nitrogen fixation targets in pastures and concurrently undertake in-depth consultation with industry (producers and advisors) to determine contemporary management practices as they relate to pasture legume management. As a result of this process we were able to identify gaps in knowledge and identify key areas for future investment to improve legume function in pastures which will likely increase pasture production and potential for improvement of livestock production.

Executive summary

Background

Recent surveys of pastures in southern Australia have found that the overwhelming majority (>90%) contain legumes that are inadequately nodulated. This presents a significant issue for industry as legumes are the primary means by which nitrogen is supplied in pastures and are the component of the pasture most responsive to addition of management inputs such as phosphorus and sulphur (i.e. single superphosphate) fertiliser. Thus, legume dysfunction has the capacity to hamper overall pasture production and therefore livestock productivity. Herbicides and other pesticides are important tools to manage weeds, pests and disease in pastures, yet they have the capacity to negatively impact legume nodulation and nitrogen fixation through impact on the host plant, the rhizobia and/or the formation of an effective symbiosis. Similarly, routine farm management practices such as management of pasture renovation and general management of established pastures also has the capacity to impact legume function and persistence in pastures. The main questions addressed in this project were:

- What is known about herbicide, other pesticide impacts and general on-farm management practices on the capacity of pasture legumes to fulfil their role as nitrogen fixers and contributors to provision of high quality forage in pastures and are there gaps in knowledge that need to be addressed?
- How are legumes managed in contemporary farming systems and are there management issues that are impeding legume performance?
- From analysis of the literature and contemporary management practices, what are the main issues impeding legume function in pastures? Subsequent to this:
    - Does industry currently have the tools (as a consequence of past research) to overcome these issues?
    - Where current tools or knowledge does exist, what are the gaps and how should these gaps be prioritised for future RDE&A investment to improve legume performance in pastures?

To answer these questions a review of the literature was undertaken with concurrent in-depth consultation with industry to determine contemporary pasture management practices. As a result, we have identified key gaps in knowledge and prioritised these for investment consideration.

Objectives

- To identify what is known from the literature of the impacts of herbicides, other pesticides and general pasture management tactics on performance of legumes in pasture systems with particular reference to the effect of such tactics on the capacity of legumes to fix nitrogen. Through this process identify gaps in knowledge which may require investment to overcome
- To quantify contemporary management practices used in industry and identify management issues that may contribute to poor legume performance and also to ascertain from industry priorities for investment
- Using results of the literature review and industry consultation develop investment priorities to improve legume function in pastures that will deliver improvements in overall pasture productivity and livestock production.

Methodology

A thorough review of the published and grey literature was undertaken. An in-depth survey of producers (n=155) and advisors (n=44) was completed to determine contemporary pasture management practices.

Results/key findings

There are considerable gaps in knowledge in the published literature of the effects of herbicide and pesticide usage on pasture legumes and their capacity to fix nitrogen. Published literature in terms of herbicide knowledge has not kept pace with farming system practices and change. Published literature has focussed on effects of single herbicide application whereas in industry multiple herbicides are frequently applied together in a single spray operation with multiple spray operations per season. Further, published literature does not adequately cover the impact of changes in crop-pasture integration and use of fertilisers. For example, the increased usage of TT canola and Clearfields crops has exposed subsequent pastures to increased herbicide residue loads for which little information on impact is available. Additionally, new herbicides and herbicide spikes, some with new modes of actions are about to be released, the implications of which are unknown for pasture legumes. From industry consultation, there are gaps in general management that could be immediately addressed to improve legume success (for example, sowing rates, clean up duration prior to sowing), but equally there are gaps that require considerable investment, for example options for dry sowing and climate change (legume plus rhizobia delivery technology) and the need for improved information on herbicide and other pesticide impacts. There was strong agreement between gaps we identified in the literature and the areas of investment prioritised by industry for future investment.

Benefits to industry

Legumes are pivotal to the supply of nitrogen for non-legume pasture components and are largely responsible for the responses observed where phosphorus and sulphur-based fertilisers are applied to pastures. However, these pivotal functions are not a given and rely on adequate and effective nodulation and nodule function for pasture legumes. Additionally, pasture legumes contribute positively to improvement in soil conditions including supporting of increases in microbial biomass and therefore nutrient turnover rates. Legumes have the capacity to contribute to achievement of sustainability goals on farm and by industry more widely (e.g. ecocredentials, attainment of carbon-neutrality). There are now legumes available with improved adaptation to climatic and soil physiochemical challenges prevalent across southern Australia. Investment in the RDE&A priorities identified in this project will close the gap between actual and potential nitrogen fixation by pastures legumes resulting in increased pasture growth and livestock production.

Future research and recommendations

Key areas identified for investment from the literature review and consultation with industry were:

- Investment in the development of pasture legumes and associated rhizobia with capacity for adaptation to variable climatic conditions and improved reliability of performance (rated 9/10 by industry)
- Investment in improved technology for dry sowing. The majority of pastures are now established by dry sowing which exerts considerable pressure on the capacity of legumes to

form an effective symbiosis. This technology needs to focus on resilient plants and rhizobia delivery technology (rated collectively at 8/10 by industry)

- Investment in understanding the effects of herbicides and herbicide application strategies of contemporary farming systems across variations in soil type, climate and host-rhizobia associations on legume function (rated 9.5/10 by industry)

Table of contents

1. Background

Pasture legume are integral to profitability of the farming enterprise. Directly, pasture legumes provide high quality, highly digestible feed to support livestock production when grazed or conserved as silage or hay (Kaiser et al. 2004). Indirectly, legumes contribute to increasing production from non-legume components of pastures or to the yield and grain quality of following crops as a result of their capacity to capture and fix nitrogen (Howieson et al. 2000, Peoples and Baldock 2001). However, adequate growth of legumes to support livestock production and adequate nitrogen fixation to support non-leguminous plant production targets is not assured in farming systems. Indeed, recent paddock surveys of southern Australia have revealed more than 90% of legumes ae inadequately nodulated (Hackney et al. 2019) and therefore unlikely to be contributing the quantities of nitrogen that are reported in the literature of 20-25 kg N/t shoot dry matter (Peoples and Baldock 2001).

Over the last 30 years, there have been numerous reports in the literature of pasture decline (e.g. Wheeler 1986). Such decline has been variously attributed to changing climatic conditions, declining use of fertiliser on pastures, changing soil conditions including increasing acidification and poor adaptation of pasture plants to various combinations of the aforementioned constraints (Wheeler 1986, Helyar 1991, Howieson et al. 2000, Perera et al. 2020). Specifically, for pasture legumes, these changing conditions have challenged the adaptation of the most widely sown legumes in southern Australian farming systems, subterranean clover and medics. The shallow root systems of these plants and their relatively determinate growth pattern have resulted in increasing vulnerability particularly to changing climatic conditions resulting in increased incidence of false breaks and difficultly in setting adequate seed, leading to seedbank run down and in some cases, exhaustion of the seed bank (Howieson et al 2000, Loi et al. 2005).

Concurrent with decline in reliability of climatic conditions to facilitate reliable production of traditional legumes has been the intensification of cropping systems particularly within the mixed farming zone of southern Australia (Howieson et al, 2020). Longer cropping phases combined with increasing reliance on a broad and increasing spectrum of herbicides, insecticides and other pesticides has resulted in greater exposure of plants and soil microbes to an ever increasing array of stresses either delivered directly by the pesticide or potentially through residual effects of the pesticide (Rose et al. 2019). Aligned with intensification of the cropping systems are likely other changes in management of pastures that deviate from previously suggested practices to optimise pasture and particularly legume performance. However, assessment of contemporary farming practices as they pertain to management of legume inputs has not been undertaken at a scale to provide insight on how these practices may have changed over time or indeed, the impact such changes may have on legume performance. Similarly, agricultural research has a tendency to focus on components, for example the effects of soil acidity on particular plants or the impact of a specific herbicide applied on a given soil type to a particular plant growing in that soil. However, within the agricultural system, plants are exposed to a number of stresses simultaneously. In the case of pasture legumes, management decisions can impact both the host plant, its rhizobia and the capacity of the legume and rhizobia to form an effective symbiosis and therefore fix and provide nitrogen.

To better understand the limitations to pasture legume production and the capacity of legumes to not only reliably provide high quality feed for livestock, but also reach potential nitrogen fixation targets a concurrent review of the literature on management factors likely to impact legume production was combined with a large scale survey of industry to gain an understanding of contemporary pasture management. The objective of this was to determine gaps that exist in knowledge in terms of pasture legume management and to devise an investment strategy to ensure future legume-based pasture systems are capable of supporting livestock and crop requirements in the future.

2. Objectives

The original proposal contain four key hypotheses to be tested. These are listed below along with our progress in answering these:

- Herbicides, their persistence and toxicity thresholds result in sub-optimal rhizobia function, nodulation and N-fixation of pasture legumes
    - Our evaluation of the literature found this to be true. However, there are considerable gaps in knowledge and misalignment of what is known in the literature compared to herbicide use in practice by industry.
    - Our consultation with industry found significant potential for sub-optimal legume performance as a result of herbicide usage. We also found that herbicide usage on farm and the potential for legume damage could not be quantified using what is currently known in the literature.
- On-farm management of soil physicochemical constraints interact with herbicides limiting legume growth, rhizobia function, nodule formation, overall N-fixation and pasture production
    - We have collected and analysed a large data set (n=155 farming businesses, n=44 industry advisers) and have identified key general management constraints likely to be impeding legume performance, including nitrogen fixation. This has included but is not limited to the interaction of soil physiochemical constraints and herbicide usage.
    - Our analysis of the literature found soil physiochemical constraints are widespread and are likely to impact legume performance, including nitrogen fixation potential and interaction with herbicides. There is insufficient knowledge in the literature to be able to accurately predict the outcome of these interactions particularly coupled with contemporary farm management practices.
- Identification of knowledge gaps will lead to RDE&A investment strategies increasing red meat production via improved reliability of pasture legume N-fixation and pasture production
    - Based on literature review and industry consultation we have developed three key areas for investment based on gap analysis. Investment in these areas will improve legume function in pastures.
- Review of the literature enables development of reinoculation strategies and broader pasture management strategies increasing the reliability of legume nodulation, N-fixation and pasture production and such strategies can be evaluated in future RDE&A investment
    - A number of tips and tools draft brochures have been prepared for consideration following the findings of the literature review and industry consultation.

3. Methodology

This project involved three key components:

i) Undertaking a thorough review of the literature (published and grey) to determine what is known regarding the impacts of herbicides, other pesticides, soil physiochemical constraints and farming management practices such as sowing time, sowing rate and fertiliser usage of legume function including nitrogen fixation.

ii) Undertake comprehensive consultation with industry via survey of producers and consultants to determine on-farm contemporary management strategies for legume-based pastures including use of herbicides and other pesticides, pasture establishment methodologies, management of established pastures and key areas industry see as requiring RDE&A investment.

iii) Undertake gap analysis of i) and ii) above and determine congruency in approach to pasture management relative to thresholds developed through research. Determine, based on gap analysis, priorities for investment in future RDE&A to improve legume function in pastures and farming systems more broadly.

In terms of industry consultation, a survey was developed as part of the milestone requirements for this project. The survey was then piloted with 10 producers and three advisors with minor review to the questions following the assessment of the pilot feedback. The intent was to undertake the survey at 2020 pre-season scheduled events but COVID-19 largely prevented this. As a result, surveys were distributed to producers and advisors by consulting contact lists held by the various project partners. This made the process of data acquisition more costly in terms of the time to collect the data.

4. Results

Comprehensive results are presented in the literature review, attached separately. However, the key results can be summarised below.

A comprehensive review of the literature and consultation with industry (producers and advisors) has been undertaken to ascertain how current management practices may be impacting legume performance and to identify gaps in knowledge and prioritise them for future investment.

Identification of gaps in knowledge via the literature aligned well with industry identified priorities for investment. Firstly, changing climatic and soil conditions were found to be challenging the capacity of traditional legume to meet the needs of producers in attaining their livestock production goals. Indeed, traditional annual legumes were only effective in meeting these goals half the time or less. Thus, there is a need for development of legume species and their symbionts to cover this gap. This was also identified by industry as a high priority (score 9/10) while continued investment in overcoming the adaptation deficits of traditional legumes scored <4/10. This clearly signals industry want for step rather than incremental change in overcoming limitations of adaptational deficit to legume performance.

Significant knowledge gaps were also identified in capacity to effectively deliver and maintain rhizobia populations under dry soil conditions. Indeed, the majority of new pasture sowings were made under sub-optimal soil moisture conditions and industry identified this and the need for robust and cost-effective carriers as a high priority for investment (score 8/10).

Finally, an overwhelming gap in the knowledge of herbicide impacts on legume function was identified. Where information is available on the effects of herbicides, it is almost always on the impacts of single herbicides applied to a specific soil under the same climatic condition on a particular host or range of hosts. In industry, multiple herbicides are frequently applied in a single spray operation with multiple spray operations undertaken within a growing season. Therefore, the stress effects of herbicides on legume function are likely significantly underestimated. Further, knowledge of herbicide impacts has not kept pace with farming system change. The last 30 years has seen intensification of cropping systems and the introduction of various crops including TT canola and Clearfields crop technology meaning an expanding array of herbicides many with long residual activity have the potential to cause injury to subsequently sown pastures or pasture legumes capable of surviving the cropping phase. Additionally, new preemergent herbicides, many with long periods of activity against weeds are poised for release, some with completely new modes of action where the effects on pasture legumes are not known. The need for investment in herbicide research as it pertains to pasture legume function was seen as the highest priority (score 9.5) by industry.

In conclusion, we would state that investment should consider implementation of a systems approach combining these three priority areas.

5. Conclusion

Our review of the literature and survey of industry (producers and advisors) identified numerous gaps likely to be limiting pasture legume performance. Our identification of gaps in the literature aligned well with industry identified needs for future investment.

Firstly, traditional legumes are failing to meet producer expectations in terms of livestock production goals at least half of the time. This failure is attributable to the poor adaptation of traditional legumes to changing climatic, soil and farming systems. Fortunately, there has been development of legume germplasm and their symbionts in the form of domestication of new genera (e.g. Biserrula; Howieson et al. 2000), new species (e.g. bladder clover, gland clover; Loi et al. 2005) and an expanded range of new cultivars of relatively recently domesticated alternative legumes (e.g. hardseeded French serradella varieties, more readily harvestable yellow serradella). However, these new legume options alone do not currently and will not in the future, cover all the likely scenarios of soil, climate and farming system requirements. Analysis of the literature shows that additional scope in legume and rhizobia germplasm is required and industry has identified this as a high priority need for investment with a rating of 9/10. Industry have also clearly signalled that investment to overcome the shortcomings in adaptation of traditional legumes, subterranean clover and annual medics is not a high priority (rating 3.75-5). Clearly industry is signalling they require a step-change rather than incremental change to overcome issues of poor legume adaptation.

Secondly, coupled with the need for development of new legume germplasm is the need for improved technology to support dry sowing. Our investigation of the literature found that survival of rhizobia delivered to dry soils was poor which has capacity to severely compromise the formation of an effective symbiosis. Further, with increasingly erratic rainfall and increased periods of moisture stress now evident in farming systems in comparison to 20 years ago and increasingly likely in the future (Perera et al. 2020), survival of rhizobia over time in the soil is also likely to become further compromised. Our consultation with industry revealed that already, the majority of pasture sowings are occurring in conditions of sub-optimal soil moisture and under conditions where traditional rhizobia delivery systems are likely to be severely challenged. This represents a major risk to industry. Industry too, in their feedback were very cognisant of the need for farming systems to become more adaptable to variable climatic conditions and for the development of more robust inoculant delivery systems to meet climatic challenges (ratings of ~8 for each).

Thirdly, our analysis of the literature with respect to impact of herbicides on legume and rhizobia function identified many gaps. Importantly we found that reports in the literature of herbicide effects generally only considered the impacts of application of a single herbicide in a particular soil on one or several host plants. In industry, multiple herbicides are frequently applied in a single spray operation with multiple spray operations happening within a growing season or calendar year. Hence the potential for herbicide damage or the impact of herbicide residues impacting legume function is much greater than reported in the literature. Further, as herbicide applications in the literature frequently occur only on a single soil type under one set of climatic conditions, there is a paucity of information of how herbicides may impact legumes on other soil types. This information is critical as it is known that soil conditions such as acidity, texture and organic matter content can have a significant impact on herbicide breakdown and therefore possible plant and rhizobia injury. Additionally, information on herbicide impacts on legume function has not kept pace with changes in farming systems. Over the last 30 years, there have been drastic changes in cropping systems with the release of TT and Clearfields crops which has resulted in increased used of herbicides with increased capacity for residual damage. The impact of such practice change on legume function has not been well quantified. Further, new herbicides are entering the market, particularly pre-emergent herbicides with long periods of activity against weeds as well as spikes to improve the performance of existing herbicides. Some of these groups include completely new modes of action where the effect of the herbicide on legume function is completely unknown. Our perception of this as perhaps <u>the most significant gap in knowledge was supported by industry who rated investment in understanding herbicide impacts as the highest priority need for investment (score 9.5).</u>

We conclude from our review of the literature and consultation with industry that the highest priority for investment is in the mixed farming zone. This zone is extremely dynamic with much change in farming systems and as such there is capacity to positively influence outcomes for legume function. Improvements in legume function are likely to see greater capacity to attain livestock production goals and also to positively impact the whole farming system through provision of increased quantities of biologically fixed nitrogen. The mixed farming zone is the hub of livestock production in southern Australia providing breeding animals to both the rangelands and permanent pasture zone while turning off or supporting the turn-off of the majority of finished livestock directly from grazed pastures and forage crops or indirectly through production of grains and fodders which are often utilised in other zones. The mixed farming zone is generally well equipped with the necessary infrastructure (machinery) and has a ready network of advisers who can be upskilled in the management of legumes and support producers in developing robust farming systems for the future.

6. Future research and recommendations

From our review of the literature and consultation with industry, the following were found to be the highest priorities for future RDE&A investment:

i) Development of legume and rhizobia germplasm to overcome the shortcomings of traditional legume adaptation to changing soil, climatic and farming system requirements. This was identified in the literature review and by industry (with industry rating it a 9/10 priority for investment). Industry have also clearly signalled that investment to overcome the shortcomings in adaptation of traditional legumes, subterranean clover and annual medics is not a high priority (rating 3.75-5).

ii) Improved technology to support dry sowing which includes investment in appropriate germplasm (plant and rhizobia) and rhizobia delivery technology. With the majority of pastures currently sown in sub-optimal moisture conditions with most sown using non-robust inoculant delivery technology, this is a major potential failure point in optimising legume function. This was identified in the literature review and rated 8/10 by industry as an investment priority

iii) Investment in improving the understanding of herbicide impacts on pasture legumes particularly with respect to the use of herbicides in contemporary and future farming systems. Such investment needs to consider that within a single spray operation or growing season, multiple herbicides are applied together (whereas literature considers impact singularly), likely exposure of legumes to herbicides is changing because of activities in other enterprises (e.g. herbicide-ready crops increasing exposure to residues to subsequent pasture legumes), emerging herbicides likely to become prevalent in future farming systems – some with new modes of action where effect on pasture legume function is unknown and the effect of soil physiochemical and climatic influences on herbicide activity and persistence of residues. The latter is a critical point as the vast majority of the literature presents herbicide impacts on a single soil type under one set of climatic conditions, yet it is well known that these factors singularly or in combination affect herbicide breakdown rates and likely exposure to residues. This area of investment was rated 9.5/10 by industry.

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8. Appendix

8.1 Draft tips and tools brochure: Reinoculating established legume pastures – do you need to?

Recent field surveys of established pastures in southern Australia has revealed suboptimal nodulation of legumes as a major issue. Legumes need to be adequately (sufficient number) and effectively (right rhizobia strain) nodulated to achieve the expected nitrogen fixation targets of 20-25 kg N/ t shoot dry matter produced. The recent survey of Hackney et al. (2019) revealed 93% of the 225 paddocks surveyed in NSW were inadequately nodulated. This has led to an increase in enquiry regarding re-inoculation strategies for pastures to improve legume nodulation. However, the question has to be asked, is this the most logical step in achieving increases in legume nodulation. Before we get to that there are a few important things to consider.

What does adequate nodulation look like and what are the implications of not achieving it?

Yates et al. (2016) defines adequate nodulation as a legume having 20 to 40 small (<5mm diameter) and/or 3 to 4 large (>5mm) pink nodules on the root system of a legume plant that has been carefully extracted from the soil and washed at 12 weeks after germination.

Where adequate nodulation is not achieved, it is likely that the legume will satisfy further nitrogen requirements from the soil. This means it will not build soil nitrogen by biological nitrogen fixation to the degree that a well and effectively nodulated plant would. Where nodulation fails completely, then the legume will need to access all of its nitrogen from the soil and will not contribute to building soil nitrogen reserves.

An inadequately nodulated legume or one that has completely failed to nodulate will be less effective in utilising phosphorus and sulphur fertilisers applied and this will result in overall decreased pasture production. Non-legume plants are largely reliant on legumes to respond to applied phosphorus and sulphur and supply biologically fixed nitrogen for them.

If my pasture is inadequately nodulated, should I re-inoculate it?

This is frequently the first question asked if legumes in an established pasture are inadequately nodulated. Before proceeding to re-inoculation, it is important to consider and identify why nodulation is currently inadequate. Failure to identify why nodulation is poor and immediately proceeding to re-inoculation may result in some short term benefit, but it is likely that nodulation will again slip below optimal levels. Possible reasons for poor nodulation include:

1. Soil acidity – this is a widespread and increasing issue in southern Australia. Legumes and their associated rhizobia differ in their pH tolerance. However, the rhizobia for any specific host legume may require a 0.5-2.0 pH units higher than its host legume to function optimally. For example, for subterranean clover, the plant will grow with minimal restriction down to a pH_{Ca} 4.8 but its rhizobia requires a pH_{Ca} >5.5 for optimal function. For lucerne, the plant will grow with minimal restriction down to pH_{Ca} 5.0 but optimal function of its rhizobia requires pH_{Ca}>7.0. Recent surveys of established pasture paddocks in NSW revealed soil acidity to be the main reason for suboptimal nodulation in pasture legumes. Low soil pH aside from impacting rhizobia survival, can impact host legume root growth, especially if high levels of aluminium or manganese are available. Under such conditions, the host legume root systems can become distorted with fine root hair growth severely affected. Rhizobia gain entry to the host legume via these fine hairs and under acidic soil conditions such root hairs are less prolific or become thickened or otherwise distorted restricting rhizobia entry and thereby reducing nodulation.
2. Herbicides and herbicide residues – many herbicides can have direct effects on the capacity of a legume to nodulate, maintain nodules throughout the growing season and reach nitrogen fixation targets. Similarly, the residues of herbicides used in previous years can also pose a problem for formation of nodules and the capacity of these to function and attain expected nitrogen fixation targets. Sulfonylurea herbicides (Group B) and clopyralid and dicamba (Group I) are particularly problematic in terms of persistence in the soil and can negatively impact legume nodulation. Herbicide and herbicide residues can impact both the host plant root system and rhizobia impeding nodulation or if nodulation does occur, impede nodule function and therefore the amount of nitrogen fixed.
3. Climatic conditions – rhizobia populations vary through the year and usually reach their lowest levels in summer and early autumn as hot, dry conditions result in population decline. Under reasonable seasonal conditions, rhizobia numbers usually rebound quickly following autumn rainfall. However, if prolonged drought conditions are experienced then the population may be depleted significantly. Where legumes regenerate under marginal moisture conditions, nodulation may be reduced or delayed due to low rhizobia numbers and/or slow root development.

4. Soil texture – soils with a low clay content are less well equipped to maintain high rhizobia populations over time. Clay helps maintain soil moisture which is essential for rhizobia survival, and clay soils often have a more nutrient-dense rhizosphere than coarse textured soils,providing a better energy source for rhizobia in their free-living state. Coarse textured soils will usually show a greater response to re-inoculation due to limited capacity to retain high background rhizobia populations. In contrast, soils with a high clay content may show poor response to reinoculation due to the presence of large background rhizobia populations of variable effectiveness which compete with newly introduced rhizobia.

These are just some of the issues that may affect nodulation in established legume-based pastures. Clearly, it is critical to identify the main issue(s) that have resulted in poor nodulation. In situations where acidity and/or herbicides are likely to be impacting nodulation, then reinoculation is unlikely to result in a long-term increase in nodulation. Such issues may require rectification for nodulation to improve. Interestingly, in cases where acidity is the issue, correction of acidity alone through liming has been shown to result in a significant increase in nodulation of subterranean clover without the need for any further intervention (Evans et al. 1988). In situations where legume nodulation is poor and liming is not an option, investigation of the use of more acid tolerant legumes and rhizobia may be required. In cases where herbicides and herbicide residues are the likely cause, then requirements for breakdown (time, rainfall, and specific soil moisture conditions) need to be met prior to a likely increase in nodulation.

Options for re-inoculation

There are several methods of re- inoculation currently practised. Each have varying levels of success.

Options for drilling in inoculant

1. Drilling of inoculated seed into existing stands – this is a relatively effective means of delivering rhizobia into existing stands. Peat-inoculated seed is drilled into moist soil preferably just prior to emergence of the host legume. This strategy also enables more legume seed to be delivered to the existing pasture potentially increasing legume populations. To be effective, this strategy requires soil to be moist as there is rapid desiccation of peat-delivered rhizobia in dry soils. Use of disc machinery for drilling will result in less disturbance of existing pasture, especially where perennial grasses are part of the mix.
2. Drilling of granular inoculants – these inoculants may be drilled alone or with seed into existing pastures. Granules available differ in their capacity to be used under dry soil conditions. Granules with a high moisture content are unsuitable for sowing into dry soils as they will rapidly desiccate. Low moisture clay granules are better suited to use in dry soil situations.

Options for spreading inoculants

Surface application of inoculants is less likely to deliver high numbers of viable rhizobia to the soil than drilling in inoculants. Surface application results in high levels of desiccation of rhizobia in wet inoculant delivery systems. Producers will often spread inoculated seed over existing pastures in the hope of introducing new inoculant but rhizobia death under these conditions is high due to exposure on the soil surface to the drying effects of wind and temperature, as well as the direct effects of UV light. Similarly, spraying of inoculants is unlikely to result in a high degree of success for the same reasons.

Recently, surface application of low-moisture granules has been proposed as a mechanism for re-inoculation of pastures. However, the success of this practise is yet to be independently verified.

Conclusions

Re-inoculation of existing legume-based pastures should not be undertaken without first identifying the reasons for inadequate nodulation. Failure to identify the reasons for current poor nodulation may result in limited success of re-inoculation.

8.2 Draft tips and tools draft brochure: Consider soil moisture at sowing to improve legume nodulation

Issue: A recent industry survey has shown that 40% of all pasture sowings occur under suboptimal soil moisture conditions and where there may be a prolonged period until germinating rainfall is received. This is likely to become an increasingly important issue for pasture establishment given the changes in rainfall pattern in autumn over the past 20 years and estimates of future climate scenarios.

For pasture legumes, this can result in inadequate nodulation and therefore poor nitrogen fixation. Wet inoculant delivery systems, such as peat and liquid injection, deliver very high numbers of viable rhizobia to the soil provided correct preparation procedures are followed. However, these systems rely on good soil moisture for survival of the rhizobia and their subsequent capacity to initiate nodulation in pasture legumes.

It is critical to remember that if a legume does not nodulate effectively it will utilise nitrogen from the soil nitrogen pool rather than contribute to building soil nitrogen. Additionally, the efficiency of utilisation of other management inputs, such as phosphorus and sulphur fertilisers, are reduced where legume nodulation does not occur or is suboptimal. It is largely legumes that respond to application of these nutrients and then they provide nitrogen via biological nitrogen fixation to drive production of other pasture components. Therefore, where nodulation fails or is suboptimal, response to phosphorus and/or sulphur application is reduced and feed supply and quality for livestock can be restricted resulting in reduced livestock production.

Improving nodulation when establishing new pastures

There are two main options when sowing pastures to improve nodulation if soil moisture conditions are suboptimal.

1. Delay sowing until sufficient rain is received to ensure rhizobia survival. This option will increase rhizobia survival when they are delivered via wet inoculant delivery systems such as peat or liquid injection. However, the downside of this strategy is that if sufficient rain is not received until mid to late autumn or even early winter, then there will be a significant reduction in the growth of the newly established pasture due to low temperatures. Pasture legumes are capable of germinating at very low temperatures, but their emergence will be significantly delayed and this may cause a decline in viable rhizobia. This strategy may then result in having very small plants which are more susceptible to spring moisture stress due to their poorly developed root systems

2. Use a more robust inoculant delivery system. In recent years, more robust inoculant delivery systems have been developed. These systems use clay granules as the delivery system. The clay, which is dried to a low moisture content during manufacturing, protects the rhizobia from desiccation due to high temperature and low moisture conditions in the field. Clay granules contain less rhizobia cells per gram of product, but their stable form means they can survive for extended periods of time once sown with the seed.

Other considerations when dry-sowing pastures

Traditional pasture legumes such as subterranean clover and annual medics are highly susceptible to moisture stress at sowing due to their slow developing and shallow root systems and poor capacity to control moisture loss through their leaves. As such, they are high risk options if you are faced with dry sowing.

Conversely, annual legume species such as serradella, biserrula and arrowleaf clover have more rapidly developing and deep root systems. This allows them to better withstand moisture stress at sowing. In addition, biserrula has the capacity to better regulate moisture loss through its leaves by regulation of leaf stomata and angulation of its leaves. If these species are suited to your soils and you are having to sow pastures when soil is dry, these species may be better suited than traditional legumes.

Also remember for any pasture establishment, having a 2-3 year clean-up phase and achieving complete control of weeds will enhance establishment success. Similarly, be mindful of herbicides that have been applied in preceding years as there are many herbicide residues that can impact legume growth and nodulation. Keep accurate records and check herbicide labels for plant-back periods.

8.3 Draft tips and tools brochure: Consider the impact of herbicide residues when establishing legume-based pastures

Establishing new pastures is an expensive process. Herbicides are an important tool in the leadup to sowing of new pastures to reduce weed populations. Competition from weeds is the main cause of establishment failure for newly sown pastures.

While herbicides play an important role in controlling weeds prior to pasture establishment, residues from previously applied herbicides can cause issues at establishment. This is particularly so for pasture legumes where herbicide residues may impact legume growth (root and shoot), rhizobia survival and the formation of an effective symbiosis (the formation of nodules) between the legume and its rhizobia. One of the most common effects of herbicide residues is to disrupt normal root growth. Rhizobia are attracted to the host plant via mutual signalling processes. In the plant, this signalling is initiated from the fine root hairs. Once appropriate rhizobia are in the vicinity of the legume root system, they gain access through the fine root hairs. The residues left by some herbicides interfere with the development of fine root hairs on the host legume or these root hairs can be damaged when they extend into the part of the soil profile where the residues exist. Damage to the root system can vary from thickening of the root hairs, reduction in root hair length or absence of root hairs. Such damage reduces the capacity of the host legume to form functioning nodules through the following, interrelated processes:

1. There is a reduction in signalling between the legume and the rhizobia resulting in less chance of encounter between the two; leading to reduced nodulation.

2. Rhizobia entry to the host plant is restricted or impossible due to increasing thickness of root hairs or their absence.
3. Nodulation is reduced or absent due to failure of the rhizobia to gain entry to the plant.
4. Where nodulation does occur, nitrogen fixation may be reduced due to inability of the plant to access sufficient moisture and nutrients due to loss in root hair function and/or root length.

Herbicide residues may also impact directly on rhizobia survival through direct toxicity or by impacting rhizobia function and acquisition of nutrients. In some cases, mutations in rhizobia populations have been reported as a consequence of herbicide residues.

Where legume nodulation is reduced due to the presence of herbicide residues, the host legume becomes increasingly reliant on mineral nitrogen from the soil to satisfy its requirements for growth and hence can become a net user, rather than builder, of soil nitrogen. Of course, in situations where there is complete nodulation failure due to the presence of herbicide residues then the host legume is completely reliant on access to soil nitrogen for its nutritional requirements and does not contribute at all to building soil nitrogen through nitrogen fixation.

What factors affect whether herbicides residues are likely to impede nodulation and nitrogen fixation?

A number of factors that can singularly or in combination give rise to the potential for herbicide residue damage in pasture legumes. These include but are not limited to:

1. The herbicide used and its rate of application;
2. For some herbicides, specific characteristics of the soil to which it was applied (e.g. soil pH, organic matter content);
3. Time elapsed since application – herbicides vary in the time taken for their breakdown;
4. The amount of rainfall received since the herbicide was applied; and
5. Specific requirements for maintenance of particular soil conditions for a specified period of time.

Some herbicides may carry no requirement for plant back of sensitive plants, but others may require one or more of the above factors to be observed. For example, some herbicides will specify certain periods of time must have elapsed with a particular amount of rainfall required and soil moisture to be a specified content for a particular period of time before a sensitive plant can be reliably sown. It is important to keep accurate records, read herbicide labels carefully and abide by the recommendations outlined on labels.

Which herbicides pose the greatest risk?

Many herbicides have residues that can reduce nodulation or result in complete nodulation failure. However, high risk herbicides include the sulfonylureas (Group B) and some Group I herbicides such as dicamba and clopyralid. More recent research has shown the growth and nodulation of some legumes is affected by the presence of some Imidazolinone herbicides (Group B) herbicides.

How can the risk of herbicide residues affecting legume performance be managed?

It is important to keep accurate records of herbicides used, their rate of application and rainfall received between application and sowing. Also, it is important to have a good understanding of soil factors in your paddocks as this can affect the breakdown of some herbicides. Read herbicide labels carefully and consult with advisors if you are in any doubt of the potential for herbicide residues to impact your planned legume sowings. Additionally, recent industry surveys revealed up to 20% of producers were using Group B herbicides in fallow sprays prior to sowing pastures. This is a very high risk strategy and likely to result in significant damage to legumes sown in the following months. Be mindful of and keep records of all herbicides used not just those applied within the growing season.

What’s the bottom line on herbicide residues? Herbicides are a very important tool for weed control leading up to the sowing of pastures. Be wise in the selection of herbicides used in the years leading up to sowing a new pasture and where possible choose herbicides that are likely to pose a low risk forming a persist residue in the soil particularly in the 12 months leading up to pasture sowing. Keep accurate records, read herbicide labels thoroughly for information of plant-back periods and factors affecting it such as time, rainfall, moisture and soil factors. Always consult with an adviser if in any doubt. Pasture renovation is expensive; don’t let herbicide residues impact the success of this operation on your farm.