Australian Grassland Association Inc.

SOIL CONSTRAINTS TO PASTURE PRODUCTIVITY

Inveresk Campus, University of Tasmania

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Soil Constraints to Pasture Productivity

Proceedings of an Australian Grassland Association Inc Symposium

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Editor

Brendan Cullen

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Program

Time	Speaker	Title
DAY 1 - Tuesday 12 February		
10:00 AM	**Opening Address - AGA President - Stuart Kemp**	
10:10 AM	**Session 1. CHAIR: Mark Norton**	
10:15 AM	Brendan Cullen	Fertiliser use in the 21st Century - value of getting it right, cost of getting it wrong
10:50 AM	Lee Menhenett	Soil nutrients and fertiliser - trends and drivers
11:20 AM	**MORNING TEA**	
11:45 AM	Richard Rawnsley	Improving the nitrogen fertiliser efficiency in grazing systems
12:15 PM	Beth Penrose	Micronutrients limiting pasture production in Australia
12:45 PM	Fiona Leech	Influences of alternative fertilizers on pasture production and soil community structure
1:15 PM	**LUNCH**	
	Session 2. CHAIR: Beth Penrose	
2:00 PM	Jeff Kraak	Quality assured fertilizer recommendations for graziers
2:30 PM	Meredith Mitchell	Strategies for effective use of phosphorus in sown and naturalised temperate pastures: a review
2:50 PM	Malcolm McCaskill	Responses of native, naturalised and sown pasture species to Olsen P in glasshouse soil cores and field conditions
3:10 PM	Phil Ward	Nutrient status and cycling under perennial pastures grown with crops in the low rainfall zone of Australia
3:30 PM	**AFTERNOON TEA**	
3:55 PM	Bill Cotching	Fertiliser best management practices – science, anecdotes and gaps
4:25 PM	Cameron Gourley	The development of pasture yield responses to phosphorus, potassium and sulphur fertiliser in Australia using meta-data analysis and derived soil-test calibration relationships
4:45 PM	**Housekeeping: Stuart - dinner venue, time etc.**	
	Informal Symposium dinner (included in registration)	
DAY 2 - Wednesday 13 February		
8:45 AM	**Day 2. Opening Address - housekeeping for the day: Rowan Smith**	
8:55 AM	**Session 3. CHAIR: Lee Menhenett, Incitec.**	
9:00 AM	David Masters	Minerals in pastures - are we meeting the needs of livestock?
9:35 AM	Lambert Brau	Update on soil microbiology research - review and opportunities
10:10 AM	**MORNING TEA**	
10:35 AM	Yingjun Zhang	Arbuscular mycorrhizal fungi (AMF) play a key role in plant community productivity and ecosystem stability of steppe grasslands
11:05 AM	Richard Hayes	Potential of commercial rhizobia strains for new and existing legume cultivars
11:25 AM	Sofie De Meyer	RHIZO-ID^{TM} as a novel technology for direct rhizobia identification
11:45 AM	Geoff Dean	Effect of subsoil manuring on dry matter production and feed quality of forage rape (*Brassica napus*) in northern Tasmania
12:05 PM	**LUNCH (bagged and on bus)**	
return 6:00pm	**FIELD TOUR. Chair: Bill Cotching. Visiting properties at Symons Plains and Longford.**	
	Symposium Dinner at Peppers Silo Hotel. Guest Speaker: Kevin Reed. Incitec Speaker: Rebecca Hall	

Time	Speaker	Title
DAY 3 - Thursday 14 February		
9:15 AM	**Day 3 Opening address**	
9:20 AM	**Session 4. CHAIR: Peter Johnson, Dairy Australia**	
9:25 AM	Richard Simpson	Improving the P-efficiency of grassland production in southern Australia
10:00 AM	Gavin Peck	Legumes and phosphorus fertiliser could dramatically improve productivity and returns from sown pastures in the Brigalow Belt bio-region of Queensland
10:30 AM	Daniel Kidd	Physiological tolerance or physical avoidance? How some Australian forage legumes tolerate aluminium
10:50 AM	**MORNING TEA**	
11:20 AM	Clare Edwards	Increased emphasis on soil management for improved pasture legume productivity
11:35 AM	Phil Nichols	Tolerance and recovery of messina (*Melilotus siculus*), burr medic (*Medicago polymorpha*) and balansa clover (*Trifolium michelianum*) to salinity and waterlogging
11:55 AM	David Peck	A new pasture development program for southern Australia's low rainfall mixed farms; opportunities for legume improvement
12:15 PM	**LUNCH**	
1:00 PM	**Session 5. CHAIR: Cameron Allan, Meat & Livestock Australia**	
1:00 PM	Richard Hayes	Prospects for improving perennial legume persistence in mixed grazed pastures of south-eastern Australia through improved soil nutrition
1:20 PM	Rowan Smith	Mapping pasture species suitability using fine scale soils and climate data
1:40 PM	Mary-Jane Rogers	Survival of perennial ryegrass over summer in northern Victoria without irrigation
2:00 PM	Donna Lucas	Designing practical extension and training programs
2:20 PM	**Symposium Close - Brendan Cullen**	
2:30 PM	**TEA & COFFEE**	

Contents

Introduction

Welcome to the Australian Grassland Association (AGA) symposium on 'Soil Constraints to Pasture Productivity'. This is the fourth in a series of AGA research symposia following on from the 'Australian Legume Symposium' (2012), 'Perennial Grasses in Pasture Production Systems' (2014) and 'Livestock Productivity from Pastures' (2017).

The Australian Grassland Association Inc. (AGA) was established to facilitate the ongoing improvement and development of the pasture industry. We do this through providing a forum which brings together a wide range of industry stakeholders in order to:

- Facilitate the interaction and exchange of ideas and provide an opportunity for research to be presented and published;

- Provide an opportunity for all interested stakeholders to review and contribute to the advancement of pasture-based industries through science; and

- Consider and discuss the state of the pasture industry and the research needed in order for it to meet the challenges of today and be prepared for the future.

This symposium, 'Soil Constraints to Pasture Productivity' will include themes of fertilizer, biology and managing soil constraints. As with the previous symposia, we are working a special issue of the journal Crop & Pasture Science containing the papers presented at the symposium. In the past our special issues have been highly successful and rank as some of the most viewed online.

We would also like to thank the symposium sponsors Dairy Australia, Meat & Livestock Australia and Incitec Pivot.

We trust you will have an informative and enjoyable symposium and look forward to meeting you all during the course of the symposium.

Kind Regards,

Australian Grassland Association committee

Fertiliser use in the 21st Century - value of getting it right, cost of getting it wrong

A. Sinnett, B. Malcolm and B. Cullen

Faculty of Veterinary & Agricultural Sciences, University of Melbourne

Abstract: In the 21st century, it is expected that the weather will be hotter, drier and more variable. How will such an environment affect the profitability of investing to increase pasture production on grazing farms? One farmer investment is to improve soil fertility, with or without introduced pasture species. It is well documented that improving soil fertility improves pasture growth. Similarly, studies have highlighted the economic advantages of investing in improving with fertilizer and introduced pasture species in southern Australia. Even with decades of practical experience and research findings about the merit of improving pastures, many pastures in the region are in low-production, degraded states. This is, perhaps, because pasture investments are inherently risky. Relatively few studies of pasture investment decisions include an explicit and comprehensive analysis of the risk associated with the investment. To better understand the decision to invest in improving pasture, a real farm in south west Victoria producing prime lambs was modelled using simulations of pasture growth, farm budgets and development budgets of investment in improved pasture, under risky rainfall and price conditions. The case study drew on pasture production and species composition data from the Long-Term Phosphate Experiment at Hamilton and used Grassgro to estimate sustainable stocking rates and production levels for degraded and improved pastures. A Monte-Carlo simulation approach was used to analyse the profitability of pasture improvement using actual historical runs of predominantly 'wet' and 'dry' seasonal conditions. Historical variation in phosphorus fertiliser and supplementary feed costs as well as commodity prices were used to represent some of the volatility that might be anticipated to occur in the future. This study has shown that increasing soil fertility without introducing improved pasture species, and instead retaining poor quality pastures, is not expected to increase farm profit substantially when compared to increasing fertility and improving the pastures. Further, this study has shown that the more soil fertility is improved (along with pasture improvement) the greater the profit – up to a point. Risk matters. There is a high level of fertility, pasture production and stocking rate where the extra fertiliser adds little extra to profit because of the effect of the principle of diminishing marginal returns. This study has also shown that the weather conditions for each year of the investment are expected to have the greatest positive impact on profit. Finally, this study shows not taking one form of risk inevitably incurs some other risk; by not improving pastures as well as soil fertility, farm profit is less than it could be otherwise. Investing to introduce improved pasture species, to an acceptable level of risk, builds a farmer's wealth. Without investing in improving pasture the business may struggle to remain competitive, business growth is impeded and in some cases survival may be threatened.

Notes:

Soil nutrients and fertiliser - trends and drivers

L. Menhenett

Incitec Pivot

Notes:

Improving the nitrogen fertiliser efficiency in grazing systems

R.J. Eckard [A], R.P. Rawnsley [B], A.P. Smith [A], K. Christie [B] and M.T. Harrison [B]

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Abstract: The nitrogen (N) nutrition of dairy pasture systems in southern Australia has changed from almost total dependence on legumes in the early 1990s, through to strong reliance on N fertiliser by 2010. While some tactical N fertiliser is applied to sheep and beef pastures, mainly to boost late winter growth, the majority of N fertiliser applied to pastures is in the dairy industry. This transition to higher reliance on N fertiliser has been driven by intensification, with consequent increases in stocking rates highlighting the limitation of legume derived N to drive the higher pasture growth rates required to support additional feed demand.

This increased use of N fertiliser through intensification has dramatically increased N loading, leading to greater potential N losses through volatilisation, leaching and denitrification. Increased concerns over climate change has further highlighted implications of N losses via nitrous oxide.

This paper summarises a series of recent modelling studies, investigating options for improving N use efficiency (NUE) through improved N fertiliser management. These modelling studies demonstrate that application of best management practices (BMPs) can improve NUE, with increasing sophistication of precision technologies playing an important role informing the application of BMPs.

With increasing focus on the environmental impact of livestock production, reducing N loading on dairy farms will become critical to the longer-term sustainability of the dairy industry, with the expectation that Australia will join the majority of developed countries regulating N loading in catchments. Application of N fertiliser best practice can contribute to meeting these targets.

Notes:

Micronutrients limiting pasture production in Australia

R. Bell[A], R. Brennan[B] and B. Penrose[C]

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[B] Department of Agriculture, Western Australia
[C] Tasmanian Institute of Agriculture, University of Tasmania

Abstract: Low levels of micronutrients were a feature of many soils in southern Australia due mostly to highly weathered soil parent materials. Productive legume-based pastures were possible when the deficiencies of micronutrients were diagnosed and corrected. Widespread Cu, Mo and Zn deficiencies for crop and pasture production were diagnosed in the 1950-1980s. Treatments involving micronutrient fertiliser incorporated in soils, or applied as additives to superphosphate were effective in most cases. The removal of micronutrients in wool and meat is small compared to rates added in fertiliser. Hence, in general, the residues of soil-applied micronutrients fertilisers remain effective for many years: up to 30 years has been reported for Cu. The exceptions with short residual values involve Mn on highly calcareous soils and Mo on acid soils. In the last two decades there have been a number of farming system changes with likely implications for micronutrient status in pastures. Firstly, increased cropping intensity and low prices for wool and meat meant that less attention was paid to nutrient management in pastures or the pasture phase of rotations with crops. When pastures were rotated with crops, some on-going additions of Cu, Zn, Mo are common. In cropping phases of farming systems, lime application and zero tillage may have altered the chemical and positional availability of micronutrients to pastures. However, there has been little study of the economic impacts of these changes on micronutrient status of pastures. The intensification of dairy production systems may also have altered the demand for, and removal rates of, micronutrients. Industry informants suggest that there is low and declining use of plant tests for pastures. Additionally, soil tests are not very reliable for Mn or Mo deficiencies, and well calibrated soil tests for B, Cu, Zn have only been developed for limited areas of pasture production. In conclusion, there is limited knowledge of the current micronutrient status of pastures and its effects on animal health. Pasture production would benefit from targeted survey of micronutrients status of pasture soils, pasture plants and micronutrient-linked animal health issues.

Notes:

Influences of alternative fertilizers on pasture production and soil community structure

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Abstract: Alternative fertilizers are commonly promoted for use on pastures by commercial agricultural fertilizer companies to improve pasture productivity and support a ‘healthy’ soil microbial environment. However, minimal field-based research has been conducted to validate such claims. A six year study (2009-2014) conducted near Yass, NSW has investigated the topdressing of a range of alternative fertilizers with variable nutrient content to native perennial-based pasture as compared to a control (nil fertilizer) and a superphosphate treatment as the industry standard. Annual measurements of pasture herbage mass during winter and spring were conducted as well as an economic assessment based on the pasture grown. Fertilizer products with substantial quantities of P resulted in significantly higher pasture production, when compared to the unfertilized control. The cost effectiveness of the products varied considerably and was a function of rate and frequency of application as well as amount and solubility of P applied. A soil community structural analysis under each fertilizer treatment was undertaken in the sixth year of the study to determine impact on bacterial, fungal and archaeal diversities. Despite large differences in pasture growth, there was no significant effect of the alternative fertilizer treatments on community structure within each microbial kingdom when compared to the control or single superphosphate treatments. However, overall variation in bacterial, fungal and archaeal community structures across all fertilizer treatments was commonly best explained by soil pH (or aluminium concentration). Fungal community structure was also correlated to pasture productivity parameters. These findings illustrate the highly resilient nature of the soil communities present.

Notes:

Quality assured fertilizer recommendations for graziers

J.C. Kraak

Fertilizer Australia, Barton ACT 2600: jeff.kraak@fertilizer.org.au

Abstract: Graziers attempt to balance maximising pasture yield with the cost of inputs like fertilizer and soil amendments. Clearly it is in grazier's interests to optimise the return on their fertilizer investments while managing risks, such as, commodity price, weather and offsite nutrient movement. Unfortunately, the quality of soil and plant nutrition advice that graziers generally receive from both fertilizer supply companies and independent advisory businesses, varies widely. Whilst the author is not aware of any formal studies on the quality of farm nutrient advice in Australia, anecdotal evidence suggests a significant proportion is unlikely to meet minimum standards. Advice to farmers does not always adequately address matters, such as, pasture yield and quality, profitability, nutrient use efficiency, environment and food safety, and may ignore the available evidence. Currently there are no legal or registration requirements to qualify an individual to provide soil management, plant nutrition or fertilizer recommendations to farmers. Anyone can call themselves an agronomist and start providing nutrient advice to graziers, either as part of a service package associated with the supply of soil and plant nutrition products, or as an independent advisory business. Soil and fertilizer advice given to graziers will come under increasing scrutiny from, not only the recipients, but also a range of other stakeholders including branded food processors, Natural Resource Managers, Government and consumers. The Fertcare® Accredited Advisor program provides an objective basis to assess the competence of advisors providing soil management, crop nutrition and fertilizer recommendations.

Key words: soil, plant, fertilizer, advice, agronomist, accreditation, Fertcare

Introduction

The Food and Agriculture Organisation of the United Nations (FAO) have estimated that the world's population is likely to reach 9.1 billion by 2050, requiring an overall food production increase of 70%, between 2005/07 and 2050 (FAO 2009). It is generally accepted that much of the increased food production will come from intensification of agriculture. Higher yields will remove more nutrients from the soil. If soil fertility is to be maintained, these nutrients will need to be replaced.

Optimising crop and pasture yield and profitability, through the addition of nutrients from fertilizer and other sources, can increase the risk of offsite nutrient movement which can have negative environmental effects.

The Australian fertilizer industry, through Fertilizer Australia, has taken a responsible approach to the management of the risks associated with fertilizer use. The industry has made a commitment to balancing the promotion of productivity and protecting the environment through the national product stewardship program, Fertcare®.

Fertcare® is designed to improve the skills and knowledge of all people involved in the supply of fertilizer products and services. As the greatest environmental risks are at the point of end use, Fertcare® focuses on ensuring high quality advice is provided to the users of fertilizers. This advice assists users to optimise productivity while minimising environmental and food safety risks. Fertcare® also provides a vehicle for the fertilizer industry to constructively engage with stakeholders and participate in the development of public policy with regard to nutrient management and food safety matters.

There are 3 main components of the Fertcare® program:

- Fertcare® training;
- Fertcare® Accredited Advisor (FAA); and
- Accu-Spread®.

This paper focuses on Fertcare® training and the FAA parts of the program. Examples of how the fertilizer industry has used Fertcare® to constructively engage in nutrient issues, in the dairy industry and in the Great Barrier Reef (GBR) catchments, is also provided in this paper.

Fertcare® Training

The Fertcare® training program equips industry staff with the competencies required to meet their responsibilities with regard to food safety and environmental risk management. It includes the competency to warn and advise, then refer customers to information about the risks and how to manage them.

An important theme running through the Fertcare® training material to aid effective use of fertilizer, is the "4R Nutrient Stewardship". The 4Rs are, applying the Right source of nutrients (product), at the Right rate, at the Right time and in the Right place. Whilst the concept is simple, the implementation is knowledge intensive and site specific.

The Fertcare® training program was developed by professional educators and was overseen by a technical committee that included leading public and private sector expertise in plant nutrition, food safety and environmental sciences. The Fertcare® program continues to be updated with the latest information, practices and guidelines as new science-based information comes to hand.

Fertcare® training is delivered nationally by independent and qualified providers, through a Registered Training Organisation. Each training course meets national competency standards under the Australian Qualifications Framework.

At the time of writing this paper, over 3,400 people have completed Fertcare® training, since 2003, when the competency based program commenced.

In addition to the competency based Fertcare® training, the program also offers opportunities for advisors to augment their ongoing professional development through the provision of training on topical subjects such as nitrogen use efficiency and greenhouse gas management.

Fertcare® Accredited Advisor

Currently, there are no legal or registration requirements to qualify an individual to provide soil management, plant nutrition or fertilizer recommendations, in Australia. The quality of advice farmers receive from both fertilizer supply companies and independent advisory businesses can vary widely and may not always adequately address matters such as, crop / pasture yield and quality, profitability, nutrient use efficiency, the environment or food safety.

The FAA program provides farmers and other stakeholders with confidence that soil management and fertilizer advice, based on soil and or plant testing, is of a high standard. It provides assurance that the process of making recommendations, the underlying supporting data, sampling methodology and laboratory competence are based on good practice and accepted science in Australia.

The FAA program assesses the competence of advisors to make nutrient recommendations. Assessment is based on standards set by Australasian Soil and Plant Analysis Council (ASPAC), which have been mapped to national competencies. The standards cover sampling, analysis, interpretation, recommendations and monitoring. Advisors recommendations are tested for completeness and for appropriate management of environmental and food safety risks. The standards are based on accepted scientific consensus with new information incorporated as it comes to light.

Soil and plant analysis must be conducted by a laboratory that follows accepted procedures and participates successfully in the ASPAC inter-laboratory proficiency program.

Once advisors have been assessed as competent, they are subject to a biennial audit of randomly selected recommendations made in the preceding two-year period. The audit is a quality assurance process to ensure that competence is being routinely applied and provides mechanisms to improve and rectify any underperformance.

At the time of writing this paper, there were 270 FAA operating across Australia.

The FAA program draws on key texts and national industry initiatives like the "Better Fertiliser Decisions for Cropping Systems" project, in the grains industry, "Better Fertiliser Decisions" project, in the intensive grazing industries and "Six Easy Steps" in the sugarcane industry, to ensure appropriate recommendations are made and that environmental and food safety considerations are properly taken into account. The FAA program brings together sound science and good practice to inform and assist policy development and implementation.

Why should agronomists should be recognised as an Accredited Advisor?

There are three main reasons why an agronomist should be recognised as a FAA:

- the FAA logo signifies the provision of high quality, independently audited advice based on sound practices and accepted science in order to promote farm productivity while protecting the environment;
- the process of accreditation invariably leads to improvements in the quality and or consistency of advice; and
- nutrient management, along with off-site impacts e.g. eutrophication, feature amongst the issues that are of high priority to the community, consumers and marketers of branded food and fibre products. Assurance on these issues is increasing being sought throughout the supply chain. In seeking this assurance, not only are the practices employed by farmers to produce the food being scrutinised but also the quality and source of professional advice farmers receive is also being questioned by resource manger's and branded food and fibre processing companies. Through the training provided, each FAA is well positioned to address these matters.

The dairy industry provides an example of how supply chain assurance is likely to impact on nutrient advice to farms. The Australian dairy industry is a Unilever Sustainable Supplier, at a country level. This status assists the Australian dairy industry to market Australian milk products.

The "Australian Dairy Sustainability Framework" initiative provides the substance for this recognition as a Unilever Sustainable Supplier, in the form of industry targets and high level evidence. Furthermore, the "Fert$mart" program along with other dairy industry BMP's, tools and guidelines underpins the Sustainability Framework.

Dairy farm nutrient management plans are a key measure in the Australian Dairy Sustainability Framework. Dairy Australia's intention is to move toward all nutrient management plans being developed by a FAA in the next year or so.

How does FAA & public policy link together?

Concern about effects of runoff from agricultural land causing negative consequences (eutrophication) on the World Heritage listed Great Barrier Reef (GBR) has attracted local, national and international concern over the last couple of decades.

In Oct 2009, the Queensland government amended the Environmental Protection Act to add reef protection measures. This amendment focused on the sugarcane and grazing industries north of and including Mackay. The amendment requires cane farmers to conduct soil tests at the start of each crop cycle, use appropriate analysis and the prescribed methodology ("Six Easy Steps") to determine appropriate, site specific nitrogen and phosphorus rates. The reef protection measures also suggest that farmers seek professional fertilizer advice, from an advisor that has the same units of competency that the FAA program is based upon and is assessed by. Fertcare® meshes well with reef protection measures and is an example of how fertilizer industry is working co-operatively with Governments to improve outcomes.

Conclusions

World populations are growing, increasing food demand. As the available agricultural land is limited, fertilizer will be one of the tools used to sustain and increase food production. Increasing the concentration of nutrients in the soil can also raise the environmental risk associated with nutrient movement.

Fertcare® is effective in achieving the practical application of the "4R" approach to optimising yield whilst managing nutrient risks. It has been developed by the Australian fertilizer industry to equip industry people to provide advice to farmers, provide assurance that competence is being routinely applied and sound practices are being followed in the development of fertilizer recommendations, based on soil and plant analysis.

When engaging with public policy issues, the fertilizer industry is committed to basing its advice on the best available science. The Fertcare® program is offered as an effective tool in implementing science-based policy programs and standards. This approach is the basis for strong and credible engagement with land managers, Governments, industry bodies and environmental organisations. The GBR is an example of how Fertcare® and an evidence-based approach can be used to assist in improving outcomes for all stakeholders.

As new scientific information and technology becomes available, Fertcare® will adapt this into practical advice for industry staff to pass on to farmers.

References

Fertcare Accredited Advisor Participant Manual. Available at http://www.fertilizer.org.au/Portals/0/Documents/Fertcare/Fertcare%20Accredited%20Advisor%20Participant%20Manual.pdf?ver=2018-01-30-153523-493

Food and Agriculture Organisation of the United Nations (2009) How to feed the world in 2050. Available at http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

Notes:

Strategies for effective use of phosphorus in sown and naturalised temperate pastures: a review

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Abstract: A gradual increase in phosphorus (P) prices is expected as the more easily-accessible rock phosphate deposits are mined out. Pasture agronomy research on P has been focussed on pastures sown to improved species with relatively high fertility requirements. The focus of producer-oriented decision support has been on fertilising to a steady-state economic optimum that requires substantial additional investments in pasture sowing and additional livestock, rather than incremental investments at P rates below this optimum. Many areas are constrained from full sowing to improved species because of financial constraints and land classes unsuitable for sowing. In many instances the application of fertiliser has been as a response to subsidies than science.

This paper reviews mechanisms of P response in sown pastures and stages of P response. It also examines native pastures, looking at the role of non-native species in 'native' pastures and the associations between native grass species and soil fertility. The review concludes with current recommendations on how to manage/fertiliser pastures and whether nil P is an option for some pastures.

Notes:

Responses of native, naturalised and sown pasture species to Olsen P in glasshouse soil cores and field conditions

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Abstract: Phosphorus (P) is the nutrient most commonly applied to pastures grazed by sheep in much of south-eastern Australia, but a gradual increase in the real price of P is anticipated, leading to interest in pasture plants that can maintain growth at lower levels of soil test phosphorus than the pasture plants that are commonly sown. The growth response of 20 species that included native grasses, naturalised legumes and sown species to soil test P in a series of glasshouse and field experiments based on the Long-term Phosphate Experiment at Hamilton were compared.

There was no overall trend for the native grasses or naturalised legumes to have lower P requirements as evidenced by the Olsen P level at which 80% of maximum dry matter yield was obtained. Instead, in each experiment the species with the highest growth rates at low P also had the highest growth rates under high P conditions. In the glasshouse experiments this was *Panicum maximum* and *Trifolium subterraneum* and in the field experiment was *Rytidosperma caespitosum*. Despite the high production of *T. subterraneum* under low P conditions in the glasshouse, this species forms a relatively low proportion of the pasture sward under the same P conditions in the field. In low-P environments there is a much stronger selection pressure for low relative palatability than for P efficiency. It was concluded that to maintain desirable species, sufficient P needs to be applied to maintain fertility above a threshold at which the less palatable species begin to invade.

Notes:

Nutrient status and cycling under perennial pastures grown with crops in the low rainfall zone of Australia

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Abstract: The integration of cropping and pastures is important in many areas of southern Australia, especially in situations where soils may not be suitable for continuous cropping. Farmers are testing 'pasture cropping' systems in which tropical grasses are grown over summer, and crops can be sown into the pastures during their dormant winter months. We determined the ability of the tropical grasses to recycle nutrients within the soil profile. Soil samples were taken to a depth of 4.0 m from a deep sandy soil at Moora (WA) and 1.0 m from a loamy sand at Karoonda (SA), and analysed for nitrate, ammonium, phosphorus, potassium and sulphur. All perennial options were excellent scavengers for nitrate, which was maintained at low levels under the perennial grasses, but increased at depth under the crop. At Moora, potassium concentration was also higher at the surface, and lower at depths of 3-4 m, under the perennial pastures compared with the continuous crop. Perennial pastures have a role in preventing loss of nitrate and possibly potassium from farming systems, and so can increase the sustainability of farming systems in southern Australia.

Notes:

Fertiliser best management practices – science, anecdotes and gaps

W.E. Cotching

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Abstract: Using fertiliser is about applying the right product at the right rate at the right time and in the right place for maximum profitability. However, best fertiliser management practice also includes soil sampling and analysis, appropriate interpretation of soil test results, an understanding of other soil constraints, undertaking a nutrient budget, avoiding nutrient losses to the environment, as well as good record keeping. Science can inform us about what the optimum soil nutrient levels are and the best time to apply them, but does not necessarily dictate what the farmer's desired levels are and if the budget can afford the cost. Alternative soil amendments and nutrient balance come with considerable hype but have you seen the science based evidence or is it speculation based on a good sounding theory. There may be a lot to gain from understanding and managing what the existing soil limitations are in your paddocks. Farmers have concerns about the rates of decline in soil nutrient levels but perhaps they should be more concerned about existing nutrient variability around the farm. Precision agriculture and the use of variable rate technology may offer a way to better manage the application of soil nutrients for some farmers but there are also gains to be made from understanding the management factors that influence soil nutrient distribution and fertility transfer.

Notes:

The development of pasture yield responses to phosphorus, potassium and sulphur fertiliser in Australia using meta-data analysis and derived soil-test calibration relationships

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Abstract: An improved ability to predict pasture dry matter (DM) yield response to applied nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) is a crucial step in determining the production and economic benefits of fertiliser inputs with associated environmental benefits from reducing inefficient nutrient use. The adoption and application of soil testing can make substantial improvements in nutrient use efficiency but soil test interpretation needs to be based on the best available and most relevant experimental data. This paper reports on the outcomes of the Better Fertiliser Decisions for Pastures project (BFDP) including the development and adoption of improved national and regionally specific soil test – fertiliser - pasture yield response functions.

National in scope, a team of around 50 scientists and fertiliser agronomists from all states of Australia contributed to the collation of a comprehensive set of pasture production - fertiliser response data from existing field studies, dating back almost 60 years. The project unearthed unexpectedly large amounts of data which has not previously been co-ordinated in any way. More than 300 experimental data sets were collated, consisting of approximately 80,000 yield response measures from 2500 sites and 4500 experimental trial years. The national data sets were standardised and compiled in a specifically designed relational database, where the data could be explored and interpreted. Key data included soil and site descriptions, pasture type, fertiliser type and rate, nutrient application rate, DM yield measures and soil test results (i.e. Olsen P, Colwell P, P buffering, Colwell K, Skene K, exchangeable K, CPC S, KCl S). These data were then analysed and quantitative non-linear mixed effects models based upon the Mitscherlich function were developed. Where appropriate, disparate datasets were integrated to derive the most appropriate response relationships for different soil texture and phosphorus buffer index classes, as well as interpretation at the regional, state, and national scale. Overall, the fitted models provided a good fit to a large body of data, using readily interpretable coefficients, but were also limited by patchiness of meta-data and uneven representation of different soil types and regions. The models provided improved predictions of pasture yield response to applied fertiliser as a proportion of obtainable yield and can be scaled to absolute response using a specified maximal yield by the user. Importantly, the response function exhibits diminishing returns, enabling marginal economic analysis and determination of optimum fertiliser application rate to a specified pasture. These derived relationships form the basis of the national standards for soil test interpretation and fertiliser recommendations for Australian pastures and grazing industries and are incorporated within the major fertiliser company decision support systems. However, the utility of the national database is limited without a contemporary web-based interface, like that developed for the Better Fertiliser Decisions for Cropping (BFDC) national database. An integrated approach between the BFDP and the BFDC would facilitate the interrogation of the database by farmers and advisors to generate yield response curves relevant to the region and/or pasture system of interest and provides the capacity to accommodate new data in the future.

Notes:

Minerals in pastures - are we meeting the needs of livestock?

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Abstract: In Australia ruminants rely on introduced pastures or native vegetation for most or all of their nutritional requirements. Recent pasture selection and breeding programs have focussed on improving or facilitating the establishment, persistence and growth of plants, with little emphasis on nutritive value or mineral composition. In some cases, such as selection for phosphorus (P) utilisation efficiency, mineral supply from plants may even decrease. Currently a significant proportion of pasture plants contain less calcium (Ca), P, magnesium (Mg), sodium (Na), sulfur (S), copper (Cu), iodine (I), zinc (Zn), selenium (Se) or cobalt (Co) than is required for growth and reproduction, with significant genetic variation among and within legumes and grasses. Young crops and shrubs are now also an integral part of grazing systems. Many young crops contain concentrations of Ca, Mg, Na and potassium (K) that are low or imbalanced for ruminants. Conversely many shrubs contain minerals at levels higher than required by livestock. Livestock requirements may also have changed in recent years with animals selected for more efficient feed conversion and flock and herd structures changed to increase productivity. New studies have also indicated higher mineral supply may be beneficial during periods of oxidative stress related to growth, reproduction and external stresses such as heat and parasites. These results indicate mineral supply from pastures is not sufficient to support high levels of production for at least part of the year and that designing grazing system to incorporate the complementary benefits of grasses, legumes, crop forage and shrubs may improve the mineral status of grazing ruminants.

Notes:

Update on soil microbiology research - review and opportunities

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Notes:

Arbuscular mycorrhizal fungi (AMF) play a key role in plant community productivity and ecosystem stability of steppe grasslands

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Abstract: Soil microbe arbuscular mycorrhizal fungi (AMF) are important components of ecosystems and play critical roles in above-ground productivity and the maintenance of plant diversity. More than 80% of plants in steppe grasslands in China are colonized by AMF. AMF are often considered classical mutualists that promote plant growth, provide soil resources for plants and receive photosynthates in return. However, how do AMF respond to the management practices of grazing or fertilizing grasslands? We used a benomyl fungicide to reduce AM fungal abundance in the simulated grazing treatment or phosphorus application. Our results indicated AM fungi promoted *Artemisia frigida*, with a simultaneous reduction in *Stipa krylovii* growth; AM fungi and defoliation jointly suppress S. krylovii biomass; however, prolonged defoliation weakens mycorrhizal influence on plant community composition. These findings give new insight into dominant plant species shifts in degraded steppe grasslands. In the phosphorus addition experiment, AMF contribute to the temporal stability of plant communities. AMF suppression increased productivity at the plant species, functional group and community levels under high P addition rates. At the zero P addition rate, AMF did not affect plant community productivity, as the dominant species *Artemisia frigida* was more abundant in control plots with AMF, while the subdominant species *Stipa krylovii* was more abundant in the benomyl treated plots with reduced AMF abundance. Compensatory effects between C3 grasses and non-N2- fixing forbs were observed in the control plots with AMF along the gradient of P addition rates, but these effects were not detected among plant species in the benomyl-treated plots under AMF suppression above an addition rate of 4.76 P_2O_5 per m^2 per year. Although AMF suppression did not influence the diversity of the plant communities, it did decrease the diversity of N2-fixing forbs at the zero P addition rate and above an addition rate of 18.90 g P_2O_5 per m^2 per year, indicating that AMF play key roles in the maintenance of N2-fixing forbs at these P addition rates. P addition led to biodiversity losses at application rates below 2.36 g P_2O_5 per m^2 per year at the community level. These findings indicate that AMF and soil P availability interact to influence the productivity and temporal stability of a plant community by mediating compensatory effects among plant species and functional groups.

Notes:

Potential of commercial rhizobia strains for new and existing legume cultivars

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Abstract: Research is underway to identify productive perennial legumes for the high rainfall zone where nitrogen (N) deficiency limits pasture productivity. However, the effectiveness of commercial rhizobia strains in forming root-nodules with perennial legume hosts and contributing to herbage production and biological N-fixation is poorly understood. This study screened current commercial rhizobia strains and their capacity to form effective nodules on 13 perennial legume hosts; white clover (five cultivars), Talish clover (1), red clover (1), strawberry clover (1), Caucasian clover (1), Caucasian x white clover hybrid (1), lotus (1) and lucerne (2). Cross-nodulation capacity and impact on biomass production was also assessed under laboratory conditions. Commercial rhizobia strains used were CC283b, RRI128 (Group AL), SU343, TA1 (Group B) and WSM1325 (Group C). Our results found while WSM1325 and CC283b formed root-nodules on some white clover cultivars (cvv. Tribute, Nomad and AberLasting) and red clover (cv. Rubitas), biomass production and/or N-fixation was poor, and TA1 remained the most effective strain for N-fixation. Other white clover cultivars (cvv. Trophy, Haifa and Storm), strawberry clover (cv. Palestine), and Talish clover (cv. Permatas) formed effective nodules with both TA1 and WSM1325. Some legume species (strawberry and Talish clovers) and some cultivars within species (e.g. Haifa white clover), formed ineffective root-nodules with CC283b. Only commercially recommended strains resulted in root-nodulation for lucerne (cvv. Titan 9 and Sardi Grazer with RRI128), lotus (with SU343) and Caucasian clover (cv. Kuratas with CC283b). Ensuring effective legume nodulation is critical for driving pasture production, particularly where multiple legume species are sown in a mix.

Notes:

RHIZO-ID™ as a novel technology for direct rhizobia identification

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Abstract: In recent years clover pastures have been struggling around Australia and have therefore become a less reliable source for animal production. Consequently, this project aimed to understand if the lack of good quality inoculant rhizobia in the legume root nodules was contributing to this decline. Bacterial identification is a tedious and very time-consuming job and therefore alternative technologies were explored to identify rhizobia. RHIZO-ID™ was developed for rapid and efficient root nodule bacteria identification without the need to culture the bacteria. This novel method determines protein markers to detect the different strains and their unique fingerprints. Specifically, it utilises MALDI-TOF MS specific selected protein markers rather than full spectra comparisons to distinguish between different rhizobia strains and allows differentiation of current inoculant strains, old inoculant strains and background/native rhizobia. This novel technology has been utilised to analyse commercial pasture paddocks across Australia. The RHIZO-ID™ results were analysis in relation to paddock establishment age, inoculant history, nodule score, pH and herbicide usage for each of the investigated regions and this is presented. Further, pasture improvement strategies are suggested for the different pasture cases.

Notes:

Effect of subsoil manuring on dry matter production and feed quality of forage rape (*Brassica napus*) in northern Tasmania

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Abstract: Organic amendments placed at depth have been demonstrated to improve crop productivity in texture contrast soils with poorly structured subsoils in south-eastern Australia. A subsoil manuring trial was established on a brown Sodosol at Epping Forest, Tasmania in May 2015. Treatments consisted of poultry manure, poultry manure + straw, deep ripping with no amendment and no ripping/no amendment (standard practice). Forage rape (*Brassica napus* cv. Rangi) was sown across the trial site on 13th Oct 2017 and dry matter production measured on 18th Dec. With the poultry manure-only treatment there was a highly significant increase in dry matter compared with both the deep ripping only and standard treatments (7.0 t/ha compared with 4.2 and 4.1 t/ha respectively). Feed quality tests also showed 84% higher crude protein content in the manure-only treatment. This study has shown the considerable potential of subsoil manuring for improving forage productivity on sodic texture contrast soils.

Key words: soil structure, organic matter amelioration, sodic soil, clay aggregation

Introduction

Texture contrast soils, where shallow topsoils overlie clay, comprise 63% of soils in the Tasmanian high rainfall (>500 mm) cropping agro-ecological zone of south-eastern Australia (MacEwan *et al*. 2010). The major constraints to root growth in these soils are physicochemical, the result of dense clay subsoils with high bulk density and low macro-porosity and water infiltration. Many texture contrast soils in south-eastern Australia are also sodic at depth and dispersive which further exacerbates subsoil constraints (Gill *et al*. 2009, MacEwan *et al*. 2010). Sodic soils, where sodium comprises over 6% of the cation exchange capacity (CEC) in the B horizon, are estimated to occupy 23% of the Tasmanian land area (Doyle and Habraken,1993) with most of this area being used for grazing and increasingly, broadacre cropping (Cotching *et al*. 2001).These subsoil constraints commonly restrict root growth and are limitations to productivity of pastures (Greenwood *et al*. 2006) and cropping across much of the high rainfall zone of south-eastern Australia (MacEwan *et al*. 2010).

A number of field studies in these soils, particularly in the HRZ of south west Victoria, have demonstrated the benefits of subsoil manuring (SSM) where high nutrient quality organic amendments, such as poultry manure litter, are slotted at depth into the clay subsoil. Across 11 site x season trials, Peries and Gill (2015) cite a 63 % average increase in cereal yields with application of 10–20 t/ha of composted poultry manure compared with nil and ripping-only treatments. While productivity gains have been attributed to enhanced nutrition (Celestina *et al*. 2018), significant improvements in soil structure through reduced bulk density and increased macro-porosity and saturated hydraulic conductivity have been recorded (Clark *et al*. 2009, Gill *et.al*. 2009). Improvements in soil structure encourage deeper root growth in the clay horizon and increases in plant available water capacity have also been well documented (Gill *et.al*. 2009; Peries and Gill, 2015; Armstrong *et al*. 2017). Rainfall/soil moisture during grain fill is commonly yield limiting on these soils and access to increased soil water at depth is important for improved productivity.

This study was conducted to evaluate the effects on plant productivity and soil quality of slotting a high nutrient quality organic amendment (poultry manure) into a sodic soil in a crop and pasture rotation in northern Tasmania. The first two years of the trial examined crop growth and grain yield responses in wheat crops. This paper reports on the effects of subsoil manuring on dry matter production and feed quality of forage rape in the third year of the trial.

Methods

Site, treatments and experimental design

The trial site was established at Epping Forest, northern Tasmania (41°44'26" S, 147 21'10" E) in May 2015. The soil type is a brown Sodosol with a fine sandy loam topsoil generally 20–25 cm deep overlying a bleached sandy loam A2 horizon of variable thickness (commonly 5–10 cm) and beneath this a B horizon of medium clay. General soil chemical and physical properties are presented in Table 1. Common to many sodic soils used for agricultural purposes in Tasmania, the subsoil is only moderately sodic (6–15% ESP) but in addition there are high levels of exchangeable Mg (over 50% of the CEC). Rainfall was recorded at the Australian Bureau of Meteorology weather station at Epping Forest (Forton; 1927 - present), 3 km from the trial site.

Table 1. Summary of soil chemical and physical properties at commencement of subsoil manuring trial, Epping Forest, 2015. EC, Electrical conductivity (1:5 water); OC, organic C; available N, total of nitrate-N + ammonium-N; CEC, cation exchange capacity; ESP, exchangeable sodium %; EMP, exchangeable magnesium %; BD, bulk density.

Horizon	Depth	pH	EC	OC	Avail N	P Colw	K Colw	CEC	ESP	EMP	BD
	(cm)	($CaCl_2$)	(dS/m)	(%)	(mg/kg)	(mg/kg)	mg/kg	(cmol/kg)	(%)	(%)	g/cm3
A	0–10	5.7	0.08	2.0	41	105	260	10.9	2.7	19.4	1.02
A2	20–27	6.2	0.07	0.5	19	19	91	5.4	6.8	29.2	
B	35–45	6.1	0.11	0.6	8	7	276	22.9	8.8	51.6	1.38

Treatments consisted of no ripping/no amendment (standard commercial practice), deep ripping with no amendment (control) and ripping with poultry manure (15 t/ha, fresh weight). As wheat straw is commonly in surplus on-farm and has a high C/N ratio, a fourth treatment was included comprising wheat chaff added to poultry manure at a ratio of 2:1 by volume (2.1 : 4.9 t/ha on a weight basis). This resulted in an amendment with a significantly higher C/N ratio (10.3 compared with 6.8). Plots were 3.6 m wide x 20 m long and there were four replicates.

Amendments were slotted at a depth of 30–35 cm forming a concentrated 'sausage' of material. This depth was generally into the top of the clay B horizon but was not consistent due to the inherent variability in this soil type. The slotting operation used a custom-made subsoil manure ripper (see acknowledgements) with two rippers spaced at 80 cm. With appropriate soil moisture conditions, ripping will generally result in significant shattering of the clay subsoil. However, due to the compactness of the clay only narrow points could be used on the ripper tynes; consequently, there was only moderate shattering of the subsoil during the ripping operation.

Trial management and measurements

Plots in the first two years of the trial (2015 and 2016) were comprised of two 1.8 m wide raised beds and wheat was grown in both years. In 2017 the raised beds were disced in and the trial area sown with forage rape (*Brassica napus* var *napus* cv. Rangi) on 13th Oct at a sowing rate of 3.5 kg/ha. Basal fertiliser of DAP was applied at 80 kg/ha. No herbicides or pesticides were required during growth of the forage crop.

Dry matter cuts (2 m^2/plot) and normalized difference vegetation index (NDVI) measurements, using a Trimble GreenSeeker handheld crop sensor, were taken on 18th Dec 2017 at BBCH crop growth stage 30 (late rosette). Subsamples were oven dried at 56°C for 48 hours. Crude protein, ash and fibre content, digestibility and an estimate of metabolisable energy were determined by near infrared reflectance at FeedTest Laboratories, Werribee. All quality data are reported as a percentage of dry matter (DM). Differences between treatment effects were analysed by ANOVA using R version 3.5.1 (2018/7/2). The least significant difference (l.s.d.) was calculated at *P* =0.05 for testing differences between treatments.

Results and Discussion

Plant establishment was good and there were no visible differences between treatments in early growth. Rainfall prior to sowing and during the growing season (April-Dec) was 399 mm and close to average (Decile 5). DM production was also likely influenced by rainfall distribution with over 70 mm rainfall in early December.

Growth of forage rape in the manure-only plots was substantially greater than in other treatments and this was reflected in NDVI ratios at GS 30 which were significantly higher compared with both the control and standard practice (Fig. 1A). The poultry manure + straw treatment was intermediate and significantly different to the other treatments. DM production showed a similar ranking with comparable values for the standard practice and control (4.1 and 4.2 t/ha respectively) and a large, highly significant (*P* <0.001) increase in DM with the manure-only treatment (7.0 t/ha; Fig. 1B).

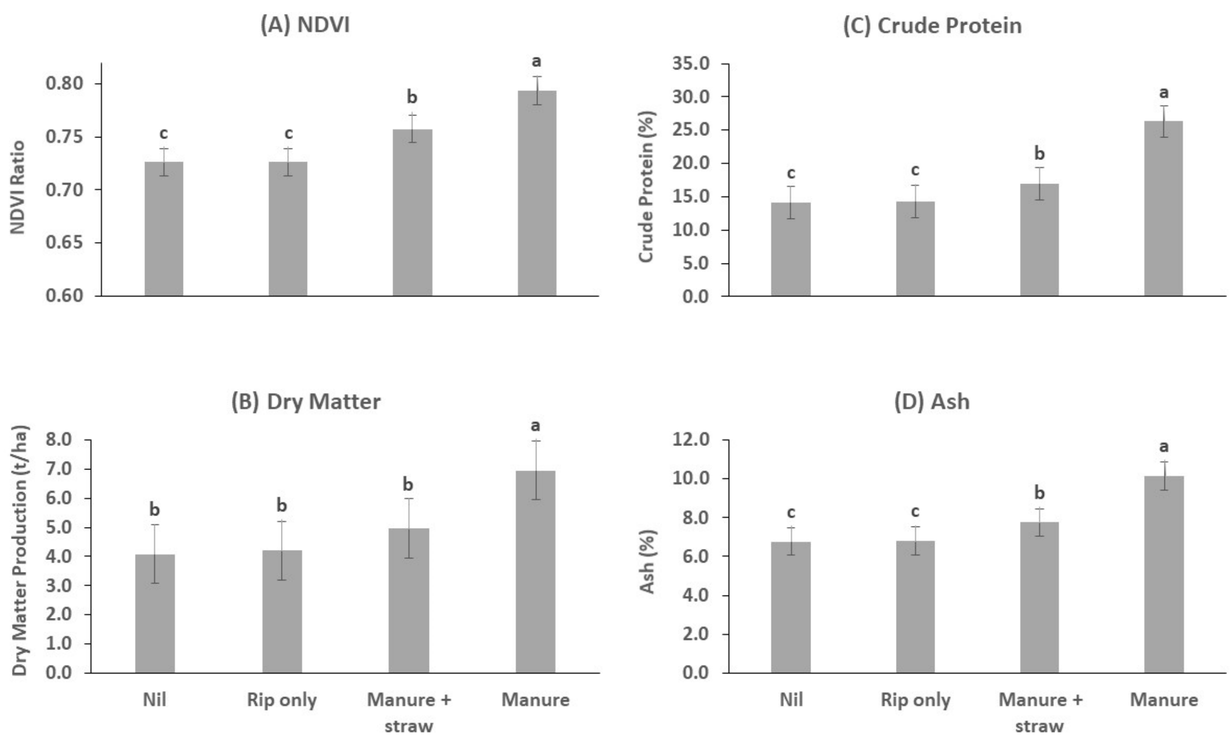

Figure 1. Effect of deep ripping and subsoil manuring on normalized difference vegetation index (A); Dry matter production (B); Crude protein content (C); Ash content (D). Means with the same letter are not significantly different (P =0.05).

Results from previous SSM field trials have varied from a mean grain yield increase of 63 % recorded across 11 site x season trials between 2005 and 2012 in south west Victoria (Peries and Gill, 2015) to little or no grain yield increases (Celestina *et al*. 2018). Differences in responses may relate to variation in growing season rainfall and the distribution of this rainfall (Armstrong *et al*. 2017) with low seasonal rainfall and a sharp finish limiting the benefits of SSM, particularly in the establishment years. In the current trial rainfall was slightly above average with sufficient soil recharge over winter.

Unlike grain yield data, there have been surprisingly few SSM field trials where biomass has been documented. However, in all trials where vegetative response has been recorded (Gill *et al*. 2008, Gill *et al*. 2012) this has been considerably greater than that of grain and comparable with the large increase in DM production obtained in this study. While there have been significant increases in crop yields with SSM there may be potentially greater benefits with fodder crops/pasture. In the latter productivity gains are a measure of total biomass production compared with grain yield where, with a harvest index of approximately 50%, only half of the additional biomass is taken into consideration as an improvement in productivity. The timing of this extra biomass is also important for grazing management and with visual responses apparent in late August in other trials, SSM will likely provide opportunity for additional feed before the end of winter.

Where large increases in grain yield have been obtained, in addition to nutrient response, it has been hypothesised that organic amendments additives stimulate soil microbes which generate extra-cellular polysaccharides “cementing” clay particles to produce stable macro-aggregates (Clark *et al*. 2009). Root growth at depth also proliferates producing root exudates and mucilage which provide further aggregation of clay particles as well as supporting additional microbial activity (Gill *et al*. 2009). Finally, aggregation is also enhanced by soil wetting and drying cycles with subsequent root growth extending into regions of the B horizon beyond the immediate zone of application (Gill *et al*. 2009, Armstrong *et al*. 2017). The outcome of this is greater root exploration in the B horizon and increased plant available water capacity and extraction of subsoil water. Of note, on a fresh weight basis in the current study there was a 160 % increase in yield with the manure-only treatment; the moisture content of the manure treated plants was significantly higher (P <0.001) than from standard non-ripped plots (89.9% compared with 84.6%; data not presented) presumably through greater access to moisture in the clay subsoil. To confirm this detailed soil water and physics measurements will be conducted at the end of the 2019 season to compare with benchmark soil tests from the first year of the trial.

Ripping without amendment provided no production benefit compared with the standard of no ripping (Fig. 1). While the results in this study are from 3 years after the ripping operation there was also no difference in wheat crop growth and grain yield between these two treatments in the first year of the trial (data not presented). Previous studies have also generally recorded few positive crop responses from ripping alone on poorly-structured clay soils (e.g. Gill *et al*. 2008, McBeath *et al*. 2010).

Feed quality characteristics generally showed significant improvements in quality with both the manure-only and manure + straw treatments. For example, crude protein and ash content were respectively 84% and 50% higher with the manure-only treatment compared with the standard practice (Fig. 1 C and D). Other studies have shown similar improvements in quality. Increases in grain protein in SSM trials sown with wheat have ranged from 20-39% (Gill *et al*. 2008, Gill *et al*. 2012, Peries and Gill, 2015).

Conclusions

Application of poultry manure at depth significantly increased DM production and feed quality and this study has shown the considerable potential of SSM for improving forage productivity on sodic texture contrast soils. While the majority of SSM field trials have been associated with grain production there is considerable scope to improve forage crop and pasture productivity with this practice. The site at Epping Forest was sown with ryegrass/clover pasture in 2018 and trial work will continue in 2019 to determine the longevity of subsoil manuring effects on crop and pasture production, changes in soil-water characteristics and the economics of application.

Conflicts of Interest
The authors declare no conflicts of interest.

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Notes:

Improving the P-efficiency of grassland production in southern Australia

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Abstract: Major objectives for achieving more efficient use of phosphorus (P) fertilisers are, firstly, to maximise pasture yields and optimise use of farmland and rainfall resources. However, ultimately we also aim to reduce the amount of P that must be applied for high grassland production. Presently, the first objective is being achieved through increasing recognition of critical soil test benchmarks for high pasture yield, attention to the suite of soil nutrients that must be managed, and by implementing soil test protocols that can deliver optimal soil fertility management. The second objective will be harder to achieve but there is opportunity. The P-balance efficiency ($PBE=100*P_{output}/P_{input}$) of pasture production is low (10-30%), mainly because P accumulates in the soil. A long-term field experiment (LTFE) has confirmed that P accumulation is positively related to the soil test P (STP) concentration at which a soil is maintained. In pastures managed without N fertiliser, legumes (e.g. subterranean clover) determine the critical STP because they have higher P requirements than their companion grasses. A search for an alternative legume with a lower critical STP requirement than subterranean clover (Olsen P ~15 mg/kg) has identified serradellas as likely candidates (critical STP ~10 mg Olsen P/kg). The LTFE data suggest that serradella use may reduce P-fertiliser inputs by ~30%. However, replacement of a well-adapted, productive pasture legume with an alternative is no small task. It will depend on whether yield, agronomic merit and persistence prove equivalent or better than subterranean clover. We report how pieces of this jig-saw puzzle are coming together.

Notes:

Legumes and phosphorus fertiliser could dramatically improve productivity and returns from sown pastures in the Brigalow Belt bio-region of Queensland

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Abstract: More widespread and successful adoption of pasture legumes in both sown and native pastures has been identified as the most widely-applicable and cost-effective means of improving productivity for grazing industries in many regions of northern Australia. The largest areas of sown pastures in northern Australia are on relatively fertile soil types in the Brigalow Belt bio-region and have been planted only with grass. This has led to very low (almost nil) use of phosphorus (P) or other fertilisers, which contrasts dramatically to southern Australia where the use of superphosphate on legume based pastures is common.

Producers and farm advisors have traditionally thought that P fertiliser is not cost-effective for legume-based pastures growing on inland areas of Queensland, despite there being little if any data on production responses or their economic outcomes. Recent studies in the Brigalow Belt bio-region show large and increasing areas of low plant available soil P and large responses by pasture legumes to P fertiliser. Economic analysis suggests good returns should be achievable from the use of fertiliser in many instances with similar results likely in other regions with similar or higher rainfall. For industry to realise the benefits from fertilising legumes it is recommended that research be conducted to better quantify the P requirements of available legumes and the likely impacts of P fertiliser on productivity and profit on major soil types in key climatic zones. Development and extension activities are required to demonstrate the commercial impacts of applying P fertiliser to legume based pastures.

Sown pastures in northern Australia

Sown pastures have been widely used in northern Australia, however the largest areas are in the Brigalow Belt bio-region of southern and central Queensland. Of the total area planted to sown pasture in northern Australia, 70% has been sown only with tropical grasses, with buffel grass (*Pennisetum ciliare*) being the most widely used species comprising over 75% of the area sown pasture (Walker and Weston 1990). Queensland contains 90% of the area suited to sown pastures within northern Australia (Walker *et al.* 1997) with most of the sown pasture development occurring on fertile soils that have been cleared of Brigalow and Gidgee (*Acacia spp*.) woodlands and associated land types in the Brigalow Belt bio-region (Peck *et al.* 2011).

Importance of the Brigalow Belt bio-region

The Brigalow Belt bio-region occupies approximately 36 million hectares of Queensland and New South Wales, stretching from Dubbo in the south to Townsville in the north. The Brigalow Belt bio-region is an important part of the northern Australian beef industry as it carries a high proportion of the herd and supports relatively high stocking rates and growth rates. The Queensland portion of the Brigalow Belt carries approximately 30% of the northern Australian beef herd on 15% of the grazed land area (ABS Agricultural survey 2010-2011). This high productivity is largely due to sown grass pastures growing on relatively fertile soils in a moderate rainfall zone.

Although these sown grass pastures are highly productive compared to most of northern Australia, their productivity has declined dramatically since establishment due to ‘pasture rundown’. ‘Pasture rundown’ is the decline in grass growth due to a decline in available nitrogen in the soil with increasing age of the pasture stand. Pasture legumes have been identified as the best long-term option to increase the productivity and returns from rundown sown grass pastures through their ability to biologically fix atmospheric nitrogen. Despite impressive results from a number of legumes in trials and some commercial pastures, adoption levels remain very low in the Brigalow Belt. For example, leucaena is one of the most widely grown pasture legumes, however it has been adopted on <3% of the area of pasture land to which it is adapted (Peck et al. 2011). These very low adoption rates mean there is a huge opportunity to increase beef production through the wider *successful* adoption of pasture legumes in the Brigalow Belt, and provide significantly higher returns for decades to come. However, for legumes to grow well and fix large amounts of nitrogen they need adequate plant available nutrients in the soil. Phosphorus (P) is the most commonly limiting nutrient for pasture legume growth.

Phosphorus paradigm in northern Australian beef industry

Phosphorus deficiency is common in cattle across northern Australia. It has been estimated that 70% of soils in northern Australia have P levels low enough to cause P deficiency in cattle (i.e. Colwell P < 8-10mg/kg (McCosker and Winks 1994). The notable exceptions to the generally low P levels in northern Australia are the Brigalow Belt bioregion, Mitchell grass downs soils, the Channel Country in western Queensland and other alluvial soils elsewhere, and some areas along the coast of Queensland.

The low soil P, relatively low stocking rates combined with strong animal response to supplements has led to a paradigm for P where graziers and their advisors within the beef industry of northern Australia generally believe (Jackson *et al.* 2012):

- Severe P deficiency in lower productivity environments in the west and north of Queensland, Western Australia and the Northern Territory is best addressed through directly supplementing stock.
- In high rainfall areas, predominantly along the Queensland coast, the higher pasture production potential means that fertilising pastures with P is economically worthwhile.
- The clay soils of the Brigalow Belt with the largest areas of sown pasture have been considered to have adequate P for both cattle, pastures and grain cropping.
- In moderate rainfall environments like the Brigalow Belt, fertilising with P is considered to not be economically viable on low P soils despite there being few if any trials to support this conclusion.

Due to the paradigm described above, phosphorus research for the grazing industries in northern Australia has focussed on supplementing livestock with limited investment in research on fertilising legumes.

Reality of phosphorus fertility in the Brigalow Belt

Soil P levels in Brigalow soils have been widely thought to be adequate for both grazing animals and sown pastures, which has resulted in very low use of P fertiliser on pastures. Unfortunately, there is increasing evidence that suggests this widely accepted belief is inaccurate and that the beef industry should consider using P fertiliser to improve productivity. Recent studies on P in the Brigalow Belt show that:

- Low plant available P levels are common in Brigalow Belt soils (Lawrence *et al.* un-published data; Table 1).
- Long histories of cropping and export of P in grain and via erosion has led to reductions in soil P levels and other nutrients (Bell *et al.* 2010). When these cropping soils are abandoned or sown to pastures the resulting pasture productivity is often constrained by low nutrient levels.

- Even where plant available P is adequate when pastures are first established, P availability is expected to decline with time and could lead to P deficiency for pasture legumes (Thornton *et al.* 2010).
- Pasture legumes, either those commonly used or those showing promise as permanent pastures, respond strongly to applied fertiliser P on low P soils (Peck *et al.* 2015).
- Cattle in two recent grazing trials on Brigalow clay soils had low and marginal P levels respectively, suggesting P deficiency of stock could be more widespread than previously thought (Peck *et al.* 2015).

Table 1. Number and percentage of soil samples across all land types within Colwell P level ranges at 0-10cm depth with corresponding mean BSES P levels (Lawrence *et al.* un-published data).

Colwell P (0-10cm)	All Soils		
	No of samples	Percent of soils	P acid (Mean)
< 4 mg/kg	14	2%	6
4-6 mg/kg	53	9%	19
7-9 mg/kg	71	12%	13
10-15 mg/kg	134	22%	29
16-25 mg/kg	130	21%	57
>25 mg/kg	205	34%	325

Legume requirements for P

Critical P requirements for legumes used in the Brigalow Belt bio-region are shown in Table 2. The legumes P require range from shrubby stylo at 8 mg/kg which is marginally deficient for P supply to grazing livestock to 15-25 mg/kg for leucaena.

Likely economic returns

Bio-economic modelling suggests good returns from fertilising legume based pastures in the Brigalow Belt bio-region (Peck *et al.* 2015):

- Highly profitable returns when applying P fertiliser to already established grass with legume pastures. Returns of 12 – 24% on the extra input costs.
- The returns from establishing legumes into existing sown grass pastures are positive. Internal rates of return ranged from 9-15%. The modelling assumed a relatively high cost but more reliable legume establishment technique; cheaper establishment techniques should be possible for some legume species.
- Establishing legumes into soils with adequate P can provide returns of 15-30%. Where possible, soils with higher P levels should be developed with legumes first.
- Direct supplementing of stock on P deficient soils can provide good returns, although lower than fertilising legume based pastures.

Table 2. Critical P (Colwell P) requirements for legumes (to achieve 95% of maximum yield potential) that have potential as permanent pastures in the Brigalow Belt ranked in order of increasing P requirement. Legumes that have not had trials to determine critical P levels have been included, with their place in the order based on field observations.

Species	Critical P* (mg/kg)	Trial type	Reference
Shrubby stylo (cv Seca) (*Stylosanthes scabra*)	8	Field	Gilbert and Shaw (1987)
Caribbean stylo (cv Verano) (*Stylosanthes hamata)*	10-12	Field	Probert and Williams (1985); Hall (1993)
Fine-stem stylo (*Stylosanthes guinensis* var. intermedia)	?		
Round-leaf cassia (*Chamaecrista rotundifolia*)	?		
Caatinga stylo (*Stylosanthes seabrana*)	?		
Desmanthus (*Desmanthus* spp.)	?		
Siratro (*Macroptilium atropurpureum*)	10-14	Field	Rayment *et al.* (1977)
Leucaena (*Leucaena leucocephala*)	>15 25	Field observation	Dalzell *et al.* (2006); Buck pers. comm.
Butterfly pea (cv Milgarra) (*Clitoria ternatea)*	25	Pot	Haling *et al.* (2013)
Annual medics (*Medicago spp.*)	12-30	Field	Reuter *et al.* (1995)

* Expressed for Colwell P except shrubby stylo which is acid extractable P and Caribbean stylo where both Colwell and acid extractable P critical P levels were similar.
? No trial results found which determined critical P levels.

Research, Development and Extension priorities

There is limited trial data and very limited commercial experience in using P fertiliser on sown grass with legume pastures in the Brigalow Belt. RD&E priorities therefore focus on improving the understanding of soil, plant and animal responses to applied phosphorus:

1. Determine the critical P requirements of important legume species used in northern Australia. Critical P and S requirements are not known for several of the more recently released tropical legume species used in northern Australia. For some species that have published information on P requirements, the experiments did not consider the buffering capacity of the soil.
2. Quantify the impact of P fertilizer on pasture and cattle productivity on important soil types in key climatic zones. There are very limited trial results on the legume production response to applied fertilizer for the species used in northern Australia.
3. Quantify the effect of application method (surface broadcast, drilling banding) on legume response. This could be particularly important for leucaena which is a tree generally grown in hedgerows approximately 10m apart.
4. Develop a better understanding of the extent and impact of P deficiency on the beef industry through improved interpretation of soil mapping and soil tests; and greater screening of herd P status.

5. Test the extent of other nutrient deficiencies (e.g. sulphur, potassium) for pasture legumes in higher production zones of northern Australia.

Conclusion

Pasture legumes are the most promising option for improving the productivity of rundown sown grass pastures in the Brigalow Belt (Peck *et al.* 2011). For legumes to realise this promise they need to become more reliably productive on commercial properties. Ensuring adequate P (and other nutrients) is likely to be a large part of the solution to improving the commercial productivity of legumes and the associated grasses in Brigalow Belt pastures.

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Notes:

Physiological tolerance or physical avoidance? How some Australian forage legumes tolerate aluminium

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Abstract: Southern Australia has large areas of acid, infertile soils with low pH (<5.0) and associated high levels of exchangeable aluminium (Al). Current agricultural practices such as the application of fertilisers further acidify the soil. The use of lime to ameliorate soil pH is often cost prohibitive. Therefore to improve productivity in Australian livestock systems there is a need for forage legumes with tolerance of soil acidity and associated soil constraints.

Serradella is a forage legume that is highly productive in light, sandy soil types with low pH where the traditional options, subterranean clover and lucerne, fail to persist. There has been little research on Al tolerance in Australian forage legumes and much of this past research now describes superseded cultivars. Therefore, we grew a number of serradella cultivars in hydroponics to determine their physiological Al tolerance by measuring root length response to increasing concentrations of Al. We also conducted a pot experiment with field soil to determine whether these species alter root distribution in response to an Al toxic subsoil.

We found significant variation in physiological tolerance among cultivars in hydroponics. Generally, yellow serradella were more tolerant of Al than French serradella, which proved quite sensitive. However, in the pot experiment, when grown with an Al toxic subsoil, French serradella cultivars had greater topsoil root exploration, better nodulation and shoot growth than yellow serradella.

Thus, physiological tolerance is only one means to aid persistence in Al toxic soils and physical avoidance may be equally or more important under field conditions.

Notes:

Increased emphasis on soil management for improved pasture legume productivity

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Abstract: Two hundred and twenty-five commercial pasture paddocks across the Central Tablelands, Central West, Monaro and Riverina regions of NSW were sampled to determine soil chemical characteristics (0-10 cm), botanical composition and legume nodulation. Forty percent of paddocks had Colwell available phosphorus (P) lower than critical P based on phosphorus buffering index (PBI). Seventy-three percent of paddocks had available sulphur (S) below critical levels (8 mg/kg; KCl-40 extraction). Ninety-eight percent of paddocks had a $pH_{Ca}<7.0$ with 78% $pH_{Ca}<5.5$. Phosphorus deficiency was more prevalent in the Central Tablelands (63% of paddocks) while S-deficiency occurred more frequently in the Central West (95% of paddocks). Average legume content was highest in the mixed farming-dominant regions (Central West and Riverina) at 50 and 52% respectively compared to the permanent pasture-dominant regions (Central Tableland and Monaro) at 27 and 24% respectively. Ninety-three percent of all paddocks had inadequate legume nodulation (score <4/8). Regression tree analysis found differences in legume nodulation to be associated with host legume species, soil pH, availability of P and/or S and cation exchange capacity (CEC) which collectively accounted for 73% of variation. For Trifolium spp., where soil $pH_{Ca}>5.5$, nodulation was predicted to be adequate. Adequate nodulation could be achieved where $pH_{Ca}<5.5$, however, higher CEC and P were required with soil $pH_{Ca}>5.3$. These results suggest a primary focus for improving legume capacity to supply nitrogen for pasture growth should involve addressing soil acidity constraints along with provision of adequate levels of essential plant nutrients, specifically P and S.

Notes:

Tolerance and recovery of messina (*Melilotus siculus*), burr medic (*Medicago polymorpha*) and balansa clover (*Trifolium michelianum*) to salinity and waterlogging

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Abstract: Messina (*Melilotus siculus*) is a new annual pasture legume species with tolerance to both severe salinity and winter waterlogging. This paper describes the response of *M. siculus* cv. Neptune to waterlogging, salinity, and these stresses combined, compared with burr medic (*Medicago polymorpha*) cv. Scimitar and balansa clover (*Trifolium michelianum*) cv. Frontier. Plants were grown in a glasshouse in soil inoculated with appropriate rhizobia. Drained non-saline controls, and treatments of waterlogged non-saline, drained 100 mM NaCl and waterlogged 100 mM NaCl were imposed on 5 week-old plants for 3 weeks, after which plants were allowed to recover under drained non-saline conditions for 4 weeks. In the waterlogged saline treatment shoot dry mass of *M. siculus* was 63% of the control after 3 weeks, compared to 5% for *M. polymorpha* and 10% for *T. michelianum* and after the recovery phase was 75% of the control for *M. siculus*, 4% for *M. polymorpha* and 58% for *T. michelianum*. Foliar Na+ concentrations of *M. polymorpha* were 2.8-fold and *T. michelianum* were 3.3-fold higher than for *M. siculus*. *Melilotus siculus* alone developed aerenchymatous phellem in roots under waterlogged treatments. This study supports field observations that *M. siculus* is better able to tolerate and recover from the combined stresses of waterlogging and salinity than *M. polymorpha* and *T. michelianum*. The greater tolerance of *M. siculus* can be attributed to regulation of leaf Na+ concentrations in saline conditions and the formation of aerenchymatous phellem to enhance O_2 supply to roots in waterlogged soils.

Notes:

A new pasture development program for southern Australia's low rainfall mixed farms; opportunities for legume improvement

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Abstract: A diverse group of annual pasture legumes is being evaluated across the low rainfall zone (250 – 450 mm) of southern Australia. Included are representatives from the legume genera Medicago, Ornithopus, Biserrula, Trifolium, Lotus, Trigonella and Astragalus. The potential impact of six soil based constraints (pH, texture, herbicide residues, boron toxicity, rhizobial compatibility and soil-borne disease) on the performance of these legumes is briefly examined.

Key words: pasture, rhizobia, acidity, alkalinity, herbicide, boron, disease

Introduction

Annual pasture legumes have been pivotal to the sustainable agricultural development of low rainfall (250-450 mm) mixed farming systems in southern Australia (Puckridge and French 1983). Covering an area of more than 30 M ha, the majority of soils have relatively poor fertility and depend on significant inputs of nitrogen to maintain production (Bell and Moore, 2012; Hamblin and Kyneur 1993).

Common soil types in the zone include coarse textured deep acidic sands in West Australia, fine-textured alkaline soils in the swales and coarse-textured sands on the dunes in the areas referred to as Mallee in south-east Australia and acidic, texture contrast soils in NSW. The different soil types are strong determinants of legume species performance and account for some of the strong regional legume preferences. Most notably, species such as serradella (*Ornithopus* spp.) and biserrula (*Biserrula pelecinus)* are widely grown in Western Australia and parts of NSW (Loi *et al*. 2005), whereas annual medics (*Medicago* spp.) are widely grown in the Mallee of south-east Australia (Tideman 1994).

Opportunities to improve the legume content and production of pastures in the zone remain substantial. The performance and persistence of traditional pasture legumes such as sub clover (*Trifolium subterraneum*) and annual medic is poor in some areas (Hackney *et al*. 2015; Coventry *et al*. 1998) with multiple factors implicated, including the use of superseded cultivars, pest and disease incursions, reduced rainfall, intensification of cropping and a range of abiotic and biotic soil constraints. Legume options are limited for areas such as the deep sands in the Mallee of South Australia and Victoria and, more generally, renovation rates are limited by the high cost of pasture seed. Several recently domesticated and hitherto undomesticated legume species whose seed can be harvested with a grain harvester and re-sown on farm have shown promise, but wider evaluation is required to understand the full range of their adaptation.

A diverse group of more than 30 annual pasture legumes is being tested in the field at sites spanning Western Australia to central NSW. The program aims to provide:

- A critical assessment of the regional performance of existing and new pasture lines,

- Quantification of the benefits provided by new pasture legumes to livestock and cropping systems.

In this paper, we briefly examine soil based constraints known to affect the performance of the legumes being evaluated and describe some of the new legume material being developed to address the constraints.

Soil based determinants of pasture performance in the low rainfall zone

Soil pH and texture
Emphasis in the extension literature on pH and texture as the primary soil criteria for selecting pasture cultivars recognises the distinct preferences of different legume species. These preferences have been significant to the development and adoption of the different species in regions within the low rainfall zone. That said, the recommended pH and texture boundaries are imprecise for many pasture species. Studies of legume pH tolerance (e.g. Guo *et al*. 2012; Evans *et al*. 1990) have mostly focussed on acidity and so, with the exception of the annual medics, the adaptation of many legume species to neutral-alkaline soils is not well understood.

Briefly, the annual medics and their rhizobia perform best on neutral and alkaline pH soils and therefore dominate the Mallee regions in SA and Victoria. Soils on western Eyre Peninsula where they are grown can exceed pH 8 ($CaCl_2$). Strongly acidic soils and levels of exchangeable Al >5% are not tolerated by the medics, although some niche species have been commercialised for moderately acid soils. Nichols *et al*. (2012) reports a soil pH ($CaCl_2$) requirement of ≥5.8 for all medics except burr (*Medicago polymorpha*) (≥5.2) and murex (*Medicago murex*) and sphere (*Medicago sphaerocarpus*) medics (≥4.8). There are however several reports from NSW that suggest the barrel medics (*Medicago truncatula*) are also able to perform well on soils with pH levels as low as 4.8 (Dear and Jenkins 1992; Little *et al*. 1992). The acid soil sensitivity of medics is often associated with poor nodulation (Brockwell 2001; Howieson and Ewing 1986), the result of poor persistence and colonisation of the rhizobia (*Sinorhizobium* spp.) and inhibition of the nodulation processes. This facet will continue to limit the use of medics on soils below pH 4.8.

On strongly acidic soils (pH <5), serradellas and their rhizobia have provided a resilient option and are mostly grown on acidic sands in Western Australia and NSW (Clark and Hudson 2014). Serradella is also reputed to tolerate exchangeable aluminium levels of up to 30%, but may be limited in some parts of NSW by manganese toxicity (Scott *et al*. 1991). So far, the intolerance of serradella to high pH soils has probably limited its use in the SA and Victorian Mallee region, but soil acidification may extend the area where it can now be grown, noting that narrow-leafed lupin (*Lupinus angustifolius*) which prefers similar soils is grown on Mallee soils with low levels of free lime. The intolerance of serradella to high pH is more likely associated with root impairment and iron deficiency rather than poor rhizobial survival since high numbers (>1000) of the rhizobia have been found to persist in alkaline soils for many years (Mock and Gibson 1993; Tang and Robson, 1993).

The pH tolerance of other legumes is less well understood. Biserrula is reported to be slightly less tolerant of acid soils than serradella (Guo *et al*. 2012). The pH tolerance of *Trigonella balansae* is unknown, but likely to be similar to the medics given it is closely related and would face the same rhizobial limitations. Bladder clover (*Trifolium spumosum*) is recommended and has been grown in soils with pH ($CaCl_2$) ranging from 4.8 to 6.0 in NSW and in its native range grows on soils with pH up to 8.0 (Hackney *et al*. 2010), indicating a level of alkaline soil tolerance. Guo *et al*. (2012) found it to be less acid tolerant than both serradella and biserrula. Most other pasture legumes (e.g. Rose clover, *Trifolium hirtum*) are conservatively recommended for soils between pH 5.0 and 7.5, in the absence of reliable information to support their use on more acid or alkaline soils. The broad host range and acid tolerance of clover rhizobia strain WSM1325 (Howieson *et al.* 2005), should allow the reliable evaluation of a range of *Trifolium* spp. including gland (*Trifolium glanduliferum*), arrowleaf (*Trifolium vesiculosum*) and bladder clovers on soils with pH as low as 4.2.

Overlaying the preference of pasture legumes for neutral or alkaline soils has been the recognition that they also favour different soil textures. Productive legume options are most lacking for the deep infertile sands, identified by growers as an area of priority for pasture development. Currently, the best options for sandy soils are serradella (pH 4.0 to 6.5), biserrula (pH 4.5 to 7.5) and disc medic (*Medicago italica*) (pH 5.8 to 8.5). Whilst disc medic performed well in trials at Lameroo, Minnipa and Loxton in 2018, there is currently no commercial seed production of any disc medic. A cohort of disc medic has been developed to address this deficiency. Margurita serradella (*Ornithopus sativus*), SARDI Rose clover and *Trigonella balansae* line 5045 are being tested at several sandy soil sites to better understand the extent of their adaptation. It is anticipated that new strand medics (*Medicago littoralis*) will be better suited to sandy loams, typified by the mid-slopes in the Mallee. In NSW, there is opportunity for improvement on soils where acidic sandy loams abruptly change to heavy clay with depth and periodic waterlogging occurs, which serradella and biserrula are unable to tolerate.

Herbicides residues in soil

A feature of contemporary farming practices has been the widespread use of sulfonylurea (SU) herbicides such as chlorsulfuron and triasulfuron and their successors in the cereal-livestock zone. Residues of these herbicides often persist beyond the cropping year, particularly in areas with alkaline soils and low rainfall, where their breakdown by microbial action and chemical hydrolysis is significantly reduced (Noy 1996). Hollaway *et al*. (2006) reported that in alkaline soils in north-western Victoria and South Australia, chlorsulfuron and triasulfuron persist at levels which are potentially harmful to sensitive crops for up to 5 years. Two years after an SU herbicide application, reductions in barrel medic dry matter production of up to 75% have been reported (Black *et al*. 1999; Noy 1996). It can also be an issue on acid soils where lime is applied but not incorporated, the increased pH of the surface soil delaying the breakdown of herbicide residues (Burns *et al*. 2017).

Angel strand medic was the first pasture legume developed which can tolerate SU residues. Field evaluation of Angel strand medic by Howie and Bell (2005) measured increased production (+80%), seed yields (+172%), persistence (+112%) and N fixation in the presence of SU residues. The SU tolerance in Angel also gives it tolerance to Intervix (imazamox and imazapyr) residues.

The SU tolerance trait has since been transferred from the strand medic cultivar Angel into other medics, including Sultan-SU barrel medic and PM250 strand medic, which are being evaluated in the current pasture program. The trait has also been maintained in a new cohort of strand medics developed for the program. Legumes that lack tolerance may be disadvantaged where Group B herbicide residues persist in soil.

In addition to the production advantages provided by medics with SU and Intervix tolerance, the tolerant cultivars provide the opportunity to control less desirable background medics and other weeds.

Boron and salinity

Boron toxicity is an issue affecting Mallee soils in south-eastern Australia (Nuttall *et al*. 2003) and Western Australia (van Gool 2006). The impacts are mostly seen in the swales (sub-soils and finer textured soils) where boron is not easily leached out of the root zone. It is therefore more likely to affect pasture species that grow in the finer textured soil zones. Salinity also commonly occurs at levels limiting to plant production in the areas affected by boron.

High levels of boron reduce dry matter production of susceptible medic cultivars (Paull *et al*. 1992; Bogacki *et al*. 2013). Howie (2012) studied boron tolerance of 24 annual medic genotypes and found that all five spineless burr medic cultivars were rated as sensitive. This may in part explain the inconsistent agronomic performance of this species in parts of South Australia and Victoria, particularly on the loam soils of the Murray Mallee and upper Eyre Peninsula.

Boron tolerant burr medics have since been identified (Peck *et al*. unpublished data) and crossed with the burr medic cultivars Scimitar and Cavalier, which coincidently have a useful level of salt tolerance (Nichols *et al*. 2008). The growth of a bulk progeny line tested in 2018 has been sufficient (106% and 101% of site means at Minnipa and Lameroo respectively) to encourage the further testing of 20 new lines in 2019.

The relative boron tolerance of other pasture genera is useful to understand their performance where boron toxicity occurs. Single accessions tested of birds-foot lotus (*Lotus ornithopodioides*) were rated as tolerant of boron; balansa clover (*Trifolium michelianum*), rose clover, gland clover and *Trigonella balansae* as moderately tolerant; and biserrula (cv. Casbah) as very sensitive (Howie 2012). This may explain why biserrula, despite being recommended for neutral and alkaline sandy loam soils (Loi *et al*. 2004), has not performed as well as expected in some parts of south-eastern Australia.

Compatibility with soil rhizobia
An important output of annual pasture legumes is the biologically fixed N they provide for their own production and to the farming system when their residues break down.

Observations of poor nodulation on clovers and medics (Hackney *et al*, 2017, Brockwell 2001) combined with the development of sub-optimally effective populations of rhizobia in soils indicates that N-fixation is likely constrained in some areas. Studies that have benchmarked the performance of the soil rhizobia against highly effective inoculant strains indicate that average efficiency of soil rhizobia is about 50%, but can be much lower in specific paddocks (Drew *et al*. 2012; Ballard and Charman 2000).

To deal with ineffective rhizobia in soils, a cohort of eight strand medics with improved N-fixation capacity (bred to form effective associations with soil rhizobia) will be tested in the field in 2019. The N-fixation capacity of *Trigonella balansae* which is nodulated by medic rhizobia (Howie *et al*. 2001) will also be examined further. In 2018 trials, the nodulation of *Trigonella balansae* at the two sites tested was 4-fold greater compared to the strand medic cultivar Herald.

Milk vetch (*Astragalus hamosus*) was the only pasture species evaluated in 2018 where nodulation failure occurred. The erratic performance of the species has been previously linked to rhizobial issues (Anon 1977). The rhizobial requirement of this plant will be reassessed, based on its reasonable agronomic performance, despite the nodulation issue.

Soil borne diseases
An important outcome of the pasture ley is to reduce the levels of soil borne diseases that damage subsequent cereal or oilseed crops. The low rainfall soils of southern Australia are known to commonly host a complex of disease organisms that include root rot pathogens from the genera *Rhizoctonia* and *Pythium*, and the root lesion nematode *Pratylenchus neglectus*. The survival of *Rhizoctonia* is increased in minimum tillage systems that have been widely adopted (Gupta *et al*. 2012).

After more than 50 years of legume cultivation, the production of medic and clover-based pastures is almost certainly constrained to some extent by the aforementioned pathogens

(Barbetti *et al*. 2006). Moderate levels of root disease damage is commonly observed in pasture trials. The failure of previous efforts to measure any positive field response in medics selected for *Pratylenchus neglectus* tolerance (RA Ballard, Unpub. data) indicates that the fungal pathogens are more likely to be the source of the observed root damage. A possible advantage of introducing alternative legume genera is that they may initially be less prone to damage by the existing pathogens, although this remains to be demonstrated.

Although some pasture species are themselves damaged by soil borne pathogens, they can still sometimes reduce pathogen levels and the risk of damage to crops that follow. For example, medics are reported to reduce the levels of *Pratylenchus neglectus* in the field (Ballard *et al*. 2006; Taylor *et al*. 2000) and should therefore reduce the damaging effects of this pathogen in the crop phase.

We are not aware of any studies specifically examining the effects of different pasture legume genotypes on the inoculum levels of fungal pathogens, but suggest it is an area worthy of investigation.

Conclusions

A number of soil constraints are known to limit the performance of annual pasture legumes in areas of the low rainfall mixed farming zones of southern Australia. The constraints may occur singly or more often as multiple stresses and make the interpretation of legume performance difficult. For several of the constraints described, improved legume material has been developed. Rigorous testing at multiple well characterised field sites will help to better understand the impact of the soil constraints on legume adaptation and prioritise future pasture legume development work for the low rainfall zone.

Acknowledgments

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Notes:

Prospects for improving perennial legume persistence in mixed grazed pastures of south-eastern Australia through improved soil nutrition

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Abstract: Nitrogen (N) deficiency remains a key constraint to pasture and livestock productivity across much of the high rainfall/permanent pasture zone of south eastern Australia, with production systems still overwhelmingly reliant upon N inputs from legumes. Legume biomass, and therefore N input, is largely constrained to the winter growing season of the dominant species *Trifolium subterraneum* L. which is poorly adapted at utilising the summer/autumn rainfall that commonly comprises a substantial proportion of total annual rainfall across this broad region. An opportunity exists to better utilise incipient rainfall through the greater incorporation of perennial legumes in the pasture base. However, the range of viable perennial species remains narrow, with periodic moisture deficit limiting the utilisation of species such as *Trifolium repens* L. to only the most favourable districts. Despite various plant breeding efforts it seems likely that, for the foreseeable future, graziers will be limited to the narrow range of perennial legume options presently available. Without the prospect of increasing water supply to these extensive dryland grazing enterprises, this review examines the question of whether a substantial increase in perennial legume persistence might be achieved through improved soil nutrition. The generally acidic, shallow and infertile soils that predominate across this region infer that present soil management may fail to meet the needs of productive perennial legumes. A renewed focus on aspects that enhance access to soil water, such as reduced aluminium toxicity and reduced potassium and phosphorus deficiency may help to alleviate the sensitivity to water stress that presently impedes these species.

Notes:

Mapping pasture species suitability using fine scale soils and climate data

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Abstract: Appropriate pasture species selection is a key to high productivity and persistence of pastures. In making this choice, producers currently rely on their own experience, advice from agronomists and seed merchants, and experimental trial data. This project sought to assess the benefit of using fine-scale soils data and long-term climate data to spatially determine the suitability of growing perennial ryegrass and Lucerne across Tasmania, Australia. Suitability rules were developed for each species involving growth responses to soil characteristics (pH, soil depth, electrical conductivity, drainage, and coarse fragments), and climate characteristics (precipitation). Suitability classes were defined as: well suited, suitable, moderately suitable, and unsuitable, with additional sub-classes to account for soil limitations that could be mitigated through management. Soils data from approximately 6,500 new and existing sites was modelled using Digital Soil Mapping techniques. Rainfall data from 539 Bureau of Meteorology rainfall-recording sites was modelled using Regression Kriging interpolation. Drainage was found to be the major constraint on lucerne suitability, with 36.7% of land constrained by imperfectly or poorly drained soils. Improving drainage reduced this figure to 18.8%. Perennial ryegrass was constrained by soil pH, where 38.6% of land had pH of less than 5.5. However, liming would reduce this constraint to just 4.3%. Matching species characteristics with fine scale geospatial data to determine suitability has proven successful for these two species in Tasmania. The feasibility of expanding this approach to a larger area of South Eastern Australia and across a wider range of pasture species is currently being assessed.

Notes:

Survival of perennial ryegrass over summer in northern Victoria without irrigation

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Abstract: Perennial ryegrass is the predominant perennial forage species in temperate irrigated dairy systems in Australia; however, its production can be poor over summer despite few soil constraints. This research investigated the effects of genotype and summer irrigation on perennial ryegrass production and survival.

Ten perennial ryegrass cultivars, three hybrid ryegrasses and two cultivars of tall fescue were evaluated under full irrigation and restricted irrigation over three years. Measurements made included pasture accumulation, botanical composition, sward density and stubble carbohydrate concentrations.

Apart from differences in dry matter production (DMP) between irrigation treatments, there were few differences in cumulative DMP between cultivars until Year 3. Plant frequency (sward density) declined in the restricted irrigation bay in Years 2 and 3 compared with the full irrigation bay but there were no cultivar differences. The recovery pattern in DMP following recommencement of irrigation varied across years. In Year 1, plants recovered rapidly once irrigation recommenced in autumn. However, in Years 2 and 3, autumn and winter pasture accumulation in the restricted irrigation bay was 30-35% less than in the fully irrigated bay. It was suspected that these differences were related to decreases in plant frequency, as well as to differences in the amounts of residual pasture mass (or carbohydrate reserves) that were present when growth ceased. In Year 3, analyses of the water-soluble carbohydrate concentrations in the pseudostem during summer and autumn showed differences in sucrose, fructan and total water-soluble carbohydrate concentrations between genotypes and irrigation treatments.

Notes:

Designing practical extension and training programs

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Abstract: This presentation explores:

- the practices used by producers to manage their feedbase including their approaches to pasture re-sowing and variety selection,
- the role of tools, technologies and advisors in pasture management decision-making, and
- what makes an effective extension or training program, who should drive it and who should be involved.

We also describe types of decisions (simple, complicated and complex), how they relate to livestock farming systems, and what that means for extension professionals.

We draw on findings from Tasmanian and national work including the Tasmanian Beef Pasture Feedbase Survey (2017) which was funded by the Tasmanian Beef Industry (Research and Development) Trust.

Notes:

Field trip farm profiles

Oakdene, Symmons Plains

Landowners/Managers: Bill and Jill Chilvers

Farming system/enterprise: Dairy and cropping

Rainfall: 550 mm

Soils: Shallow duplex soils - Brickendon sandy loam, Brumby loam

Tour focus: Soil improvement through lime and fertiliser

Background: Oakdene has for the most part been a dryland grazing property. Over time the Chilvers' intensified into irrigated cropping and lamb production. However, perhaps the most dramatic change came with the $1.3M dairy conversion in 2010. A share farming partnership with Grant and Kim Archer saw them take out Dairy Business of the Year in 2015. The Chilvers' have been able to adapt to the challenging duplex soil type by grazing less intensively, but more frequently, resulting in less pugging issues. Furthermore, it has resulted in an improvement in feed quality and an increase in clover content of the sward. The soil has been improved steadily through cropping phases by the addition of lime.

Notes:

Woollen Park, Longford

Landowners/Managers: Rob and Jo Bradley

Farming system/enterprise: Mixed farming operation that incorporates sheep and dairy grazing with pasture seed, canola, wheat, carrot seed and peas.

Rainfall: 600-700 mm

Soils: Gradational clay loam over clay soils - Cressy shaley loam and Kinburn clay

Tour focus: Soil improvement through drainage

Background: The Bradley's have embarked on a $1M capital investment program in drainage, with the estimated return to be in the order of $200,000 per annum. The returns stem from reduction in grain yield losses to waterlogging and better access during winter for control of weeds. Draining of the soils also allows intensification of the livestock enterprise where high stocking rates previously resulted in pugging issues in pastures. Draining areas prone to waterlogging in winter has also allowed lucerne to be grown productively where it couldn't before. The Bradley's developed a drainage plan in consultation with Dr Bill Cotching and have employed a range of drainage techniques and infrastructure including the implementation of open surface drains, underground pipe drains and mole drains.

Notes:

Even Fertilizer Spreading Contributes to Farm Profit in Grazing Enterprises

Jeff Kraak - Fertilizer Australia (E: jeff.kraak@fertilizer.org.au)
Chris Lightfoot – Independent Farm Economist (E: Chris@lightfoot.com)

Key Points

- The majority of fertilizer spreaders deliver highly variable spread patterns. This compromises pasture profitability as some areas within the paddock receive too much fertilizer and others too little.
- Uneven urea spreading on dairy pasture can result in $15 - $40/ha reduction in the value of dry matter (DM) for a single application. This means you can have a significant effect on profitability by ensuring fertilizer is being spread evenly on dairy pasture.
- Spreader modifications and adjustments can result in wider bout width while still achieving an acceptable spread pattern as measured by the Accu-Spread testing procedure.
- If you engage professional contractors to spread fertilizer, you should engage an Accu-Spread certified operator from the list at www.fertcare.com.au

What is the potential issue with broadcast spreading of fertilizer?

Typically a single pass of a broadcast spreader produces higher application rates close to the centre line of the spread and lower rates further away from the centre line of the spread. Even application across the paddock is achieved by overlapping the spread pattern of the previous run. The distance between spreader runs to provide the overlap is called the bout width.

Uneven application means some areas of the paddock receive insufficient fertilizer and pasture growth may be reduced in these parts of the field, while the areas close to the centreline of the spread are over fertilized, which reduces profitability and increases the risk of off-site nutrient movement. The effects of uneven fertilizer application over several seasons are compounded when spreading in controlled traffic farming systems. Using GPS guidance on spreading equipment can have a similar effect to controlled traffic.

Accu-Spread testing allows operators to determine what bout width to drive at to achieve the industry standard for spread pattern which is ≤15% coefficient of variation (CV) for fertilizers and ≤25% for lime and gypsum. CV is a measure of the evenness of the fertilizer application rate across the paddock, after accounting for the overlap. CV is a useful indicator to guide machinery adjustments to achieve uniform spread at larger bout widths. Whilst the CV industry standard may not always produce the bout width resulting in the theoretical maximum profit for a given situation, it is a useful practical guide.

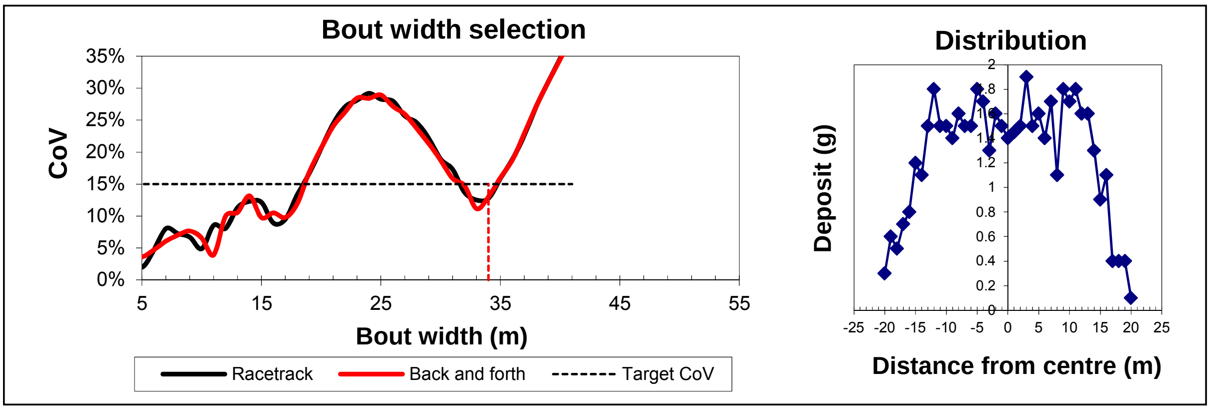
Different fertilizer products have different physical characteristics and so they spread differently. It’s normal for the same machine to have different bout widths for each product. Driving accurate and consistent bout widths is critical to achieving an even spread. A typical Accu-Spread machine will have test graphs, and different bout widths, for each type of product spread.

Accu-Spread graphs explained

The graphs provide data on two driving patterns i.e. race track (around the paddock) and back and forth across the paddock. When the race track pattern is employed, opposite sides of the spreader discharge are overlapped, e.g. the right discharge gets placed on top of the left discharge. For back and forth driving pattern, the spreader discharge from the same side is overlapped, e.g. right discharge gets placed on top of the right discharge.

The first graph plots the CV against the bout width for the product spread by a particular spreader. The desirable bout width is where the red and black lines are under the target industry benchmark. Any part of the graph over the target is outside the Accu-Spread standard. The second graph, the distribution graph, shows the evenness of spread in a single pass behind the machine. The zero on the X axis represents the centreline of the spread or line of travel and the dot points on the graph reflect the collection trays either side of that centreline.

The Accu-Spread graph below indicates the recommended maximum spread width for both racetrack and back and forth is 34 m in this example. Increasing or reducing the bout width to wider (e.g. 36m) or narrower bout widths (e.g. 25 m) would result in a sub-optimal urea spread pattern for this machine. Alternatively spreading at bout widths of 17m or less would produce an acceptable spread pattern.



Testing of Farmer Spreaders

The South West Catchments Council (SWCC) WA and Department of Agriculture and Food Western Australia (DAFWA) facilitated the testing of dairy farmer spreading equipment from 2013 to 2015. The Accu-Spread testing methodology was used to evaluate the spread patterns for a range of fertilizer and soil amendment products. This work revealed that the majority of fertilizer spreaders are delivering a high level of variation in spread pattern and that a new machine is no guarantee of an even application.

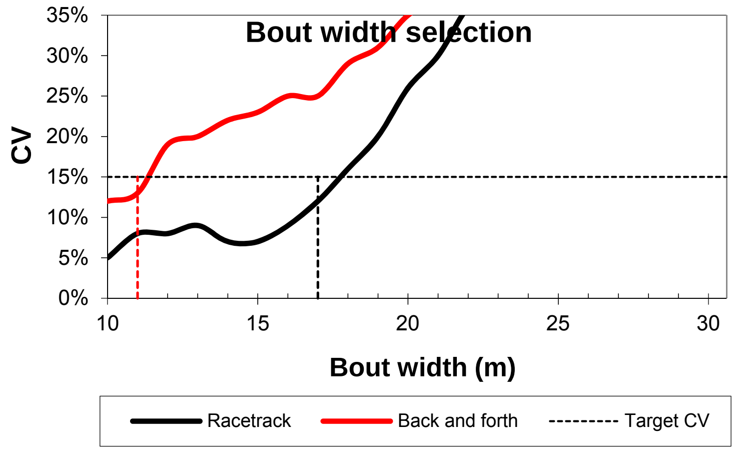
Recent improvements to the Accu-Spread model now allow objective pasture yield and gross return outcomes from varying nitrogen fertilizer spread patterns to be assessed for the WA dairy industry. This assessment is based on accepted nitrogen response functions, income and expenditure data.

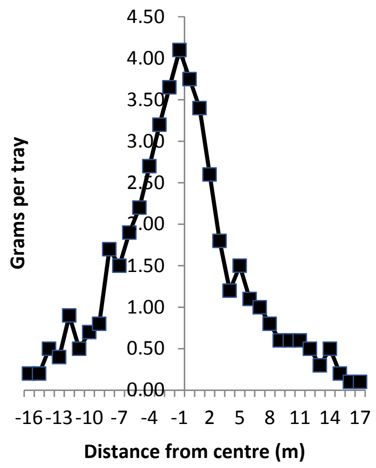
The economic implications of urea spread patterns for 19 spreading machines have been evaluated. Clearly each situation is different, however this work shows uneven urea spreading on dairy pasture can resulted in $15 - $40/ha reduction in the value of pasture for a single application when pasture is valued at $150 / t DM.

Below is an example of the outputs of the evaluation.
Key assumptions:

- WA Spring nitrogen (N) pasture response function as published by Chia and Hannah (http://vro.depi.vic.gov.au/dpi/vro/vrosite.nsf/pages/nitrogen-advisor)
- Value of the extra pasture production: $150/t DM
- Base spreading cost: $13/ha

Spreader 6





Back and forth

Bout width (m)	22	18	14	11
Product value at farm gate ($/ha)	$188.72	$232.60	$257.53	$267.93
Difference in pasture value from the 11m bout width ($/ha)	**-$79.21**	**-$35.33**	**-$10.40**	

To achieve a 15% CV spread pattern driving back and forth in the above example, the bout width should be 11m. If the operator drove at an 18m bout width, the value of DM would be reduced by $35.33/ha compared to an 11m bout width. Similarly if the operator drove at a 22m bout width, the reduction in pasture value would be $79.21/ha compared to an 11m bout width. This is due to some areas of the paddock receiving insufficient fertilizer and pasture growth being reduced, while other areas are over fertilized.

This example is for a single application of urea on pasture. Multiple applications of urea over the growing season are common in dairy pasture systems. This means the cumulative effect of poor urea spread patterns over a growing season is likely to be much larger, particularly if the same tracks are followed.

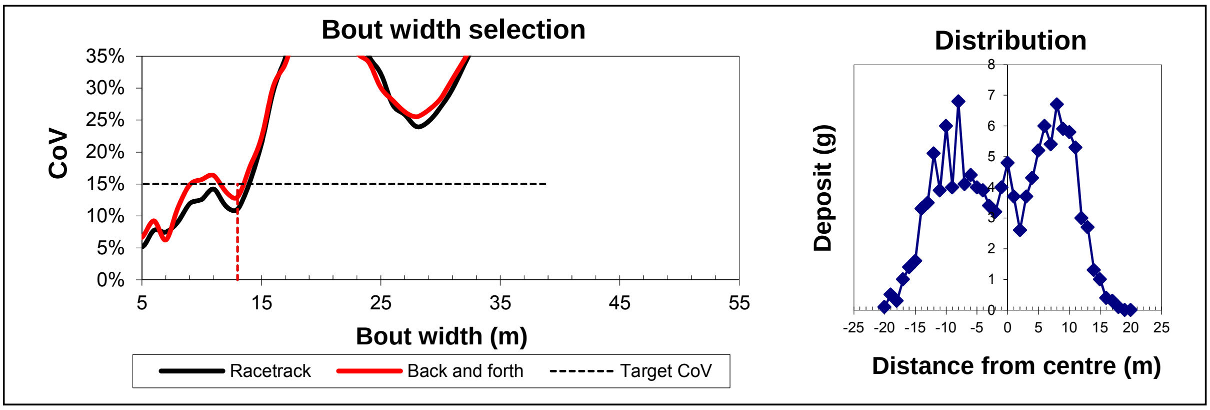
These examples demonstrate it is worth spending time and effort to ensure fertilizer is being spread evenly on dairy pasture.

What improvements in bout width are possible?
It is not uncommon for a skilled technician to be able to increase bout widths by 5 – 9 m whist still achieving an acceptable spread pattern depending on a range of factors.

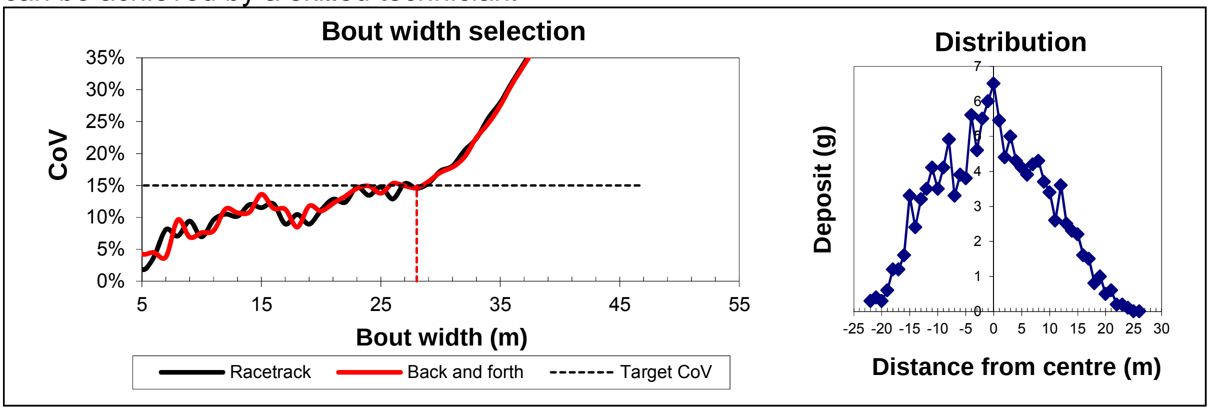
When spreader adjustments are made, the aim is for both red and black lines to closely follow one another on the Accu-Spread graph and not be separated. This means that regardless of the driving pattern an operator chooses, a similar bout with can be used.

It is also desirable to have an Accu-Spread graph with both driving pattern lines beginning on the left with a low flat gradual slope, remaining under the target CV until wider bout widths inevitably result in an unacceptable spread pattern.

Below is an example of the spread pattern from a new spreader achieving a bout width of 13m for back and forth driving pattern.



After adjustment to the same machine, a bout width of 28m was achieved for the same driving pattern and fertilizer product as shown in the graph below. This demonstrates what can be achieved by a skilled technician.



What are the main factors impacting on spread performance?

- **Machine setup and maintenance**
  - Ensure there is no product build up on spreader components, e.g. on spinners, chutes or splash plates. Clean the spreader regularly, both during and after use.
  - Check the machine for general 'wear and tear,' replacing parts where appropriate, e.g. worn or bent spinners and or vanes, splash plates or guide chutes with holes, dents or bent ends. Follow the manufacturer's maintenance advice.
  - Use the suggested spreader settings for each individual fertilizer product as a guide, e.g. spinner speeds, gate opening, "drop on point" on the spinner and agitator, etc. Check application rates and distribution before using the machine over larger areas.

- **Fertilizer product characteristics**
  - The main product characteristics affecting spread patterns include product density, particle size (mean and distribution) and particle shape.
  - Small particles will not travel far off the centreline of a spreader, whereas larger, spherical, denser particles will travel much further.
  - Even when using the same type of fertilizer from the same supplier, loads can vary in product characteristics to some extent. A size guide box or particle sieves are simple ways to determine the size distribution of fertilizer particles and are regularly used by Accu-Spread contractors.
  - How a machine responds to changes in product depends on individual machine design elements.
- **Environment where the spreading is taking place**
  - Wind speed and direction in relation to direction of machine travel.
  - Air humidity, as some fertilizer types absorb moisture from the air more readily than others.
  - Ground conditions e.g. slope and evenness of the surface. Ground slope can influence the "drop on point" on the spinner which can distort the spread pattern or change flow rate. Spreader testing is typically done on flat ground.
  - Crop or stubble height.
- **Operator competence**
  - Basic fertilizer knowledge: Fertilizer types. Understanding product labels. Bulk density. Particle size distribution. Safety Data Sheets. Factors which could lead to problems, e.g. mixes of fertilizers with very different particle sizes or incompatible mixes and product handling, e.g. avoid augers and double handling if possible.
  - Spreading skills: Consequences of poor spreading (agronomic and environmental). Awareness of the influence of wind. Choosing an appropriate bout width. Being able to operate to a consistent bout width. Interpreting information to be able to know what settings on spreading machinery are needed for various fertilizers and fertilizer characteristics in order to achieve the correct application and bout width. Adjusting spreader equipment. Factors affecting the performance of the machine over time, e.g. fertilizer build-up. Handling spillage.
  - Safe driving skills

How can I choose a professional contractor that will spread fertilizer evenly?
Professional spreading contractors can have their equipment independently tested resulting in Accu-Spread certification, given the driver is Fertcare® trained. This provides farmers and natural resource managers with peace of mind; knowing farmers are using contractors who are applying the correct rate of fertilizer where they want it in the landscape.

When seeking professional spreading services, farmers are encouraged to engage a contractor with an Accu-Spread certified machine for the product type to be applied. A list of Accu-Spread contractors is available at www.fertcare.com.au. The product graphs for each machine are also publically available at www.fertcare.com.au

References
N pasture response function http://vro.depi.vic.gov.au/dpi/vro/vrosite.nsf/pages/nitrogen-advisor

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Notes:

Common Spreader Maintenance & Safety Issues

Below are some common spreader maintenance and safety matters which can contribute to even spread patterns and safe machinery operation.

Ensure there is no product build up on spreader components, e.g. on spinners or splash plates. The pictures below are examples of what to avoid.


Product build-up on spinner vanes

Check the machine for general ‘wear and tear’, replacing parts where appropriate, e.g. worn or bent spinners and or blades, splash plates or guide flutes with holes, dents or bent ends. Follow the manufacturer’s maintenance advice. The pictures below are examples of what to avoid.


Worn spinner vanes tips

Ensure the machinery is operating in a safe manner, e.g. safety guards are in place. The pictures below are examples of what to avoid.


Chain guard missing