Grassland Society of NSW Inc.

Pathway to Productive Pastures

Proceedings of the 32nd Conference
of the Grassland Society of NSW Inc.

VIRTUAL CONFERENCE, 20–21 JULY 2021

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Edited by Chris Houghton, Rod Hoare and Helena Warren

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Grassland Society of NSW Inc.

A unique blend of people with a common interest in developing our most important resource – our Grasslands

The Grassland Society of NSW was formed in March 1985. The Society now has about 300 members and associates, 75% of whom are farmers and graziers. The balance are agricultural scientists, farm advisers, consultants and executives or representatives of organisations concerned with fertilisers, seeds, chemicals and machinery.

The aims of the Society are to advance the investigation of problems affecting grasslands husbandry and to encourage the adoption into practice of results of research and practical experience. The Society now holds a biennial conference, publishes a quarterly newsletter, holds field days, and has established regional branches throughout the State.

Membership is open to any person or company interested in grassland management and the aims of the Society.

Audiovisual:

Andrew Britton, South East LLS, Berry;
Helena Warren, Convenor; Alex James,
Small Farms Network, Capital Region

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Enquiries and additional copies:

Grassland Society of NSW
PO Box 471, Orange NSW 2800
Email: secretary@grasslandnsw.com.au
Website: www.grasslandnsw.com.au

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Preface

On behalf of the Grassland Society of NSW Inc. it gives me great pleasure to extend a very warm welcome to all members and non-members attending this, the 32nd Conference of our society. Conducted 'biennially', our conference 'moves' around the state, and this year is being held at Mittagong on the NSW Southern Highlands.

Having navigated through 2020, this year we are hoping that Covid-19 remains at bay and attendees get the full benefit of the terrific program the organising committee has put together. "Pathway to Productive Pastures" follows a terrific 2020 season for most, after what was a devastating three years prior. In many paddocks, everything known to 'person' germinated, leaving many of us with a weed spectrum we didn't recognize. There will be plenty of messages over the next two days, and opportunities to converse with others as to how some are looking to regain control of their pastures.

Our society deems the sharing of our conference locations as a very strong attribute, trying to disseminate the current research and extension work as widely as we can. A recent survey to our members has reinforced the wish to have and attend our conferences and see the society as an integral part in extending the research. Our past activities with the MLA funded 'Pasture Updates' proved very successful. Last year and this year, some half day events have and are being conducted in conjunction with other organisations, trying to continue to spread the research and farmer experiences even wider.

A lot has occurred since the 2019 conference, and farmers have worn the brunt of it all. From drought, fires, floods, and mice, there has also been some terrific positives. Livestock prices, for those that were able to keep them through the drought, are at all time highs, and seemingly are set to stay that way for now. Hopefully the 2021 season can get a wriggle on and present us with a wet Winter and Spring to boot. We have to adapt what we do to cope with such challenges, as it appears nothing is 'normal' anymore.

The conference will provide a great mix this year, from new tools to use for forecasting, exclusion fencing to allow producers to 'eat more of what they grow', and to really drill down into what I call the basics in looking after our most valuable asset, our soils. While the basics aren't new, hearing of new approaches to improve our soil health, and how our producer speakers are making the best of their soils and pastures to be leaders in their field, the learnings will be invaluable. I encourage everyone to ask questions and learn from the experiences of others.

Sponsors are an integral part of our society. They continue to provide great assistance, either financial or in-kind, and it is their involvement that makes many of the society's activities possible. To those sponsors of our society for the 2021/2022 year, I would sincerely like to thank each and every one of you for your contribution. We continue to pray for good seasons and hope that you too can benefit from these. I encourage all conference delegates to visit the commercial displays and take the time to talk with the representatives. Their product knowledge and the resources they have available may be just the key to improvements you can achieve in your own business.

To the conference organising committee, thank you. The enthusiasm and organisational skills that you brought to this year's event are greatly appreciated. I would also like to thank the many employers of the conference committee, as it is 'their time' that is contributing to the conference program. Many hours of voluntary work have come together for all our benefit, and for that we are grateful. We look forward to hearing and seeing the wonderful program that has been put together.

In encouraging 'non-member' delegates to consider joining our society and reap the year-round rewards on offer, I wish all delegates in attendance the best for the conference; it is provided for your learning and enjoyment. Should you have any ideas, comments or concerns, I would encourage you to share them with any of the organising committee. Your feedback is always welcome and our society can only improve on the back of people's collective input.

Enjoy your time here, David Harbison, President

Virtual Conference Program

DAY ONE: TUESDAY 20 JULY	
Time	**Topic and Speaker**
8.45 am	**Opening virtual conference room**
9.00 am	**Welcome** David Harbison, President, Grassland Society of NSW
9.30–10.15 am	• *Farming Forecaster* – Phillip Graham, Graham Advisory
10.15 am	**Trade Displays and Morning Tea**
10.45–11.30 am	• *Permanent electric fencing – A solution for many guardians of the land* – Graeme Mulligan, Gallagher Fencing and Duncan Abbey, Weston Fencing
11.30 am – 12.15 pm	• *Laggan Grazing Demonstration – observations and key lessons after six years* – Matt Lieschke, SE LLS
12.15–1.00 pm	• *Getting started on the pasture pathway* – Bella St Clair, Producer angora goats and beef cattle
1.00–1.30 pm	**Lunch**
1.30–3.30 pm	**Presentation of virtual contributed poster papers** • *Pasture dieback on the North Coast of New South Wales.* 1. Initial diagnostics to identify the causal agent – SP Boschma, A Daly, PS Gillespie, O Wildman, M Shrivasatava, N Jennings, JM Geary and SJ Baker • *Pasture dieback on the North Coast of New South Wales.* 2. Symptom development and current recommendations – SP Boschma, N Jennings, JM Geary and SJ Baker • *Desmanthus is more persistent than lucerne through drought on the North-West Slopes of NSW* – SP Boschma, CA Harris, MA Brennan, C Murray, SJ Baker and S Harden • *A 'second go' at pasture improvement on "Mt Somers", Neville* – Cook • *Legume content and sub-optimal nodulation linked to soil acidity and nutrient availability in the Mudgee region of the Central Tablelands, NSW* – C Edwards and B Hackney • *A preliminary evaluation of perennial legume persistence on the Southern Tablelands of NSW* – C Hayes, MT Newell, WB Bargery, CA Harris, GD Li, A Price, NR Munday, RS Stutz and RA Culvenor • *Investigating producer interest in and experience with tropical perennial grasses in inland NSW* – Sinclair, AL Curtis, SJ Baker and SP Boschma • *Soil water dynamics and water use efficiency of tropical pastures in Central West NSW* – MJ Uddin, WJ Smith, SR Murphy, SP Boschma and Y Alemseged

DAY TWO: WEDNESDAY 21 JULY	
Time	**Topic and Speaker**
8.15 am	**Opening virtual conference room**
8.30–9.15 am	• *Understanding and management soil acidity – the key to sustainable and productive grazing systems* – Helen Burns, NSW DPI, Development Officer, Pastures
9.15–10.00 am	• *Soil Fertility – You can't manage what you don't measure* – Helena Warren, Producer and Advisor, Cador Murray Greys
10.00–10.30 am	**Trade Displays and Morning Tea**
10.30–11.15 am	• *Rejuvenation of run-down perennial pastures* – Fiona Leech, SE LLS and Roger Garnsey, Roger Garnsey Agronomy
11.15 am–12.00 noon	• *Managing the establishment of productive perennial pastures* – Hamish Best, Agricom, Stephen Pasture Seeds and Auswest Seeds
12.00–12.45 pm	• *An insight into graze and grain systems in a high rainfall zone environment – a producer perspective* – Peter and Cait Brooks, Berrima, 2020 Woolworths Protein Supplier of the Year
12.45–1.15 pm	**Lunch**
1.15–2.00 pm	• *Opportunities to build Soil Organic Carbon in a challenging environment; climate change and shifting paradigms* – Dr Susan Orgill, NSW DPI, Research Officer
2.00–2.45 pm	• *Adding "Carbon Farming for Carbon Trading" to your productive pastures* – Louisa Kiely, Carbon Farmers of Australia
2.45–3.30 pm	• *Carbon Neutral by 2030 roadmap for the Australian red meat industry* – Margaret Jewell, MLA
3.30 pm	**Conference Close**

Sessional Papers

Farming Forecaster

Phil Graham

Graham Advisory, Yass, 2582, phil@grahamadvisory.com.au

Abstract: *New technologies collecting more data are of little use to producers unless they can access the analysed data in a form and time frame that suits their operation. Farming Forecaster does that by combining products that have been used for the last decade and automating the collection, processing and presentation of quality data via a web-based application. The automation has reduced the cost to provide information to producers. These efficiencies have enabled the network to be expanded, increasing the number of sites and value to producers.*

Key words: Seasonal forecast, producer relevant data, digital technology

Introduction

The Farming Forecaster website (https://farmingforecaster.com.au/) was released in April 2020. At present Farming Forecaster covers the south east region of NSW, with plans for it to be expanded to cover the northern and central tablelands and the eastern riverina during the next 12 months.

The website provides current anda historical soil moisture, soil temperature and rainfall data from 29 sites. In addition to field data, the website also provides current and future weather details (based on five square kilometer grids), current and future pasture mass, predicted levels of ground cover and livestock data for the next four months on a risk basis. Weather and soil moisture data are updated daily and the pasture/livestock data every third day.

For breeding enterprises, changing the number of breeding females has long-term impacts (both negative and positive) on the business and hence needs to be carefully considered. Farming Forecaster provides the most comprehensive set of data to assist livestock producers in making decisions about future stocking strategies. Producers have commented that this data improves their confidence to take timely actions.

History

The first moisture probe network in grazing areas was established by CSIRO in 1998 under the name 'Across the Fenceline' in the Bookham and Harden regions of NSW. Producers accessed the data by a website.

In 2001 Australian Wool Innovation funded a project which resulted in Bookham Agricultural Bureau (BAB), CSIRO and NSW DPI working together to use the GrassGro™ (Moore *et al*. 1997) program to examine major questions that livestock producers were concerned about. The capacity of the program to produce seasonal outlooks for the next three to four months was positively received by the producers.

Over the next decade NSW DPI staff continued to use GrassGro™ to produce seasonal outlooks as part of their district work. Monaro Farming System (MFS) started in the early 2010s to do seasonal outlooks in autumn and early spring on annual basis. This was well received by members. Tablelands Farming System (TFS) began the same process a few years later. The development of a bigger moisture probe network in the south east started in 2016. This included developing a new website where the data display was further advancement on the earlier 'Across the Fenceline' website.

By the late 2010s, members from MFS and TFS wanted to be able to access the seasonal outlook information on a more regular basis, but the cost of producing the outlooks prevented this from occurring. In 2018 a consortium of MFS, TFS, BAB and Local Land Services (LLS) were successful in obtaining funding from the Australian Government's National Landcare Program which allowed the development of Farming Forecaster. CSIRO and Square V were contracted to develop the required computer systems and website.

Farming Forecaster has been developed with producers and has used the 20 years of experiences of producers and advisors with moisture probes and GrassGro™ to refine the material that is now displayed.

Site layout

The front page can be divided into four segments,

- top left: Probe – the data from the moisture probes,
- top right: Pasture Forecast – the data from GrassGro™ on pasture and livestock projection,
- bottom left – an information area for the farming system groups to use and where Farming Forecaster training videos are located,
- bottom right – weather details.

For each segment there are buttons which allows you to access more detailed information.

You select a site to view via a box in the top right with a drop-down box listing all 38 locations.

There are some sites that do not have a moisture probe (n=9) so there is no data in the top left segment. The most expensive part of developing a site is the buying, installing and maintaining a moisture probe so the groups decided to expand the coverage of Farming Forecaster by developing sites with just the GrassGro™ and weather outputs. (Thomas *et al*, 2019)

Information provided

Network

There is a 'view network' button on the left-hand side of the front page. This shows a map of the 29 probe sites and this can be examined for daily or monthly rainfall and soil moisture status via a drop-down box. This allows you get a quick idea of conditions on a regional basis which can be useful for marketing or feeding decisions.

Probes

This data is collected daily (check when the last update occurred as this tells you if there has been a communication issue) from the probe network and is displayed as tables or graphs. On the front page the table describes the percentage of available soil moisture at 4 depths, 10, 20, 40, 60 cm. and changes that have occurred over 3 time periods.

By clicking on the 'more detail' button, graphs of the soil moisture at the listed depths are display over a number of different timeframes. The probes also record soil temperature and rainfall and this data is available. In the rainfall graph the monthly 30-year average (1990 to 2019) from the BOM grided data is provided. Producers can compare their farm data for the same period against these values to see how their farm sits in relation to the gridded data.

A description and pictures of the soil type at the probes are provided to allow producers to compare their soils to each site.

Pasture forecast

All data in the section has been generated from the GrassGro™ model using farm systems developed in consultation with the producer groups and the BOM gridded weather data.

The graph of green available herbage contains historical data based on the weather from 1990 to 2019. This information is indicated by the shaded coloured areas expressed on a percentile basis. The tactical or forecast data for the next three months is displayed as coloured lines. You can select the percentile lines you want to look at. The black line tracks the actual model performance during the month. A new three monthly forecast is done at the start of each month. The key is to look at how the forecast lines compare to the historical shading for the same percentile.

The more detailed information covers current soil moisture compared to the last 30 years. It shows the potential changes over the next three months for ground cover, female condition score and liveweight of young livestock. The potential supplementary feeding required for all stock is provided in two graphs expressed as a probability, so you can see the risk associated with a short-term feeding strategy. At the top of the detailed section, you have a description of the modeled farm system, covering soil and pasture type and the livestock enterprise used with some details on management and stocking rate.

Weather forecasts

This data is a combination of BOM and CSIRO material. A brief 7-day forecast is on the front-page which includes a sheep grazier's alerts if appropriate. Next to the alert (sheep icon) is an index value which is based on temperature, rainfall and wind speed. An alert is listed if the value exceeds 1100. In severe conditions this index can exceed 2000, so by listing the value producers can get a feel for the intensity of the weather event.

The more detailed information that sits behind the front page provides a weather forecast on a 3-hourly basis for 7 days and a 3-month rainfall forecast. The information above the forecast should be read before making use of these details.

Farming system groups

There are contact details for the farming system groups in SE NSW.

Discussion

The time and support from producer groups and individual producers over the last two decades has been important in achieving the current program. Key advisors and researchers have used producers' experiences and comments to develop the information and the type of displays used on the Farming Forecaster website.

The new system means that the number of sites and frequency of information can be increased with only minor extra costs. There is the potential for expansion of Farming Forecaster across NSW and there is current interest from groups in Tasmania.

Any new developments to the science underpinning GrassGro™ will automatically flow to producers without the need from extension programs. New sensing technology could also be aggregated and used by the website. Livestock producers in SE NSW now have the ability to access quality data when they want it to give them more confidence in decision making. The site allows each producer to select the information they need to help with a particular decision. How producers will use the site will vary during the year and between years depending on the circumstance they are facing. It provides data not answers.

The expansion and maintenance of this site will need to be driven by producers if it is to become a long-term tool for livestock producers.

Acknowledgments

The financial support from the Australian Government's National Landcare Program has been critical to the development of Farming Forecaster. This support has also covered the probe network expansion from 2016.

The development of GrassGro™ was also supported by MLA and AWI in the 1990s.

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Permanent electric fencing – A solution for many guardians of the land

GW Mulligan[A] D Abbey[B] and A Fitzgerald[C]

"Gallagher Westonfence", Epping VIC 3076, and Parkes NSW 2870:
graeme.mulligan@gallagher.com

Abstract: *The attributes of permanent electric fencing are being well recognised but there is considerable opportunity for increased uptake to further protect pastures and environmental plantings. Electric fence efficiency has been on a journey from the 1960's. Early designs featured a dumb box with 5 joules of stored energy that at best could generate just 5000 volts of energy. Earthing systems were fragile in the arid landscapes of Australia and attracted more criticism than accolades. Moving forward fifty years, we now have sophisticated technology that can deliver high voltages over significant distances. A 10,000i series fence unit now stores 100 joules of energy and punches out a minimum 10,000 volts with a well-designed technically advanced earthing system. Smart technology allows constant monitoring and management of the fences. Over a similar period, we have witnessed the introduction of high-density polypropylene (HDPE) droppers made from 100% recycled material sourced from Australian farm waste. The strength and versatility of this system is providing a cost effective, low maintenance fence with the ability to protect stock, crops and pastures from a variety of pest animals. The ingenuity of two farming families has revolutionised fencing today.*

Key words: Energiser, intelligent, fence selection, productivity, return

Introduction

Sir William Gallagher, second-generation ambassador of the 83-year-old family business, is still active today in the company, esteemed for its advanced technology, innovation and manufacturing. In Australia, Gallagher Animal Management operates out of Epping VIC delivering a range of fencing products to farmers and land managers. There is a team of people throughout Australia which offer expertise direct to customers and resellers through a hub of senior management, customer service and technical support.

Westonfence is a family-owned business based in Parkes NSW, manufacturing a unique fencing system and droppers. The late Peter Weston developed the Westonfence solution for the family's 80,000-acre property. The business, now operated by Duncan Abbey and his wife Maria (nee Weston), has grown since the days a neighbour asked Peter if he could supply him with some high-density polypropylene (HDPE) droppers. The family has now supplied over 20,000 km of suspension fence to farmers around the country.

The recycled HDPE resin used in the manufacture of the droppers is derived from farm waste, mostly chemical drums and plastic bins through Pelletek, a subsidiary company of Westonfence. The range of fence designs developed by Westonfence has grown over the years, providing solutions for the exclusion of feral animals and internal subdivision for livestock management. The products have been used extensively in regenerative and environmental programmes with organisations such as Landcare.

In the last six years Gallagher has formed a partnership with Westonfence to supply a permanent electric fencing solution for not just farmers but for a raft of guardians of the land.

The Historical Myths

Farmers still bear the scar tissue from their experience of using electric fencing in the 1980s. For some, it was a bad experience and not a permanent solution. It was said maintenance was high, voltage inconsistent, earthing did not work, electric fences started fires and the list goes on. In part, the Kiwi designed energisers were suited to the well earthed soils of New Zealand, but some farmers there also experienced problems to find the right earthing system.

Today, with the benefit of an additional forty years of rigorous research, innovation, and manufacturing excellence, the I series energisers provide intelligence, reliability and efficiency. We also have improved knowledge on earthing requirements for specific Australian soil types. This technology has encouraged more farmers to adopt permanent electric fencing as a first-choice land management system.

Why Use Electric Fencing?

Electric fencing is more effective at containing domesticated livestock or excluding pest animals than traditional fencing. The short, safe shock creates a psychological as well as a physical barrier that is memorable enough that the animal never forgets and will avoid touching the fence again. The fence needs to be well designed and constructed to absorb some pressure from animals and the environment. The energizer must have enough power for the design of the fence and to control the animals.

Electric fences are used for various applications including:

- Pest exclusion fencing
- Rotational grazing
- Protection of environmental plantings
- Fencing riparian zones
- Protecting crops and newly sown pastures

Choosing a Fence System

- To make the right choice for fence design, it is important to consider the following issues:
- What are you trying to achieve?
- How long does it need to last?
- What animals are being included or excluded
- What is the cost of capital and operating expenses?

For example, boundary fences will need to be higher and contain more wires to exclude kangaroos, wild dogs or pigs. The design of internal fences for cattle will be different to those used for sheep.

Suspension fences using the HDPE droppers can replace two thirds of the steel posts of a conventional fence and have proven to be cost effective and easier to install. The droppers also replace the need to use pin lock insulators which are easily damaged by animals. This design of fence can absorb the energy when hit by an animal.

Choosing a Power System

The distance and size of area determines energiser size. Access to a power supply will determine if the fence is run on mains or by a battery backup solar unit.

Earthing is critical to energiser efficiency; drier areas need a different fence setup and multiple earth components. An energiser needs to have low leakage or impedence.

The only true way to compare different energizers is based on stored joules as this is a constant measure and not affected by variations in fence conditions or earthing. This stored energy is the potential energy available in the single pulse per second generated to power the fence line. The higher the stored joule rating the greater the energizer's ability to push past shorts caused by weeds and fence faults.

Handy Recommendations

- Always purchase an energizer with more power than you require.
- More power provides more confidence that the fence will perform despite unexpected shorts like vegetation growth.
- Purchase an energizer with headroom to power additional fences.
- Ensure the energiser is protected with built in modular lightening diverters.
- A rule of thumb, need a minimum of 10 Joules of stored energy to maintain 8000 volts in a fence.
- Buy smart technology so fences can be constantly monitored and reported to a mobile phone app.
- Choose a system with remote power switching and fault finding technology
- Multiple electrified wires will create an electro-magnetic field.

A Case Study

Doug Cameron of Bendoc is a great example of making a wise choice with Permanent Electric

Fencing. A family property ravaged by wild dogs four years ago is now a success story. He invested $80,000 by clearing a hilly bush line boundary and installed 13 km of Westonfence powered by an I series electric fence unit. A completed cost of $6153 per km.

Prior to the Westonfence, Doug was marking 58% lambs from his 1200 set stocked Merino ewes. With the safety of an exclusion fence, lambing survival has increased to 117% from the paddock adjoining the bush, a haven for wild dogs, kangaroos and feral pigs.

In one year, the increase of 700 live lambs only had to fetch $114 each to pay the investment back, not to mention a return of personal wellbeing for a family being able to remain on the land without the fear of wild dog incursion.

Goals or business objectives

In the short term, our collective goal is to inform farmers and land managers of the improved technology in advanced intelligent permanent electric fence systems. With added energy output of up to 15,000 to 18,000 volts at the end of a suspension fence has formed both a physical and psychological barrier so animals learn to respect the fence.

In the medium term our vision is to see permanent electric fencing as a go-to option for farmers and land managers alike for the protection of land and livestock.

Conclusions

Permanent electric fencing is a man-made product derived from innovation. It has matured into a land management/farming system solution made from recycled plastic materials derived from farm waste, together with an aesthetic contribution to our environment, which can be powered by solar energy. Wise people making wise choices are now and will be well served by man's invention.

Acknowledgments

That the innovation of farming families (Weston and Gallagher) has combined to create lifelong solutions that add to protect the wellbeing of animals and restore the environment of our communities.

Laggan Grazing Demonstration – observations and key lessons after six years

M Lieschke[A]

[A]Local Land Services, Goulburn, NSW 2580: matthew.lieschke@lls.nsw.gov.au

Abstract: *A grazing demonstration was established at Laggan NSW to measure the production response and economic advantage of applying fertiliser and lime to a native pasture of low soil fertility. The grazing demonstration commenced in 2015 and consists of three treatments: single superphosphate (SS); lime + single superphosphate (L+S); and a control (Cont). Lime was surface applied as one-off application (2.5 t/ha) at the start of the demonstration. The demonstration site is set stocked with Merino wethers. Wethers are regularly weighed and stocking rates adjusted to achieve similar average body weight across treatments. The financial performance of each treatment is based on wool returns plus meat income when wethers are sold. The application of fertiliser had an immediate impact, with the fertilised paddocks growing more pasture and sustaining higher stocking rates. Economic data from the first six years shows that when P and S are applied at this site, average stocking rates can be increased by 2 wethers/ha (143%), lifting overall profitability by around $100/ha/year. While the effect of lime on soil pH was limited to the top 2.5 cm of soil, lime appears to have had a positive effect on legume production at this site. L+S increased stocking rate by 2.9 wethers/ha (163%) and profitability by a $181/ha. With current commodity prices and high returns for livestock the data shows that adding lime to native pastures is likely to be profitable. However, applying lime is still a considerable up-front cost to the producer and any potential benefit will only be realised if deficiencies of major nutrients are addressed.*

Key words: native pastures, phosphorus, lime response, livestock production

Introduction

Australia's grazing industries were originally established on the natural grassy ecosystems found by the early explorers in the early 1800s. Native pasture species continue to play an important role in supporting livestock production throughout New South Wales, occupying several million hectares (Langford *et al*. 2004).

Although native pastures have long been associated with 'low input, low output' systems, we know that this is not always the case. A long-term grazing demonstration in the Bookham NSW district has shown that pasture production and long-term stocking rates can be doubled when major nutrient deficiencies are addressed (Graham 2012).

A long-term grazing demonstration was established in the Laggan area (14 km NNE of Crookwell NSW) to assess the economics of fertilising native pastures in the Crookwell region, which is approximately twice the elevation of Bookham (Laggan demonstration site ~1000 m; Bookham demonstration site ~ 520 m). The demonstration was also set up to assess the impact of applying lime on pasture production and overall economics. Adding a lime treatment to the demonstration was of particular interest as lime is commonly applied to the surface of established pastures (both native and introduced).

Methods

Site description

The demonstration site is located at "Carinya", Laggan NSW. The local topography is gently undulating, elevated terrain with broad ridgelines and long gently to moderately graded hillslopes (5–8%), draining to shallow depressions and drainage lines. Altitude at the demonstration site ranges from 976 m to 1008 m. Long-term average median rainfall is 868 mm with slight winter dominance (Crookwell Post Office; Bureau of Meteorology weather station 070025).

The pasture is a dense native-based perennial grass pasture with Weeping Grass (*Microlaena stipoides*) and Wallaby Grass (*Austrodanthonia* spp.) being the dominant species. The pasture also contains subterranean clover (*Trifolium* subterraneumn), native/naturalised legume species and annual grasses.

The soil is an acidic, brown Kurosol (Australian Soil Classification). Soil texture changes with depth, with a grey brown silty loam 'A Horizon' (0–25 cm) sitting over a moderately structured light clay subsoil. Soil pH in the top 10 cm is 4.0–4.1 ($CaCl_2$) with exchangeable aluminium (Al) at 40 % of Cation Exchange Capacity. Deeper soil testing at the site shows that Al % increases to 50–66 % at 20 cm.

Prior to the demonstration the site had not received any form of fertiliser for at least 13 years. Baseline soil testing showed Colwell P levels sitting around 10 mg/kg and a Phosphorus Buffering Index (PBI) between 110–120 (Table 1).

Design, treatments and sampling

During 2014 a paddock at "Carinya" was sub-divided to create three paddocks, each approximately 7 hectares in size. A reticulation system was installed to provide water to all three paddocks via troughs and baseline soil sampling was carried out.

Lime was surface applied as a one-off application (2.5 t/ha) in January 2015 and superphosphate was also applied to create the following treatments:

- Paddock 1: Lime + Single superphosphate (L+S)
- Paddock 2: Control (Cont)
- Paddock 3: Single superphosphate (SS)

In January 2015, 125 Merino wethers were weighed and randomly allocated across the three treatments. Treatments are continuously grazed by Merino wethers to simplify management. Wethers are weighed every 4–6 weeks and stocking rate is adjusted so that a similar average body weight and wool characteristics are maintained across treatments. The financial performance of each treatment is based on wool returns plus meat income when wethers are sold.

Herbage mass (kg DM/ha) measurements are taken at the end of each month using a capacitance probe (Grassmaster II). Average daily pasture consumption rates by livestock for the month are estimated using the GrazFeed decision support tool. Together, these measurements are entered into the fodder budgeting program PRO Plus to calculate average daily pasture growth rates for the month (kg DM/ha/day). A botanical composition analysis is done each spring using the 'Rod Point' technique (Little and Frensham 1993), with 200 observations recorded in each paddock

Annual soil tests are taken in late spring in each paddock along fixed transects to a depth of 10 cm to monitor soil nutrient levels, pH and soil carbon. The movement of surface applied lime down through the soil profile is also measured annually along a set 100 m transect and assessed in incremental segments to a depth of 20 cm. The top 10 cm is cut into four 2.5 cm segments. The remaining 10–20 cm section is cut into 5 cm segments. This sampling procedure is conducted in each of the three paddocks in autumn to monitor changes in pH and Al.

Wethers are shorn annually in December. Un-skirted fleeces from each animal are weighed and fibre diameter is tested on site using Optical Fibre Diameter Analyser (OFDA) technology. Micron and fleece weight measurements are used to calculate an average fleece price for each treatment on a $/head basis using wool prices at the time of shearing (obtained from the

Table 1. Baseline soil test results sampled in December 2014 (0–10 cm) for the three treatments at the Laggan Grazing Demonstration.

Treatment	pH ($CaCl_2$)	Exchangeable Aluminium (%)	PBI (L/kg)	Colwell P (mg/kg)	Sulphur (mg/kg)	Total Carbon (%)
Lime + Super	4.1	38	120	11	5.4	4.7
Control	4.0	38	120	9.4	4.8	5.0
Super	4.0	45	110	8.8	3.7	4.0

Australian Wool Exchange weekly report).

Wethers are weighed upon entry into the grazing demonstration (15–18 months of age) and at the end of each shearing to calculate annual changes in meat value as well as total meat income for the period the wethers are grazing the demonstration.

Results and discussion

Soil nutrients and soil carbon

Despite annual applications of single superphosphate, soil Colwell phosphorus (P) levels in the two fertilised paddocks (L+S and SS) remained static for the first three years (2015–2017) of the demonstration (Figure 1). However, this is not surprising given the modest rates of superphosphate application and the PBI of the soil. It is important to note that during this period the fertilised paddocks were growing more pasture and supporting higher stocking rates. These results suggest that the rates applied were only sufficient to address maintenance P requirements and not enough to build soil Colwell P levels. When using moderate rates of fertiliser, pasture, livestock production and carrying capacity are a better means of assessing the response to fertiliser inputs rather than changes in soil test values.

It wasn't until the end of the 2018 season where a significant rise in soil Colwell P levels were observed. This was driven by an increase in fertiliser application rates and drought. The lack of moisture during a drought heavily restricts pasture growth and nutrients often accumulate in the soil. While this trend can be seen in all treatments, it occurs to a much greater degree in the fertilised paddocks. This seasonal effect can also be seen in the soil sulphur (S) results (Figure 2).

Although the same rates of fertiliser were applied to both the L+S and SS paddocks in the first five years, by the end of 2019 soil Colwell P levels in the SS paddock are much higher than the L+S paddock. This can be explained by the fact that the L+S paddock has consistently grown more pasture and supported a higher stocking rate. As such, more nutrients have been used by the plants for growth, which in turn leads to a lower level of residual nutrients in the soil. This effect can also be seen with S (Figure 2).

Exceptional growing conditions in 2020 saw a significant decline in residual P and S levels in all three paddocks. These nutrients haven't disappeared out of the system, but rather are 'tied up' in undecomposed plant material either standing, on the ground or in root material. This highlights the impact that the season can have on soil test results e.g. elevated readings after a dry period and lower than normal readings following a good season.

Soil test results can vary significantly from year-to-year depending on the amount of fertiliser applied, seasonal conditions and when samples are taken. For these reasons, annual soil testing is recommended to identify trends and check the appropriateness of fertiliser application rates (Simpson *et al*. 2009).

Baseline 0–10 cm soil testing at the end of 2014 showed that total soil carbon levels measured by Dumas combustion were already high at this site, ranging between 4.0–5.0 % (Table 1). After six years of monitoring there is no clear treatment effect on soil carbon levels. The measured changes appear more related to seasonal conditions than treatment (Figure 3). Given the high initial soil carbon levels measured, it is possible that this site is very close to its upper soil carbon threshold. The high starting point also means that modest gains in soil carbon may be difficult to detect.

Soil pH

Soil testing to 20 cm shows that the lime has only had an impact in the top 2.5 cm of soil, lifting pH ($CaCl_2$) from 4.2 to 5.0 (Table 2) and reducing aluminium from 16 % to 0 % (Table 3). This was achieved within the first 16 months of application. Since May 2016 the impact of lime has not progressed any further down the profile.

While the purpose of applying lime is to alter the soil chemistry to a large proportion of the soil, history shows that getting lime into the soil to depth is a major challenge and difficult to predict. Research findings over the last 40 years have ranged from no movement to deep and

Table 2: Impact of lime on soil pH ($CaCl_2$) in the L+S paddock at the Laggan Grazing Demonstration over the period 2014 to 2020.

Depth (cm)	2014	2016	2017	2018	2019	2020
0–2.5	4.2	5.0	5.1	4.9	4.7	4.7
2.5–5	4.1	3.9	4.2	4.1	4.0	4.0
5–7.5	4.0	3.8	4.0	4.0	4.0	4.0
7.5–10	4.0	3.8	4.0	4.0	3.9	3.9
10–15	4.0	3.8	4.0	4.0	4.0	4.0
15–20	4.1	3.8	4.0	4.1	4.0	4.0

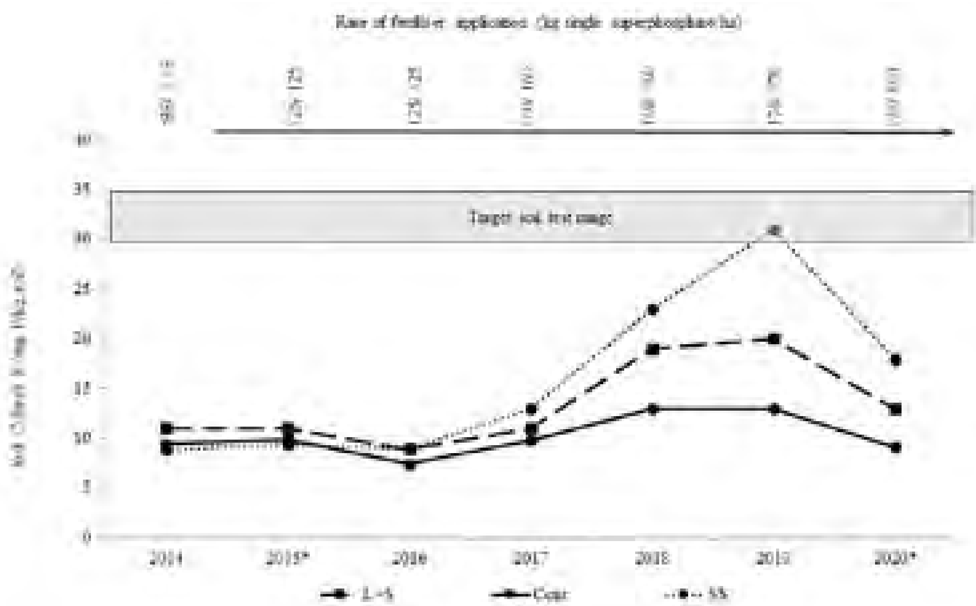

Figure 1: Fertiliser application history and annual soil Colwell P levels on the Laggan Grazing Demonstration for the period 2014 to 2020 (* indicates the years in which superphosphate was applied with molybdenum).

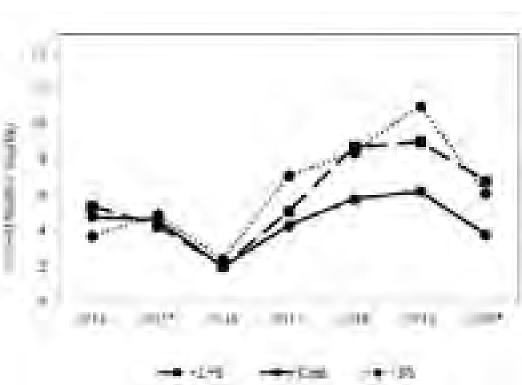

Figure 2: Annual soil S levels (KCl-40) on Laggan Grazing Demonstration from 2014 to 2020.

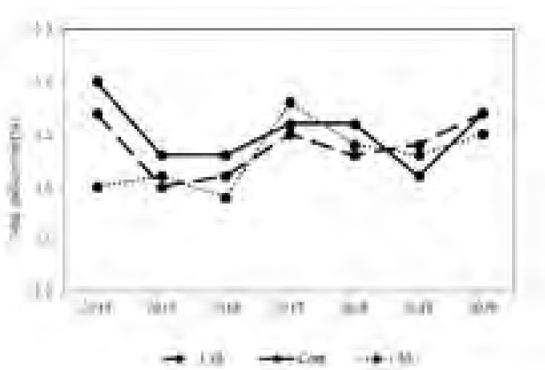

Figure 3: Annual Total Soil Carbon % (Dumas Combustion method) on Laggan Grazing Demonstration from 2014 to 2020.

Table 3: Impact of lime on soil aluminium (Al % of CEC) in the L+S paddock at the Laggan Grazing Demonstration over the period 2014 to 2020.

Depth (cm)	2014	2016	2017	2018	2019	2020
0–2.5	16	0	0	1	3	3
2.5–5	34	29	23	29	25	25
5–7.5	42	41	36	40	39	39
7.5–10	50	48	44	46	42	42
10–15	52	50	50	50	46	46
15–20	55	55	58	52	50	50

rapid penetration into the soil (Scott *et al.* 2000). Local work done on the Southern Tablelands has shown variable results from topdressing lime, with lime movement varying from 5 cm to 20 cm. Several factors influence lime movement, including soil type, soil buffering capacity, the amount of lime applied and rainfall.

The relatively high total soil carbon levels measured (>4.0 % in the 0–10 cm sample) could explain why 2.5 t/ha of lime has not been able to alter soil chemistry below 2.5 cm at this particular site. Higher rates of lime would be required to achieve deeper penetration. A long-term trial at Sutton NSW (on a soil with very similar pH and Al levels) was able to achieve a pH change down to a maximum depth of 17.5 cm (Norton *et al.* 2018), however much higher rates were used (7.72 t/ha).

Pasture production, livestock and economics

The application of fertiliser had an immediate impact, with the fertilised paddocks growing more pasture and sustaining higher stocking rates than the Control (Table 4). Over the first 6 years, stocking rates have averaged:

- Control: 4.6 wethers/ha
- SS: 6.6 wethers/ha
- L+S: 7.5 wethers/ha

These results show that when P and S is applied at this site, stocking rates on average have increased by 2 wethers/ha above the Control (Control 4.6 wethers/ha cf. SS 6.6 wethers/ha). The surface application of lime at 2.5 t/ha has increased stocking rate by a further 0.9 wethers/ha above the SS treatment. The biggest increase in livestock production has come from addressing both P and S deficiencies, with lime lifting production to a lesser degree. It is worth noting that the L+S paddock has a slight easterly aspect which could be providing some advantage over the SS and Control paddocks which both have a slight westerly aspect). Further work is required to verify the true production advantage that has been observed as a result of topdressing lime at this site. A small plot trial at the site prior to the start of the grazing demonstration did not show a visual response in pasture production to the application of 2.5 t/ha of surface applied lime.

Higher stocking rates have resulted in the fertilised paddocks (SS and L+S) cutting more wool per hectare. When averaged over the six years, annual wool production has increased from 16.9 kg/ha (clean) in the Control paddock to 24.7 kg/ha in the SS paddock and 29.3 kg/ha in the L+S paddock. Higher stocking rates in the fertilised paddocks also generated more meat income per hectare.

An economic comparison shows that SS has on average increased net profit by $99/ha above the Control. The L+S treatment has increased net profit to a far greater extent, boosting returns by $181 /ha (Table 4). While the difference in stocking rate between the SS and L+S paddock is relatively small (average of 0.9 wethers /ha), the 2015–20 period has coincided with exceptionally strong wool and mutton markets. When markets are favourable, small increases in carrying capacity can make a big difference to the bottom line.

The increase in stocking rate and economic return in the fertilised paddocks has been a result of both increased pasture growth (Figure 4) and pasture quality. As expected, the application of P immediately stimulated the legume component in the fertilised paddocks, especially in the L+S treatment. This was particularly evident in 2018 and 2019 where the L+S paddock recorded 45–49 % legume in spring. This was more than double the amount of legume recorded in the SS paddock (19–20 %). As a further comparison in 2018 and 2019, the Control paddock recorded 3–7 % legume in spring. Legume has performed poorly in the Control paddock due to low soil fertility (Table 5). It is important to note that legume must be present in the pasture in order to achieve a production response to P. This site had some background legume within the pasture which quickly responded when P (and S) was applied.

At this particular site the surface application of lime appears to have had a positive effect on the presence of legume in the pasture (Table 5) and its performance, despite the lime only having an impact on the top 2.5 cm of soil (Table 2). A replicated experiment at Sutton NSW on a soil with similar pH and aluminium levels also measured a legume response to surface applied lime (Norton *et al.* 2020), although noting much higher rates of lime were used.

A review by Scott *et al.* (2000) highlights that pasture yield response to lime is highly variable and hard to predict. Some studies have reported no measurable yield increase while others have reported large increases in response to lime. It is worth noting the majority of pasture research over the years involving lime has been done on introduced perennial pastures (e.g. lucerne, phalaris and cocksfoot) and the lime has been incorporated via cultivation.

Table 4: Livestock and economic data comparison across treatments (averaged annual results over period 2015–2020) at Laggan Grazing Demonstration.

	L+S	Cont	SS
Wethers/ha	7.5	4.6	6.6
Wool cut (kg wool/ha, clean)	29.3	16.9	24.7
Wool income ($/ha/yr)	533	316	453
Meat income ($/ha/yr)	200	86	149
Total income ($/ha/yr)	732	402	602
Total costs ($/ha/yr)	245	96	197
Profit ($/ha/yr)	487	306	405
Difference to control ($/ha profit/yr)	+ 181		+ 99

Table 5: Botanical composition of the L+S, SS and Control treatments at the Laggan Grazing Demonstration. Numbers indicate the average percentage of each species in the sward for the first six years (2015–2020).

Species	L+S	Cont	SS
Microlaena	28	47	37
Wallaby grass	13	21	15
Annual grasses	7	3	5
Legumes	37	7	23
Weeds	4	3	2
Bare ground	3	7	7
Litter	9	13	13

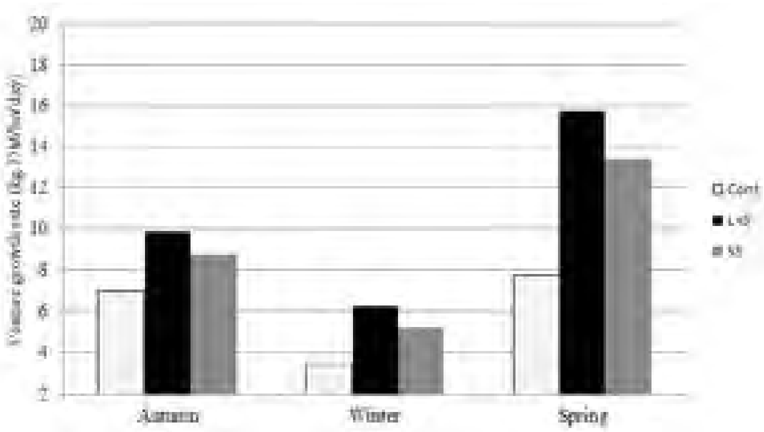

Figure 4: Average pasture growth rates (kg/ha/day) in Autumn, Winter and Spring for the L+S, SS and Control treatments measured over the period 2015–2020 on the Laggan Grazing Demonstration.

While few studies have investigated the impact of topdressing lime on native perennial grass-based pastures (Scott *et al.* 2000), a long-term grazing demonstration at Binalong NSW reported an average increase of 2.4 wethers/ha in response to surface applied lime, applied as a one-off application at 2.5 t/ha (Leech 2006). At the time of the Binalong demonstration (1999–2004) the data suggested that liming native based perennial pastures in the Yass district was – a secondary economic benefit with the largest gains in stocking rate being achieved by addressing key soil nutrient constraints i.e. P, S, Molybdenum.

In contrast, this demonstration shows a strong economic advantage of liming which is being driven by high commodity prices. Livestock returns have improved dramatically since the early 2000s, with gross margins currently sitting around $60/DSE compared with $16/DSE in 2007, representing an increase of 284%. In the same period the cost of applying lime has only increased by 21% (Francis 2021). The cost to apply lime in this demonstration ($200/ha) was annualised over a 10-year period which equates to $24/ha/yr (assuming an interest rate of 6%). With current commodity prices and high returns for livestock the data shows that small increases in production from lime are likely to be profitable. However, any potential benefit from adding lime will only be realised if major nutrient deficiencies are addressed (Peoples *et al.* 1995).

Annual monitoring of pasture composition shows that all three paddocks have maintained a very strong native perennial grass base. This is despite three drought years (2017–2019) occurring during the first 6 years (2015–2020). Pasture stability is just as important as any production increase. Native pasture species have adapted to shallow acidic soils and maintaining their presence across the landscape is important. Sowing introduced pasture species into these soils is expensive and successful establishment comes with considerable risk. Persistence of these introduced species can also be variable.

Conclusions

A grazing demonstration was established in the Crookwell NSW region to measure the production increase and economic advantage of applying fertiliser and lime to a native pasture of low fertility.

The native pastures at this site responded to the addition of fertiliser (P &S), and in particular the legume component. While the increase in pasture production is evident across all seasons, the additional growth in autumn and winter is of greatest value as this is the period of minimum feed availability and sets the annual stocking rate (Scott *et al.* 2000).

As with any pasture improvement strategy, in order to realise an economic advantage, stocking rate must be increased to utilise the extra pasture grown. Data collected from the first six years of the demonstration showed that when P and S is applied at this site, average stocking rates can be increased by two wethers/ha, or 143%. This increase in stocking rate translated into more wool and meat produced per hectare, lifting profitability by almost $100/ha/year.

While the benefits of surface applied lime in undisturbed soils have seldom been demonstrated, at this site lime appears to have had a positive effect on pasture production, especially the legume component. As a result, lime has increased stocking rate by 0.9 wethers/ha and overall profitability by $82/ha above the fertiliser only treatment (SS). With current commodity prices and high returns for livestock the data shows that small increases in production from lime are likely to be profitable. However, applying lime is still a considerable up-front cost to the producer and any potential benefit will only be realised if major nutrient deficiencies are addressed.

Acknowledgments

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Getting started on the pasture pathway

B St Clair

"Oakey Range", Biala NSW, 2581: bella@oakeyrange.com.au

Abstract: *There are many pathways to productive pastures. Each pathway depends on a number of intersecting parameters such as history of the property, topography, soil type, climatic conditions and livestock choices. Most importantly the pathway to achieving productive pastures depends on where you want to go. This presentation offers an example of the beginning steps taken on the journey. It describes the importance of learning, observing and making informed decisions.*

Keywords: Small farm, weeds, beginning steps, goats, Southern Tablelands

Introduction

My partner Catherine Fox and I purchased the rundown former sheep property in 2015 with the intention of providing a home for our thoroughbred brood mares and retired racehorses. Over six years we have had a lot to learn and the farm is being transformed to a productive operation. We now run angora goats including a breeding programme for Australian Heritage Angoras, Murray Grey cattle and horses. This paper outlines our journey on the pathway to productive pastures.

Farm Description

Oakey Range is located at Biala (-34.59061192911227, 149.26326501522942) about halfway between Gunning and Crookwell in the Southern Tablelands of NSW. The 350 acres (141 hectares) consists of a hilly landscape with numerous granite outcrops. Prior to purchase, the farm had been destocked but as it had been overgrazed, the pastures were weedy and the fences were in poor condition.

Soils and landscape

Oakey range is situated at an elevation of 700 metres. The soil is mostly granite with some alluvial creek flats.

Soil tests taken in 2018 and 2020 show that most paddocks are deficient in phosphorus and sulphur. The pH is mostly favourable with aluminium levels below 5%. The North Facing Hill paddock is a favourite stock camp and has reasonably high fertility compared to the rest of the property (Table 1).

Climate

The average rainfall for Biala is 700 mm but from 2017–19, the district experienced severe drought conditions. Since February 2020 rainfall has been above average with 890 mm recorded last year. (Bureau Meteorology Station Number 070111). Oakey Range experiences typical tableland temperatures with very cold winters and warm to hot summers.

Livestock

The property runs a commercial mixed livestock operation consisting of 200 commercial Angora goats and 60 head of Murray Grey cattle. In addition, the property is the major centre for a conservation breeding program of Australian Heritage Angoras. We also have five horses.

Pastures

The property consists of mostly native pastures typical of the Southern Tablelands, Wallaby Grass, Redgrass and Weeping Grass. Sub clover has been introduced to the native grass.

Weeds

Prior to our purchase the property had been over grazed by sheep then was destocked for several years. This provided a competitive advantage for a variety of weeds including Scotch and saffron thistle, cape weed, English broom, Briar rose and blackberries. There was also a moderate amount of serrated tussock but a high-risk level of incursion from neighbouring properties. Despite aerial spraying, weeds were still a problem. Strategic grazing using our goats have brought most of the weeds under control.

Our Pathway

We had a lot to learn. We were not farmers and had very little experience with pastures.

The learning curve has been steep and we take advantage of as many training opportunities as possible. We have participated in Prograze and have attended various short courses and field days including the NSW Grassland Society Pasture Update and Spring Pasture Walk. We find the Small Farm Network and LLS provide some very useful training opportunities.

As the property was so run down, we have had to implement an infrastructure replacement plan. We have built new goat and cattle yards and upgraded the shearing shed. The boundary fences have been replaced and a laneway system to facilitate stock movement has been installed. Internal fences have been upgraded to improve rotational grazing.

Some tree plantings have been undertaken, especially on our boundaries. We are hoping this will reduce the number of weed seeds been blown through the fence.

The next step

The water infrastructure on Oakey Range is very poor. The stock water is provided from two creeks. This has proven to be inadequate, especially through periods of below average rainfall. We are planning to build a large dam and reticulate water to the paddocks. Once we can improve the water supply, we plan to further sub divide some paddocks to improve grazing management.

Soil fertility needs to be addressed. Superphosphate application seems to be the obvious choice of fertiliser as the main deficiencies are phosphorus and sulphur and the easiest to spread on our hilly and rocky terrain.

We would like to include more trees for environmental plantings. Also, we are interested in the role of fodder and browse trees, such as tagasaste, for the goats. As we are bringing the weeds under control, we need to provide more browse for the goats. They have very poor immunity to intestinal worms so forcing them to graze the pasture can create health problems (Love and Greentree 2017).

Conclusions

Here are the three key messages for those starting out on the pathway

- Take the time to understand your environment (each property is different). Work with/ in harmony with your landscape (don't impose your will on it)
- Educate yourself first and foremost. Seek advice but don't follow blindly.
- It's ok to work at your pace. Not all pathways have to be an expressway.

Acknowledgements

Sincere thanks to Helena Warren and Rod Hoare. Their guidance, knowledge and conversations have been invaluable in helping take the first steps in understanding.

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Table 1. Soil test results from various paddocks at Oakey Range in 2018 and 2020

Test	Units	P-Highlands (2020)	Wise tree (2020)	Flats (2018)	Persia (2020)	North Hill (2018)	Maestro (2020)
pH (caci)		5.0	4.9	5.2	4.8	6.0	4.9
Phosphorus (Colwell)	mg/kg	6.3	5.8	15	9.8	56	7.8
Sulphur (KCl40)	mg/kg	<2	<2	2.5	<2	4.3	<2
SOC	%	1.9	1.7	1.6	2.0	2.6	2.2
Potassium	cmol(+)/kg	0.52	0.35	0.58	0.5	1.3	0.5
CEC	cmol(+)/kg	4.1	3.03	7.4	3.9	12	5.5
Aluminium	% CEC	4.0	3.0	N/A	4.0	N/A	3.0

Understanding and managing soil acidity – the key to sustainable and productive grazing systems

HM Burns[A], JR Condon[AB] and GD Li[A]

[A]NSW Department of Primary Industries, Wagga Wagga, NSW 2650: helen.burns@dpi.nsw.gov.au
[B]Charles Sturt University, Wagga Wagga, NSW 2678

Abstract: *The extent and severity of acidic soils in southern NSW is underestimated and much of the on-farm investment in acid soil management focuses on ameliorating existing acid soil problems. Current acid soil management practices are based on guidelines developed for less productive, traditional farming systems. They commonly involve 0–10 cm soil sampling to measure soil pH and exchangeable aluminium, often in response to plants exhibiting acid soil toxicity symptoms. The survey results showed that 39% of sites should be prioritised for liming, based on pH of 0–10 cm soil samples. This percentage increases to 78% when pH was measured in 5 cm increments to 20 cm and the same liming decision framework applied. Finer sampling identifies the depth and severity of acidity in subsurface layers, which better informs liming decisions, species selection and the role for acid tolerant species. Appropriate lime rates, applied at regular intervals, with incorporation when possible, should be able to gradually ameliorate soil acidity at 10–20 cm. There are production and environmental consequences in failing to address soil pH of soils until plants exhibit symptoms of 'acid soil problems'. The highly productive soils, normally with high acidification rates, should be prioritised for early intervention to prevent subsurface acidification. Effective acid soil management programs involving periodic sampling in 5 cm increments enable monitoring of impact of amelioration efforts, calculation of acidification rates and assessment of the effectiveness of acidic soil management efforts: crucial information to develop proactive, long-term management strategies relevant to production and sustainability goals.*

Key words: acidification, stratification, 5 cm increments, monitoring, agroecosystem.

Introduction

Soil acidity is recognized as a major agricultural and environmental problem, which affects more than 50% of agricultural land of central and southern NSW (Cregan *et al.* 1998; Scott et al. 2000; Li *et al.* 2019). A survey conducted in 1997–2003 on commercial paddocks in the medium and high rainfall zones (AAR 500–900 mm) indicated that soil pH (measured in 0.01M $CaCl_2$, pH_{Ca} hereafter) was below 5.0 for about 85% of sites in the 0–10 cm and 10–20 cm sampling depths (Scott *et al.* 2007). Many soils of these regions are strongly weathered and inherently acidic, and furthermore agricultural activities have accelerated acidification (Cregan *et al.* 1998). The optimal soil pH_{Ca} for growth of most plants is between 5.5 and 7.5. Changes in soil chemistry and biology when pH is outside this range adversely impact soil and plant processes resulting in reduced growth and yield (Slattery *et al.* 1999).

Industry focuses on ameliorating soils with an 'existing acidity problem'. Liming activities are commonly initiated in response to soil pH tests from samples collected from the 0–10 cm soil layer and/or when plants exhibit recognised clinical symptoms that are typical of low pH_{Ca} and aluminium toxicity. These symptoms include reduced growth rate, stunted root systems and poor nodulation in legumes, or manganese toxicity in broad leaf plants. However, the health and growth rate of plants can be affected once pH_{Ca} falls below 5.2 before these symptoms begin to be expressed (Cregan & Scott 1998). Subclinical symptoms such as limited root hair development, restricted rooting depth and reduced plant vigour are difficult to detect but were reported in pulse, canola and wheat crops growing in soils with acidic subsurface layers in recent studies (Burns *et al.* 2017; Burns & Norton 2018b; Condon *et al.* 2020). These studies highlighted the prevalence of stratified soil pH profiles and acidic subsurface layers between depth of 5–15 cm, including in some of the most productive soils of south-eastern Australia, although many have a long history of lime application.

The frequency that subsurface acidity is detected in actively managed agricultural land raises concerns about the effectiveness of current acid soil management practices in ameliorating soil acidity and preventing subsurface acidification. Furthermore, it should be noted that soil acidity was the only indicator of soil condition reported to be worsening in the latest NSW State of Environment report (SOE, 2018). This is despite continued increase in the amount of lime used by agriculture to the point where supply was unable to meet demand in 2020–21.

In this paper we present a proactive approach to managing soil acidity and discuss the need for attention to the environmental consequences of acidification in the development of long-term acid soil management strategies. We present soil pH profiles from soils collected from actively managed commercial paddocks in central and southern NSW between 2016 to 2020 and compare experiences of current acid soil management programs with revised management strategies, based on 5 cm sampling increments to a depth of 20 cm. The role for judicious monitoring and early intervention to prevent subsurface acidification in productive soils currently free of clinical acid soil problems is also discussed.

The environmental consequences of soil acidity

Cregan and Scott (1998) highlighted deficiencies in evaluating the influence of soil acidity in a wider farming system/agroecosystem context. They proposed that the effect of soil acidity on plant growth impacts on 'a spectrum of changes with major agricultural and environmental consequences', including reduced yields and microbial activity, failed pasture establishment, colonization of grasslands by acid-tolerant species, loss of ground cover leading to erosion and loss of organic matter, reduced water use, waterlogging, rising watertables, salinisation, eutrophication and reduced stream and groundwater quality.

Low soil pH_{Ca} (<4.8) is associated with modification of biological populations and decreased activity of some microorganisms, such as nitrifiers (Slattery *et al.* 1999). Increasing soil pH of an acidic soil improves microbial activity (Holland *et al.* 2018), although increased activity may also be in response to concurrent improved plant growth. For example, poor nodulation of legumes at low pH is frequently attributed to a negative impact on rhizobia survival and activity. However, the development of functional nodules and nitrogen fixation is also dependent on root development and vigorous growth of the host plant, which is also negatively impact by low pH (Munns 1986; Burns & Norton 2018b).

Severe acidity (pH_{Ca} <4.5) contributes to the breakdown of clay minerals in the soil via dissolution weathering. This coincides with increasing concentrations of soluble forms of aluminium and manganese in the soil solution and leaching of cations such as calcium, magnesium and potassium further down the soil profile (Slattery *et al.* 1999). Breakdown of clay minerals at below pH_{Ca} ~4 is permanent and results in irreversible soil degradation (Kwamee *et al.* 2013).

Holland *et al.* (2018) suggested that agriculture has changed focus from one solely of production to include maintenance of a healthy environment and consideration of the soil's ability to deliver ecosystem services such as nutrient cycling and carbon sequestration. The challenge is to translate the focus into management practices that effectively manage soil acidity. The current environmental report card (SoE 2018) indicates a proactive approach to acid soil management is needed:

> *"On a statewide level, the increasing acidification of agricultural soils due to the intensification of land use continues to be the land degradation issue that contributes most to ongoing declines in soil condition and productivity across NSW"*

(The State of the Environment Report 2018).

Soil acidity in agricultural systems

Soil pH is the principal driver for lime application. The pH scale is used to quantify soil acidity, measuring the negative log concentration of hydrogen ions (H+) in the soil solution on a scale from 1 to 14. The lower the pH the more acidic the soil, with pH_{Ca} of 7 being neutral and becoming more alkali as pH increases. It is a negative logarithmic scale, which means that a small decrease in pH is equates to a large increase in acidity. For example, soil with a pH_{Ca} of 4 is 10 times more acidic than pH_{Ca} of 5 and 100 times more acidic than pH_{Ca} 6. Soil pH is measured either in water or weak calcium chloride solution, the latter providing results that better reflect the conditions experienced in the soil solution by roots and microbes.

Soil pH values usually refer to acidity measurements of soil samples collected from a sampling depth of 0–10 cm. However, as approximately 80% of the root system of annual species is concentrated in the 0–20 cm surface layer (Hamblin& Tennant 1987), the pH of 0–10 cm samples do not accurately describe the soil environment experienced by the majority of plant roots.

The negative impact of soil acidity on agricultural production is generally well understood, limiting crop yield and species options. Application of fine-grade, high quality lime is the practical and widely adopted method of ameliorating acidity and eliminating toxicity symptoms in plants grown on acidic soils in NSW. Liming activities are usually triggered when pH_{Ca} of 0–10 cm soil samples are <4.8 and lime application rates are generally calculated to achieve a target pH_{Ca} 5.0–5.2 (Condon *et al.* 2020). The rationale for these pH values was based on the inverse relationship between low soil pH and toxic aluminium concentrations in the soil solution (Scott *et al.* 2007; Andersson and Orgill 2018) and the assumption that Alex will be maintained below toxic concentrations if lime application occurs to ensure pH_{Ca} remains above 4.8.

Upjohn *et al.* (2005) advised that liming to achieve a pH_{Ca} target of 5.2 in the 0–10 cm soil depth 'will remove most of the problems associated with an acidic soil'. However, in soils with acidity to depth they recommended higher initial lime application rates and a liming regime to maintain pH_{Ca} ≥5.5 in the 0–10 cm depth and gradually increase pH in the 10–20 cm layer, as reported by Li *et al.* (2019). In the late 1990s relatively very high interest rates, low land and commodity prices meant that treatment of subsurface acidification was not considered economically viable (Cregan & Scott 1998). Consequently, the focus was on increased production on lime-responsive sites and rapid return on lime investments, and so the lower target of pH_{Ca} 5.2 was adopted and remains standard practice, irrespective of depth of acidic layers. Minimal investment in acid soil research since the early 2000s has meant that the effectiveness of the acid soil management practices implemented on farm has not been monitored.

Despite intensification of farming systems, low interest rates, favourable commodity prices and large increases in land prices, the current guidelines are outdated and have not been revised for contemporary farming systems. Lime rates of up to 2–2.5 t lime/ha have produced acceptable yields from wheat, canola and lucerne in soils that would have otherwise been too acidic. Producers' soil test results from 0–10 cm sampling depths indicate that traditional practices are successfully maintaining soil pH_{Ca} in industry's aspirational range of 4.8–5.2. However, recent studies have highlighted that this approach to acid soil management has not addressed acidity further down the profile. The amount of lime applied has been insufficient to amend existing acid soil problems below 5 cm and subsurface layers have been acidified (Scott *et al.* 2007; Norton *et al.* 2018; Li *et al.* 2019).

Condon *et al.* (2020) proposed an increase in the soil pH thresholds to trigger liming. The plant and soil function and production potential would be already compromised if lime application is delayed until pH and exchangeable aluminium reach plant critical values, or plants show deficiency or toxicity symptoms associated with soil acidity. They also advocated an increase in pH targets after liming, in order to ameliorate or prevent subsurface acidification, based on field studies by Conyers & Scott (1989) and Li *et al.* (2019). These studies demonstrated movement of alkali from dissolved lime, below the depth of placement when soil pH_{Ca} was maintained above 5.5. An example of the benefit of this practice change has been demonstrated at the long-term field experiment near Book

Book, NSW, where a 'vigorous liming regime' that maintained pH_{Ca} ≥5.5 in the 0–10 cm depth prevented further acidification in the subsurface layers and increased soil pH in the 10–20 cm layer by more than 0.9 units over 18 years (Li *et al*. 2019).

Surveys of commercial paddocks in central and southern NSW identified that most soils exhibited stratified soil pH profiles, with elevated pH in the surface 0–5 cm layer but reduced pH at 5–15 cm (Scott *et al*. 2017; Burns & Norton 2018a). Subsurface acidity is not detected from soil samples collected at traditional sampling depths of 0–10 cm. Finer sampling at increments of 5 cm is necessary to identify the depth and severity of acidity in the subsurface layers. This detailed information is particularly important in guiding liming decisions and species selection, including the role for acid tolerant species (Scott *et al*. 2000).

Methods

Soil samples were collected from 104 sites between 2016 and 2020 from near Albury NSW in the south (35°49'16"S, 148°05'03"E) to near Molong NSW in the north (32°55'27"E, 148°56'26"S) within the medium to high rainfall zone (annual average rainfall 500–900 mm). The paddocks sampled represent productive, actively managed land supporting perennial pastures and/or crops in the mixed farming systems. Acid soil management practices varied between sites from nil liming history to those with up to 4 lime applications over about 30 years, at various rates but commonly at 2–2.5 t/ha of fine grade lime.

Soil samples were taken in 2.5 cm increments to a depth of 15 cm, then from 15–20 cm and 20–30 cm layers at 63 sites, and in 5 cm increments to a depth of 20 cm at the other 41 sites. At each site, soil was collected using 25 mm diameter cores at 20 random locations, composited to designated depths from an area of approximately 100 m^2. Soil pH_{Ca} was measured according to the method used by Rayment & Lyons (2010). The pH of the samples for the 63 sites collected in 2.5 cm increments was averaged to provide mean soil pH for 0–5 cm, 5–10 cm and 10–15 cm layers as a comparison with those on the remaining 41 sites. The pH of the 0–5 and 5–10 cm layers was then averaged to provide an estimated mean of soil pH for the 0–10 cm layer for each site to mimic the current soil sampling regime.

Results and discussion

Soil types of the sites sampled include Yellow, Red and Brown Chromosols, Kandosols and Dermosols with an effective cation exchange capacity (ECEC) of ~4 to ~14 cmol (+)/kg in the 0–10 cm sample (Isbell 1996).

The dataset with 104 sites was firstly grouped based on soil pH from 0–10 cm soil samples depth to simulate current acid soil management practice used by most producers (i.e.:<4.5; 4.5–5.2; and >5.2); then re-grouped based on soil pH_{Ca} of samples collected in 5 cm increments to a depth of 20 cm and presented with a revised liming guideline for acid soil management practice in modern farming systems.

Current liming practice (C): a reactive approach to managing soil acidity

Currently, lime application is triggered when pH_{Ca} decreases to about 4.8, with lime rates targeting pH_{Ca} 5.2 (Helen Burns, unpublished survey data). The presumption is that by maintaining pH_{Ca} of 0–10 cm soil samples between 4.8–5.2, concentrations of toxic forms of aluminium will be kept below critical values for most commercial crop and pasture species. Based on these criteria, Group C1 (n=41 sites), which includes only 39% of the 104 sites, had a critical value pH_{Ca} <4.8 in 0–10 cm (mean pH_{Ca} 4.5 + 0.2) and so were likely to be prioritised for liming, particularly those scheduled to be sown to acid-sensitive crops. Twenty-eight percent (28%) of sites (Group C2: n=29) with pH_{Ca} 4.8–5.2 in 0–10 cm (mean pH_{Ca} 5.0 + 0.1) were marginal for lime application. Acid soil management programs for these would depend on the rotation, the acid-sensitivity of species to be sown and the producers' approach to managing soil acidity.

The remaining 33% of sites (Group C3: n=34) had pH_{Ca} > 5.2 in 0–10 cm (mean pH_{Ca} 5.6 + 0.4). These sites either had inherently high soil pH, in which case it may be assumed that they had no existing acid soil problems, or alternatively they had recently received a significant lime application and acidity in the 0–10 cm surface soil was being effectively managed. Future soil testing would likely be sporadic for Group C3 sites. A 2012 survey indicated that 93% of livestock producers used soil testing but only 18% of these tested their most productive paddocks (Helen Burns, unpublished data).

Under current acid soil management programs, about 2.0 t/ha of lime would be surface applied to sites represented by the mean pH_{Ca} in Group C1. This would increase pH_{Ca} of the 0–10 cm layer from 4.5 to ~5.2, assuming an ECEC of 5 cmol (+)/kg (Upjohn *et al.* 2005). At the next soil testing cycle, commonly at 6 yearly intervals, it is expected that the pH_{Ca} in 0–10 cm would be maintained within the aspirational range of 4.8–5.2. However, although the surface-lime applied provides enough alkali to neutralise acidity at 0–10 cm, there is no guarantee that pH throughout the 0–10cm depth would reach the target pH 4.8–5.2, due to slow lime movement, and is unlikely to influence pH further down the profile (Scott *et al.* 2007).

Maintaining 0–10 cm pH_{Ca} ~4.8–5.2 is common practice among producers operating on the acidic soils of south-eastern Australia (Helen Burns, unpublished survey data), which is only a reasonable short-term approach for soils with pH_{Ca} >5.0 below 10 cm. Numerous studies caution that the likely outcome is elevated pH in the shallow surface layer and further acidification in subsurface layers below 5 cm (Li *et al.* 2019; Burns & Norton 2018a; Norton *et al.* 2018; Scott *et al.* 2017). If this is not addressed, the long-term impact will be loss of agricultural production, reduced biodiversity and diminishing ecological services in farming systems as the depth and severity of soil acidity in the subsurface layers increases. The outcome will be irreversible soil degradation, with crop and pasture options ultimately being limited to acid-tolerant species (Crawford *et al.* 2006). It is essential that these soils are monitored for declining pH in subsurface layers and liming actioned early to reduce risk of subsurface acidification and associated incremental loss of production.

The sites in Groups C2 and C3 are typical of acidic soils that support the most productive farming systems of the targeted area, including Dermosols, Kandosols and Chromosols. The averaged pH of 0–10 cm suggest that these sites are free of acid soil problems. However, if pH stratification is considered there are likely to be soils within these groups with severely acidic subsurface layers (i.e. pH_{Ca} < 4.5). Therefore, production response to lime application on these soils depends on the acid sensitivity of species sown and the depth and magnitude of acidity in subsurface layers (Burns & Norton 2018b), which is not revealed by soil pH of samples collected from 0–10cm.

Revised liming regime (R): a proactive approach to managing soil acidity

The revised liming regime is based on soil sampling in 5 cm intervals, which provides detail essential for development of acid soil management programs that will effectively: (i) ameliorate existing acidic subsurface layers; or and (ii) halt the development of subsurface acidity.

The dataset from those 104 sites were re-grouped into 5 groups as described below and reported in Table 1.

- Group R1: pH_{Ca} <4.8 throughout profile; indicative of inherently acidic soils with limited liming history.
- Group R2: pH_{Ca} <4.8 in layers within 5–20 cm depth; mean pH_{Ca} <5.5 in 0–10 cm depth. Elevated pH in 0–5 cm layer with acidic subsurface layers.
- Group R3: pH_{Ca} <4.8 in layers within 5–20 cm depth; mean pH_{Ca} >5.5 in 0–10 cm depth. Elevated pH in 0–10 cm layer overlying acidic layers.
- Group R4: pH_{Ca} <4.8 layers within 0–10 cm depth; pH_{Ca} > 5.0 in layers within 10–20 cm.
- Group R5: pH_{Ca} 5.0–5.5 within 5–20 cm subsurface layers; increasing with depth at most sites.

Based on revised liming guideline, 87% of sites (Groups R1, R2 and R3) have soil pH_{Ca} <4.8 in subsurface layers (below 5 cm), in which 78% of sites should be prioritised for lime application whereas 9% of site in Group R3 do not require additional lime at present as the mean pH_{Ca} within the 0–10 cm depth is >5.5 (Table 1). Applying lime to the revised target of pH_{Ca} > 5.5 within 0–10 cm will enable pH increases in the 10–20 cm layer over time to an aspirational target of pH_{Ca} >5.0 for the 10–15 and 15–20 cm layers. Only 13% of sites in Groups R4 and R5 have pH_{Ca} >5.0 in these layers.

Table 1. The mean soil pH_{Ca} in 5 cm increments (sampled or calculated from 2.5 cm increment soil samples) at 104 field sites from central and southern NSW, grouped according to mean pHCa of 0–5, 5–10, 10–15 and 15–20 cm layers and the location of acidic layers. Numbers in brackets are standard deviations from the means.

Depth (cm)	Group R1 (n=31)	Group R2 (n=50)	Group R3 (n=9)	Group R4 (n=5)	Group R5 (n=9)
0–5 cm	4.6 (0.2)	5.5 (0.4)	6.2 (0.2)	5.1 (0.2)	5.6 (0.6)
5–10 cm	4.3 (0.2)	4.6 (0.2)	5.4 (0.4)	4.8 (0.2)	5.3 (0.4)
10–15 cm	4.4 (0.2)	4.5 (0.2)	4.7 (0.2)	5.3 (0.2)	5.4 (0.2)
15–20 cm	4.6 (0.3)	4.7 (0.3)	4.7 (0.4)	5.6 (0.3)	5.5 (0.4)

Revised acid soil management guideline

The revised approach to acid soil management we propose requires a considerable shift in mindset. A comparison between the current approach and the changed management proposed is listed in Table 2.

Ameliorating soils with existing subsurface acidity. The pH profile of Group R1 sites is typical of soils with acidity to depth, making up 30% of all sites. There were sites within this group with no history of lime application, while others have received sporadic applications over a long period. In contrast, the pH profile of Group R2 sites (48%), with intense stratification and elevated pH in the surface layer is typical of highly productive soils supporting intensive crop and crop/livestock operations within the

Table 2. Traditional approaches to acid soil management need updating to mitigate and prevent soil acidification in modern farming systems.

Current/traditional management practices	Changed management proposed
Soil test results (i.e. pH, % Al) from samples collected at traditional sampling depth of 0–10 cm guide the decision to apply lime.	Sample at 5cm intervals to a depth of 20 cm in order to detect the extent and depth of acidic subsurface layers. Subsurface acidity is not detected by 0–10 cm soil samples.
Lime* application is triggered when 0–10 cm soil pH_{Ca} is between 4.5–4.8 or when exchangeable aluminium approaches 5%. This prioritises lime application on about 39% of commercial paddocks surveyed in southern slopes and tableland of NSW that are constrained by acidic subsurface layers.	Increase the critical pH that triggers lime application (pH_{Ca} 5.5). Monitor pH of all soils; don't ignore the most productive soils, which are at high risk of acidification. Implement amelioration efforts before subsurface pH reaches critical levels and plants show toxicity symptoms and suffer production loss.
The amount of lime applied is enough to raise pH in the 0–10 cm layer to about 5.2, i.e. sufficient to reduce % Alex to non-toxic levels.	If subsurface acidity is detected, apply enough lime to increase 0–10 cm pH_{Ca} above 5.5. This will neutralise acidity in the surface soil and the lime benefit will gradually move down the profile and increase subsurface pH.
Re-liming intervals are sporadic, guided by crop toxicity symptoms, soil test results or cropping/pasture programs.	Monitor soil pH. If the aim is to increase subsurface pH, maintain 0–10 cm soil pH_{Ca} above 5.5 and relime before subsurface pH declines.
Lime is surface applied and only incorporated by sowing.	Strategic tillage to incorporate lime speeds up the lime reaction and increases the lime effect to the depth of cultivation.
Lime is applied immediately before sowing sensitive species	Delay sowing acid-sensitive species for at least 18 months after lime application to allow time for the lime to react and raise pH.

*NOTE: Reference to liming material assumes the material is fine-grade, high quality lime with neutralising value (NV) > 95 and fine particle (90% passes through a 150 µm sieve).

medium and high rainfall zones. The Group R2 sites had received up to 4 applications of surface-applied lime since the late 1980s, using the traditional target pH_{Ca} of 5.0–5.2. Despite this long history of lime application, the frequency and rates of lime applied was insufficient to prevent subsurface acidification.

Producers with soils represented by Groups R1 and R2 need to adopt very different strategies to ameliorate subsurface acidity. Sites in both groups should be prioritised for lime application, with a revised target pH_{Ca} >5.5 within the 0–10 cm depth. Monitoring these sites and maintaining pH_{Ca} >5.5 will ensure alkali movement and gradual increase in pH below 10 cm (Norton *et al.* 2018; Li *et al.* 2019; Condon et al. 2020).

Although Group R3 sites (9%) were acidic to depth, elevated pH_{Ca} >5.5 to a depth of 10 cm indicates recent applications of relatively high rates of lime. To prevent further decline in subsurface pH, these sites should also be monitored closely to ensure timely lime application to maintain pH_{Ca} above 5.5 in the 0–10 cm layer.

Preventing subsurface acidification. The pH profiles of sites within groups R4 and R5 were typical of highly productive soils of the survey area, with high pH buffering capacity and soil pH within the range suitable for most crops. However, they made up only 13% of sites surveyed. Being highly productive these would also have the highest acidification rates, so must not be ignored in acid soil management programs.

The pH profile of Group R4 sites indicated formation of an acid throttle. The 5–10 cm layer was the most acidic, with pH_{Ca} ranging from 4.6 to 4.9 at various sites. While most commonly grown crops did not display acid toxicity symptoms, reduced root growth in barley and poor root development and nodulation in acid-sensitive legume species was reported at some sites. Such soils exemplified the case for early intervention, particularly if lime incorporation is not an option. Large quantities of lime and considerable time will be required to ameliorate acidic subsurface layers if they form in these soils with high pH buffering capacity. For example, as pH refers to H+ concentration on a logarithmic scale, 1 t lime/ha applied at pH_{Ca} 5.0 increases pH much more than that same quantity of lime applied at pH_{Ca} 4.5. If untreated, subsurface acidification would continue, acidity would move further down the profile and the opportunity for successful and affordable management of subsurface acidity would be missed.

The sites within group R5 (9 sites) are slightly acidic with pH_{Ca} above the aspirational target of 5.0 throughout the profile. However, individual sites have stratified pH profiles, with the 5–10 cm layer the most acidic, as low as pH_{Ca} 5.0 on several sites. Monitoring and early intervention aimed at arresting subsurface acidification is also relevant to these sites.

Monitoring is an essential component of effective acid soil management. A framework that enables monitoring of soil pH change at the paddock or soil zone scale is necessary to measure in paddock acidification rates, assess the effectiveness of acidic soil management efforts and confidently develop proactive, long-term management strategies relevant to producers. An effective monitoring framework includes establishment of geo-located sites on soil types representative of agricultural systems, recording baseline soil data in 5 cm increments and monitoring pH change with periodic soil sampling, e.g. re-testing pH profiles at 3 to 5 year intervals, depending on soil pH buffering capacity and production system (Burns & Norton 2018b).

In collaboration with project partners, Grassland Society of NSW and Holbrook Landcare Network, 60 monitor sites have been established in the central and southern slopes and tablelands of NSW. They represent soil types and management systems typical of mixed farming and perennial pasture systems. Over time, information collected from these sites will inform the response of pH change to management, the rate and depth of acidification, and provide growers and advisors with the confidence to adjust lime rates, re-liming intervals and implement more aggressive programs, such as strategic cultivation to enhance lime incorporation (Crawford et al. 2006; Burns & Norton 2018b).

Conclusions

Our current management of acid soils such as soil sampling in 0–10 cm intervals and generic rules of thumb that inform many liming decisions are proving to be ineffective in addressing subsurface acidity. Reported worsening of the condition of agricultural soils is supported by surveys of commercial paddocks, which show intense pH stratification and subsurface acidity in 87% of sites.

There is a need for producers and advisors to make a mindset shift from treating acid soils to preventing acidification of agricultural soils; a move from reactive to proactive land management. Soil sampling in 5 cm intervals in the surface 20 cm enables the depth and magnitude of acidic subsurface layers to be identified and monitored. This information can then be used to formulate liming strategies; decisions of rate, application method and paddock prioritisation are able to be tactically made. Initiating lime application before acidity develops to an extent that impacts plant function, to when pH_{Ca} is around 5.5 results in greater efficiency of lime application to change pH and facilitates movement of the liming effect to deeper in the soil. These changes represent an effective method of treating and addressing the formation of acidic subsurface layers. The challenge for producers is to prioritise and customise acid soil management actions to achieve medium and long-term production targets and environmental management goals.

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Soil Fertility – You can't manage what you don't measure

HM Warren[A] and AP Britton[B]

[A]Cadfor, Binda, NSW 2583: helena@cadfor.com.au

[B]South East Local Land Services, Berry, NSW 2535

Abstract: *The pH of many southern NSW soils under pastures has been reducing slowly due to nitrate leaching due to the addition of sub clover and increased product removal. Also, since the 1990s the amount of fertiliser applied to grazing pastures has declined. 252 soil samples from the South Coast, Southern Highlands and Southern Tablelands of NSW were tested for* pH_{cacl}*, Colwell phosphorus, sulphur (KCl40) and exchangeable potassium. The Southern Tablelands had the most soils with below optimum levels of pH (61%), phosphorus (56%), sulphur (65%) and potassium (33%). On the other hand, some of the South Coast and Southern Highlands soils had test levels in excess of the desirable amount (22% of phosphorus, 7% of sulphur and 26% of potassium tests). Farmers should be encouraged to regularly monitor their soils and apply adequate quantities of fertiliser to suit their enterprise.*

Key words: soil sampling, interpreting soil tests, soil nutrients, fertiliser

Introduction

Taking measurements and record keeping is not something new to farmers. The most commonly asked question after a rainfall event is "how much rain did you get?" Farmers will discuss calving and lambing percentages, weaning weights, numbers of wool or hay bales produced, recent prices at the sales yards. However, many farmers do not appear to have the skills to be able to match soil fertility to pasture production and animal needs. Farmers may not ask for help until there is an obvious problem with a pasture, their livestock or farm profitability. Since the introduction of sub clover and superphosphate in the 1920s (Bayley 1951), pH declines in the order of 5.2 to 4.2 over 50 years in soils in the Southern Tablelands have been recorded (Williams 1980). This has resulted in poor nodulation due to unsuitable pH for ryzobia, which has subsequently led to reduced pasture production and reduced survival of legumes (Hackney *et al* 2017, Norton *et al* 2019).

In addition, fertiliser use has been declining in the region, with many farms having no fertiliser applied for decades (Johnson 2012). Burns *et al.* (2014) reported a national downward trend in fertiliser application to pastures since the late 1990s except in the dairy industry. It was also reported that the majority of livestock producers from the wider population are making fertiliser decisions in the absence of soil test information. Problems caused by deficiencies as well as some complex interactions between nutrients are being recorded. This year producers in the Central and Southern tablelands experienced cattle losses due to grass tetany, a disorder that can be caused by an imbalance of potassium and magnesium in pastures (Watt 2021). Johnson and Watt (2011) reported phosphorus deficiency in cattle and Johnson (2012) investigated lameness and ill thrift in sheep grazing unfertilised, phosphorus deficient pastures in the Central and Southern Tablelands.

There are many tests available to provide information on the physical, structural and chemical properties of soils. These tests and the recommendations made from them have been developed following many decades of research. However, some farmers do not trust the results. In a survey conducted by Burns *et al* (2014) it was reported that 16% of the respondents "lacked confidence in the accuracy of soil tests".

Other forms of monitoring pastures and soils can be implemented. Soil pH test kits, nutrient budgets, fertiliser test strips or window plots and visual observations can all guide fertiliser use in the absence of soil tests. It should also be noted that relying on any of these techniques without soil testing may not provide reliable information to guide fertiliser use.

This paper investigates the degree and extent of low pH and nutrient deficiencies and excesses in soils that have resulted from the change of use of fertiliser and categorises the results from soil samples taken from the high rainfall zone (above 650mm) of eastern New South Wales. The suggested criteria for optimum, deficient and excessive nutrient levels are taken from the NSW DPI booklet *Fertilisers for Pastures* (Havilah *et al.* 2006) and as described by Gourley *et al.* (2019). I will also discuss the importance of nitrogen in pastures and how to reduce the impact of nitrate leaching on pH decline in soils.

Methods

Results from 252 soil tests from surface (0–10 cm) soils from farms in the South Coast (n=131), Southern Highlands (n=64) and Southern Tablelands (n=57) were evaluated. Samples are from various sources including natural resource management projects and private clients. There were a large variety of farms represented in this survey covering properties running a variety of livestock (sheep, cattle, goats and horses) and sizes from small holdings to large sheep, dairy and beef properties.

The soil samples were analysed at NATA accredited laboratories (NSW Department Primary Industries, Wollongbar or Nutrient Advantage, Werribee) measuring pH (1:5 Ca_{Cl}) and available nutrients phosphorus (Colwell), sulphur (KCl40) and potassium (exchangeable cation).

Results

pH

Table 1 shows the trend for a low pH is evident in the soils in the Southern Tablelands with 37% of samples having pH values below 4.5 compared to 7% on the South Coast and 16% in the Southern Highlands. The lowest value for pH in this data set was 4.0 for the Tablelands and Highlands soils and 4.4 on the coast. Only 8%, 5% and 16% of samples tested in the South Coast, Southern Highlands and Southern Tablelands respectively had pH values above 5.5.

Phosphorus (Colwell)

The proportion of soil tests with phosphorus results below the optimum level for pasture production is high for all regions (Table 2). The South Coast, Southern Highlands and Southern Tablelands recorded 42%, 34% and 56% of samples with a Colwell Phosphorus result below 30 mg P/ha. The lowest value measured in this study was less than 5 mg P/ha.

High phosphorus use was evident on the South Coast and Southern Highlands with 22 % of samples exceeding 100 mg P/kg. Of these, five samples on the South Coast and four in the Southern Highlands exceeded 300 mg P/ha. Only 2% of samples in the Southern Tablelands exceeded 100 mg P/ha, the highest value was 110 mg P/ha.

Sulphur

The proportion of tests with extractable sulphur levels below 5 mg S/kg were 6%, 19% and 37% for the samples in the South Coast, Southern Highlands and Southern Tablelands respectively. A further 28% of samples in the three regions had results between 5.1 and 8 mg S/kg with these soils requiring some input of a sulphur fertiliser (Table 3).

There were some extremely high (>100 mg S/kg) results from the South Coast which could indicate acid sulphate soils may be present deeper in the soil profile.

Potassium

Table 4 shows that one third of the soils tested in the Southern Tablelands were below the optimum level of 0.3 cmol (+) K/kg. Five percent of coastal soils and nine percent of soils in the Southern Highlands were found to have results below optimum.

A large proportion of soils had excessive potassium levels. On the South Coast 20% and the Southern Highlands 26% of soils had results above 1 cmol (+)/kg, with results as high as 3.4.

Discussion

Soil testing is a valuable tool to better manage pastures for the grazing industries. Farmers can be confident that the results from a soil test are accurate, as long as the soil used for testing is representative of the soil in their paddock. Samples taken accurately to 10 cm, while avoiding potential hotspots (camps, manure, around gates and water troughs and old fertiliser stockpiles) and tested at a NATA accredited laboratory, will provide an accurate measure of the nutrient levels in soil.

Interpretation of soil tests can be confusing for most land holders. Natural resource management courses such as Landscan and Five Easy Steps have been operating since the early 2000s. These courses have been designed to train farmers to interpret soil test and match soil fertility to production outcomes. These courses have had a positive response from farmers with many indicating they will change their fertiliser program in the future (Leech *et al.* 2021).

Once a nutrient deficiency is identified, the amount of fertiliser needed to raise the fertility of the soil to an optimum level can be calculated. Considerations such as cost, livestock and environmental safety, ease of application, availability of equipment or environmental limitations should be taken into account when choosing the product or products to be applied.

Application rates will depend on the properties of the soil (eg phosphorus buffer index or texture) or the intensity of the enterprise. The advice is usually based on bringing the soil fertility to the optimum level for almost maximum production of fertility responsive pasture species. However, these recommendations may not always suit the desired outcome. Pastures based on fertility-intolerant species such as Themeda triandra have a lower fertility requirement than improved pastures (Mitchell 2019). A low input, low output system may suit some farmers but this could lead to nutrient deficiencies in their livestock, so monitoring soil nutrient status should remain a priority.

Correcting pH requires the application of a liming product such as superfine lime. The amount will depend on soil texture. To raise the pH from 4.2 to 5.2, a light sandy soil requires 1.5 tonnes of lime / ha but a heavy clay will require 4 tonnes/ha to achieve the same outcome. Other products such as dolomite or sewage ash will also raise the pH of a soil.

Table 1: Frequency distribution and range of soil pH_{cacl} across different districts

	Soil pH_{cacl}					
District	**<4.5**	**4.5–4.8**	**4.9–5.1**	**5.2–5.4**	**>5.5**	**Range**
South Coast	7	33	34	18	8	4.0–6.2
Southern Highlands	16	38	36	20	5	4.4–5.6
Southern Tablelands	36	25	14	9	16	4.0–6.3

Table 2: Frequency distribution and range of Colwell Phosphorus across different districts

	Phosphorus (Colwell) **mg/kg**				
District	**<30**	**30–50**	**51–100**	**>100**	**Range**
South Coast	42	22	14	22	5.0–380
Southern Highlands	34	25	19	22	6.7–440
Southern Tablelands	56	25	17	2	7.8–110

Table 3: Frequency distribution and range of sulphur across different districts

	Sulphur (KCl40) **mg/kg**					
District	**<5**	**5–8**	**8.1–12**	**13–60**	**>60**	**Range**
South Coast	6	28	35	24	7	2.6–470
Southern Highlands	19	28	31	22	0	2.8–39
Southern Tablelands	37	28	19	16	0	2.5–23

Table 4: Frequency distribution and range of exchangeable potassium across different districts

	Extractable Potassium cmol(+)/kg					
District	**<0.2**	**0.2–0.3**	**0.31–0.6**	**0.61–1**	**>1**	**Range**
South Coast	1	5	47	27	20	0.18–2.8
Southern Highlands	2	7	41	24	26	0.18–3.4
Southern Tablelands	12	21	42	23	2	0.12–1.3

Nitrogen is one of the most important nutrients for pasture production but surface soil tests for are a poor indicator of nitrate levels. To avoid nitrogen being leached below the root zone, nitrogenous fertilisers need to be applied to moist soils to pastures that are actively growing.

There are three key strategies to ensure that pastures are supplied with nitrogen:

- No fertiliser, relying on pasture nitrogen being supplied from legumes. This method is suitable for low to moderate stocking rates.
- High fertiliser, used for high stocking rates such as dairy farms. Nitrogen is applied after every grazing or every second grazing while pasture is growing. This strategy is also useful if legume populations are low.
- Strategic fertiliser nitrogen use relies on pasture nitrogen being supplied from adequate legume populations when the soil temperature is above 10°C at 10 cm depth but fertiliser nitrogen is applied to fill short term feed gaps when the soil temperature is between 5 to 10°C.

Clover can contribute about 150 kg N/ha per year (Brogden and Miller 2017) if the soil has a pH is suitable for the rhizobia population and essential nutrients are in adequate quantities (Hackney *et al.* 2017). If choosing the high or strategic use of nitrogen fertiliser, it is important not to exceed 40 kg N/ha in each application, except when using an organic form of fertiliser, which releases nitrogen more slowly into the soil.

Nitrogen from fertilisers and clovers has an acidifying affect on soils, so monitoring soil pH is essential. Some nitrogenous fertilisers, such as ammonium sulphate and mono-ammonium phosphate (MAP), are more acidifying than others, for example urea and poultry litter, so this should be considered when choosing a fertiliser.

The optimum level of Colwell phosphorus is between 30 to 50 mg P / ha but this depends on the phosphorus buffer index (PBI) of the soil. Levels as high as 70 may be more suitable for very high production from nitrogen fertilised, irrigated soils. To correct soils deficient in phosphorus, application rates for soils with a PBI between 50 and 300 require about 20–40 kg P/ha to raise the Colwell test value by 10 units, which is equivalent to 230–460 kg superphosphate/ha.

Excessive phosphorus fertiliser application was evident in 22% of paddocks in the South Coast and Southern Highlands with values as high as 440 mg/kg Colwell P. These pastures do not require further phosphorus fertiliser until soil test levels drop to the optimum level.

The optimum result for the sulphur KCL40 soil test is between 8–12 mg S/kg, however a response to additional sulphur may not be evident if the result is between 5 to 8. More than 50% of paddocks tested in the Southern Tablelands were deficient in sulphur. These low sulphur levels appear to be linked to the reduction in the use of fertilisers containing sulphur, especially superphosphate. The application of 15 kg sulphur/ha is required on a sandy loam soil with an extractable sulphur (KCl40) test result less than 5 mg/kg, while 10 kg S/ha is required if the test is between 5 to 10 mg S/kg. Superphosphate applied at 145 kg/ha or 100 kg/ha gypsum will supply 15 kg S/ha.

Coastal soils with sulphur levels exceeding 100 mg/kg may require additional testing to determine if acid sulphate material is present. It is advisable to seek specialist advice when excessive sulphur is identified.

Soils most likely to be deficient in potassium are sandy and light textured and low in organic matter. A surprisingly high proportion of soils reported here were low in potassium. Removing product such as wool, hay or silage and the relocation of dung and urine to stock camps from the more productive parts of a paddock are all responsible for reducing potassium levels in soils.

An application of 60 kg of muriate of potash to a non-irrigated pasture is required to correct the deficiency of a soil with an exchangeable potassium soil test result below 0.2 cmol (+) /kg. Higher application rates are required for irrigated lucerne and dairy pastures and following hay and fodder conservation.

About one quarter of soils tested in the South Coast and Southern Highlands had high levels of potassium. Most of these came from dairies or former dairies in paddocks where animals have been yarded or following the use of dairy effluent and reclaimed sewage water. High potassium levels in pastures can cause animal health issues such as grass tetany and milk fever. Harvesting hay or silage will reduce soil potassium levels but monitoring potassium levels is essential if choosing this strategy.

To reduce the risk of high uptake of potassium by pastures and associated health disorders, avoid applying potassium fertilisers in early spring and at calving in seasonal herds. Split autumn and late spring applications are recommended in high rainfall areas or when high rates are applied. For best results apply potassium fertilisers to moist soils.

Conclusions

If graziers accurately sample their soils and monitor its fertility by regular testing, they will be able to apply the correct amount of fertiliser for their enterprise. This will have many benefits to productivity, animal health and the environment. Natural resource management programs such as the Landscan and Five Easy Steps program and more recently the Better Land Management Practices project are a valuable source of training for landholders to gain soil test interpretation skills. Farmers need to have confidence that consultants and resellers are providing accurate and relevant advice and recommend cost effective products that will provide the correct amount of nutrient to soils.

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Rejuvenation of run-down perennial pastures

FJ Leech[A] and RB Garnsey[B]

[A]South East Local Land Services, Yass, NSW 2582: fiona.leech@lls.nsw.gov.au
[B]Roger Garnsey Agronomy Pty Ltd, Canberra, ACT 2615: roger@rogergarnseyagronomy.com.au

Abstract: *Persistence of productive, high quality perennial pastures remains one of the greater challenges in our grazing systems. Pasture decline can be the result of several causal factors, including overgrazing, lack of soil fertility, drought or poor species selection. An assessment of existing pastures is required before embarking on any renovation program, to determine the most appropriate course of action. In many cases, complete pasture re-sowing is not required and less expensive pasture manipulation techniques can be used to rejuvenate these paddocks into highly productive perennial pastures. Techniques including non-sowing management options as well as over-sowing of existing stands are discussed in detail.*

Key words: degraded, management, over-sowing.

Introduction

Run-down perennial pastures lead to lower productivity usually as a result of a low proportion of desirable species. Perennial pastures, both introduced and native, can become degraded for various reasons including, overgrazing, lack of fertility, drought and inappropriate choice of species at sowing. The cost to establish new pastures is significant and can be in excess of $450/ha. With variable seasons and market fluctuations, often it can be difficult to recoup these costs within a reasonable time frame (Leech *et al.* 2009). It is not uncommon to find it may take at least 7 years to get a return on investment when establishing new pastures and if one or more seasons are very dry the payback period will be even longer. The decision to either replace or attempt pasture species manipulation or rejuvenation should involve (Leech *et al.* 2009):

- assessment of the current species present;
- understanding the contribution of each species to the pasture system and their agronomic requirements;
- understanding techniques available to manipulate pastures; and
- development and implementation of a plan to progress pasture composition to more desirable species.

A summary of pasture assessment strategies and pasture manipulation techniques are discussed including both non-sowing management options as well as over-sowing an existing run-down pasture.

Assessing the pasture

Don't be too quick to condemn an existing run-down pasture. Before commencing any program to rejuvenate a degraded perennial pastures, it is important to consider the following questions (Leech *et al.* 2009):

- Why has the pasture degraded?
- How much of the paddock has degraded?
- What is the proportion or percentage of desirable pasture species still present?
  - if perennial cover is limited (<5 perennial plants/m^2) consider re-sowing pasture;
  - if >5 perennial plants/m^2, consider techniques to thicken pasture. This would be species specific.
  - Note these figures are only a guide and not based on field research.
- What other issues (e.g. pest animal grazing, weeds, ground cover and erosion) need to be managed? If aggressive weeds (e.g. serrated tussock, fireweed, African lovegrass, Paterson's curse, vulpia) are present there may be no choice but to clean the paddock up by cropping for a few years to deplete weed seed banks, followed then by re-sowing of a new pasture. If kangaroo numbers are high an exclusion fence may need to be erected as the first part of the plan.

Addressing these questions will help to decide the state of the existing perennial pasture and whether action is required to rejuvenate or improve the pasture.

There are many factors that can lead to pasture degradation and lower productivity but some of the more common ones include declining soil fertility levels, overgrazing, drought, limited soil depth, harsh aspect, inappropriate species choice at sowing, pest damage and weed invasion. If strategies are taken to thicken-up a run-down pasture it is important that future management be aimed at maintaining the improved pasture and recognise this may require a change in management (Leech *et al*. 2009).

Key factors in assessing run-down pastures include:

- Determining species composition: learn to identify/recognise the species present and their contribution to the production system during the year;
- Consideration of ground cover throughout the year;
- Determining pasture variability across the paddock due to aspect, changes in soil type, wet gullies, uneven grazing and competition from weeds. This will help to decide if it is best to treat the paddock as a whole or in sections. Re-fencing of the paddock maybe a consideration;
- How does the paddock fit within the system? Is it used for lambing due to location? Is it part of a bigger grazing rotation? Does it help provide winter feed for ewe carrying capacity or summer feed for finishing?
- If there are large areas of degraded pasture, is it more economic to run less stock but not have the expense of pasture sowing?
- Soil testing: phosphorus (P) and sulphur (S) are key drivers of productivity in grazing systems. If P and S levels are low these nutrients may need addressing as a priority. Soil pH must also be monitored and attention given to increasing soil pH where more acid sensitive species are present or are to be sown.
- Can it be just as productive as an annual species dominant pasture for the current enterprises?
- Prioritise works: it is rarely possible to achieve perfect pastures in every paddock.
- Mapping and colour coding different treatment areas may be an important part of your plan.

Methods to improve pasture composition

Various techniques can be employed to improve the composition of desirable pasture species and the resulting productivity. Often simple and less expensive non-sowing management options can be very successful. Where there is more severe pasture degradation, over-sowing and introducing new species into the existing pasture may be a better option.

1. Non-sowing management options

Non-sowing management options can take several years to achieve a significant change in pasture composition, but they may prove to be the most cost-effective. It is important to recognise that often several options may be required to sufficiently improve pasture composition and productivity in order to avoid the need for costly pasture re-sowing (Leech *et al*. 2009). The following discussion highlights the key non-sowing management options available.

Herbicides

- *Selective spraying* to kill specific broadleaf or grass weeds to reduce competition and allow the desirable species to grow and dominate the pasture (e.g. the technique of 'winter cleaning' with simazine to remove some annual grasses and spraying broadleaf weeds with selective herbicides).
- *Spray grazing* involves the selective removal of broadleaf weeds using sub-lethal rates of hormone herbicides combined with heavy grazing (sheep only, using at least double normal stocking rates). This technique results in no permanent damage to established pasture legume, has no effect on grasses and is inexpensive due to the use of low rates of herbicide.
- *Spray topping* involves the application of low rates of specific herbicides (e.g. glyphosate or paraquat) applied after head emergence of the annual grass weeds and some other broadleaf weeds, e.g. capeweed. This technique prevents the formation of viable seed and reduces

the density of the weeds in question in the following years.

Fertiliser

- Fertilising to address key nutrient deficiencies will help desirable pasture species to remain productive. Under low fertility, useful pasture species tend to decline, and low production weed species (e.g. vulpia, flatweed, sorrel) can invade and dominate.
- Deficiencies of nitrogen (N), phosphorous (P), sulphur (S) and molybdenum (Mo) are common in many pastures. A healthy legume component in the pasture is crucial to improve feed quality and to provide nitrogen to the grass component. Legumes have a higher requirement for P, S and Mo than grasses and without legumes grasses will require N fertilisers to persist and produce.

Grazing Management

Strategic grazing can be used to manipulate the pasture to favour the persistence and productivity of the desirable species. This involves a combination of spelling and hard grazing where the timing of rest or heavy grazing must coincide with particular stages of plant growth. Following are some examples of strategic grazing management techniques:

- Heavy grazing of annual grass and broadleaf weeds at flowering time can be used to reduce the seed set of these less desirable species.
- Some native perennial grass pastures need to be grazed reasonably hard in spring to reduce annual grasses and broadleaf species from shading and outcompeting the desirable natives, e.g. redgrass and wallaby grass.
- In paddocks with large amounts of dry matter present, heavy grazing in summer is useful to reduce the bulk, in preparation for allowing pastures to respond to an autumn break. It can also be useful to heavily graze some paddocks in late winter/early spring to avoid excess biomass accumulation, especially where it is logistically difficult to graze down prior to autumn, e.g. paddocks that have no secure water over summer;
- Spelling or light grazing of a pasture can allow desirable plants to set seed for recruitment, e.g. ryegrass/cocksfoot in late spring and most native grasses in late spring/summer.
- For temperate pastures (e.g. cocksfoot) that have been allowed to seed in spring, a heavy autumn grazing may help recruitment of useful species by reducing trash and trampling seeds into the ground. It is important to note that allowing new seedlings to successfully establish after germination will require a spell from grazing, particularly with sheep.
- Continuous vs rotational grazing: continuous grazing over an extended period of time may damage some desirable species in the paddock (e.g. perennial ryegrass and lucerne), compared to rotational grazing (particularly at higher stocking rates).
- During extended dry conditions, drought lot feeding is a useful tool to spell and preserve desirable perennial pastures.

In run-down pastures a combination of grazing management techniques can often be used to successfully increase the perennial pasture species population. There is no one size fits all, but an example of a grazing plan is as follows:

- Rotational grazing from autumn through to late winter, involving a resting period of 10-12 weeks between grazing events, will allow perennial plants to recover and accumulate leaf area/root reserves;
- Following the above with conservative set stocking in early spring/summer to encourage good seed set of the perennial plants.

An example of how grazing management can affect pasture density was shown by Ward (2008) on a Gunnedah property where pasture decline was a key issue during the late 1990's. A change in grazing management from set stocking to rotational grazing in 1998 resulted in a decrease in the amount of bare ground from 85% in January 1998 to 15% by March 2006. Plants of all types increased ground cover from 3% to 57%, and the average distance between perennial plants decreased from 37 cm in 1998 to 3 cm in 2006 (Figure 1). This was despite some very dry periods where the farm received around half its average annual rainfall in 1999, 2000 and 2002 (average rainfall was 500–600 mm and summer dominant). Initially paddocks were dominated by tap-rooted weeds, such as saffron thistle and poppies, but this gradually changed over time with more grasses dominating the sward.

2. Over-sowing new species into an existing pasture

Sowing new pasture species into an existing pasture is termed over-sowing and can be an effective tool to thicken-up degraded pastures. This over-sowing method is non-destructive to the existing pasture sward and may be considered when there is an insufficient quantity of legume or when levels of desirable perennial pasture species are low and require topping up (Leech *et al*. 2009). Note that in heavily degraded perennial pastures i.e. nil or minimal desirable perennial species left, it is advised that a complete re-sowing of new pasture should occur. Complete re-sowing of new pastures is expensive and may take the paddock out of production for 12–18 months to ensure good establishment of the newly sown species. Over-sowing strategies can range from relatively cheap (e.g. broadcasting legume seed) to almost as expensive as complete re-sowing (e.g. removing weeds and direct drilling perennial grasses).

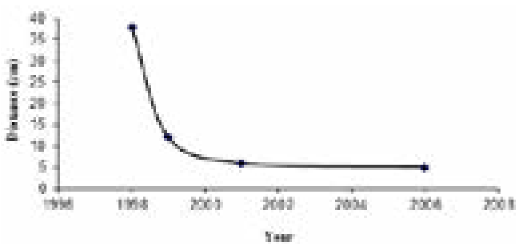
In any pasture establishment program there can be a high level of risk involved. Success will depend on many factors such as rainfall, stored soil moisture, weed competition, suitability of pasture species being sown and the time of year. Each of these factors should be considered to give some context as to where and under what circumstances this strategy will work and allow for an economic comparison of options (Leech *et al*. 2009). The 'NSW DPI Eight Steps to Successful Perennial Pasture Establishment' (Ayres *et al*. 2016) is a useful guide to follow when over-sowing into an existing pasture to help minimise risk factors. These steps are outlined as follows:

1. *Assess, select and plan early (1–2 years before)*: Assess existing pasture, weeds, pests and soil fertility.
2. *Control of weed and pests in planning years*: Prevent weeds and pests from seeding/reproducing.
3. *Pre-sowing activities*: Remove excess plant material before sowing.
4. *Absolute weed and pest control*: Allow full weed germination after rain then graze to keep weeds small until moisture in the profile is right for sowing. Use appropriate herbicides just prior to sowing to control all grass and broadleaf weeds present.
5. *Adequate soil moisture*: Temperate species: do not dry sow – ensure a moist profile from the surface to 200 mm. Tropical species: ensure 1 m stored soil moisture and soil temperature >18°C at 9 am for 3 consecutive days.
6. *Accurate seed placement*: Aim for 5 mm of tilth over the seed. Direct drill rule of thumb: 5% of seed and/or fertiliser still visible in the furrow.
7. *Monitor weeds and pests*: Look for pests and weed seedlings every 10–14 days after sowing.
8. *Grazing*: Temperate species – do not graze unless plants are well anchored, soil is moist and plant height is a minimum of 150 mm. Preferably graze with younger stock. Tropical species – do not graze until plants have seeded down.

The following are some examples of the range of over-sowing techniques used in NSW.

- Addition of legume seed by broadcasting or direct drilling lime pelleted, inoculated legume seed into a native or legume deficient perennial grass dominant pasture. In most situations a lower establishment can result from broadcasting legume seed compared to drilling the seed into the soil.
- Using an appropriate herbicide and rate to selectively remove unwanted species or retard useful pastures and direct drilling new species

Figure 1. Effect of rotational grazing on perennial plant survival and density. Distance (cm) between perennial plants along a permanent transect on the property "Glenbrae", Gunnedah, NSW are shown.



Source: Ward 2008.

into the existing pasture (e.g. paraquat, low rates of glyphosate or a selective herbicide, such as MCPA, 2,4-D or dicamba). Take care not to use residual herbicides such as metsulfuron or dicamba too close to sowing (always refer to herbicide label plant back details).

Over-sowing may involve the whole paddock or may only be required in some parts of the paddock where the useful species have thinned out. Doing only part of the paddock will always be a cheaper option but may require either temporary or permanent re-fencing. This will enable the area not sown to still be grazed while the re-sown area can be established and then managed to prevent the loss of the newly sown species. Grazing of the newly sown pasture should only occur once the plants are sufficiently well established (well anchored) or in some circumstances has set seed. For example, perennial grasses over-sown into existing pasture in late autumn/winter may need to be rested until late summer or the following autumn.

Successes, failures, traps

Be aware that there are no shortcuts when over-sowing pastures. A planned approach is essential for optimum results. There is no set recipe to follow, but some general principles to follow include:

Year 1 – In the year before sowing:

- Contain seed set of annual grasses and broadleaf weeds by using either the winter cleaning (selective herbicides used in winter to kill the annual grasses) or spray topping (herbicides used in spring to sterilise the annual grass seeds) techniques.
- It will be important to control earthmite numbers during establishment of new pasture species. The inclusion of an insecticide in the spring prior to establishment and also in the autumn at sowing is a recommended Integrated Pest Management (IPM) strategy. For the control of red-legged earth mite (RLEM) only it is important that this is done in conjunction with the Timerite® program (Ridsdill-Smith TJ and Pavri 2015).
- Soil test to correct fertility and soil acidity constraints. The 'Five Easy Steps' Phosphorus Tool is a useful resource to help guide graziers on fertiliser management (Simpson *et al. 2009).*

Year 2 – In the year of sowing:

- Wait for the annual weeds to germinate and then spray with either glyphosate or a mix of paraquat/diquat herbicides. The pasture can be grazed prior to spraying. The critical point is to keep annual weeds small to ensure they have a small root system. It is important to leave from 1–2.5 cm height of leaf on plants prior to spraying to allow the applied chemical to work effectively.
- Over-sow with additional perennial grasses/herbs suitable for the pastures intended purpose and soil/climatic constraints.

Year 3 – Maintenance phase:

- Maintain soil fertility by annual topdressing in accordance with soil test results and understanding of key critical soil nutrient thresholds (Simpson *et al.* 2009) and implement grazing strategies for persistence and production. PROGRAZE® offers landholders guidance for best practice management of perennial pastures for sustainable and profitable grazing systems (Graham 2017).

Failures typically occur when short cuts are taken. Each of the above steps is critical to the success of the pasture over-sowing technique. However, if a more opportunistic approach is taken (e.g. no annual grass control in the previous spring), the technique becomes a much riskier strategy. A more opportunistic approach may suffice as a short-term solution for run-down paddocks particularly if sowing species with good seedling vigour (e.g. perennial ryegrass).

Conclusion

Degraded pastures can eventuate for a variety of reasons, including overgrazing, declining soil fertility, drought, or poor species selection. Before embarking on an expensive re-sowing program, always assess the current status of your pasture to determine the best course of action. Once all factors have been considered, implement a planned approach to rejuvenate the pasture for optimum success. Finally, ensure management practices are employed to ensure ongoing survival and persistence of the rejuvenated pasture.

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Managing the establishment of productive perennial pastures

HK Best[A]

[A]AusWest and Stephen Pasture Seeds, Truganina, VIC 3029

Abstract: *The establishment phase of a perennial pasture is when the pasture is the most vulnerable. Farmers are often reluctant to invest in modern perennial pastures due to the perception they do not persist. This paper aims to simplify the decision-making process when deciding which perennial species to plant by outlining the importance of factors such as temperature, annual rainfall, rainfall distribution, soil type and expected insect pressure. It also outlines some of the key steps involved in successfully establishing temperate perennial pasture species such as planning, paddock preparation, sowing depth, soil temperature, insect control, weed control and early grazing technique. After taking note of these important factors, farmers should be able to renew pastures with increased confidence.*

Key words: Temperate grasses, C3 & C4 grasses, species selection, management, grazing, pest control.

Introduction

Temperate Australian grasslands experience a range of conditions that lead to pasture deterioration. These include drought, flooding, pest pressure, over grazing, lack of fertility, acidic soils, and poor grazing management. These all factors lead to a decline in dry matter yield and persistence. Pasture renewal is an important tool that farmers can use to increase the productivity of their farm, however many farmers see this process as a cost rather than an investment for the future. The economic benefits of pasture renewal are well documented (Scott, Lodge, & McCormick, 2000) (Fraser, Moss, Dale, & Knight, 1999) with benefits coming from increased forage yield and improved quality. Modern endophytes (NEA, AR37, Max P) are an example of improvements in modern pastures which provide insect protection whilst minimizing animal health concerns. Traits in legumes such as increased stolon density, grazing tolerance and red legged earth mite tolerance (RLEM) are examples of choices that farmers can make to help increase their profitability.

Degraded pastures in the high rainfall zone can be transformed from a carrying capacity of 6 dry sheep equivalents/ha (DSE/ha) to 20–25 DSE/ha by re-sowing a degraded pasture (reference to removing native pastures excluded because of legal issues (Biodiversity Conservation Act, 2016)) to a high-performance perennial pasture (Malcolm, Smith, & Jacobs, 2014). Personal experience of replacing old degraded pastures with continental tall fescue, cocksfoot and prairie grass (cv. Hummer, Savvy and Atom, respectively) in the New England (NSW) and Southern Tablelands (NSW) has shown this lift on a large scale across multiple sites, despite challenging growing conditions in the previous 5 years.

Despite the benefits on offer from perennial pasture renewal, many farmers view it as too risky. This paper aims to provide insight into key establishment factors, helping farmers minimize the risk associated with establishing perennial pastures.

Discussion

Planning

Underperforming paddocks should be identified 12 to 18 months prior to sowing. Whether pasture decline is due to invasion of undesirable grass species [bent grass (*Agrostis capillaris*), silver grass *(Vulpia* sp), paspalum (*Paspalum dilatatum*) *etc*], too many broadleaf weeds or the sown species don't grow enough forage, the problem needs to be identified.

'Break crops' are an essential tool for pasture renewal as they lengthen the pasture reversion time. Renewing paddocks from an old degraded pasture straight to a perennial pasture rarely succeeds as the original weed species quickly become dominant again (Lane, Addison, & Van Plateringen, 2009), an outcome that is usually very frustrating and costly for farmers. One way to minimise this is to use at least 3 'label rate' glyphosate sprays over a 12-month period, with two of the sprays being in separate autumns. Weed grasses like kikuyu (*Pennisetum* *clandestum*), couch (*Agopyron repens*), bent grass and paspalum are rhizomatous, meaning they have underground stems. The initial glyphosate spray won't kill every plant. Reversion rates back to kikuyu are shown in Table 1 below, paddocks that received 3 glyphosate treatments over 12 months all had significantly less kikuyu reversion in year 3 compared to treatments that had 1 or 2 sprays respectively. A break crop will enable multiple glyphosate sprays, therefore planning and break crops are an essential part of pasture renewal (Lane, Addison, & Van Plateringen, 2009).

Planting Suitable Species

Choosing the correct species for a paddock will have more effect on performance and persistence than cultivar choice. Factors affecting species suitability for any farm include; temperature (both maximum and minimum), total rainfall, rainfall distribution, soil type, expected insect pressure and fertility. If farmers can identify the best species and cultivars to suit their farm system, they should achieve a perennial pasture that will be robust enough to handle their conditions.

Temperature

Temperature regimes affect grasses in different ways, C4 (warm season growth) grasses (e.g. kikuyu and paspalum) start growing around 10°C but optimum growth rates occur near 30°C, whereas C3 (cool season growth) grasses (ryegrass (Lolium perenne), tall fescue (*Festuca arundinacea*), cocksfoot (*Dactyylis glomerate*), phalaris (*Phalaris aquatica*)) start to grow at temperatures around 5°C, reach maximum growth near 18–25°C and will slow down to zero when temperatures reach 27°C–35°C (depending on the species) (Sharpe & Rayburn, 2019). In warmer regions, there may be a benefit from having separate areas of C3 and C4 grasses to complement each otherThey should not be mixed together in a pasture if a long-term perennial pasture is desired. In areas where the day time temperatures get above 35°C degrees and night time temperatures aren't below 20°C perennial ryegrass should not be planted.

Native pastures across temperate NSW differ, the New England is dominated by warm season perennials, due to its 'summer dominant' rainfall pattern which leads to feed deficits in cooler months (Reid, 2017). Southern Tablelands pastures tend to revert to Wallaby grass (*Austrodanthonia* spp.), Microlaena (*Microlaena stipoides*), Red grass (*Bothriochloa macra*), barley grass (*Hordeum leporinum*), silver grass and brome grasses (Clements, *et al.* 2003). Most of these native species will have a short growing window and provide low quality forage throughout the year with limited carrying capacity. For the large parts of the New England, central and southern Tablelands areas in NSW, the limiting temperature for growth is low temperatures from April – September (Clements, *et al.* 2003), which makes pasture species such as cocksfoot, tall fescue, perennial ryegrass, prairie grass and phalaris ideal perennial species.

Rainfall

When deciding between the temperate perennial species above, rainfall and its distribution throughout the year must be considered. Locations where rainfall is distributed through autumn, winter and spring suit species that

Table 1: Kikuyu reinvasion after various glyphosate treatments in Whangarei, Northland NZ (adapted from Lane, Addison and van Planteringen, 2009)

Treatment	No. of sprays	Season of spray	Peak % kikuyu in late summer/autumn		
			2005	2006	2007
1. Kikuyu Pasture	0	-	91	88	88
2. Flat, Perennial ryegrass sown	1	Autumn (A)	13	77	80-90
3. Flat perennial ryegrass sown	2	Spring (S), A	7	43	80-90
4. Flat perennial ryegrass sown	3	A, S, A	0	8	0
5. Hill, perennial ryegrass sown	3	A, S, A	0	2	9
6. Hill, Tall Fescue sown	3	A, S, A	0	17	40

have summer dormancy mechanisms such as phalaris (cv. Holdfast GT, Australian, SF Mate), Hispanica cocksfoot (cv. Uplands) and Mediterranean tall fescue (cv. Flecha and Temora). These species can persist where annual rainfall is as low as 400mm/year (Easton, Lee, & Fitzgerald, 1994). Due to their dormancy mechanism, farmers should not expect growth from these species over summer.

If annual rainfall is above 600 mm with an even distribution throughout the year, continental (summer active) cocksfoot or tall fescue can be used, providing high quality feed throughout the year (Easton, Lee, & Fitzgerald, 1994). When annual rainfall gets above 750 mm per annum perennial ryegrass can be used. Perennial ryegrass is the least robust species due to its sensitivity to high summer temperatures so if true perennialism is required, perennial ryegrass is limited to small geographical pockets in NSW. It can however can provide high quality DM production for 3–5 years in more marginal areas. Sparse sporadic summer rainfall can cause tiller bud dormancy to break in perennial ryegrass which can lead to high plant death rates (Clark, 2011), therefore consistent summer rainfall or irrigation is ideal for persistence. Prairie grass can be used to increase cool season growth of pastures and will persist in 650mm+ rainfall areas, however as it is not a true perennial species, it needs to set seed every 2–3 years to remain persistent over time.

Soil type

If a soil type is not suited to a sown species it will not persist. Drainage, pH, soil fertility and water holding capacity of soil are determining factors for both production and persistence. Both pH and fertility can be altered, however drainage and water holding capacity are more difficult to change. Cocksfoot, phalaris and tall fescue all grow in similar climatic conditions but have very different soil requirements. Tall fescue and phalaris prefer deeper soil types with high water holding capacity as they have extensive root systems that can survive in water logged soils over winter (Easton, Lee, & Fitzgerald, 1994). Cocksfoot will not persist in these waterlogged soils but will perform well in light soil textures with lower water holding capacity (Lolicato & Rumball, 1994). Shallow free draining soil types reduce the advantage given to tall fescue and phalaris, hence cocksfoot will persist and perform better in these environments. Perennial ryegrass can handle a wider range of soil conditions, however it is very prone to pugging damage in waterlogged soil types (Clark, 2011). Perennial ryegrass will also require more frequent rainfall events on light shallow soil types due to the lower water holding capacity. If a paddock has a mixture of soil types (i.e. wet areas and dry areas) consider the drainage conditions that are the most common and plant the species that suit most of the paddock.

Expected insect pressure

The last major consideration to think about is the expected insect pressure throughout the lifetime of the pasture. Root feeding insects like the red and yellow headed cockchafer can cause widespread damage to the root system of shallow rooted species such as perennial ryegrass, so if they are likely to be present, perennial ryegrass will not persist (Berg, Faithful, Powell, & Bruce, 2013). Deeper and stronger rooted species like tall fescue, phalaris and cocksfoot have a higher tolerance to these pests but are still susceptible to damage under high pest loading. Other pasture pests of significance to NSW are pasture mealy bug, root aphid, African black beetle (BB) and Argentine stem weevil (ASW), studies have shown these can negatively affect production and persistence to susceptible cultivars (Kemp, *et al.* 2020).

Modern perennial ryegrass and tall fescue species can be protected by modern novel endophytes such as AR37 and NEA in ryegrass and Max P in tall fescue, which is displayed in Table 2. When perennial ryegrass and continental tall fescue are the appropriate species to plant, choose a cultivar that can be protected by novel endophyte for increased production and persistence.

Companion Species

Perennial pastures need diversity but will typically be dominated by one major species (70% ground cover) a secondary species (20% ground cover) and 2-3 other species (remaining 10%). Legumes are great companion species to a grass sward as they are high quality and can fix their own nitrogen. Legumes will also reach peak growth periods when grasses are slowing down or reducing in quality. Sub clover (*Trifolium subterraneum*), red clover (*Trifolium pratense*), white clover (*Trifolium repens*) and lucerne (*Medicago sativa*) can be used as a secondary component of a pasture mix. Herbs such as plantain (*Plantago lanceolata*) and chicory (*Cichorium intybus*) can also act as a companion species to a perennial pasture mix, they offer similar quality benefits to legumes. Herbs have also been shown to increase pasture utilisation when grazed by cattle due to their inability to selectively graze (Pembleton, *et al.* 2016). These species will persist in combination with the temperate grasses mentioned above. Mediterranean fescue and Hispanic cocksfoot are the exception as their climatic requirements mean that short season sub clover, lucerne and chicory should be considered as companion legumes.

Paddock preparation

Preparing paddocks for planting occurs 12–18 months before the perennial pasture is sown. Using break crops like barley, canola, wheat or a forage crop such as oats, vetch, grazing wheat, forage brassica, chicory, plantain or forage sorghum provides the opportunity to remove perennial weeds. They also provide an alternative source of cash flow or bulk forage to bridge a feed deficit. (Suggested inclusion) The choice of break crop can work against a good outcome if for example species such as forage brassicas, chicory and plantain exclude the use of broadleaf herbicides in-crop to remove weeds. Sowing winter cereals such as wheat, barley and triticale on the other hand increases herbicide options, in particular the use of grass selective pre-emergent herbicides, as well as broadleaf herbicides.

The establishment phase of a perennial pasture is the time when the new pasture plants are at their most vulnerable. The window of ideal germination conditions is often short lived

Table 2: Endophyte insect control ryegrass & continental tall fescue (adapted from NZPBRA, 2020)

Endophyte brand	Argentine stem weevil	Pasture mealy bug	African black beetle	Root aphid	Field cricket
Diploid perennial ryegrass					
AR1	++++	++++	+	–[2]	Not tested
NEA2	+++	(++++)	+++	++	Not tested
NEA4	+++	(++++)	+++	++	Not tested
AR37	++++[1]	++++	+++	++++	Not tested
Standard endophyte	++++	++++	+++	++	Not tested
Without endophyte	–	–	–	–	Not tested
Continental tall fescue					
Max P	Not tested	Not tested	+++	(++++)	Not tested
Without endophyte	–	–	–	–	Not tested

– No control.
+ Low level control: Endophyte may provide a measurable effect but is unlikely to give any practical control.
++ Moderate control: Endophyte may provide some practical protection, with a low to moderate reduction in insect population.
+++ Good control: Endophyte markedly reduces insect damage under low to moderate insect pressures. Damage may still occur when insect pressure is high.
++++ Very good control: Endophyte consistently reduces insect populations and keeps pasture damage to low levels, even under high insect pressure.
( ) Provisional result: Further results needed to support the rating. Testing is ongoing.
1 AR37 endophyte controls Argentine stem weevil larvae, but not adults. While larvae cause most damage to pastures, adults can damage emerging grass seedlings. In Argentine stem weevil prone areas, it is recommended to use treated seed for all cultivars with novel endophyte.
2 AR1 plants are more susceptible to root aphid than plants without endophyte.

in temperate NSW so ground preparation is essential. Sowing depth (discussed below) needs to be precise with pasture species due to their small seed size so paddocks need to be as smooth as possible. If 'no-tillage' planting is desired, the paddock needs to be sprayed out several weeks prior to planting to ensure the current species dies off and the roots of the current plants 'let go' of the soil (root release). If the paddock has been pugged or is uneven it may require cultivation to develop a fine firm seed bed to ensure even seed depth placement.

Planting

Seed depth needs to be accurate with perennial pasture species, their seed size is much smaller than cereal crops like barley and wheat. Tall fescue, ryegrass and plantain are most successful when planted at 15–25 mm depth (Thom, Fraser, & Hume, 2011) where as white clover and cocksfoot emergence is reduced when sowing depth in increased from 5 mm to 25 mm (Peri, Brown, & McKenzie, 2000). Chicory emergence is reduced when sowing depth is increased from 5 mm to 15 mm, suggesting it is very sensitive to sowing depth (Peri, Brown, & McKenzie, 2000). Table 3 below summarizes the ideal sowing depth for certain species. When sowing perennial pastures, do not drive too fast. The ideal drilling speed for most small seeds is around 8km/h (Brock, McKenzie, & Pound, 2005), if planting speed is faster than this, seed depth will start to vary, causing uneven or poor germination.

Soil temperature at sowing will also affect speed of establishment. Figure 1 shows how long it takes various temperate species to reach 75% germination at 5°C, 10°C and 15°C. All species are slower to germinate at 5°C however tall fescue and cocksfoot are significantly quicker at 15°C than 5°C, getting to 75% germination 20 and 13 days quicker, respectively (Charlton, Hampton, & Scott, 1986). The warmer the soil temperature the quicker the perennial pasture will get to complete ground cover and reach first grazing, minimising weed pressure and susceptibility to insect attack. For this reason, it is recommended that tall fescue, cocksfoot and phalaris should only be planted if soil temperature is above 10°C, whereas ryegrass can be planted at 8–10°C. Ideally temperate pasture species should also be planted in the autumn, due to the risk of soils drying out over summer. However, lower rainfall locations or dryer than normal seasons better establishment can be achieved by sowing in late May/June when soil moisture is less likely to be limiting. If irrigation or high rainfall summers are likely, pastures can be spring sown, however broadleaf and summer grass weed growth competition may be stronger.

Pest Control

The establishment phase is the most vulnerable stage of a perennial pasture's life, so even small numbers of insects can cause significant damage to establishing pastures. This is particularly the case if germination conditions are slow and the pest pressure is high. Red legged earth mite (RLEM), blue oat mite (BOM), lucerne/clover flea typically target legumes and herbs, however these pests can also damage grass species. Other pests include ASW, black beetle, yellow headed

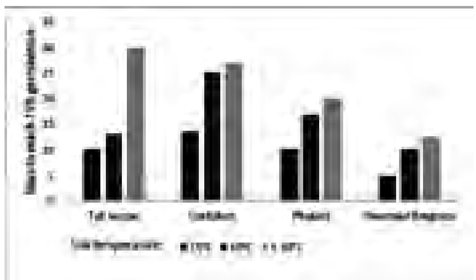

Figure 1 Germination rates of grass species at 3 different soil temperatures (adapted from (Charlton, Hampton, & Scott, 1986))

Table 3: Showing the ideal sowing depths for various perennial pasture species ((Peri, Brown, & McKenzie, 2000) (Thom, Fraser, & Hume, 2011) (Brown, Hampton, & Lill, 1998)

Species	Ryegrass	Tall fescue	Cocksfoot	Phalaris	Prairie grass	Chicory	Plantain	Red/ white clover	Sub clover
Sowing depth (mm)	15–25	15–25	5–15	5–15	10–20	5–10	5–25	5–15	5–15

cockchafer and cutworm can all cause significant damage. Best practice for insect control is to use label rates of a broad-spectrum insecticide such as chlorpyrifos with the final glyphosate spray to kill the current population of adult insects. The next step is to treat seed with Poncho® Plus seed treatment. Seed treatment will provide up to 6 weeks protection against the insects above that arrive after planting. Slugs and snails can also be a problem, especially in non-tillage systems. Monitor paddocks for these pests and if present, look at using a grain-based slug/snail bait to control as they can destroy large areas of a paddock very quickly.

Weed control

Broadleaf weeds are another cause of perennial pasture failure during the establishment phase. An important point here is that the inclusion of a well-managed break crop prior to sowing should have reduced weed seed banks to very low levels. If weeds occur they must be sprayed as early as possible before they start competing with pasture species for nutrient and moisture. Spraying weeds early means they are smaller requiring 'softer' herbicide chemistry than larger weeds, reducing the impact on companion legume species. Chemicals such as MCPB and flumetsalum need to be sprayed when clovers have at least 2 true trifoliate leaves, but weeds can't be bigger than the 8-leaf stage. Igran and Dicamba are registered to spray over plantain and most grass pastures. Clopyralid and MCPA are options to spray over grass only pastures, as they will be harmful to legumes and herbs. In New Zealand flumetsalum is registered to spray over chicory crops from the 2 true leaf stage onwards. It is recommended to talk to your agronomist for a post emergence spray regime and to spray when the weeds are smaller than the 8 true leaf stage.

First grazing

First grazing timing is very important for persistence, the intended outcome of a first graze is to remove the tips of grasses to encourage growth and tillering, not to feed animals. All perennial species need to be lightly grazed, leaving 4–5cm of growth behind, this encourages plants to tiller out and increase root depth. Do not graze below 4–5 cm until the pasture starts to hit its first 'spring flush' and keep the paddock in a grazing rotation. Early rotational grazing also prevents shading of companion species, particularly in fast establishing pastures like perennial ryegrass and prairie grass.

Grass pastures are ready for their first graze when they pass the 'pull test'. To carry out the pull test, pinch the plant 4–5 cm from the ground with your thumb and forefinger and pull upwards. Pastures are ready for a light first graze when the plant is anchored enough to not be pulled from the ground. The time taken to reach first grazing will be different amongst all species, typically the quickest will be perennial ryegrass and prairie grass, then tall fescue, cocksfoot and phalaris. Use young cattle or lambs for the first grazing as they have sharper teeth and are less likely to cause damage.

Conclusions

Establishing modern temperate perennial pasture species can significantly increase the carrying capacity of NSW Tablelands farms, which will increase the profitability of these farms. It is important to maximise the survival of the planted perennial pasture species to maintain farmer confidence in the renewal process. For perennial pastures to survive, farmers need to plan their renewal programme so that they are planting a species that will suit their climate and farm system. Planning starts 12–18 months prior to planting and the renewal process starts with a break crop. This break crop can be used to fill a feed deficit or to supply alternate source of income. Most importantly a break crop enables 3 glyphosate sprays across the paddock, ensuring a complete kill of problematic perennial weeds that don't contribute to production or profitability.

Selecting the right species is more important than selecting the correct cultivar, this is done by acknowledging annual rainfall, rainfall distribution, average seasonal temperatures, soil type and expected pest pressures of any individual paddock. Temperate perennials such as cocksfoot, tall fescue, phalaris and perennial ryegrass are suited to large areas of the NSW Tablelands environment and can suit most farms in this environment. Prairie grass is not a perennial species but has a significant fit in many perennial pastures and will persist through its reseeding mechanism.

When establishing a perennial pasture, make sure the paddock is prepared for planting by spraying out with a glyphosate-based spray in the lead up to planting. Sowing depth is very important for most perennial pasture species because of their seed size and should never exceed 25 mm in depth, some species shouldn't exceed 10 mm. If the paddock is uneven or has been pugged, it can lead to seed being placed at variable depth, so you may need to cultivate to create an even seed bed. Ensure drilling speed isn't too fast, ideal speed is 8 km/h. Species such as tall fescue, cocksfoot and phalaris are sensitive to soil temperature at establishment, so ensure soils are above 10°C when planting. When the paddock is ready for its first graze, perform a pull test on the grass. If the pasture passes the pull test it can be grazed down to 4–5 cm, preferably with a light stock class like lambs or young cattle. The goal of the first graze is to remove some leaf to encourage tillering creating a stronger plant, not to feed animals.

The final aspect to monitor during pasture establishment are weeds and insects. Best practice control for insects is a pre-plant broad spectrum insecticide and seed treatment to control insects that arrive after planting. Broadleaf weeds may also need to be controlled as they will compete with your perennial pasture for light, water and nutrients. Spraying weeds when they are small is preferable because you can use chemicals which will be less harmful on legumes and herbs.

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An insight into graze and grain systems in a high rainfall zone environment

Cate and Peter Brooks

"Merreworth", Berrima NSW 2577: pbrooks3@ozemail.com.au

Abstract: *Cate and I have been grazing pastures and crops for the past 13 years. In that time, we have learnt that the system makes large returns in good seasons and is still profitable in the poor ones. The aim of this document is to give an insight into what is required to undertake a change in management to produce forage crops that can also deliver a grain yield. We have seen two large farms completely changed in their weed profile, soil health and financial output.*

Introduction

Merreworth and Evandale aggregation is located at Berrima NSW (GPS co-ordinates 34.51858, 150.28483). It is intersected by the Freeway and Old Hume Hwy. There are three permanent waterways through the property.

The crops are grown under graze and grain principles with grazing commencing in February and locked up for harvest in August. Canola is grazed by lambs and a wheat and ryegrass system by both sheep and cattle and consists of:

- 360ha of annual ryegrass pasture
- 330 ha of late summer sown hybrid winter canola
- 320 ha of winter wheat
- 230 ha millet and brassica summer crop.

Farming description

Staff and Equipment

- 1.5 permanent staff
- Self-propelled sprayer
- 230 hp tractor
- 200 hp tractor
- 5 tonne fertilizer spreader
- 24m^3 feed mixer
- Front end loader
- Seedhawk 8 m seeder.

Fertiliser

- MAP – 100 kg/ha at Sowing
- Urea – 200 kg to 500 kg /ha per annum depend-ing on in crop rainfall.
- Chicken manure – 12 m^3/ha in 2016
- Lime – 3000 kg/ha in 2016

Soils and landscape

The farm has predominately basalt soils and has a volcanic crater on it. The farm as it moves to the west encounters a sandstone shelf.

Climate

The average annual rainfall is 760 mm per annum. However this is misleading as it often gets massive east coast falls of more than 200 mm in an event. Managing wet is a large part of the management plan.

The farm endured a cruel drought from June 2017 until February 2020 that saw two years of the lowest rainfall on record.

Livestock

- All animals are bought in.
- Annual turnover of lambs is market driven but typically 6000 per annum
- Cattle numbers are usually 3000 plus.
- We currently supply Woolworths with a grass fed MSA product that av 270 kg dressed weight.
- All animals undergo an induction protocol with a broad-spectrum drench, clostridial vaccine and ear tag.
- Cattle have individual details in a Gallagher TSI computer.
- Detailed profit and loss is calculated on each animal once slaughter results are received.
- A detailed audit of operations is undertaken half yearly by Woolworths.
- Lambs typically grow at 270 grms a day average.

- Cattle typically grow at 1.2 kg/day average.

Cropping

Preparation of the farming process starts with the end of the previous year. Typically, wheat or canola crop would follow these basic timelines:

- November – spray fallow ryegrass, grazing wheat
- December – harvest canola, wheat spray fallow stubble
- January – spray fallow
- February – sow on first available moisture usually on the calendar as there is sufficient stored moisture
- March – sow ryegrass
- April – commence grazing
- May – fertilizing with nitrogen
- June – Selective weed spraying and Nitrogen application
- July – UAN and Giberalic application to stimulate plant growth.
- August – Selective weed spraying, nitrogen application
- September – Decision on whether to lock up crops for harvest of graze out.
- October – Fungicide and insecticide on harvest crops. Sowing of summer forages.

Canola

- 330 ha of canola was sown between January and March.
- 2.5 kg/ha seed
- 100 kg MAP
- 100 kg urea
- Another 400 kg of urea added depending on soil moisture levels.
- This was grazed by lambs from March onwards.
- Liveweight gains of 300 grams/day are common.
- Locked up in July
- Harvested in December/January.

Winter Wheat

- 320 ha of wheat was sown between January and March.
- 80 kg/ha seed
- 100 kg MAP
- 100 kg urea
- Another 300 kg of urea added depending on soil moisture levels.
- This was grazed by cattle from March onwards.
- Liveweight gains of 1.5 kg/hd/per day are common.
- Locked up in late August
- Supplemented with oaten hay and Na Ca Mg mineral mix
- Harvested in December/January.

Ryegrass

- 300 ha of annual ryegrass was sown in March.
- 20 kg/ha seed
- 100 kg/ha MAP
- 100kg/ha urea
- Another 200 kg of urea added depending on soil moisture levels.
- 60 litres of UAN in two applications over winter.
- This was grazed by cattle from April onwards.
- Liveweight gains of 1.5 kg/hd/day are common.
- Grazed until January
- Supplemented with oaten hay and Na Ca Mg mineral mix

Weeds, pests and diseases

This property was covered in serrated tussock. We have found that annual cropping removes the tussock. If this country were to go back to pasture it would be covered in tussock within 5 years.

Drought strategies

- Every drought is different.
- Make decisions on hand feeding on a case by case basis.
- There is nothing wrong with reducing stocking and letting mother nature take her course.

We use soil water storage (fallows and keeping them clean) to harvest water in summer and then using the stored moisture to grow forage in the autumn.

Biggest lesson don't punt on mother nature relenting.

Keep ground cover. We use short term paddock feeding to finish stock.

Goals or business objectives

1. 800 kg of liveweight gain per ha
2. Optimum sales price.

Pathway to Pasture Production

Graze and Grain system

Since 2008 we have been involved in growing dual purpose crops at Goulburn and now Berrima. These properties were both terribly infested with serrated tussock and hawthorns.

Graze and grain is now a well established system in the high and medium rainfall regions. The basic system is sowing canola and wheat onto clean fallowed land from January until March. This produces a large amount of forage for autumn, winter and potentially spring and early summer.

In August we make calculations on whether to graze the crop out or lock up for harvest.

I am not going to preach but rather let you know what we have found in restoring over 5000 ha of land in the past 10 years using cropping for forage and grain.

- Identifying the best of the land and implementing a cropping phase has had the following results:
  - ➤ Increased stocking rates from the start base by 500%.
  - ➤ "Tirranna" Goulburn had 200 merino ewes and 120 cows and calves in 2008. 2020 saw some 12,000 prime lambs, 3000 trade cattle, 1100 tonnes of Canola and 1200 tonnes of wheat produced off the same land.
  - ➤ Merreworth had 300 ewes and 200 cattle. It now turns off 3000 plus cattle and 6000 lambs with 400 tonnes of canola.
  - ➤ Huge reduction in invasive weed species. As well as giving a mental feeling of winning the battle.
  - ➤ Lift in soil nutrients from 12 Colwell P to 39 Colwell P.
  - ➤ Lift in soil organic carbon from 1.3% to 1.9% at "Tirranna"
  - ➤ Resilience during drought. The grazing crops allowed rainfall to be harnessed to be ensure some revenue. In 2017, 2018 and 2019 we grazed canola and wheat from early storm rains to achieve excellent lamb and cattle trades and then basically shut down the farm during spring to keep groundcover and get ready for the next year.
- The system requires $600 to $700 worth of inputs per ha per annum and delivers revenues of between $1000 and $3000 depending on the season. A huge plus is that if done correctly you do not go backwards.
- The main drivers of the system are:
  - ➤ Fallow spraying of paddocks with autumn paddocks being sprayed out in September.
  - ➤ Soil testing to establish deficiencies and addressing the main ones.
  - ➤ Early sowing of crops
  - ➤ Sowing of crops with appropriate equipment (knife press wheel minimum)
  - ➤ Adequate nitrogen
- Being Nimble – We often change our strategy from more lambs to more cattle etc.

Stocking rates

- Canola is between 30 and 45 dse for 8 to 10 weeks
- Winter wheat is generally 30 to 40 dse in Autumn and then 20 dse over winter and then rising to 50 dse in the Spring early summer.
- I rate a crossbred lamb gaining 300 grms per day at 2 dse
- I rate a 400 kg steer gaining 1.3 kg per day at 15 dse.

We measure available forage with a pasture probe and visual experience.

We also temper our stocking rates with a seasonal outlook. If we feel it is getting dry and cold, we reduce our expectations and if it's warm and wet we lift them.

Knowing your numbers

We run a comprehensive budget process that covers the year, month and the individual trades we undertake.

The point is that with knowing what our fixed and variable expenses are, we can see if there is a future profit or that we need to change tactics to achieve a profit. We then measure the results through an accounting package to see how we are tracking.

The future

The red meat industry and protein in general is in for a solid rise in pricing (some has already been achieved). Producing what customers want is paramount to achieving our goals.

I believe our next stage will be partnering with capital investment to transpose what we have learnt (good and bad) into larger systems where we can greatly improve turnoff of quality stock.

Conclusions

- Done properly, adding a grazing crop can greatly improve the supply of high-quality forage at times in the year when there are deficits.
- It delivers high number of high-quality sale stock into the winter markets that is simply not able to be done on improved pastures in most years.
- Weed and soil profiles can be improved greatly with the use of cropping protocols.
- However, using good advice on agronomy is paramount. Done poorly you will lose money and done well you profit greatly.
- It also requires preparation and willingness to seize opportunity of rainfall events.
- Undertaking this type of operation is a commitment financially and mentally.

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Opportunities to build Soil Organic Carbon in a challenging environment; climate change and shifting paradigms

SE Orgill[A] and BW Murphy[B,C]

[A]NSW Department of Primary Industries, Wagga Wagga Agricultural Institute, Pine Gully Rd, Wagga Wagga NSW 2650, susan.orgill@dpi.nsw.gov.au
[B]NSW Office of Environment and Heritage
[C]NSW Soil Knowledge Network, Swan Hill, Victoria, brian.amaroo@bigpond.com

Abstract: *Soil organic carbon (SOC) is fundamental to soil health and agricultural production. There has been an increasing interest in SOC as a land-based solution to climate change. While this is a win-win opportunity, too often the discussion focuses on the uncertainty of measurement, rather than using what we have learnt over the past two decades to focus on action, traction and implementation. In our paper, we address three frequently asked questions around historic decline in SOC concentrations; increasing productivity and SOC levels simultaneously and the vulnerability of SOC to loss under a changing climate, to move the conversation forward. The purpose of our arguments are to provide a thought-provoking paper providing context and understanding for practitioners, advisers and scientists alike, rather than a rehash of basic science facts. There is evidence that soil OC can be increased in agricultural soils. Regional, landscape and local specificity will be key enablers of change to increase SOC. We need to use local knowledge and practitioner expertise to identify strategies that increase SOC for a given locality, soil type and farming system. These strategies will include grazing management (time, timing and intensity), crop and pasture rotations, practices with a focus on improved agronomy and nutrient management and restoration of degraded soils. New innovations of organic amendments, biochar, biological inoculants and biodiverse plantings show promise. The role of scientists in supporting producers to regenerate the landscape by increasing SOM in soils is critical.*

Key words: Carbon sequestration, humus, plant nutrition, microbial processes, biomass production, decomposition

Introduction

Soil organic carbon (SOC) is fundamental to healthy, functioning soils and landscapes, and underpins agricultural production (Loveland and Webb 2003; Murphy 2013). Increasing organic carbon in agricultural soil also plays an important role in mitigating climate change (Batjes 1996; Minasny *et al*. 2017) and making farming systems more resilient. Despite a considerable focus on identifying strategies to increase SOC and methods to more accurately measure and monitor changes in SOC stocks, three frequently asked questions are:

1. Are we still experiencing a decline in organic carbon in Australian agricultural soils?
2. Can we sequester carbon in Australian agricultural soils while continuing to feed and clothe a growing population?
   a. Do agricultural practices provide opportunities to sequester carbon in Australian soils?
   b. Can we maintain or increase SOC levels thereby improving soil condition and supporting increases in agricultural production?
3. If we increase SOC, how vulnerable is it to loss under our changing climate?

As is the case for many such rhetorical questions, the most accurate answer is, "*It depends*". In this paper we address these three perpetual questions to move the discussion forward and we highlight the opportunities to build SOC on Australian farms and why we should be enabling producers to do so.

Are we still experiencing a decline in organic carbon in Australian agricultural soils?

The decline in SOC from agricultural soil has been considerable in Australia, largely due to overgrazing, cultivation and continuous cropping in a dry climate on often highly weathered soils. It is estimated that SOC concentration has decreased by up to 70 % in the surface 10 cm since converting native vegetation to agricultural land use (Luo *et al.* 2010 and Sanderman *et al.* 2010). There are several reasons for this decline, including: i) reduced biomass production and/or organic matter (OM) supply to the soil, ii) increased rate of OM decomposition and mineralisation associated with tillage and altered soil aeration, moisture and temperature, iii) movement of SOC down the profile due to tillage and OM incorporation, iv) reduced capacity to protect OM in soil due to structural degradation and v) increased soil erosion by wind and water. Realistically, it is likely that a combination of these factors has resulted in SOC decline.

However, the initial sharp decline in SOC has been partially reversed by improved land management practices (Figure 1) such as crop rotations, nutrient application (e.g. superphosphate), inclusion of pasture phases (e.g. grasses with fibrous root systems and legumes with high nitrogen content) in cropping rotations, erosion control and conservation farming practices (Hamblin and Kyneur 1993; Williams and Lipsett 1961; Russell 1960; Pratley and Rowell 2003; Nichols *et al.* 2012; Packer *et al.* 1992; Freebairn et al. 1993). By increasing biomass production, replacing soil nutrients and reducing the loss (erosion) or degradation (soil respiration associated with cultivation) of soil organic matter (SOM), the level SOC has been partially restored. Pastures have proven an effective and productive strategy to increase SOC (Table 1) and withstand limitations imposed by climate, especially variable and low levels of available soil moisture. For example, at the MASTER trial site located near Wagga Wagga (see Figure 2), despite seasonal fluctuations in SOC stocks and the millennium drought (2000–2010), overall there was a mean increase in SOC of 0.5 t C/ha (0–30cm). Here we feel it is important to highlight that pasture alone is not a guarantee of increasing SOC. Accumulating SOC still depends on the biomass production (including appropriate management of pasture utilisation) and OM supply to the soil, and protection of the soil surface (i.e. groundcover). If pasture establishment is poor, nutrient deficient or if grazing management is suboptimal then SOC levels can be less than for a crop (Valzano *et al.* 2005). While this is a real consequence, producers can use nutrient inputs and grazing management to maximise carbon sequestration under pastures.

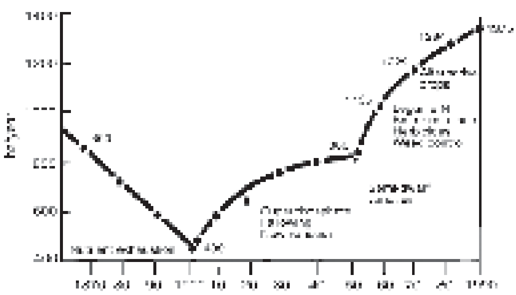

Figure 1. Trends in wheat yields (kg/ha/yr) since 1870 for Australia. (Adapted from Hamblin and Kyneur 1993).

Can we sequester carbon in Australian agricultural soils while continuing to feed and clothe a growing population?

Carbon comprises approximately 58% of SOM by weight (Baldock and Skjemstad 1999) and SOC is an indicator of soil health and soil condition (Loveland and Webb 2003; Murphy 2015). To build SOC, the supply of OM (through stubble, pasture phases, cover crops and composts etc)

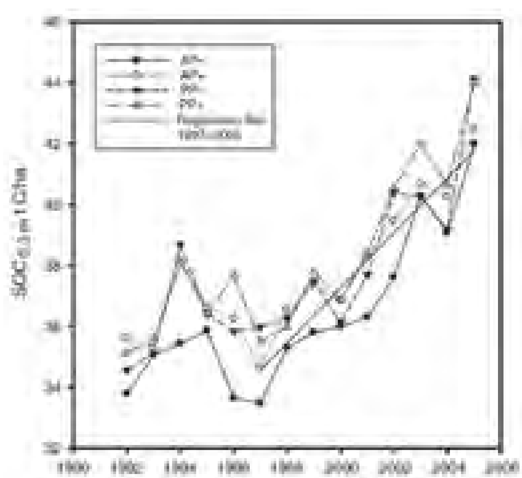

Figure 2. Trends in soil organic carbon stocks (t C/ha 0–30cm) 1992–2005 at the MASTER trial site near Wagga Wagga from Chan *et al.* 2011. Annual Pasture (AP) and Perennial Pasture (PP) with (+) and without (–) lime. All plots rotationally grazed with sheep.

needs to be greater than the loss of OM through decomposition and erosion. Increasing biomass production through good agronomy, and grazing and residue management is consistent with increasing agricultural productivity and having a net increase in the supply of OM; therefore building SOC.

Pastures and their management provide an important opportunity to sequester carbon in agricultural soils, as shown in Table 1. While the rate of carbon sequestration varies due to starting SOC levels, management, soil type and climate, evidence clearly supports a rate of change typically between 0.3 to 1.0 t C/ha/yr (0–30cm) for well managed pastures. Based on the literature, practices most likely to achieve increases in SOC stocks include converting degraded cropping paddocks to pasture and renovating or manipulating sub-optimal pasture

Table 1. Example of published soil carbon sequestration rates for NSW.

Management	Region (NSW)	C seq rate (t C/ha/yr 0–30cm)	Years	Reference
Pastures – NSW				
Liming	Riverina	0.46 to 0.55	18	Chan *et al.* 2011
Nutrient management	Southern Tablelands	0.41	>25	Chan *et al.* 2010; Orgill *et al.* 2014; Orgill *et al.* 2017
Rotational grazing	Southern Tablelands	0.35	>25	Chan *et al.* 2010
Grazing management (strategic & rotational)	Southern Tablelands & Western Division	1.04 to 1.46	>5	Orgill *et al.* 2016; Orgill *et al.* 2017
Nutrient mgmt & inc stocking rate (*60cm)	Southern Tablelands	0.60*	20	Coonan *et al.* 2019
Organic amendments	Central West	1.09 to 2.47	5	Badgery *et al.* 2020
Pastures – Australia meta-analysis				
Nutrient management		0.29	dns	Sanderman *et al.* 2010
Irrigation		0.11		Sanderman *et al.* 2010
Introduced perennial pastures		0.50	dns	Gifford *et al.* 1992
Cultivated crop to pasture		0. 50 to 0.70	22	Young *et al.* 2009; Chan *et al.* 2011; Conyers *et al.* 2015
Min till crop to pasture		0.78 to 1.33	5	Badgery *et al.* 2020
Crop to pasture – Australia meta-analysis				
Nutrient mgmt, legumes, irrigation (*30cm+)		0.30 to 0.60	dns	Sanderman *et al.* 2010
Crop with pasture in rotation – NSW				
Pasture rotations	Riverina	0.22 to 0.40	>13	Chan *et al.* 2011; Helyar *et al.* 1997
No till wheat with 2 yr pasture rotation	Riverina	0.26	25	Chan *et al.* 2011
Crop rotation with 2-6 yr pasture rotation	Riverina	0.23	18	Helyar *et al.* 1997
Crop with nutrients – NSW				
Nutrients + stubble & incorporated (*160cm)	South West Slopes	1.10*	5	Kirkby *et al.* 2016
Organic amendments + direct drill crop	Central West	0.32 to 0.64	5	Badgery *et al.* 2020

paddocks to improve productivity (Hackney *et al*, 2020). Contingent for the success of such remediation is implementation of management practices to overcome soil constraints to plant growth (e.g. acidity and sodicity), grazing management (duration, timing and intensity; Chen *et al.* 2015) and improved nutrient management (Table 1).

To understand the optimum conditions for soil carbon sequestration and rate of change, knowledge of the capacity of the soil type and climate to sequester and store SOC is essential. Soil with OC concentrations that are well below the expected levels, are most likely to have a detectable change in SOC with practice change. Thus, in many cases degraded soils may offer the best opportunities for carbon sequestration (Govers *et al.* 2013). That said, practices that focus on regenerating the landscape to improve soil function, and those that start from a healthy resource base may offer new opportunities to build SOC where existing levels may be moderate to high (HLPE 2019).

It is timely to consider the basic principles to increase SOC which are:

i) Increase the amount of above- and below-ground OM inputs to soil,
ii) Influence the location of OM inputs in the soil profile (with deeper horizons being less saturated in carbon, typically having a greater capacity to protect carbon through organo-mineral associations, and where the rate of decomposition is likely to be slower than surface soil layers),
iii) Influence the rate of fresh OM conversion to more stable forms of SOM (such as humus) through nutrient management and microbial processes, and
iv) Increase protection of OM through protecting the soil surface and enhancing soil aggregation.

While we talk of SOC, it is often SOM that is driving the processes that support agricultural production and enhance soil condition. For example, increasing SOM enhances the physical condition of the soil and plays a pivotal role in nutrient cycling (Janzen 2006). Meyer *et al.* (2015) valued the increased pasture production associated with higher SOM on average to be between \$26 and \$95/ha/yr, attributing most of this value in the low rainfall zone to be through increased plant available water, and in the high rainfall zone through nitrogen mineralisation (\$85–\$105/ha). Similarly, Ringrose Voase *et al.* (1997) estimated that a 1% increase in SOC (e.g. increasing SOC from 1 to 2%) increased gross margins by more than \$100/ha/yr in some Riverina soils in NSW. Carbon trading offers the ability to diversify farm income and incentivise practice or land use change, however there are clear economic and environmental arguments supporting the increase in SOM for agricultural production.

If we increase soil organic carbon, how vulnerable is it to loss under our changing climate?

Two major drivers of SOC stocks and flows are rainfall (frequency, intensity and duration) and temperature. Soil organic carbon may be 'lost' due to decomposition (microbial degradation of SOM) or erosion (physical removal of OM and soil particles with SOC associated). (Introduction to the following dot points?)

- Rate of SOM decomposition is a factor of soil biology, type of OM, land management, soils protective capacity (clay%, mineralogy, depth and structure) and environmental conditions (temperature, rainfall, soil water content and atmospheric balances). These are the same factors that drive productivity; some can be changed (e.g. plant type and soil structure) and others cannot easily be changed (e.g. clay content and soil depth).
- Vulnerability of soil to wind erosion is determined by ground cover, soil moisture, wind speed and aerodynamic roughness. Vulnerability of soil to water erosion is determined by rainfall intensity/amount (erosivity), soil type (erodibility), ground cover, slope length and slope steepness. It is important to account for loss of SOC via erosion when considering changes in SOC content and stocks. The amount of SOC removed due to erosion is a factor of the

rate of loss and the enrichment ratio (that is, SOC content of the eroded fraction). Figure 3 (from Chappell *et al.* 2019) presents global hot spots for loss of SOC via wind erosion. This figure highlights the impact of climate on carbon loss from soils and draws attention to the important role that practices which increase ground cover could play in the Australian rangelands.

Due to climate change, NSW is becoming hotter and drier with changing patterns of temperature, rainfall, fire, drought and heavy rainfall all of which impact on the stocks and flows of SOC. For example (DECCW 2010) in NSW:

- Mean summer temperatures are expected to increase by 1.5 to 2.0°C in central and north west NSW (e.g. Narrabri, Guyra, Murrurundi and Dubbo) and by 2.5 to 3.0°C in the Riverina (e.g. Corowa, Mildura and Deniliquin) by 2050. Such increases have the potential to increase the rate of decomposition of SOM.
- Mean winter rainfall is expected to decrease by between 20 to 80 mm/yr depending on location by 2050. This has the potential to reduce the biomass production necessary for accumulating SOC.

Climate change may increase the vulnerability of the more labile fraction of SOC to loss but this doesn't have to mean a decline in SOC. Producers and their land management will play a key role in keeping carbon in agricultural soil. Grazing management is a key driver of the provision of ground cover which protects the thin skin of soil that has the highest SOC concentration. Cropping practices which use minimal disturbance and that retain residues also protect the soil surface. Deep rooted perennial pastures enhance aggregate-protected SOM, regulate fluctuations in temperature and moisture and have the capacity to add SOC deeper in the soil profile through their fibrous roots and associations with microbes. Legumes and their associated rhizobia supply biologically fixed nitrogen which can enhance grass growth as well as build SOC through contributing OM with narrow C:N ratios. While currently not regarded as an economically viable option in many broadacre systems, we know increasingly more about nutrient management to create stabile SOC (building humus), optimising compost production and the pyrolysis of OM to make stable char (biochar). In addition, innovations in the field of optimising water use efficiency through rotations, species selection

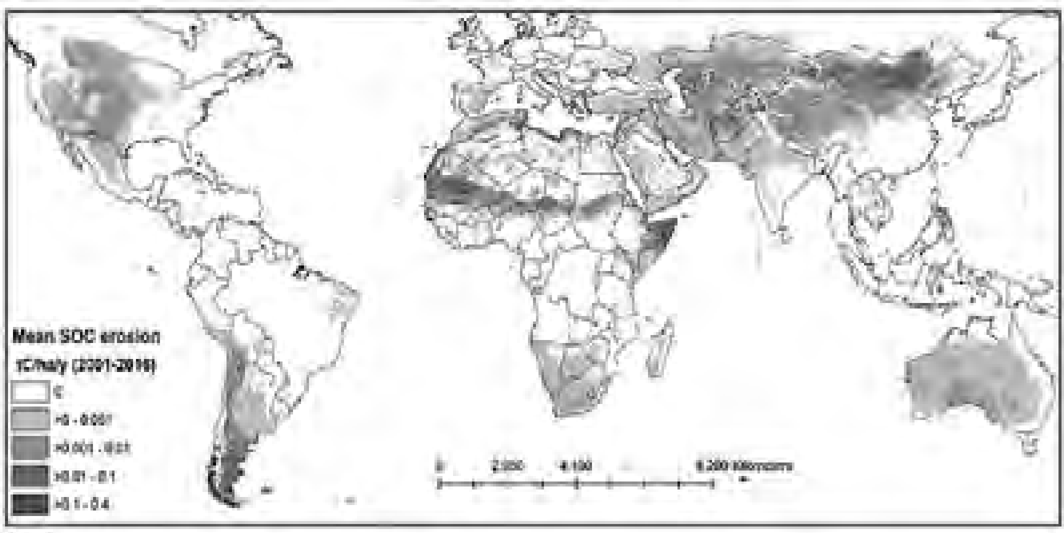

Figure 3. Mean soil organic carbon (SOC) loss in dust from Chappell *et al.* (2019).

and diverse plantings offer opportunities to be flexible under changed soil water regimes.

Conclusion: it is possible build soil organic carbon!

There is evidence in the peer reviewed literature that you can increase OC in agricultural soils. There is no dispute that increasing SOM is important for agricultural production, soil condition, resilient farming systems and mitigating climate change. Measuring SOC concentration (% or g/100g soil) is cheap and provides valuable information on soil condition particularly when considered within the context of the region, or soil type and climate. We need to focus on action, traction and implementation as soon as possible to realise the full potential for increasing SOC in our soils.

Regional, landscape and local specificity will be key enablers of change to increase SOC. It is at the landscape and local scale where there are opportunities to improve the knowledge and understanding of SOC dynamics and measurement, and the influence of SOM on the water and nutrient cycle. We need to use local knowledge and practitioner expertise to identify strategies that increase SOC for a given locality, soil type and farming system. The effects of grazing duration, timing and intensity on soil carbon sequestration offer an opportunity to increase SOC, while improvements in crop and pasture rotations and practices with a focus on improved agronomy and nutrient management offer another. Implementation of these practices at the operational level needs to be undertaken by producers with nuance to maximise benefits in diverse and often complex landscapes. Restoration of degraded soils is also an area for carbon sequestration that can be better utilized. Incorporation of organic amendments (Badgery *et al.* 2020), biological inoculants (Mukasa Mugerwa 2017) and biodiverse plantings (Yang *et al.* 2019) are promising innovations in the field of SOC sequestration science. We need a greater level of understanding of these practices through replicated trials across different climates and soil types. The role of scientists to support producers to regenerate the landscape by increasing SOM in soils is critical.

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Adding "Carbon Farming for Carbon Trading" to your productive pastures

Louisa Kiely, Director, Carbon Farmers of Australia Pty Ltd

5 Brumbys Run, Clifton Grove NSW 2800 louisa@carbonfarmersofaustralia.com.au

Abstract: *Carbon farming and trading has been gaining momentum over the past 10 years. Farmers can sell the carbon stored on their land but can then reap the benefits of the stored carbon, such as better water holding capacity, better soil structure and more shade and shelter for livestock.*

Key words: Carbon farming, soil carbon credits, carbon trading

Introduction

After more than 10 years gaining momentum, several factors now lead to Carbon Farming and Trading trending to be mainstream.

- Much higher aspirational emissions reduction targets both in Australia and Internationally.
- Recognition in the corporate world of the requirement to show responsible behaviour in the face of the 'known risk' of a warming climate
- Willingness of farmers worldwide to diversify income while improving on farm productivity.
- A new and increasing market to bring all the facets together.

There is no need now to explain the 'co-benefits' of increased carbon sequestration in both soils and vegetation. These are now well documented – better water holding capacity, better soil structure, better shade and shelter – into drought later, out of drought sooner.

It is the action of increased biomass above and below ground that does this. If you have more and more productive grasses, the act of photosynthesis takes carbon *out* of the air, as they 'breathe' in CO_2 and the plant uses the carbon in their own structures and take the carbon down into the soil where microbes use it and over time it is stored in the soil.

So, while agriculture is a high emitter, farmers are also the managers of the *largest* carbon sink – giving agriculture the *best* chance of reducing the effects of climate change. No amount of lowering emissions or changing light bulbs will reduce the temperature enough – because it is the level of CO_2 in the atmosphere from the last 70 years of emissions which are driving the temperature increase at the moment.

But, what the Carbon Farming Trade Markets can do is 'value' these benefits, using CO_2e as the 'currency.

This is due to the happy co-incidence that as you increase the carbon in soils and vegetation you *also* take that carbon *out* of the atmosphere, assisting to cool the planet.

Another important feature of this market which makes it so appealing is that for the first time, a farmer can sell the product – CO_2e, *but* keep the benefit on farm – better soil health, better shade and shelter. The 'product' never leaves the farm! This should be factored into any gross margin calculations on the benefits of a Carbon Farming Project.

Australia is leading the pack in Soil Carbon Methods *and* Soil Carbon Projects. It is now widely recognised that the soil is the largest carbon sink under our control, with farmers stewarding over 50% of the Land Mass world-wide. It is no wonder then that there is a desire to find the best ways to sequester carbon on farms.

For smaller farmers there is also the potential to 'pool' their carbon under an aggregation model. The role of the 'aggregator' is to assemble tradable amounts by combining units from several growers. Aggregation can be done well by grower groups e.g. Landcare, Beef or Sheep Groups.

Australia is the first country to sell Paris Agreement compliant Soil Carbon Credits, using multi species pastures to improve the soil carbon using the approved Soil Carbon method.

We now have the second generation Soil Carbon method, which will offer more flexibility and an easier pathway to developing your Soil Carbon project. In the 2021 budget the federal government allocated $200 million for the National Soil Strategy, including rebates for farmers who provide soil data.

Carbon Farmers of Australia can assist farmers to understand what is required under a Soil Carbon or Vegetation method, and give you the information you need to make sure such a method is consistent with your farming goals and aspirations.

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https://carbonfarmersofaustralia.com.au/carbon-farming/

Carbon Neutral by 2030 roadmap for the Australian red meat industry

Margaret Jewell

Meat and Livestock Australia: mjewell@mla.com.au

Abstract: *The Australian red meat industry carbon neutral initiative is an aspirational target for the amount of greenhouse gasses released by the industry to be equivalent or less than the amount of additional carbon stored in grazing land. Emission sources include animals, fertiliser, land management and waste management. There will be multiple benefits to stakeholders including improved genetics and nutrition, legumes in pasture systems, stored soil organic carbon and more trees in the environment. The red meat industry have already made great progress with 53% reductions in emissions since 2005.*

Key words: Carbon neutral, net zero greenhouse gas, emissions reduction

What does carbon neutral mean?

Under the Australian red meat industry's CN30 initiative, carbon neutral means net zero greenhouse gas (GHG) emissions on an annual basis. This means that the amount of GHGs released to the atmosphere by industry is equivalent or less than the amount of additional carbon stored in soils or vegetation in grazing lands in a given reporting year.

The three most relevant GHGs from the Australian red meat industry are:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O) (Figure 1).

Emission sources from the Australian red meat industry include:

- Cattle, sheep and goats (enteric methane, methane and nitrous oxide from waste management)
- Fertiliser use in production of livestock feed (nitrous oxide emissions from fertiliser use in some pasture and crop production)
- Land management practices (deforestation, savanna burning)
- Waste management in meat processing and energy use (including transport)

Land management practices (revegetation, avoided deforestation) also represent a carbon sink, or store.

Work areas paving the way to carbon neutrality

There are four work areas that provide a framework for MLA's CN30 research, development, and adoption activities. These are:

1. Leadership building – Building leadership capability and competency across industry is vital to enabling the transition to a carbon neutral position by 2030. By investing in our people, industry will develop the skills and knowledge to adopt the technologies presented in the CN30 Roadmap.
2. GHG emissions avoidance - Involves research, development and adoption of technologies that avoid carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) emissions from grazing management, lot feeding and processing.
3. Carbon storage – To achieve CN30, technologies that avoid GHG emissions and increase carbon storage in grazing lands are required. Increasing carbon storage can provide multiple benefits, including increased land and animal productivity, land remediation, increased biodiversity and improved water quality through reduced sediment run off into waterways.
4. Integrated management systems – Involves activities that enable environmental, economic and social impact measurement, accounting and reporting (MAR) throughout the red meat value chain.

Stakeholder action plan

Achieving CN30 will require the effort of many industry stakeholders. The CN30 Roadmap is built with the following stakeholders in mind:

- Industry (peak industry councils, state farming organisations, producers, feedlots, processors and retailers)
- Customers, consumers and communities
- Governments
- Partners (such as other agricultural research and development corporation, research organisation and private sector solution providers)

Industry's approach to achieving the CN30 target is focused on delivering multiple benefits to stakeholders:

- Herd/flock management practices, genetic technologies and novel animal feeds/ supplements can both increase productivity and reduce enteric methane emissions.
- Legumes can raise animal and soil productivity and reduce enteric methane emissions.
- Increases in organic carbon storage in soils improves soil health and drought resilience and removes carbon dioxide from the atmosphere.
- Appropriate integration of trees and shrubs into grazing management can improve carbon storage, animal health and welfare, and biodiversity.

Progress to date

We have already made great progress towards CN30 since the 2005 baseline year. Greenhouse gas emissions from the Australian red meat industry have fallen 53% since 2005, and red meat and manufacturing are the only major sectors in the Australian economy to reduce emissions since 1990, with red meat making by far the greatest reduction.

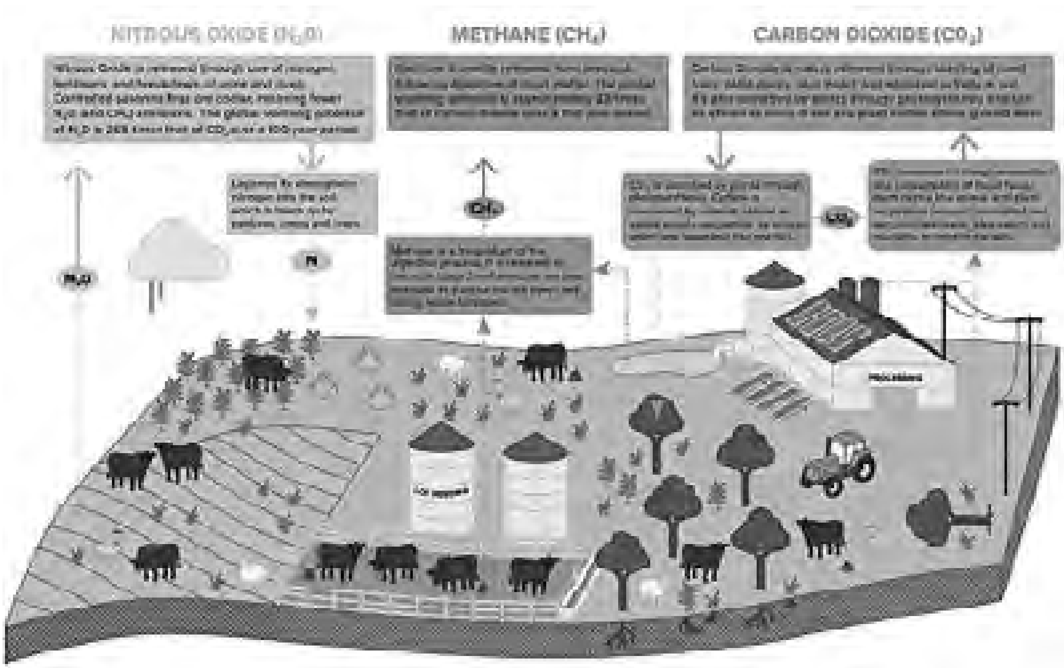

Figure 1: Greenhouse gas emissions sources and sinks in the Australian red meat and livestock industry

Contributed Papers

Pasture dieback on the North Coast of New South Wales. 1. Initial diagnostics to identify the causal agent

SP Boschma[A], A Daly[B], PS Gillespie[C], O Wildman[B], M Shrivasatava[B], N Jennings[D], JM Geary[D] and SJ Baker[A]

[A]NSW Department of Primary Industries, 4 Marsden Park Rd, Calala NSW 2340: suzanne.boschma@dpi.nsw.gov.au

[B]NSW Department of Primary Industries, Woodbridge Road, Menangle NSW 2568

[C]NSW Department of Primary Industries, 1447 Forest Road Orange NSW 2800

[D]North Coast Local Land Services, 79 Conway Street Lismore NSW 2480

Abstract: *Pasture dieback is a complex condition that results in poor growth and premature death of summer growing grasses. The condition has become widespread since 2015 and was identified on the North Coast of NSW in March 2020. In NSW, symptomatic and non-symptomatic plants, soils and insects were collected and analysed by the NSW Department of Primary Industries diagnostic laboratories. A range of fungal organisms were isolated including* Gaeumannomyces, Fusarium, Curvularia, Rhizoctonia *and* Bipolaris *spp. A number of species of nematodes were detected, though only a few were plant parasitic species. Samples were tested for viruses and several possible* Luteovirus-*like particles were observed. Insects identified included pasture mealybug (*Heliococcus summervillei*) which is associated with the condition in Queensland and mealybug ladybird (*Cryptolaemus montrouzieri*) which is a predator of mealybug.*

Key words: Plant Health Diagnostic Service, Biosecurity Collections Unit, fungi, virus, insect.

Introduction

Pasture dieback (PD) is a condition affecting large areas of sown and native summer growing grass pasture in Queensland (Buck 2017, 2021; AgForce 2019) and more recently on the North Coast of NSW. Dieback affected grasses are unthrifty and die prematurely. The condition was reported in buffel grass (*Cenchrus ciliaris*) pastures in Central Queensland in the 1990s (Graham and Conway 2000; Makiela 2008). However, there has been significant spread throughout eastern Queensland since 2015, with many grass species now affected. The area affected by PD in Queensland is difficult to determine, but estimates range from a conservative 200,000 ha to 4.4 million ha (AgForce 2019).

Buffel grass dieback in Central Queensland has been investigated several times but no specific cause, neither abiotic or biotic, has been established (Graham and Conway 2000; Makiela 2008; Makiela and Harrower 2008). Since 2017, in response to the current outbreak, Meat and Livestock Australia (MLA) in collaboration with multiple organisations has been conducting research to identify potential causal agent(s) (e.g. MLA 2018). Two insects are under investigation for their role in the condition: pasture mealybug (*Heliococcus summervillei;* Brookes 1978) (QUT 2018) and white ground pearl (*Margarodes australis*; Jakubuski 1965) (Thomson 2019; Thomson *et al*. 2021). Work is also being conducted to understand the role pathogens and the environment may be contributing to undermining the health of pastures leaving them more vulnerable to attack by these insect pests.

Pasture dieback was confirmed in the Tweed Valley on the North Coast of NSW in March 2020. To identify agent(s) that may have a role in the condition in NSW, we collected and analysed symptomatic and non-symptomatic plants, soil and insects from across the region. In this paper we summarise the findings of our initial analyses. Details of the expression of pasture dieback in the field and agronomic activities underway are provided in Boschma *et al. (2021).*

Methods

We collected samples of symptomatic and non-symptomatic plants from PD affected and neighbouring areas. Plant and soil samples were placed in plastic bags and kept cool. Insects found in affected areas were collected and placed in sealed vessels. All samples were inspected by NSW Department of Primary Industries' Plant Health Diagnostic Service and Biosecurity Collections Unit teams using a range of diagnostic techniques to identify microorganisms, nematodes and insects including light and electron microscopy, general and selective agar culture and DNA sequencing of taxonomically informative gene regions.

Results and discussion

We collected and assessed about 80 plant and insect samples from 30 sites. The symptomatic plants were predominantly *Paspalum* spp. (e.g. broadleaf paspalum and common paspalum), plus kikuyu (*Pennisetum clandestinum*) and Rhodes grass (*Chloris gayana*). A range of fungal organisms that can be pathogenic to plants were isolated. They included isolates from genera: *Gaeumannomyces, Rhizoctonia, Fusarium, Cladosporium, Alternaria, Curvularia, Bipolaris* and *Stemphyllium*. *Pythium* was occasionally detected also. However, no microorganism was isolated from all symptomatic samples or locations (Table 1). Additionally, we detected several possible Luteovirus-like particles via electron microscopy. Plant parasitic nematodes were detected at several sites, but only in low numbers not expected to be harmful (Table 1). The nematodes we identified were similar to those from a study conducted in Southern Queensland (Young *et al.* 2019).

We identified a range of insects, including pasture mealybug which was found at all sites. This same species is associated with the condition and under investigation in Queensland (QUT 2018). Mealybug ladybird (*Cryptolaemus montrouzieri*), native ants (Solenopsis sp.) and mites were also detected. The larva of mealybug ladybird, which is sometimes called mealybug destroyer is a known predator of mealybug (QUT 2018) while ants can aid mealybugs (QUT 2018). We did not detect ground pearl at any PD sites.

Pasture mealybug is not a new pest in Australia. It was first identified in the Cooroy district, Queensland in 1926 (Summerville 1928) then in Atherton, Queensland in 1938 (Brookes 1978). It was identified again in 2018 (Schutze *et al.* 2019) and was found at many, but not all, pasture dieback sites in Queensland. This mealybug was responsible for extensive damage to grass species in New Caledonia (Brinon *et al.* 2004). We believe that pasture mealybug is associated with the condition in NSW as it has been found at all sites; those sampled and described above, and sites we have visited subsequently. It is unclear whether the insect is a sole agent, vectoring a pathogen (e.g. virus or non-culturable microorganism) or the final component in a complex interaction of multiple agents and factors. It is important to note that morphological and molecular identification of specimens of *H. summervillei* from Queensland and NSW are the same species, but they show some variation to the specimens described by Brookes (1978). This may mean that the mealybug associated in pasture dieback is a different species. However, the differences are small and ecologically this mealybug fits the same niche and habits as that of its twenty plus northern European congeners.

The inconsistency in symptom expression of PD (M. Thomson, UQ, pers. comm.) and presence/absence of different pests and pathogens across sites in Queensland suggests that multiple conditions may be operating even though they are commonly referred to as 'pasture dieback'. We think that defining, accurately naming and understanding each agent needs to be a priority so that effective strategies can be developed for each. This will allow targeted research to be conducted addressing specific agents and be a better outcome for industry.

R&D priorities for NSW

Pasture mealybug is associated with PD on the North Coast NSW. However, it is not understood whether it is acting alone, vectoring a plant pathogen, or if it is the final pest that results in the collapse of a pasture that has been compromised by other agents and environmental factors. Current activities being conducted in Queensland would benefit by being extended to NSW. The southward spread of PD into different climates and poses a risk to different farming and grazing systems to most of Queensland.

There is a need to model the potential distribution of pasture mealybug using models such as CLIMEX. This analysis could predict the potential impact of this mealybug on a range of industries that may be threatened. In Queensland, PD is predominantly distributed throughout areas with 600+ mm annual average rainfall (S. Buck, QDAF, pers. comm). Based on rainfall alone, this means that large areas of northern NSW and along the NSW coast may be at risk of this condition. The interaction with temperature also needs to be evaluated.

In NSW, work is needed to understand the effect of the condition and pasture mealybug on sown and native summer and winter growing annual and perennial grass pasture and forage species as well as crops. As PD moves south and west in NSW, more species, farming systems and enterprises are at risk of becoming affected. Some native grass species have been identified as susceptible to the condition in Queensland. There are potentially many more susceptible native species. New species and systems will be exposed if PD moves into new agroecological zones.

Conclusions

Pasture dieback is having a devasting impact in pasture productivity and therefore livestock production on the North Coast of NSW. Work is continuing to identify the components of this complex condition in Queensland and NSW.

Acknowledgements

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Table 1. Microorganisms found in association with symptomatic pasture dieback samples.

Grass species affected	Microorganisms identified	Taxon	Method of Identification	Microorganisms not detected as a result of specific assays[1]
Digitaria eriantha	*Gaeumannomyces*, *Rhizoctonia*-like, *Fusarium*, *Alternaria*, *Absidia* and *Penicillium* spp.	Fungus	Light microscopy, agar culture, DNA sequencing	*Xylella*, *Phytophthora*, bacteria spp.
	Pythium sp.	Oomycete (water mould)	Selective agar culture	
Cenchrus ciliaris	*Gaeumannomyces* sp. and *Fusarium incarnatum/equiseti*	Fungus	Light microscopy, agar culture, DNA sequencing	N/A
Pennisetum clandestinum	*Gaeumannomyces*, *Curvularia*, *Bipolaris*, *Fusarium* and *Penicillium* spp.	Fungus	Light microscopy, agar culture	*Phytophthora*, *Pythium*, *Verrucalvus* spp. (water moulds)
Paspalum sp., *Chloris gayana*	*Fusarium* and *Epicoccum* spp.	Fungus	Light microscopy, agar culture	*Phytophthora* spp.
C. gayana	*Pythium* sp.	Protist	Selective agar culture	
P. clandestinum	*Gaeumannomyces* sp.	Fungus	Light microscopy	N/A
Paspalum sp.	*Gaeumannomyces*-like, *Rhizoctonia*-like, *Stemphyllium*, *Cladosporium* and *Epicoccum* spp.		Light microscopy	N/A
Unknown	Slime mould	Protist	Light microscopy	N/A
P. notatum	*Gaeumannomyces* sp.	Fungus	Light microscopy	WSMV, BYDV, CYDV
	Pratylenchus zeae	Nematode	Light microscopy, DNA sequencing	N/A
Paspalum sp.	*Gaeumannomyces*, *Cladosporium* and various *Dematiaceous* spp. (e.g. *Curvularia*) and *Fusarium chlamydosporum/equiseti*	Fungus	Light microscopy, agar culture, DNA sequencing	WSMV, BYDV, CYDV
	Ditylenchus sp.	Nematode	Light microscopy, DNA sequencing	
Cynodon dactylon	*Gaeumannomyces*-like, various *Dematiaceous* spp. (e.g. *Curvularia*)	Fungus	Light microscopy	WSMV, BYDV, CYDV
	Potyvirus-like	Virus	Electron microscopy	
Paspalum sp.	Various *Dematiaceous* spp. (e.g. *Alternaria*, *Dreschlera*-like)	Fungus	Light microscopy	N/A
	Pratylenchus zeae	Nematode	Light microscopy, DNA sequencing	
Paspalum sp	*Helicotylenchus dihysteria*	Nematode	Light microscopy, DNA sequencing	N/A
Paspalum sp.	*Fusarium* sp.	Fungus	Agar culture, DNA sequencing	N/A

Table 1. Microorganisms found in association with symptomatic pasture dieback samples.(continued)

C. gayana	N/A	N/A	N/A	Virus particles, WSMV, BYDV, CYDV
Paspalum sp.	*Fusarium solani*-like sp.	Fungus	Agar culture	N/A
Setaria sphacelata	*Bipolaris setariae*	Fungus	Agar culture, DNA sequencing	Virus particles, WSMV, BYDV, CYDV
Paspalum sp.	Possible *Luteovirus*-like particles	Virus	Electron microscopy	WSMV, BYDV, CYDV
Paspalum sp.	Possible *Luteovirus*-like particles	Virus	Electron microscopy	WSMV, BYDV, CYDV
Paspalum sp.	Possible *Luteovirus*-like particles	Virus	Electron microscopy	WSMV, BYDV, CYDV
Unknown	*Xiphinema* sp.	Nematode	Light microscopy, DNA sequencing	Virus particles
P. clandestinum	*Fusarium oxysporum*-like, *Fusarium*, *Dreschlera* and *Trichoderma* spp.	Fungus	Agar culture	*Phytophthora* spp.
	Pythium sp.	Oomycete (water mould)	Selective agar culture	
Paspalum sp.	N/A	N/A	N/A	Virus particles

[1]WSMV: wheat streak mosaic virus; BYDV: barley yellow dwarf virus; CYDV: cereal yellow dwarf virus.

Pasture dieback on the North Coast of New South Wales. 2. Symptom development and current recommendations

SP Boschma[A], N Jennings[B], JM Geary[B] and SJ Baker[A]

[A]NSW Department of Primary Industries, 4 Marsden Park Rd, Calala NSW 2340: suzanne.boschma@dpi.nsw.gov.au

[B]North Coast Local Land Services, 79 Conway Street Lismore NSW 2480

Abstract: *Pasture dieback is a condition that kills summer growing grasses and was detected on the North Coast of NSW in March 2020. The condition has spread with about 3500 ha estimated to have been affected over the last 12 months and the area is continuing to increase rapidly during autumn 2021. This paper summarises symptom expression and development in NSW, findings from local demonstration activities and current management recommendations.*

Key words: pasture mealybug, *Heliococcus summervillei,* fertiliser, microbial products, biosecurity, productivity, legumes

Introduction

Pasture dieback (PD) is a condition affecting large areas of sown and native summer growing grass pasture in Queensland (Buck 2017; AgForce 2019) and more recently in New South Wales (NSW). Dieback-affected pastures experience a productivity decline and premature plant death. Livestock avoid grazing affected areas, making them unproductive (Buck 2017; Roberts 2017). There has been a significant spread of the condition throughout eastern Queensland since 2015. The area affected in Queensland is estimated to range from 200,000 to 4.4 million ha (AgForce 2019) with reductions in pasture production of 50% and carrying capacity of 35-40% (M. Vitelli, AgForce, pers. comm.).

Pasture dieback was confirmed in the Tweed Valley of NSW in March 2020. In the subsequent 12 months, the condition has spread south to Bangalow and west to Grevillia with an estimated 3500 ha affected. The affected area has continued to increase rapidly during autumn 2021. Pasture mealybug (*Heliococcus summervillei*), one of the insects under investigation was identified at dieback affected sites in NSW (Boschma *et al.* 2021) and work is continuing to understand its relationship with the condition. In this paper, we summarise the expression of the condition on the North Coast NSW, activities that have been conducted to maintain productive pastures for livestock, and current recommendations.

Susceptible species and condition progression

The tropical grass species commonly sown in NSW and Queensland are susceptible to PD, including several native species (Buck 2017, 2021). On the North Coast, we have noted that the first grasses affected in a paddock are usually broadleaf paspalum (*Paspalum mandiocanum*) and creeping bluegrass (*Bothriochloa insculpta)*. Other species affected, in decreasing order of occurrence include: common paspalum *(P. dilatatum),* couch grass (*Cynodon dactylon*), kikuyu (*Pennisetum clandestinum*), bahia grass *(P. notatum),* Rhodes grass (*Chloris gayana*) and setaria (*Setaria sphacelata*).

Similar to reports in Queensland (Makiela 2008; Makiela and Harrower 2008), PD on the North Coast starts as circular-type patches. Often, we first observe symptoms under trees or tree belts on the sides of hills. The symptomatic area spreads from this location in all directions and does not appear to be associated with slope, aspect or wind direction. Occasionally, the spread will form a 'dieback line' and move across an area evenly, but more often the spread is by random patches that join to cover larger areas. Often, pastures on the sides of hills are severely affected. These soils are typically shallow with lower fertility [particularly low phosphorous (P), sulphur (S) and nitrogen (N)] and are highly acidic (pH_{Ca}<4.8) with high levels of exchangeable aluminum. Commonly, flats with deeper soils and better P (>50 mg/kg colwell P), S, N fertility are less affected and slower to succumb to the condition.

Pastures with high grass biomass (>5 t DM/ha) also appear to succumb more rapidly than pastures that are more frequently grazed with less standing biomass (~3 t DM/ha), irrespective of species. Monoculture grass pastures appear to be more severely affected and die faster than pastures with several grass species, possibly because species succumb to PD at different rates. The presence of legumes in a grass pasture can give an illusion of improved resilience as they are not affected by PD, but the grasses can still be affected and die. Symptomatic plants can stop at fence lines or a vehicle or stock track. Appearance of PD seems to be random and its presence in a district does not mean that all farms or pastures in the area are or will be affected. Several impacted properties have an immediate neighbour who is virtually unaffected.

Spread of the condition has caused rapid and dramatic loss of productivity for beef and dairy producers on the North Coast. Reductions in carrying capacity vary depending on the proportion of the farm affected. Producers have reported 50–75% reduction in carrying capacity. Some severely affected properties (>95% affected) have been destocked. Most affected producers have increased supplementary feeding and/or sown annual forages resulting in an increase in their cost of production to maintain some animal production.

Maintaining productivity by resowing pasture/forage species into dieback affected pastures

In late October 2020, we sowed two demonstrations at a site located at Nobbys Creek (23.306502°S, 153.346238°E), 7 km north-west of Murwillumbah, NSW in conjunction with a local beef producer group. The pasture was a mix of broadleaf paspalum, common paspalum, bahia grass, kikuyu and setaria that had died from PD by May 2020. Both demonstrations included ten tropical grasses (teff grass (*Eragrostis tef*; annual), kikuyu, signal grass (*Urochloa decumbens*), digit grass (*Digitaria eriantha*), creeping bluegrass, Bambatsi panic (*Panicum coloratum*), green and Gatton panics (*Megathyrsus maximus*), diploid and tetraploid Rhodes grass), six tropical legumes [burgundy bean (*Macroptilium bracteatum*), siratro (*M. atropurpureum*), glycine (*Neonotonia wightii*), round-leaf cassia (*Chamaecrista rotundifolia*), desmanthus (*Desmanthus* sp.), greenleaf desmodium (*Desmodium intortum*)], a tropical legume blend (siratro, round-leaf cassia, glycine), annual forage legume [cowpea (*Vigna unguiculata*)] and a pasture herb chicory (*Cichorium intybus*).

Each grass treatment was sown in a strip 24 m long x 2.4 m wide. We sowed the legume and herb strips perpendicular to the grass strips to enable each species to be in pure or mixed swards. Each demonstration was sown with the same treatments but different methods; one direct drilled and the other broadcast. The producer group decided several management options for the demonstrations including sowing rates, fertiliser application and weed control. All grasses were sown at 20 kg/ha equivalent except teff grass which was sown at 10 kg/ha. Legumes were sown at 8 kg/ha, cowpeas at 35 kg/ha and chicory at 8 kg/ha. Plots were sown with 150 kg/ha of forage starter (15% N, 7% P, 12% potassium (K), 10% S). No broadleaf weed control was conducted. The area was grazed in mid-February 2021, then 120 kg/ha di-ammonium phosphate (DAP; 18% N, 20.2% P, 1.5% S) applied, and an additional 100 kg/ha urea (45% N) applied in March. Good rainfall (85 mm) was received following sowing, then dry conditions for 7 weeks until mid-December when 220 mm fell. From mid-December 2020 to 1 April 2021, the site received 1241 mm of rain.

Most grass species germinated following the December rainfall event. Teff grass, signal grass, the panics, and both Rhodes grasses in the drilled demonstration area established successfully with >15 plants/m^2. Bambatsi panic, creeping bluegrass and digit grass established poorly (<5 plants/m^2) and kikuyu failed to establish. We noted some regeneration of the background pasture (average 4 plants/m^2) from the soil seed bank in the control strip (no pasture sown); the grasses were patchy, lacked vigour and had significant broadleaf weed invasion. Legume establishment was poor due to broadleaf weed competition. Siratro and round-leaf cassia were the only legumes that established achieving about 5 plants/m^2 in mixed swards and an average of 10 plants/m^2 in pure swards. Chicory germinated quickly on the first rainfall immediately after sowing but died due to poor follow up rainfall.

Direct drilling seed into the soil resulted in better plant establishment (>15 and 5–10 plants/m^2 for the grasses and legumes/herb, respectively) for all species than broadcasting seed onto the soil surface (averaged 9 and 3–5 plants/m^2 for the grasses and legumes/herb respectively). Regardless of the sowing method, the plant densities achieved for the sowing rates used were poor making perennial pasture establishment into PD affected areas expensive. We were unable to determine whether poor establishment was due to seasonal conditions, PD or an interaction of the two.

No PD symptoms were observed in the grasses four months after establishment. We will continue to monitor this demonstration as the grasses may become affected by PD in the future. In Queensland, some resown perennial grass pastures have been reported to succumb to the condition again within 12 months of establishment (S. Buck, QDAF, pers. comm). If the perennial species do succumb to pasture dieback, annual species such as teff grass are more cost-effective short-term feed and ground cover solutions.

Our demonstrations have shown that tropical perennial grasses can be sown directly into PD affected pastures. However, all the standard agronomic factors for successful establishment need to be considered, including suitability of species to the climatic and soil conditions. Legumes/herbs are not affected by PD, but competition from other species can restrict establishment, therefore broadleaf weed control prior to sowing is important. Additionally, establishing the legumes/herbs first, then oversowing grasses later may be more effective. The regeneration of a number of grasses from the soil seed bank has led to some producers questioning if 'doing nothing is as good as doing something'. Whilst it is too early to confirm, this may be an option, however the rate of return to previous plant densities of desirable grasses and overall production appears to be slow. The decision to not sow grasses can make sense from a seed cost point of view, but broadleaf weed invasion and the associated control costs need to be considered, as does potential toxicity of weed species to livestock.

Increasing productivity of a dieback affected pasture with fertiliser and microbial products

In December 2020 two demonstrations commenced on pastures affected with PD located at Eungella (28.3490328°S, 153.3094742°E), 11 km south-west of Murwillumbah. We applied five commercial fertilisers and four microbial products paired with soil conditioner at label recommended rates to a pasture. The pasture was a mix of broadleaf paspalum, setaria, bahia grass and kikuyu. The fertilisers applied were 120 kg/ha sulphate of potash (17% S, 41.5% K), 110 kg/ha urea, 150 kg/ha DAP, 180 kg/ha CK88® (Incitec Pivot; 15.1% N, 4.4% P, 11.5% K, 13.6% S), 250 kg/ha single superphosphate (8.8% P, 11% S, 19% calcium). The microbials were Nutri-Tech Solutions® products with soil conditioners: Nutri-Life Myco-Force™ (three rates: 50, 500 and 1000 g/ha + liquid humus (3 L/ha), Myco-Force (1 kg/ha) + Phos-life Organic™ (3 L/ha), Myco-Force (500 g/ha) + Farm Saver® Multi-Plex (3 L/ha; 10% N, 10% P, 10% K), Myco-Force (500 g/ha) + BAMTM (5 L/ha) and Myco-Force (500 g/ha) + liquid humus (3 L/ha) + Tricho-Shield™ (500 g/ha) + liquid humus (3 L/ha). The plots were grazed over a 2-week period in late January 2021 and the treatments reapplied in February. Each treatment was replicated twice.

There was significant pasture response on all plots which received an N-based fertiliser (i.e. urea, DAP, CK88) two weeks after the first application and 100 mm rainfall. Growth was proportional to the amount of N applied and 2–10 times greater than the control (nil treatment applied). Dieback symptoms in the responsive plots appeared to dissipate, although mealybug numbers were observed to be higher. There was little to no pasture growth response to the other fertiliser and microbial treatments compared to the control.

In early March 2021, following over 500 mm rainfall since the second treatment applications, we observed no pasture growth response. Plants in all plots showed advanced symptoms of PD with broadleaf weeds and legumes germinating in all plots irrespective of the treatment. We did note that mealybug numbers were noticeably higher in the plots that received N-based fertiliser relative to the control.

In the second demonstration, a mixed pasture of kikuyu, setaria, and paspalum was fertilised to increase pasture growth and grazed to manage pasture biomass. A single application of lime (Ozcal™ applied at 300 kg/ha) was surface applied to increase soil pH. From December 2020, the pasture was grazed to maintain biomass <3 t DM/ha and 150 kg/ha of DAP applied after every second grazing. From late February, 100 kg/ha urea was also applied every second grazing. The patches of PD present when the demonstration commenced appeared to subside after the initial fertiliser application. However, by early March, we found that PD symptoms were again evident though milder and less advanced in the fertilised and grazed pasture area than the neighbouring untreated area. This was despite higher mealybug numbers in the fertilised area.

Our demonstrations have shown that PD affected pastures can respond to N fertiliser but growth should be utilised to maintain biomass at a maximum of about 3 t DM/ha. Nitrogen fertiliser resulted in increased mealybug activity which supports Queensland reports (QUT 2018). Fertiliser application without regular grazing resulted in proliferation of mealybug and accelerated progression of PD symptoms to plant death. Based on our observations and results, we suggest that fertilising a PD affected pasture with a low fertility status could be a strategy to increase growth and suppress PD symptom development and spread. However, fertiliser application may not be economic as the effects are only short term and the pasture will still suffer premature death. The most resilient pastures appear to be those with good fertility status prior to infection.

We often see legumes, such as Shaw creeping vigna (Vigna parkeri) or round leaf cassia colonise PD affected pastures once the grasses have died. This is most likely due to the reduced competition from the grass. Whilst the effects of PD are devastating for productivity and ground cover, this is an opportunity to improve compatible legumes as grass pastures in the region commonly have a low legume component.

Current recommendations for producers

Recommendations change as new information becomes available.

Biosecurity

- Practice 'Come clean, go clean' by ensuring vehicles, equipment, footwear and clothing are clean and free of soil and plant material when entering or leaving the property. Ensure staff and visitors adhere to the property biosecurity plan and only use property vehicles to move around the property.
- Monitor grass pastures and crops regularly, especially following rainfall. Additionally, monitor areas where pasture grass (e.g. Rhodes grass) hay sourced from known pasture dieback areas has been stored and fed. Do not bale and sell dieback affected pasture.

Maintaining productivity and ground cover

- In areas with new outbreaks of PD, stock the pasture with high stock numbers as soon as possible to utilise the pasture before it becomes unpalatable.
- Fertilising pastures, especially with N, will result in increased pasture growth. However, when conditions are suitable, there will likely be a corresponding increase in mealybug activity. Utilise the pasture to prevent biomass accumulating above 3 t DM/ha to maximise the benefit of fertiliser application and minimise the effect of pasture dieback.
- Until effective control strategies are developed, quality forage for livestock and ground cover can be maintained by sowing annual forages or pastures, or perennial pastures that are not

susceptible to pasture dieback. For example, legumes such as siratro, glycine and round leaf cassia could be sown provided they suit the soil and environmental conditions of the property.

- Encouraging legumes that regenerate in the bare patches will also provide some feed and ground cover, and improve soil seed banks for the time when grasses are resown/regenerate.

Managing pasture mealybug

In the long-term, the most cost effective, environmentally friendly and effective method to control pasture mealybug will be through integrated pest management. In the short-term insecticides may be useful for control in new outbreaks or small affected areas. However, mealybugs are difficult to control effectively as they live in the soil and dwell protected amongst plant litter and foliage. Additionally, insecticides can also kill beneficial insects. Insecticides currently available for use under minor use permits issued by Australian Pesticides and Veterinary Medicines Authority are: imidacloprid (PER87423; expires 28 Feb 2028), spirotetramat (PER88482; expires 30 Sep 2022), chlorpyrifos (PER90238; expires 31 Oct 2022), also carbaryl, diazinon, malathion and methomyl (PER90239; expires 31 Oct 2022). Seek advice before use and adhere to permit and label details.

Conclusions

Pasture dieback is having a devasting impact on pasture productivity in the North Coast of NSW. Pasture mealybug is associated with the condition on the North Coast. Research is continuing in NSW in collaboration with MLA and organisations associated with the MLA/ Department of Agriculture, Water and the Environment, Australia PD program.

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Desmanthus is more persistent than lucerne through drought on the North-West Slopes of NSW

SP Boschma[A], CA Harris[B], MA Brennan[A], C Murray[B], SJ Baker[A] and S Harden[A]

[A]NSW Department of Primary Industries, 4 Marsden Park Rd, Tamworth NSW 2340: suzanne.boschma@dpi.nsw.gov.au

[B]NSW Department of Primary Industries, 444 Strathbogie Rd, Glen Innes NSW 2370

Abstract: *Lucerne (*Medicago sativa*) and desmanthus (*Desmanthus *spp.) were the most persistent species in mixes with digit grass (*Digitaria eriantha*) after 4 years in experiments at Bingara and Manilla in northern NSW. Plant frequency assessments (assessed over time providing a measure of persistence) were continued through the 2018–19 drought until autumn 2021. At both locations the plant frequency of all lucerne cultivars and burgundy bean (*Macroptilium bracteatum*) declined during the drought and failed to recover post drought. Plant frequency of the most persistent cultivars of desmanthus (cvv. Marc and JCU 2) increased post drought to be highest of the three legume species assessed. The importance of management to allow seed set and recruitment to maintain desmanthus long term is discussed.*

Key words: Tropical grass based pastures, recovery, seed set, management, North-West Slopes

Introduction

Sown tropical perennial grasses are an important component of the feed base for grazing systems in northern inland NSW. They are highly responsive to fertiliser, particularly nitrogen, but regular applications are required to maintain productivity (Boschma et al. 2014a, 2016). Productive companion legumes that are nodulated with effective rhizobia are a cost effective and sustainable means of providing nitrogen in tropical pastures (Peck et al. 2012). Additionally, in a mixed pasture legumes are important for animal production due to their high protein content.

The North-West Slopes is characterised by hot summers and frequent winter frosts (Hobbs and Jackson 1977). Also, it has a summer dominant rainfall distribution (≥60% falling October–March). This environment offers both opportunities and challenges for a range of temperate and tropical annual and perennial companion legumes (Boschma et al. 2014b) and research has evaluated these different types of legumes (e.g. Harris et al. 2019; Boschma et al. 2021). In a 4-year study which concluded in autumn 2016, we identified lucerne (Medicago sativa L.) and desmanthus (Desmanthus spp.) as the most persistent perennial legumes of those evaluated. Additionally, several lines of burgundy bean also persisted at Bingara (Boschma et al. 2021). We maintained these experiments beyond 2016 with irregular assessments. Drought was a factor during the experiment, especially at the Bingara site, but the 2018–19 period was particularly dry. Significant rainfall in autumn 2020 allowed tropical pastures to regrow followed by good rainfall during the 2020–21 summer. These summers provided an opportunity for us to assess the persistence of these legumes during extended drought.

This paper describes the persistence (assessed as plant frequency) of lucerne, desmanthus and burgundy bean (Macroptilium bracteatum (Nees & Mart.) Maréchal & Baudet) over the 8-year period to autumn 2021. The last 3 years included both drought and drought recovery periods. Our hypothesis was that lucerne, desmanthus and burgundy bean would have similar persistence post drought.

Methods

Our study consisted of two experiments located at sites near Bingara (29°42’39” S, 150°27’07” E; 297 m above sea level (ASL); 740 mm annual average rainfall [AAR]) and Manilla (30°42’11” S, 150°30’10”; 412 m ASL; 616 mm AAR) on the North-West Slopes of northern NSW. These sites had Brown Chromosol soils (pH_{Ca} 5.0–6.1) and represent areas where tropical perennial grasses are currently grown.

Our experiments consisted of 18 treatments: 14 cultivars of eight species of tropical legumes, and four cultivars of two temperate perennial legumes. A full list of species and cultivars is provided in Boschma *et al.* (2021). The cultivars described in this paper are: lucerne cvv. Pegasis, Q31 and Venus; desmanthus cvv. Marc, JCU 1, JCU 2, JCU 3, JCU 4 and JCU 5 and burgundy bean cv. B1 and experimental lines AT101 and AT121). All legumes were sown as mixes in plots with digit grass (*Digitaria eriantha* Steud.) cv. Premier. Each experiment was a randomised complete block design with three replicates (total 54 plots). The grass and legumes were sown in alternate rows into plots 1.5 × 6.0 m. The Manilla experiment was sown in December 2012 and the Bingara experiment in January 2013. Digit grass was sown at 1 kg/ha viable seed and the legumes at commercially recommended rates (adjusted for germination percentage). All legumes were inoculated with the recommended strain of Rhizobia. We applied 200 kg/ha single superphosphate (8.8% P, 11% S) during spring most years. The experiments were mown not grazed. Full details on sowing, site history and management can be found in Boschma *et al.* (2021). We used rainfall data recorded in a manual rain gauge located 2.5 km from the Bingara experimental site. For the Manilla site we used the BOM site located 8 km from the experimental site (55331).

Data collection

We assessed the frequency of plant occurrence, herein called plant frequency, of digit grass and legumes in a fixed location in each plot in spring and autumn each year 2013–16 and irregularly 2017–21. Plant frequency was assessed as the proportion (%) of cells containing a portion of a live digit grass or sown legume plant (Brown 1954). Estimates were generally taken 0–10 days after defoliation when there was green leaf present. At each assessment, we placed a 1.0 × 1.0 m quadrat (divided into 100 cells, each cell 0.1 × 0.1 m) across the middle 4 rows of a plot in an area that had good plant density of both digit grass and the sown legume. We assessed plant frequency a total of 10 times at both Bingara and Manilla. The temporal response of plant frequency over multiple assessments provided a measure of the persistence of a species.

Statistical analyses

We modelled frequency of the legume and grass components of each treatment over time with smoothing splines within a linear mixed model (Verbyla *et al.* 1999) using the R package ASReml (Butler 2018). Frequency at the last assessment was analysed by linear model with terms for treatment (legume/grass combination) and replicate. We did not need to transform the data. Least significant differences of means (P = 0.05) were calculated for significant effects.

Results

Rainfall at Bingara site was below average (≤80% of LTA) during 4 of 8 years that the experiment was conducted (Fig. 1). The period 2018–19 was exceptionally dry with annual rainfall being 40 and 20% of the LTA. Rainfall at the Manilla site was below average 2 of 8 years; 2018–19 being particularly dry years with annual rainfall 52 and 40% of the LTA respectively. Good rainfall was received January–May 2020; suitable for tropical pasture recovery (Fig. 1). Additionally, rainfall during summer 2020–21 was also above average e.g. 50% above LTA at Bingara.

At the Bingara site, plant frequency of the legumes was highly variable at the initial assessment; lucerne cultivars had the highest values, burgundy bean intermediate and desmanthus variable ($P < 0.05$). Plant frequency of lucerne peaked in 2015 then had a downward trend which accelerated from 2019 with final values in autumn 2021 of 11–17%. Desmanthus cultivars were variable at the initial assessment and this variability continued through the 8-year period. Cultivars Marc and JCU 2 consistently had the highest plant frequency throughout the 8 years; plant frequency values increased following rainfall in 2020–21 to be highest of the legumes in the experiment in autumn 2021 ($P < 0.05$; Fig. 2a). Burgundy bean had lowest plant frequency values in autumn 2021 ($P < 0.05$); the values were lower than those preceding the 2018–19 drought period. Plant frequency of digit grass was lowest in 2015, then increased. The range in values remained relatively consistent irrespective of the companion legume, although values increased from 10 units in 2016 to be 17 units by autumn 2021 (Fig. 2c).

At the Manilla site, plant frequency of the legumes peaked within 3 years of establishment then declined as dry conditions commenced (Fig. 2b). Plant frequency of burgundy bean peaked in 2014, lucerne peaked in 2014–15 while the most persistent cultivars of desmanthus (cvv. Marc and JCU 2) peaked in 2015–16. The

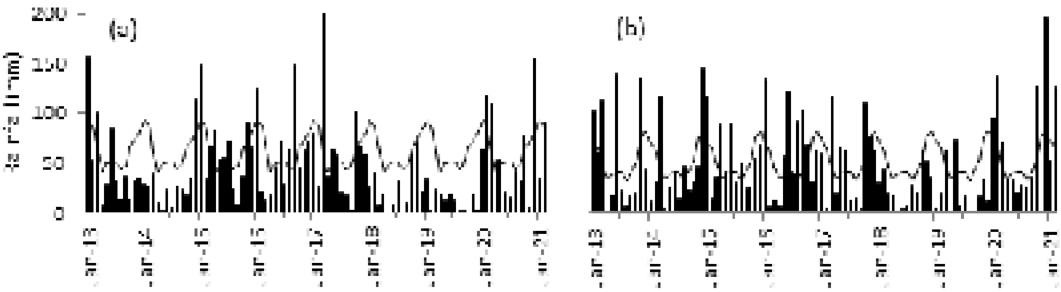

Figure 1. Actual (bars) and long term average (line) monthly rainfall (mm) at (a) Bingara and (b) Manilla, January 2013–February 2021. Long term average data are from BOM sites (a) 054004 (1878–2021) and (b) 55331 (1983–2021).

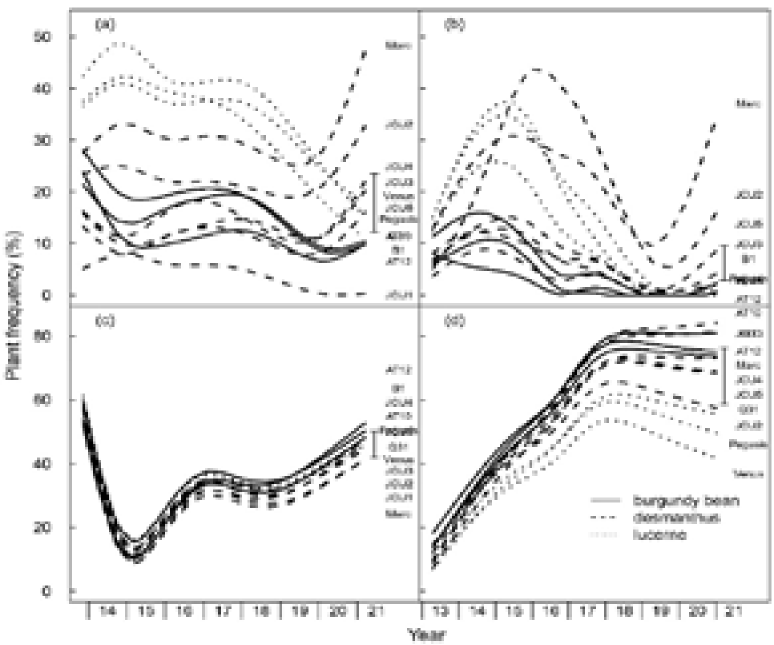

Figure 2. Predicted plant frequency of (a, b) legume and (c, d) digit grass in legume–grass mixtures at (a, c) Bingara and (b, d) Manilla, NSW, from February 2013 to February 2021. Shown on each figure are a least significant differences (P = 0.05) bar for comparison among treatment means at the final assessment, also the cultivar names.

lowest plant frequencies of all three species were recorded in 2018–19. Of the three species, desmanthus was the only species that showed strong recovery post drought. However, there was significant variation among cultivars with cv. Marc having the highest plant frequency in autumn 2021 (37%) followed by cv. JCU 2 ($P < 0.05$). Plant frequency of digit grass increased from the initial assessment (Fig. 2d). Plant frequency either peaked or plateaued in 2017–18. Unlike the Bingara site, the range in values diverged over time. Digit grass was generally ranked high in mixes with burgundy bean but ranked lowest in mixes with lucerne.

Discussion

Desmanthus cvv. Marc and JCU 2 were clearly the most persistent cultivars, with all cultivars of lucerne and burgundy bean showing poor drought recovery, thus our hypothesis is rejected. In a previous paper we reported that lucerne and desmanthus were the most persistent species in mixes with digit grass (Boschma *et al.* 2021). However, we noted that lucerne may have been declining at the Manilla site, while desmanthus had increased, plateauing at a higher level than that at establishment. Now 8 years after establishment and following severe drought the longer-term persistence of the legumes is evident. Plant frequency values of lucerne have declined to levels where resowing would be recommended. The persistence of lucerne for about 5 years is typical for the region when lucerne is managed well, despite the drought. Also, burgundy bean had low plant frequency and did not recover post drought. In contrast, plant frequency of desmanthus cv. JCU 2, and especially cv. Marc, increased post drought.

Digit grass is a productive and persistent grass in this region (Boschma *et al.* 2014a). The high and/or increasing plant frequency values of digit grass post drought for most treatments substantiates this. We noted a lower plant frequency of digit grass in mixes with lucerne in 2016 at the Manilla site (Boschma *et al.* 2021). We suggested it was likely due to competition between the two species and now, 5 years later, the effect of competition is clear with both species affected.

The experiment was left undefoliated from around April each year to allow seed set. We conclude that desmanthus was able to recover post drought due to seedling recruitment from this seed bank. The success of cvv. Marc and JCU 2 both *D. virgatus* (L.) Willd., and failure of *D. leptophyllus* Kunth cv. JCU 1 was likely due to species/cultivar adaption rather than seed set alone. Seed set and recruitment are important characteristics and grazing management needs to be targeted to allow plants to set seed at least every 2–3 years to maintain a large seedbank. Strategic grazing is required to ensure recruited seedlings establish successfully to form part of the productive legume stand. The different flowering maturities of the desmanthus lines needs to be considered with grazing management for seed set. For example, cv. Marc is early flowering, therefore resting the pasture following significant rainfall anytime from December could allow seed set. Conversely longer season cultivars such as JCU 1 flower later in the growing season and we recommend they are best to rested from around March to allow seed set. Desmanthus has high levels of hard seed (Lawrence et al. 2012), although differences have been observed between desmanthus cultivars (Boschma *et al.* 2018).

Conclusions

We observed that plant frequency of all lucerne cultivars fell sharply during the dry 2018–19 period and failed to recover with the return of reasonable seasonal conditions. In contrast, the frequency of several desmanthus cultivars increased, in particular cvv. Marc and JCU 2. Desmanthus stands can thicken due to seedling recruitment. Plant frequency of burgundy bean was declining prior to 2018–19 and failed to recover. We conclude that grazing management which allows seed set and recruitment of adapted species/cultivars is important for their persistence through variable seasons.

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A 'second go' at pasture improvement on "Mt Somers", Neville

Julian Cook

"Mount Somers", Neville NSW 2799: cookie82.jc@gmail.com

Abstract: *I describe the recovery of my grazing land, which was 'sterilised' by years of superphosphate and legumes. On treated paddocks, applications of lime + gypsum have raised the pH and reduced the levels of aluminium ions in the topsoil and, with sufficient phosphate to stimulate legumes, the treated pastures and livestock have since thrived. I plan to continue this improvement on "Mt Somers" and take advantage of other opportunities. After consultations with colleagues, I record some ideas about why producers may follow various pathways to the future. Further research and demonstration work involving producers is needed on acid soil topics such as pH stratification and lateral zonation in topsoils, ion movement from topsoils into subsoil and a proactive approach to lime use.*

Key words: superphosphate, acid soil, lime, gypsum

Introduction

I grew up on a family farm comprising 280 ha of cleared land south-east of Neville, NSW (GPS co-ordinates 33.72800, 149.18418), purchased by my father in 1957. The soil type consists of red and grey granite and some shale at an elevation of 1000 metres. Mean annual rainfall is 800 mm. The farm runs SRS Merino ewes joined to White Suffolk rams, with replacement ewes are sourced from other growers. Upon completing my schooling, I worked for the NSW Soil Conservation Service for 5 years, before joining my brother in a business that maintained tractor/earthmoving equipment. When my father died in 1999, I took over "Mount Somers".

During the next 10 years, the standard program of farm improvement continued, topdressing with superphosphate and direct drilling grasses and legumes regularly to the 'improved' pastures (180 ha, with the remaining area comprising native pastures and woodland). However, by the end of the millennium drought (2002–2009) the soil on the 'improved' portion of my land (derived from granite, and previously used for grazing with occasional crops of oats or potatoes) had become 'sterilised' by cycles of plough-sow-fertilise. At that time, the pastures had reverted to silver grass and summer grasses. This account describes how my paddocks were returned to productivity.

A new approach

I was impressed with the improvement of an adjoining property that had been acquired by Des and Sally Green, who had implemented a program (described by Green and Wolfe 2017) of applying lime and gypsum in order to raise soil pH towards a target of pH_{Ca} 5.5, to remove exchangeable aluminium (Al3+) in the topsoil and to increase the levels of calcium (Ca) and sulfur (S) in the soil profile. I began implementing a paddock-by-paddock program, about 10 ha at a time, starting with a spring 2012 topdressing of 2:1 lime:gypsum at a total rate of 2.5 t/ha, followed by additional topdressing on the worst patches. Paddocks were sprayed with roundup in spring 2013 and again prior to sowing in autumn. The first paddock was direct drilled in May 2014 with phalaris (Australian Commercial and Landmark cultivars), Victorian ryegrass and subterranean clover (*Trifolium subterraneum*). I chose Trikkala sub-clover that belongs to the sub-species yanninicum (and later balansa clover, *T michelianum*), because my country was prone to waterlogging. At sowing, phosphatic fertiliser (DAP @ 80 kg/ha) was applied and since then there have been two dressings of high analysis P fertiliser + Mo. I have no particular system of grazing management beyond being careful not to overgraze the newly-sown pastures.

Results

The early results were promising enough to extend progressively this topdressing and sowing program to the cleared areas of my farm. At Neville, the years from 2012 including the drought year of 2019 were not as severe as elsewhere, and during the favourable years of 2016 and 2020 the pastures and stock thrived. On one paddock, I missed a scheduled re-sowing after the lime + gypsum, but sufficient phalaris was evident after treatment for me to nurse that paddock along until the phalaris and clover content recovered. Another paddock of 10 ha, which was not much better than 'beach sand' a few years ago, has in 2020 maintained 204 ewes and their 279 lambs on a three to six-week rotation, with feed to spare. Areas of paddocks that were at one time waterlogged and were a trap for vehicles have 'dried up'. Occasional soil tests on my paddocks have confirmed the worth of lime + gypsum. The lime raises soil pH and reduces the proportion of aluminium ions in the topsoil. The gypsum is adding calcium, offsetting any soil sodicity and boosting the soil sulfur content, a limiting factor in building organic matter.

The rapidity and extent of the overall turnaround on my property from sterile soil to productive pastures has boosted my confidence in the future of my land. This confidence has spilled over into other pursuits. I now work, casually but regularly, implementing a similar plan of lime-gypsum-super on a neighbouring cattle property, while also supervising the livestock.

I now have 130 ha back in full production with 50 ha to go. My current plan at "Mt Somers" is to have one paddock ready for pasture, one paddock ready for a second spreading of lime/gypsum on the poor areas and a third paddock receiving its first spreading of lime/gypsum. This plan suits my farm cash flow situation but I am considering speeding up the rehabilitation of the remaining cleared areas on the property. The other advantage is we are cutting more wool and the lambing percentage has increased.

Discussion

Like me, many graziers on the tablelands and upper slopes have become frustrated with the failure of the 'sub and super' approach to pasture improvement, steering them towards beliefs along the lines of biodynamics, holistic grazing and regenerative farming. These approaches fail to deal with the underlying causes of poor productivity in the high-rainfall zone, causes that include soil acidity, low phosphate and low legume content (Hackney *et al.* 2019). Recently, I have been discussing (and thinking) with Des Green and Ted Wolfe about why many livestock producers on the upper slopes and tablelands seem slow to recognise the potential value of lime (and lime + gypsum) in correcting the problems of acid soils. One factor on grazing lands is that the feedback loop from thinking about an issue (e.g plant nutrition) to management action (e.g soil testing, apply fertiliser) and eventual payback (adding and selling livestock) is longer than on croplands (paddock selection, fallow, crop choice, sow, harvest, sell).

In my case, I was fortunate enough to have Des Green as my neighbour. With his many years of experience in rectifying acid soil and aluminium toxicity, he educated me in the application of top dressing with a lime and gypsum mix and encouraged me to apply his programme to my property. I found the feedback pathway relatively rapid, initially in terms of soil tests (confirming progress towards targets of a soil pH of 5.5 and near-zero aluminium levels in the 0–10 cm topsoil), along with the strong visual responses of my pastures and livestock. I am now aware that the scientific evidence (pulled together for me by Ted) supports what I have done. Virgona and Daniels (2010) advocated the importance of evidence-based decision-making in agriculture. Condon et al. (2019) assessed the current response of many growers and advisors to soil acidification as 'reactive'; they recommended a more pro-active approach to management (e.g., prevention rather than mitigation, higher lime rates) needed to reduce the extent of acid zones in the topsoil layers and inter-row spaces, and to reverse or prevent subsoil acidification.

In conclusion I encourage further investment in research and demonstration work to fine-tune the knowledge bank of scientists, advisors and producers on acid soil issues targeting issues such as pH stratification, lateral zonation in topsoils, ion movement from topsoils into subsoils, the proactive approach to lime use and the suitability of various soil types to lime + gypsum mix.

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Legume content and sub-optimal nodulation linked to soil acidity and nutrient availability in the Mudgee region of the Central Tablelands, NSW

C Edwards[A] and B Hackney[B]

[A]Central Tablelands Local Land Services, Mudgee NSW 2850; clare.edwards@lls.nsw.gov.au
[B]NSW Department of Primary Industries, Cowra Research Station Cowra NSW 2794

Abstract: *A recent survey of pasture paddocks (n=24) in the Mudgee region of the Central Tablelands found 89% of the sub-clover plants sampled were below the industry benchmark for adequate nodulation. Soil chemical analysis of the sub-clover paddocks revealed 90% of paddocks had* pH_{Ca} *< 5.5 with 80% and 60% below the critical level of phosphorus and sulphur respectively. We propose that persistence and performance of sub-clover in this region is partly being limited by natural soil constraints, as well as current soil and landscape management factors.*

Introduction

Legumes are an important component of pastures and they support animal production in the extensive grazing landscapes of the Central Tablelands of New South Wales. Legumes can also contribute to the supply of nitrogen, an essential nutrient for plant growth and quality. The introduced cool season annual subterranean clover (*Trifolium subterraneum*) has traditionally been the most widely sown legume in these landscapes.

Previous botanical surveys of pastures on the Central Tablelands and slopes revealed that there are a wide variety of pasture types in this area. These range from native grass dominant swards, through degraded or naturalised mixtures to sown pastures dominated by introduced grasses (Kemp and Dowling 1991, Garden *et al.* 2000). These mixtures included subterranean clover (or 'sub-clover') as a pasture species.

In recent years, there has been much discussion on the factors which reduce the persistence and performance of legumes including sub-clover (Hackney *et al.* 2019, Nicols *et al.* 2007). For example, low commodity prices and/or drought in the period 1990–2009 resulted in reduced application of phosphorus, sulphur and lime. Seasonal condition variability and the timing of autumn rains (up to 2–4 weeks later, over the last 30 years) could also have an impact on germination, establishment and the ability of legumes such as sub-clover to produce adequate seed for ongoing regeneration (BOM 2019). Furthermore, soil conditions such as acidity have also been shown to affect legume nodulation (Hackney *et al.* 2019).

This paper reports on a legume survey in the Mudgee region in the Central Tablelands of NSW. The survey aimed to investigate the botanical composition of perennial-based pastures, the soil conditions of these pastures and the soil and pasture management circumstances in which they grow. In addition, the survey investigated legume nodulation. This paper reports on the sub-clover part of the survey.

Methods

In winter-spring 2017, 24 pasture paddocks were surveyed in the Mudgee region of NSW. Paddock criteria for the survey included that it contained legumes, the paddocks were used for agricultural purposes, and good management records were available. The methodology protocols were similar to the Hackney *et al.* (2019) survey. Of the 24 paddocks, 20 had sub-clover as the dominant legume.

A representative area of 20 m × 20 m was selected within each paddock. Sampling included pasture composition using the rod-point method (Little and Frensham 1993) for botanical composition. Fifteen legume plants were carefully removed for nodulation examination and scored for nodulation presence and amount using Yates *et al.* (2016). This 1–8 scale scoring system means a score of 4 (21–40 small pink nodules and/or 3–4 large pink nodules) is considered adequate. Twenty to thirty soil cores at two depths (0–10cm and 10–20cm) were taken using a push-tube 2 cm diameter sampler. These samples were kept cold (<4°C) and sent cold for analysis.

Soil and pasture management histories were collated from the participating landholders. This also included information on landholders' perspectives of legume performance.

Results

Botanical composition varied between paddocks, with the majority of the pastures being dominated by perennials (native and introduced grasses making up on average 45% of the pasture composition). The average sub-clover percentage was 18.9%, with a range of 2.5%–42.5%. The average number of pasture species found in the sample sites was 10.3.

As part of the landholder survey, pasture age since renovation (including time since seed broadcast) was examined. A larger percentage (> 63%) of the paddocks examined were sown more than 11 years ago, with 21% sown in the last five years. In terms of rhizobia inoculant delivery, 31% of participants used pre-coated seed, 10.5% used peat, 16% used none and a large number (42.1%) were unsure how the inoculant had been delivered. Of the surveyed paddocks, 42% had been supplied with fertiliser in the year of sampling. Only one had used lime in the last five years and another in the last ten years. Three paddocks had received molybdenum (Mo) in the past 10 years.

All soils were acidic, with 90% of the 0–10 cm samples having pH_{Ca} < 5.5 (Table 1). While there was no difference in the average pH between the two depths, when categorised into specific ranges, a larger proportion of samples had pH < 4.7 in the 10–20 cm sampling depth and average aluminium as a percentage of the CEC increasing with depth.

The majority of the soil samples taken at the 0 – 10 cm depth were less than the critical levels for pastures for phosphorus (80%) and sulphur (60%) based on Gourley et al. (2007) (Table 2 and Table 3). Phosphorus (Colwell P) averaged 29 mg/kg and sulphur (KCl40) 8.9 mg/kg. Potassium (Colwell) averaged of 245mg/kg and with one sample below 126mg/kg. The average CEC was 7.2 and had a range from 1.3 to 17.2.

The overall average sub-clover nodulation score was 2.1. Eighty nine percent of all sub-clover plants sampled had a nodulation score less than 4.

Landholders at the time of the survey were asked how well they believed their pasture legumes were currently performing. Fifty nine percent of the landholders responded that their legumes were 'about average', with 27% indicating that their legumes were either 'poor' or 'very poor'.

Table 1. Soil analysis (0–10 cm and 10-–20 cm depth) for pH_{Ca} and Aluminium (as a percentage of CEC) from surveyed paddocks in Mudgee region in 2017 (ranges of site values in brackets)

	pH_{Ca}	Percentage of pH in specific ranges						Exch. Al (%of CEC)
	Average	**<4.7**	**4.7–<5.0**	**5.0–<5.5**	**5.5–<6.0**	**6.0–<7.0**	**>7.0**	**Average**
0–10cm	4.85 (4.5–5.6)	40	35	15	10	0	0	6.46 (0.3–19)
10–20cm	4.87 (4.4–5.8)	47	24	12	18	0	0	11.46 (0.4–33)

Table 2: Soil analysis (0–10cm depth) for Phosphorus (Colwell) from surveyed paddocks in Mudgee region in 2017. Percentage of samples in specific ranges.

	Phosphorus (Colwell)				
mg/kg	**<30**	**30–50**	**51–100**	**>100**	**Range**
0–10 cm	70	10	20	0	6–82

Table 3: Soil analysis (0–10cm depth) for Sulphur (KCl40) from surveyed paddocks in Mudgee region in 2017. Percentage of samples in specific ranges

	Sulphur (KCl40)				
mg/kg	**<5**	**5–8**	**8.1–12**	**13–60**	**>60**	**Range**
0–10 cm	40	25	15	20	0	1.6–28.7

Discussion

Sub-clover in the Central Tablelands and slopes extensive livestock landscapes is an important legume for pasture growth and animal production. The cool season annual legume compliments the rainfall pattern and pasture types in the region. Sub-clover accounted for 2.5%–42.5% of the pasture composition. Pasture industry benchmarks defined legume content of 20–30% as ideal in a mixed pasture to fulfil the dual role of increasing sward quality and contributing to increasing soil nitrogen via biological N-fixation. While on average pastures surveyed contained sufficient legume (18.9%) according to this benchmark, it could be argued that the legume content would need to be higher to meet nitrogen fixation targets of 20–30 kg N/t DM due to less-than-adequate nodulation.

The average nodulation was 2.1 from the sub-clover paddocks; similar to that reported in a 225 paddock survey in Hackney *et al.* (2019). The Mudgee survey identified that only 11% of the sub-clover plants studied had adequate nodulation (score of 4 or above).

There was a large percentage of pastures sampled in this survey (>36%) that were > 30 years in age. Over 15% of the paddocks had never been sown but nonetheless contained legumes with the sub-clover having been self-sown, aerially sown or moved by livestock into the paddock. There was no difference in the average nodulation score between sown or self-sown paddocks in the survey.

This survey revealed a large range of legume component in pastures, tending towards the lower end of the acceptable range. However, composition can change rapidly through the seasons and is also strongly influenced by management. The type of grazing management and a previous large residual summer biomass of perennial grass species at germination, may also have impacted on germination and establishment of annual clovers. However, the herbage mass at the time of germination was not measured in this this survey.

The combination of lower amounts of legume and insufficient nodulation are essentially constraining the potential production and performance of these paddocks. Active pasture management to increase legume content is recommended including the additional supply of sub-clover seed, reduction of biomass through active grazing and pasture management in late-summer and early autumn (assuming there is a seed bank), and management at flowering and seed set.

From this survey, 90% of the soil samples recorded a pH < 5.5, with 40% a pH < 4.7. Sub-clover herbage yield has been reported to be negatively affected at a pH of 4.7 (Evans *et al.* 1990). An acidic pH can also affect nodulation and rhizobia function (Hackney *et al.* 2019, Drew *et al.* 2014). With one paddock being reported as having had lime applied in the last five years, and another in the last 10 years, this survey suggests that acid soils in the Mudgee area should be a high priority land degradation issue.

A Department of Agriculture New South Wales Soil Survey – Rylstone Bulletin (c.1964) reviewed soils in the local area to explain the persistence, or lack-thereof of sub-clover in pastures. The investigation examined alkaline soils as a possible cause of lack of persistence. The survey found that rainfall distribution and variability, the selection of suitable clover cultivars, fertiliser rates and acidic soils to be of concern for persistence of sub-clover. Fifty years on, and the same comments can also be made in regards to appropriate cultivars, soil nutrition and pH across the Mudgee region.

Mo deficiency has also potential impacts on legume performance. There is a well defined link between acid soils and Mo deficiency (Weir 2004). Improvement of acid soils to increase the availability of Mo or the use of fertilisers could address this micronutrient. Mo deficiency in perennial pastures in the area could be further investigated.

Soil nutrition is also important for legume growth and production with phosphorus and sulphur being two of the essential nutrients with linkages to the metabolism of rhizobia (O'Hara 2001). This survey found that 80% of paddocks had phosphorus levels which were less than the critical benchmarks, and 60% of sites were less than the critical benchmark for sulphur. This is notable when considering that 42% of the paddocks had received fertiliser in the year of sampling.

Conclusion

This survey reflects previous surveys and highlights some of the multitude of factors that influence sub-clover and its associated rhizobia performance and persistence. In order to keep diverse and productive perennial pastures, producers should focus on assessing pH, the appropriate soil P, S & Mo nutrition, examining -topsoil and subsoil constraints, applying soil ameliorants, grazing management (especially as relates to sub-clover germination) and understanding sub-clover seed bank longevity in order to promote sustainable and productive, legume driven pastures.

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A preliminary evaluation of perennial legume persistence on the Southern Tablelands of NSW

RC Hayes[A, F], MT Newell[B], WB Badgery[C], CA Harris[D], GD Li[A], Price[A], NR Munday[C], RS Stutz[E] and RA Culvenor[E]

[A]Wagga Wagga Agricultural Institute, Pine Gully Rd, Wagga Wagga, NSW 2650
[B]Cowra Agricultural Research and Advisory Station, Binni Creek Rd, Cowra, NSW 2794
[C]Orange Agricultural Institute, 1447 Forest Rd, Orange, NSW 2800
[D]Glen Innes Agricultural Research Station, 444 Strathbogie Road Glen Innes NSW 2370
[E]CSIRO Agriculture and Food, GPO Box 1700, Canberra, ACT, 2601
[F]Corresponding author: richard.hayes@dpi.nsw.gov.au

Abstract: *Perennial legume persistence was evaluated over three years at sites near Gurrundah, Tirranna, Middle Arm and Paling Yards on the Southern Tablelands. The persistence of white clover was the most consistent across all sites, and of 6 cultivars tested, cv. Haifa consistently had the highest year 3 frequency and cv. Nomad the lowest. Lucerne, strawberry, Talish and Caucasian clovers persisted adequately at the Paling Yards and the Tirranna sites but failed at the Gurrundah and Middle Arm sites. It remains uncertain whether any perennial legume cultivar is suitably robust to persist across a broad range of Southern Tablelands environments. The persistence values reported here are in pure swards where there is limited competition. The ability of perennial legumes to persist in these environments with a productive perennial grass is doubtful. Nevertheless, niches clearly exist for species such as lucerne for certain environments.*

Introduction

Environments across the Southern Tablelands of New South Wales (NSW) are generally considered to be high rainfall, nominally receiving >650 mm of average annual rainfall. However, there is no seasonal pattern to rainfall with similar average totals recorded for each month. In practice, this means that substantial rainfall can occur at any time during the year but periodic droughts are also common and not restricted to a particular month or season.

Temperate perennial pasture species have adaptive advantages in such environments compared to temperate annual species due to their capacity to utilise rainfall when it occurs. Established perennial plants have a root structure already in place and reserves of carbohydrates and nutrients to draw upon to facilitate early growth, potentially giving them a competitive advantage over annual species regenerating from seed that have to grow a root system with only the reserves in the endosperm from which to draw. Moreover, in Tablelands environments where pasture growth is constrained by cold winter temperatures, species that can grow beyond the confines of the normal winter-spring growing season may be at an advantage.

For these reasons it is perhaps not a surprise that the landscape of the Southern Tablelands in its native state was dominated by year-round and warm-season perennial rather than cool-season annual species (Culvenor 2009). The irony is that grazing systems still rely overwhelmingly on cool-season annual legumes to underpin production, predominantly subterranean clover (*Trifolium subterraneum*). Legumes remain the key source of nitrogen for pastures, raising the fertility of soil and increasing the quantity and quality (especially protein content) of forage for livestock. The objective of the present study was to assess the persistence of a broad range of perennial legume species that might augment or substitute for subterranean clover in Southern Tablelands environments.

Methods

Sites and experimental design

Four field experiments were sown in May 2018 near the rural localities of Gurrundah (34°38'S, 149°20'E; average annual rainfall (AAR) 700 mm), Tirranna (34°56'S, 149°41'E; AAR 670 mm), Middle Arm (34°35'S, 149°43'E; AAR

700 mm) and Paling Yards (34°10'S, 149°43'E; AAR 800 mm), all on the Southern Tablelands of NSW. The Middle Arm site is on an acidic shale-derived soil that is relatively low in P, S and K fertility. The Gurrundah site is on a deeper soil with influences from both granite and basalt parent material. Although a rich red colour, initial cores have shown that soil acidity and aluminium toxicity exist to depths of at least 1 m. The Tirranna site is on a relatively deep, acidic, sedimentary-derived soil rich in quartz stones and also low in K fertility. The Paling Yards site, by contrast, is on a red basalt soil and has few known chemical constraints, despite the existence of many basalt 'boulders' across the site. All perennial legume species were sown as a pure stand, replicated three times, as listed in Table 1. The self-regenerating annual legume, subterranean clover cv. Leura, was included as a control. Plots were 7.5 × 2 m (6 × 2 m at Tirranna), sown with a cone seeder set at 15 cm row spacings and fitted with narrow points and press wheels. Lime was surface-applied at 3.5 t/ha to all sites immediately prior to sowing and molybdenised superphosphate (8.8% P, 11% S, 0.25% Mo) was applied at 150 kg/ha at sowing to all sites except Tirranna where it was top-dressed in autumn of year 2. All cultivars were inoculated with rhizobium strain TA1 inoculum prior to sowing, except for Caucasian clover (strain CC283b), lucerne (RRI128), birdsfoot trefoil (SU343) and subterranean clover (WSM1325). Cultivars SARDI Grazer lucerne, Nomad and Tribute white clover were sown as pre-coated seed without re-inoculation. Sowing rates of each cultivar were adjusted for seed quality to deliver 2 kg/ha of germinable seed for white clover; 4 kg/ha birdsfoot trefoil, strawberry clover and Talish clover; 5 kg/ha red clover, 6 kg/ha Caucasian clover; 8 kg/ha lucerne; and 10 kg/ha subterranean clover. The same seed source was used for each cultivar across all sites. Poor seedling emergence at Tirranna required the site to be sprayed out and resown on 5 September 2018.

Sampling and analysis

Basal frequency (%) was used as an index of persistence. It was determined by laying a 1 m × 1 m quadrat, divided into 10 cm × 10 cm cells (n = 100), at two fixed locations within each plot and counting the number of squares containing the base of a sown legume, that is, cells in which shoots of a sown legume emerged from the soil surface. At the Tirranna site quadrat sizes were 1.0 × 0.75 m, divided into 10 cm × 15 cm cells (n = 50). The initial measurement

Table 1. A list of treatments tested (•) at the four experimental sites, Gurrundah (Gh), Tirranna (Ta), Middle Arm (MA) and Paling Yards (PY).

	Species	Common name	Cultivar/Line	Site			
				Gh	Ta	MA	PY
1	*Lotus corniculatus*	Birdsfoot trefoil	LC07AUYF	•	–	•	•
2	*Trifolium ambiguum*	Caucasian clover	Kuratas	•	•	•	•
3	*Medicago sativa*	Lucerne	SARDI Grazer	•	•	–	•
4	*Medicago sativa*	Lucerne	Titan 9	•	•	•	•
5	*T. pratense*	Red clover	Astred	–	•	–	–
6	*T. pratense*	Red clover	Relish	•	–	•	•
7	*T. pratense*	Red clover	Rubitas	•	•	•	•
8	*T. fragiferum*	Strawberry clover	Palestine	•	•	•	•
9	*T. subterraneum*	Subterranean clover	Leura	•	•	•	•
10	*T. tumens*	Talish clover	Permatas	•	•	•	•
11	*T. repens*	White clover	Haifa	•	•	•	•
12	*T. repens*	White clover	Nomad	•	•	•	•
13	*T. repens*	White clover	Storm	•	–	•	•
14	*T. repens*	White clover	Tribute	•	–	•	•
15	*T. repens*	White clover	Trophy	•	•	•	•
16	*T. ambiguum* × *T. repens*	White × Caucasian clover	Aberlasting	•	•	–	•

occurred in late spring in year 1, between the 12 November–10 December 2018, while the final measurement was undertaken in year 3 on 3 March at Gurrundah, 9 April at Paling Yards, 6 August 2020 at Middle Arm and 14 September 2020 at Tirranna. Data from each site was analysed individually for each sampling date with an analysis of variance.

Results

Most species established adequately in year 1 (Figure 1), despite the generally drier than average seasonal conditions received across all sites in 2018 (data not shown). There was no difference in basal frequency at the Middle Arm site with frequency of approximately 20% for all treatments. Values were similar at the Paling Yards site although frequency of Caucasian clover cv. Kuratas (11%) was the lowest of all treatments at that site and Haifa white clover (36%) was the highest. Initial basal frequency at the Gurrundah site was around 40% for the white and red clover cultivars, significantly higher than strawberry (6%), Caucasian (19%) and Talish (19%) clovers, and birdsfoot trefoil (16%). Lucerne cultivars were intermediate at that site. At the Tirranna site, there was a significant difference in frequency between treatments with up to 75% for Astred red clover and only 21% for strawberry clover.

All species had relatively higher basal frequency in year 3 (2020) at Tirranna compared to other sites although there was something of a reversal in the order of treatments at this site with strawberry clover having the highest basal frequency (95%) and Astred red clover the lowest (19%). Frequency values for all other cultivars were above 60%. A similar trend was observed at the Paling Yards site although frequency was much lower than at Tirranna, not exceeding 41%. Red clover had diminished to negligible values, as had birdsfoot trefoil in year 3 while lucerne and the white clovers (except cv. Nomad) retained the highest basal frequencies at the Paling Yards site. At the Gurrundah site, only the white clovers persisted to year 3 with basal frequency of cv. Haifa the highest (47%) and cv. Nomad the lowest (10%). At the Middle Arm site, none of the perennial legume species persisted to year 3 (Figure 1).

Discussion

The key insight from this study was that no single cultivar had uniform performance across all sites. The white clovers were probably the most consistent species across the sites, and of those, cv. Haifa consistently had the highest frequency and cv. Nomad the lowest in year 3. There was no apparent advantage in persistence of cv. Aberlasting, a white × Caucasian hybrid, compared to either white clover or Caucasian clover at any site. Lucerne, strawberry, Talish and Caucasian clovers persisted adequately at the Paling Yards and Tirranna sites but failed at the other two sites, likely associated with higher levels of acidity and at Middle Arm, lower soil fertility. The difference in performance across sites are not easy to determine, with soil type and seasonal conditions being probable contributors. This makes general recommendations of viable perennial legume species for the Southern Tablelands problematic because our study demonstrates that the best performer at one site is no guarantee of similar performance at other sites in the same region. It also probably impacts further development of perennial legume cultivars as the potential market size of any new cultivar is likely to be constrained by differences in soil type and conditions within a given region.

Care should be taken in the interpretation of frequency data because it can bias towards or against different plant forms. For example, it is likely that stoloniferous or 'creeping' plant types will have higher values of basal frequency compared to more erect types. This perhaps contributes to the relatively favorable performance of white clover in the present study. The higher apparent values reported for the Tirranna site could be partly attributed to the different quadrats used as well as the later sampling time in year 3 compared to other sites, as well as a more fertile and less acidic soil compared to the Middle Arm and Gurrundah sites. Frequency data is therefore best used as a relative measure of persistence over time at a given site. The frequency data presented here does not capture herbage yield of cultivars which

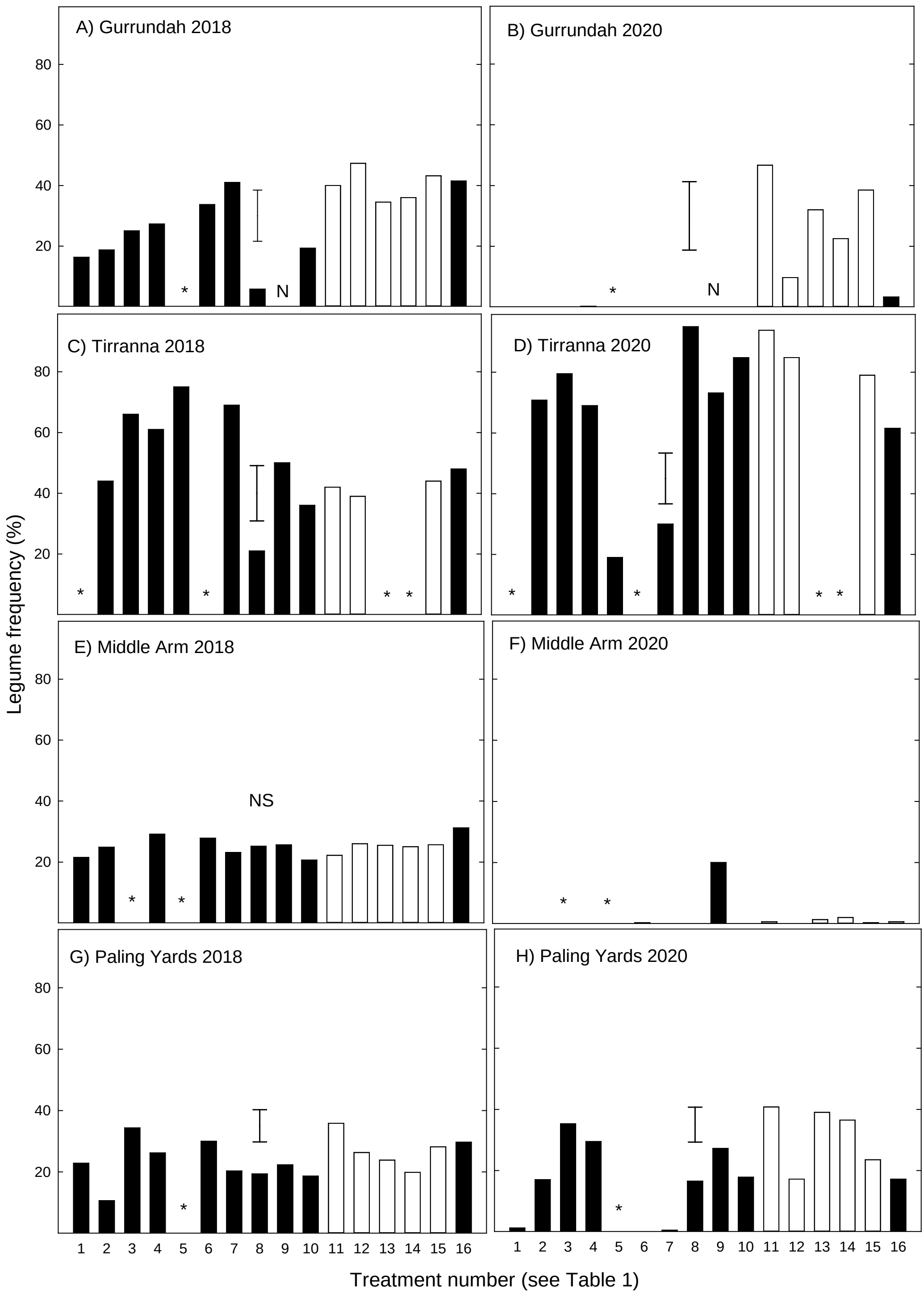

Figure 1. Basal frequency (%) of legumes at Gurrundah (A & B), Tirranna (C & D), Middle Arm (E & F) and Paling Yards (G & H) in the year of establishment, 2018 (A, C, E, G) and in year 3, 2020 (B, D, F, H). Error bars indicate significant differences at $P = 0.05$; NS, differences not significant; N, plots not sampled; *, treatment not included at that site. Species are as follows: 1, birdsfoot trefoil; 2, Caucasian clover; 3–4, lucerne; 5–7, red clover; 8, strawberry clover; 9, subterranean clover; 10, Talish clover; 11–15 (open bars), white clover; 16, white × Caucasian clover.

of course would also need to be considered in an evaluation of legumes. Nevertheless, where basal frequency is negligible as it was for most perennial legume cultivars at two of our four sites, we can assume herbage yield to also be negligible.

It remains uncertain whether any perennial legume cultivar is suitably robust to persist across a broad range of southern Tablelands environments. Our data would suggest that white clover is perhaps 'the best of a bad bunch' but even white clover seems marginal in these environments. The persistence values reported here are in pure swards where there is limited competition. The ability of these species to persist in these environments among a productive perennial grass-based sward is doubtful. This is a sobering finding when considered in the context of a previous study on the Southern Tablelands that showed there were very limited viable annual legume options besides subterranean clover (Hayes *et al.* 2015). Nevertheless, niches clearly exist for lucerne and some of the other perennial species. Further research is required to define those niches and determine the value that suitable alternative species might add to production systems in those environments.

Acknowledgments

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Investigating producer interest in and experience with tropical perennial grasses in inland NSW

K Sinclair[A,B], AL Curtis[B], SJ Baker[C] and SP Boschma[C]

[A]NSW Department of Primary Industries, Wollongbar, NSW 2477; katrina.sinclair@dpi.nsw.gov.au
[B]Graham Centre for Agricultural Innovation, Charles Sturt University, Wagga Wagga NSW 2650
[C]NSW Department of Primary Industries, Calala NSW 2340

Abstract: *Projected climate conditions and farm systems modelling suggest an extended summer-autumn feed gap for central and southern inland NSW. Tropical perennial grasses may be an effective option to fill this expected feed gap in these areas. Research has commenced to identify the key factors enabling and constraining producers to effectively trial and manage these tropical perennial grasses. Three workshops were held with experienced producers followed by two workshops with producers interested in trialling tropical perennial grasses. This paper presents some preliminary findings from these workshops. Producers identified two critical factors in establishing a tropical grass pasture: preparing a weed-free seedbed and sowing the seed as shallow as possible. Interested producers identified that they required information that was relevant for their climate and soil type. This included information relating to species selection, seasonal production and livestock performance. The experiential knowledge collected, and the identified information needs will guide research priorities so that regionally relevant packages can be developed, and appropriate support provided to producers and their advisers. Together these will reduce the uncertainty and risk for producers in central and southern inland NSW intending to trial tropical perennial grasses.*

Key words: farmers, feed gap, C4 grasses, trialling, establishment, pasture

Introduction

Projected climate conditions and farm systems modelling for south-eastern Australia (south of 33°S, east of 135°E) suggest the existing summer-autumn feed gap will be extended for red meat producers across central and southern inland NSW (Cullen et al. 2009; Moore and Ghahramani 2013; CSIRO and BoM 2015, 2018). In addition to experiencing warming temperatures, these areas are also experiencing an increase in the frequency of summer rainfall events (CSIRO and BoM 2018). To maintain productivity, additional forage options will need to be explored to address the risk associated with a reduced growing season of temperate forage species and to take advantage of summer rainfall (Cullen *et al*. 2009; Moore and Ghahramani 2013). Tropical perennial grasses may be a productive option to ensure the feedbase is sustained into the future in these areas. These grasses are responsive to summer rainfall and nitrogen applications, are persistent and recover rapidly after an extended dry period (Boschma *et al*. 2015). As well, there are species suited to a wide range of soils including acid soils (McCormick *et al*. 1998).

The multi-disciplinary research program, "Increasing livestock production by integrating tropical grasses into farming systems", is now in the fourth year of a five-year program. Field sites have been established in central and southern inland NSW to evaluate the agronomic potential of tropical grass species including digit grass cv. Premier, panic grass cv. Gatton and Makarikari grass cv. Bambatsi. A social research component in the project is exploring producer interest in and experience with tropical perennial grasses. It is also identifying the key factors enabling or constraining producers to effectively trial and manage these grasses.

The research approach for the social component is to use a mix of qualitative and quantitative methods in a three-staged approach. It was proposed to conduct a series of workshops with purposefully selected producers and key informants (Stage 1, qualitative), a broader survey of experienced and inexperienced producers (Stage 2, quantitative) and semi-structured interviews with purposefully selected producers (Stage, 3, qualitative). To date, the workshops have been completed and the survey distributed across northern and central NSW closed in mid-April 2021. The focus of this paper is on the producer workshops in which we present some important preliminary findings.

Workshop approach

Five workshops were conducted with purposively selected producers. Workshops held at Purlewaugh (near Coonabarabran), Bingara and Dubbo engaged 31 producers who had successfully established and were managing tropical grass pastures. A key outcome of these workshops was a set of 'lessons learned' (Sinclair et al. 2019). Workshops held at Orange and Cowra engaged 14 producers interested in trialling tropical grasses but have limited or no experience with these grasses. A key outcome from these workshops was a set of 'information they needed to know'.

Preliminary workshop findings

"Lessons learnt by experienced producers"

The experienced producers identified what they believed were critical 'success' factors in establishing and managing tropical grasses in northern inland NSW. Two key factors identified by these producers were:

1. Prepare a weed-free seedbed: Controlling weeds prior to sowing was critical. This may take two to three years or more if necessary, to ensure the seedbank of annual summer grasses is run down. Sowing forage and cereal crops over winter and maintaining a weed-free summer fallow was a common strategy. As one Bingara producer explained: *"We knew that pre-sowing preparation was critical. We sowed oats for two years to clean-up the country."*

2. Sow seed shallow: Sowing as shallow as possible was critical. As most tropical seeds are small, the chosen sowing method needs to place the seed just under the soil surface. As one Purlewaugh producer explained his particular sowing technique: *"Critical to sow seed shallow. From experience, [it's] fine when dropped on the ground and a press wheel following. This is one of the main reasons for failure and once a seed is too deep it isn't going to change"*.

Another three factors the experienced producers considered important included:

4. Sow small areas: Establishment costs are high and sowing small areas spreads the cost over time. It is preferable to start with the least productive country and preferably not on a heavy soil type. *"Something important for the southern blokes: we are all growing digit on lesser country"*, explained a Purlewaugh producer.

5. Store soil moisture: It is important to conserve subsoil moisture prior to sowing and to sow before an expected rainfall event. As one Dubbo producer explained: *"It's all about weed control and soil moisture … We won't sow without subsoil moisture"*.

6. Once established, maintain soil fertility: It is important to know the phosphorous, sulphur and nitrogen status by soil testing and correcting any deficiencies to ensure pasture persistence and productivity. Nitrogen needs to be applied strategically with at least an annual application or when extra feed is required. As one Purlewaugh producer explained: *"The more you feed your grasses, the better they will feed your stock. That is, healthier grasses have far higher nutritional value"*.

"What interested producers want to know"

The interested producers identified key knowledge and skills they required to assist them in their decision-making about trialling tropical perennial grasses. Critically, this information had to be relevant to their climate and soil type.

Key topics and the items interested producers identified included:

- **Establishment**: seed bed preparation, sowing window, sowing rate and depth and sowing equipment.
- **Seed:** seed availability, cost and quality (purity and viability) for the various grass species.
- **Species selection:** species selection appropriate for local conditions. For example, what species are appropriate where soil temperatures fall below 10°C in winter. Also, the potential for species mixes and legume options.
- **Soil nutrition:** soil testing for nutrient levels and fertiliser requirements to maintain pasture productivity.

- **Seasonal production and forage quality:** seasonal pasture growth rates and changes in forage quality with regrowth.
- **Grazing management:** grazing strategy to maintain persistence and livestock (beef cattle and sheep) performance.

The interested producers also identified several benefits in adding tropical grasses to their feedbase. A major benefit was the ability of tropical grasses to provide feed in summer and autumn enabling livestock to achieve targetted liveweight gains which under traditional temperate grass-based pastures (i.e. phalaris, cocksfoot and fescue) is difficult. As one Orange producer explained: *"If we can have a grass that can fill in the feed gap and can last 15–20 years … would be fantastic".*

Other benefits identified included the ability to rapidly respond to increasing summer rainfall events, provide competition for summer weeds, provide increased ground cover to reduce erosion risk and as way to more effectively utilise low productivity soils.

One constraint identified was the time required to prepare a weed-free seedbed. *"I'm interested. But my problem is that it is going to take three years for a clean paddock"* explained one Orange producer. Another identified constraint related to the perceived unavailability of high-quality seed at an affordable price. *"One of the biggest handbrakes … is seed supply … trying to get good quality seed at a fair price … it's hard"* explained another Orange producer.

These findings highlight the challenges and benefits for producers intending to include tropical perennial grasses in their feedbase. These grasses are expensive to establish requiring particular attention to controlling summer weeds prior to sowing and sowing the seed shallow to avoid an establishment failure (Lodge and Harden 2009; Lodge *et al.* 2010). They also need to be strategically managed to optimise forage quality and for long-term persistence. Using producer experiential knowledge important principles were identified that new producers can adopt to reduce their uncertainty and risk when trialling these grasses.

Conclusions

For producers in southern and central NSW tropical perennial grasses are a relatively new pasture option requiring new knowledge and skills. The experiential knowledge collected, and the information needs identified from the workshops will guide research priorities so that regionally relevant packages can be developed, and appropriate support provided to producers and their advisers in these regions. Producers intending to trial tropical grasses will have the capacity and confidence to successfully trial tropical perennial grasses.

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Soil water dynamics and water use efficiency of tropical pastures in Central West NSW

MJ Uddin[A], WJ Smith[A], SR Murphy[B], SP Boschma[B] and Y Alemseged[A]

[A]NSW Department of Primary Industries, Trangie, NSW 2823: Jasim.Uddin@dpi.nsw.gov.au
[B]NSW Department of Primary Industries, Calala, NSW 2340

Abstract: *Studies in northern New South Wales (NSW) demonstrated that tropical pastures can improve pasture productivity and resilience of grazing enterprises. Producers in Central West NSW are highly interested in these species due to their persistence, ability to respond to summer rainfall and production of large quantities of feed for livestock. This paper compares the soil water use, herbage production and water use efficiency (WUE) of three species of tropical perennial grass with lucerne (Medicago sativa) and an annual summer forage over the 2020–21 spring-summer growing season. Bambatsi panic (Panicum coloratum) had the highest total water use (486 mm), while lucerne had the lowest (460 mm). Digit grass (*Digitaria eriantha*), Gatton panic grass (*Megathyrsus maximus*) and Sudan grass (*Sorghum sudanense*) had similar water use (468–473 mm). Bambatsi panic produced the maximum herbage mass (18789 kg DM/ha), while lucerne produced the minimum (6317 kg DM/ha). Digit grass, Gatton panic and Sudan grass produced similar herbage mass (~15400 kg DM/ha). Water use efficiency was highest in Bambatsi panic (39 kg DM/ha/mm) and lowest in lucerne (14 kg DM/ha/mm). Sudan grass, digit grass and Gatton panic had similar water use efficiency (32–34 kg DM/ha/mm). All the species extracted stored soil water to a depth of 1.8 m, but Bambatsi panic extracted the greatest volume (116 mm). Our experiment will continue for three years.*

Key words: tropical pasture, herbage mass, water use efficiency

Introduction

Producers in Central West New South Wales (NSW) have shown great interest in tropical perennial grasses and legumes recently, with high attendance at field days. While the Koeppen climate class of this region is primarily temperate with no dry season, rainfall seasonality varies between a slight summer dominance in the north (Coonamble) to a slight winter dominance in the south (Grenfell) (Rawson 2016). The floodplains in the north of the region are subtropical, while higher elevations of northern slopes have warm summers. This region has a medium annual rainfall (400–600 mm), with winter rainfall generally more effective than summer rainfall. Studies of tropical grass and legume species in northern NSW have shown that they are both productive and resilient (Boschma *et al*. 2015; Murphy *et al*. 2018). This is significant, especially in a changing and highly variable climate. Producers are interested in adopting these grasses into their grazing systems, however, there is little quantitative data on their growth, productivity and soil water dynamics in this medium rainfall region. Our study's objective is to quantify the herbage production, water use dynamics and water use efficiency of several tropical perennial grasses with lucerne (*Medicago sativa* L.) and an annual summer forage in Central West NSW. In this paper we reported findings from the 2020–21 spring-summer growing season.

Methods

A randomised complete block design experiment, with five treatments and three replications, was established at the Trangie Agricultural Research Centre (31°59'40.53"S, 147°56'20.65"E, 215 m elevation). The soil is a brown Chromosol (Isbell 1996) with soil pH 5.1 and 1% organic carbon (Boschma *et al.* 2018). The average annual rainfall in the study area is about 490 mm without distinct seasonality. The site was maintained as a weed-free fallow for two months before establishing the experiment. The treatments consisted of three species of tropical perennial grass (Bambatsi panic (*Panicum coloratum* L.) cv. Bambatsi, Gatton panic (*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs) cv. Gatton, digit grass (*Digitaria eriantha* Steud.) cv. Premier), a summer-growing temperate perennial legume (*Medicago sativa* L. lucerne cv. SARDI Grazer) and a summer-growing annual forage (Sudan grass (*Sorghum sudanense* (Piper) Stapf) cv. Bankers). Each plot is 6.6 x 5 m, arranged in three rows of five plots (33 x 15 m). The perennial grasses were sown in early November 2019. Lucerne was first sown in autumn 2019, but failed due to fungal disease and was resown in November 2020. Sudan grass was sown in December 2020. All species were sown at industry recommended rates. The plots were mulched with sugarcane mulch to provide some cover for the emerging seedlings, (2000 kg DM/ha). The plots were irrigated with 20 mm of water every five days over four weeks, with 100 mm of water applied in total to assist with pasture establishment.

An aluminium access tube was installed in the centre of each plot to a depth of 2.0 m in August 2020 to measure changes in soil water content. Soil water content was estimated at 3-week intervals using a neutron moisture meter (CPN 503DR Hydroprobe; Boart Longyear Co., Martinez, CA, USA), calibrated for local conditions (Mc Kenzie *et al.* 1990). Neutron moisture meter readings were taken in the middle of 0.2 m layers down the soil profile (i.e. 0.1–0.3, 0.3–0.5,…,1.7–1.9 m). Total stored soil water for the profile (0.1–1.9 m) was calculated by summing values for each layer. Stored soil water changes and total herbage production were determined for 13 August 2020 to 8 March 2021 for the 2020-21 spring-summer growing season. Rainfall and temperature data were collected from the Bureau of Meteorology weather station located about 1 km from the study site. Water use efficiency (WUE, kg DM/ha/mm) of total herbage production (kg DM/ha) was calculated by dividing total dry matter by total water use. Herbage production was assessed every 6-weeks from September 2020 using a calibrated visual assessment technique in 4 strata of each plot, similar to Murphy *et al.* (2018). After each assessment, herbage was removed using a rotary mower to a height of 50 mm for all species except Sudan grass which was cut to 70 mm.

Results and discussion

Rainfall in the 2020–21 growing season was well above average with total rainfall for September–March approximately double the long-term average (459 *v.* 234 mm) (Figure 1a). For February and March alone, monthly rainfall was nearly three times the long-term average (135 *v.* 50 mm) and (127 *v.* 42 mm), respectively. In months with above-average rainfall, mean maximum temperatures were slightly below average (Fig. 1b). Minimum temperatures were similar to the long-term average apart from January and February when temperatures were below average.

At the start of the growing season (August 2020), soil water content was consistent among the treatments and increased gradually with depth (0.24–0.26 m^3/m^3) (Figure 2). By the end of the growing season (March 2021), all treatments were significantly drier to a depth of 1.8 m. Over the five months, Bambatsi panic extracted 116 mm of stored soil water, followed

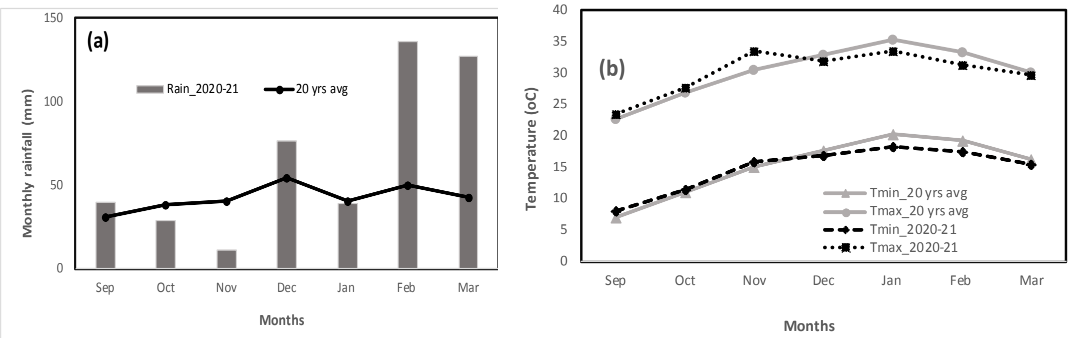

Figure 1. (a) Monthly and long term average rainfall (mm) received at the study site, and (b) monthly and long term average maximum and minimum temperatures (oC) recorded at the study site September 2020–March 2021 and the 20-year averages.

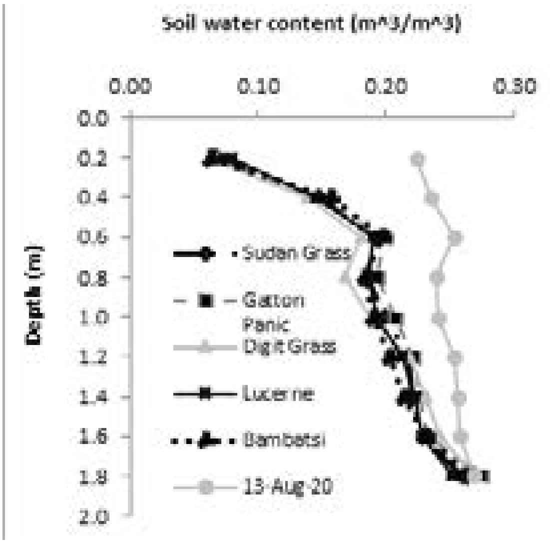

Figure 2. Soil water content (m³/m³) at the start of the season (average of all treatment on 13 August 2020) and each treatment at the end of summer (8 March 2021)

by digit grass (104 mm), Gatton panic (101 mm), Sudan grass (99 mm) and lucerne (91 mm). All treatments extracted more soil water from the upper profile (0.1–0.7 m, Figure 2), representing about 60% of total extraction. Extraction from the middle and lower layers represented 28% and 12%, respectively (Table 1). Bambatsi and digit grass extracted more water from the middle and lower profile layers (42–47 mm) than the other species (36–39 mm).

Bambatsi produced the highest total herbage mass (18793 kg DM/ha), while lucerne produced the least (6317 kg DM/ha). Low productivity of lucerne is to be expected in an establishing stand. Digit grass and Bambatsi panic produced a similar amount of herbage in spring, but digit grass lagged behind Bambatsi panic during summer. Herbage mass varied for specific assessments, but the total herbage production was similar for digit grass and Gatton panic. Total herbage mass of Sudan grass sown in November was higher than Gatton panic and digit grass (Table 2). The low cutting height (70 mm) used for Sudan grass likely impacted its regrowth and subsequently, its total production. A higher cutting height of 150 mm for Sudan grass is more in line with commercial practice, and will be used in future seasons.

For the 2020–21 growing season, total water use by Sudan grass and lucerne (460 and 468 mm, respectively) was less than other treatments (Table 2). The water used by the three tropical perennial grasses was similar (486, 473 and 470 mm, respectively). The subsequent water use efficiency was highest for Bambatsi panic (39 kg DM/ha/mm), while those for digit grass, Gatton panic and Sudan grass were similar to each other (33, 32 and 32 kg DM/ha/mm, respectively). Lucerne, by contrast, had a low

Table 1. Changes in stored soil water (mm) for different soil layers between the start of the season (13 August 2021) and the end of summer (8 March 2021).

Soil profile layer (m)	Sudan grass	Gatton panic	Digit grass	Lucerne	Bambatsi panic
0.1–0.7	60	64	62	52	69
0.7–1.3	27	26	30	26	33
1.3–1.9	13	11	12	13	14
0.1–1.9	99	101	104	91	116

Table 2. Herbage mass (kg DM/ha) and components of the water balance used to calculate water use efficiency (WUE, kg DM/ha/mm) for treatments during the 2020–21 growing season. Water balance components are rainfall (mm), profile stored soil water (0.1–1.9 m, SSW, mm) at the start (13 August 2020) and end (8 March 2021) of the growing season, total water used (mm) and water use efficiency.

Treatment	Total herbage mass (kg DM/ha)	Rainfall (mm)	Start SSW (mm)	End SSW (mm)	Total water use (mm)	WUE (kg DM/ha/mm)
Bambatsi panic	18793	370	457	341	486	39
Digit grass	15282	370	442	339	473	32
Gatton panic	15090	370	454	354	470	32
Lucerne	6317	370	432	342	460	14
Sudan grass	16094	370	442	344	468	34

water use efficiency of 14 kg DM/ha/mm. The data presented in this paper are for spring and summer, however in this zone the full growing season of all these species also includes autumn. Therefore, the data presented here do not represent total growing season production. Lucerne is a particular case. Lucerne is a 'summer active' legume, the optimum temperatures for lucerne growth are 25–30°C (Moot *et al.* 2008), therefore greater production in spring and autumn would be likely.

Conclusions

Our preliminary data provide a snapshot of the water use, herbage mass and water use efficiency of a range of perennial and annual pasture and forage species over a single spring-summer growing season. Based on the WUE data we found that Bambatsi panic had higher WUE followed by Sudan grass, digit grass and Gatton panic. Lucerne had the lowest WUE for this summer-based growing season. Measurements will continue for the next 2-years to determine the relative differences in total production, WUE, and persistence of these species.

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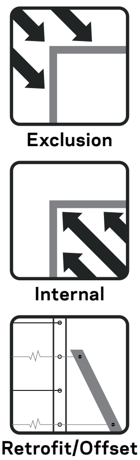

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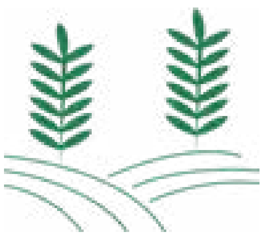

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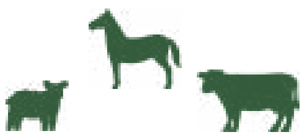

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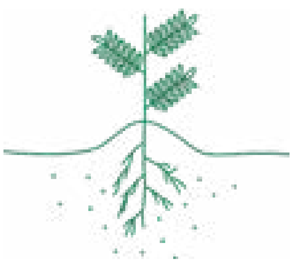

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