



Transitioning from annual fodder crops to perennial pasture in a beef cattle system

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Executive Summary

This report investigates whether beef producers on the North-West Slopes of NSW, a transitional climatic zone sitting between the temperate Northern Tablelands and the sub-tropical North-West Plains, can improve their feedbase by shifting away from annual fodder crops toward temperate perennial pasture, while maintaining productivity and profitability.

Three objectives guided the research: whether improvements can be made by transitioning to perennial pasture; how temperate species can be better managed in a transitional climate; and whether such a transition is viable while maintaining production and profit.

The traditional North-West Slopes system pairs winter annual fodder (predominantly oats) with summer sub-tropical perennial pasture. Several pressures are prompting producers to reconsider this model: rising social and market expectations around sustainability credentials, the higher fertiliser and fuel cost exposure of cropping-intensive systems, and the emergence of Australian Carbon Credit Unit opportunities tied to converting cropland to permanent pasture. But arguably the fundamental key driver is business profitability. Producers are assessing whether the system they're using is optimising productivity and profitability.

A comparison of feed quality showed forage cereals and temperate perennial pastures are broadly comparable in crude protein and metabolisable energy at the vegetative stage — meaning the choice between them hinges less on raw feed value and more on productive duration, seasonal timing, and input cost.

Case studies from Australia, Uruguay, Argentina and the USA revealed a range of approaches to managing temperate pastures in variable environments. High grazing density and daily rotation supported legume-driven nitrogen cycling without fertiliser input; tightly integrated pasture and cropping rotations (Uruguay) prioritised shorter-term persistence (three to four years) over the ten-plus years Australian producers typically expect; and adaptive, rather than prescriptive, grazing management (USA) delivered materially more grazing days. A recurring theme was that reducing the expectation of long-term persistence, in exchange for higher productivity (a combination of dry matter and feed quality) over a shorter pasture life, may make temperate pastures more competitive with annual cropping in this environment.

Key agronomic considerations examined include persistence expectations, adaptive grazing and rest strategies, the limited local success of pasture cropping (constrained by lower and more variable rainfall than comparable systems overseas), and the nutrient dynamics between legumes and companion grasses — particularly the phosphorus, sulphur and potassium requirements needed to sustain legume-driven nitrogen fixation, and the additional fertiliser demands of high-value herbs such as chicory and plantain, which do not fix their own nitrogen.

Ultimately, this research concludes that annual fodder cropping cannot be totally replaced by temperate perennial pasture on the North-West Slopes. Rather, a patchwork feedbase, combining improved annual and perennial systems, informed by adaptive management and realistic persistence expectations, offers the most viable path to optimising feed availability throughout the pasture growth curve and maintaining productivity and profitability in this variable, transitional environment.

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Keywords:

Perennial – a plant that lives for more than two years, coming back to grow and bloom year after year

Annual – a plant that completes its entire life cycle—from sprouting to making seeds and then dying—within a single growing season or year

Sward – the upper layer of soil covered by grass and other low-growing plants used for grazing livestock

Persistence – the ability of sown plant species to maintain their density and dry matter production over time, ensuring long-term farm productivity and preventing weed invasion

Temperate – mid latitudes, between sub-tropical and polar regions

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Foreword

I was born into the fifth generation on a wool growing property in the South East of South Australia, the daughter of an introverted and curious agriculturalist father and a passionate educationalist mother. I was also the granddaughter of an amateur archaeologist come botanist come saxophonist, who dabbled in sheep farming. The loss of my grandfather saw the family farm sold and my parents began their independent farming journey. This featured their own farm for a time, before interest rates and wool prices directed my father into a career of advising, corporate agriculture management and eventually a later in life venture into agronomy and soil science. This also meant a move to the New England North-West region of NSW which I have called home ever since.

On finishing high school, I knew my future lay somewhere outdoors and having inherited my grandfather's interests in plants and the natural world, I studied a Bachelor of Environmental Science. My career began in natural resource management and ecology, before an opportunity in research and extension welcomed me into the Australian cotton industry where I pivoted to agronomy and completed my Master of Science in Agriculture.

In early 2019 in the grip of a horrific drought, my son and I relocated from Moree to Myall Creek to be with my now husband on his family beef property. This move also prompted me to take up an agronomy position with McGregor Gourlay in nearby Inverell. It was a privilege to live and work in my local community, both as a producer and an agronomist. But this was a different farming system to where I was previously working and I had to learn quickly about the complexities of mixed farming.

The beef production system on the North-West Slopes consists of a patchwork of annual fodder crops, improved subtropical pasture, to a lesser extent improved temperate pasture and native pasture. Annual fodder cropping of predominantly winter cereals in this area works well, achieves excellent weight gain and is agronomically a relatively simple system. It can be complemented nicely by grazing improved subtropical pastures in the summer. However, the cost of this production system is increasing, and soil fertility is declining, so I wanted to investigate how perennial pastures can fill this gap. In particular, how to effectively integrate more temperate (winter growing season) pastures and maintain or exceed the productivity we currently have with the annual system. Faced with the same questions each day from my clients that my husband and I were grappling within our own business, I applied for a Nuffield Scholarship to endeavour to find a way to improve our production system. I was also hopeful for a journey of self-discovery, and my Nuffield experience has certainly delivered that.

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Table 1. Travel itinerary

Travel date	Location	Visits/contacts
March, 2025	Australia: Ebor NSW	Wilmot Field Day
March 3 – 6, 2025	Australia: Canberra ACT	Pre-Contemporary Scholars Conference
March 8 – 15, 2025	New Zealand: Auckland	Contemporary Scholars Conference
May 15 – 22, 2025	Singapore	GFP
May 22 – 27, 2025	Indonesia: Lampung	GFP
May 27, 2025	Qatar: Doha	GFP
May 27 – 31, 2025	United Arab Emirates: Dubai	GFP
May 31 – June 8, 2025	Germany	GFP
June 8 – 17, 2025	USA: Michigan & Washington DC	GFP
June 17 – 22, 2025	Mexico	GFP
August 3 – 5, 2025	Argentina	9 de Julio: 'Estancia Las Chicas' Alejandro Mulcahy, dairy farm Bolivar: Alfreo & Maria Alzueta, beef production
August 5 – 9, 2025	Uruguay	Colonia: 'La Reserva', beef production Colonia: Guillermo Newton, beef production Colonia Rosell y Rius: 'El Coraje', Brangus beef, seed stock & pasture seed production Trinidad: 'San Ramon' Apeo, beef production
August 14, 2025	USA: San Francisco	University of California, Davis: Professor Patrick

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		Brown, biological fertiliser solutions
August 18 – 29, 2025	USA: Texas	Texas A&M, Overton: Dr Vanessa Corriher-Olson, pasture research & extension Comanche: Dudley Brothers Ranch, beef & seed stock production Desdemona: GKB Ranch, beef, seed stock & hay production Muldoon: Triple JR Cattle Co, beef & seed stock production Hungerford: JD Hudgins Inc, regenerative beef & seed stock production
	USA: Oklahoma	Noble Research Institute: Dr Hugh Aljoe, regenerative agriculture research & extension
	USA: Mississippi	Petal: Nature's Gourmet Farm, vertically integrated regenerative production
	USA: Georgia	Bluffton: White Oaks Pastures, vertically integrated regenerative production
December 2025	Australia: Victoria	Hamilton: Hamish Roberston, wool & lamb production
June 2026	Australia: Queensland	Texas: Daryl Cleave, irrigated pasture & beef production

Acknowledgments

I want to first and foremost thank the Nuffield NSW and Nuffield Australia panels for having faith in me to take on this journey and for providing the framework and support throughout my Scholarship. Thank you to Woolworths Group for supporting my scholarship and for seeing value in the problem I was trying to solve, as well as seeing value in my role as a producer and an advisor.

To all the many people I have met over the course of this Scholarship, thank you for welcoming me into your homes and businesses and for allowing me to learn from your knowledge and experience. To rest of my 2025 cohort, I am so privileged to call you friends and to have shared this experience with a group of such impressive individuals – I have felt out of my league on countless occasions.

Thank you to McGregor Gourlay for supporting me in furthering my development and to all of my clients who patiently put up with my absences and allowed me to regale them with my tales on my return.

To my Mum and Dad, thank you for being rockstar grandparents to allow this experience to be possible, for your guidance and counsel over my whole life, and for instilling a passion for agriculture in me. To Trevor and Colleen for giving Dane and myself the opportunities that you have, and for imparting your knowledge and wisdom on us both. And to Dane, for always encouraging me to stretch myself and for your unwavering belief. Thank you for letting me tear you away from the farm to join me on my individual travels, so that we could build a vision of our dream together.



Figure 1 – Author (Source: Author)

I acknowledge the use of Claude AI in this report. All recounts, opinions and recommendations are my own.

Abbreviations

NSW	New South Wales
Ha	Hectares
DM	dry matter
ME	metabolisable energy
MJ	megajoules
Kg	kilogram
K	Potassium
N	Nitrogen
P	Phosphorus
S	Sulphur
C	Carbon
Ca	Calcium
LWG	liveweight gain
ACCU	Australian Carbon Credit Units

Objectives

- To investigate whether there are improvements to be made by transitioning away from annual fodder crops to perennial pasture.
- To investigate how temperate pasture species can be better managed in a transitional climate.
- To assess whether it is viable to replace annual fodder crops with improved perennial pasture in a beef cattle system and maintain productivity and profitability.

Chapter 1. Introduction

1.1 The current system - The North-West Slopes of NSW

The grazing of modified pastures occurs across 21,490,000 hectares (ha) in Australia, accounting for just under 5% of total agricultural land use, while the grazing of native vegetation is much more vast covering 361,000,000 ha (ABARES, 2026). The definition of “modified pasture” is extremely broad, as it can encompass sown permanent pasture and intensive annual fodder crops, as well as fertilised, ameliorated or direct seeded native pasture. For this reason, the productive capacity of modified pasture varies greatly across regions and environments. The regions which utilise modified pasture for livestock production, do so to increase this productive capacity, relative to the value of land and scale of operations.

The variability of production potential in modified pasture for beef production is evident throughout many different landscapes across Australia, but the focus for this report is the North-West Slopes of New South Wales. To the east of this area lies the Northern Tablelands of NSW, where elevation reaches up to 1300m and the land use is dominated by sheep and cattle production on mainly modified pasture. To the west the North-West Plains consist of vast alluvial floodplains and deep vertosol soils dominated by broadacre and irrigated cropping, with livestock production on mainly native pasture. The Slopes in the middle, where this report is centered, vary in elevation around 300-800m and average annual rainfall around 650mm (NSW DPI, 2014). Whilst technically a summer dominant rainfall pattern, seasons are variable and this region fits more accurately into the transitional climatic zone.

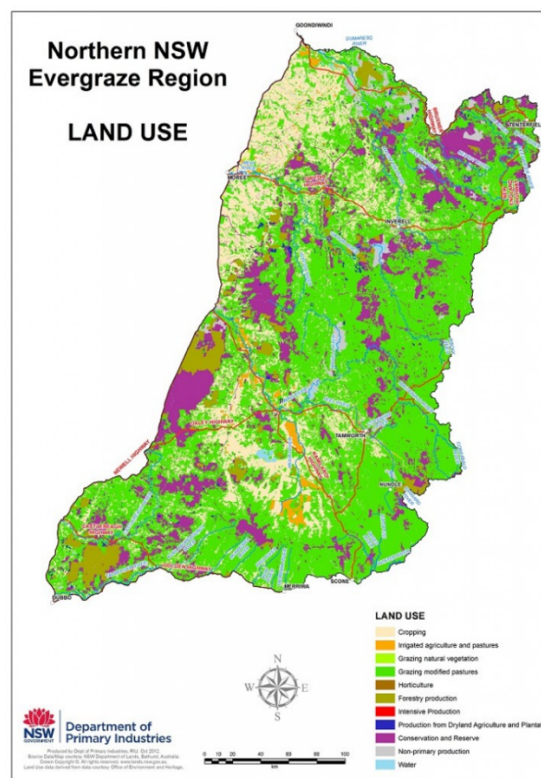


Figure 2 - Primary land use in the Northern NSW EverGraze region. (NSW DPI, 2014)

Landuse across the North-West Slopes is dominated by mixed farming enterprises, consisting of mainly beef cattle but also some wool and lamb production, intertwined with broadacre cropping for grain or other cash crop production as well as intensive annual fodder for grazing and hay. The transitional environment allows both summer and winter growing seasons for the production of a wide variety of crops such as wheat, barley, oats, chickpeas, canola, faba beans, linseed, sorghum, dryland cotton, soybeans, mungbeans, corn and sunflowers. Annual fodder production has traditionally been dominated by oats, but newer forage varieties of wheat and barley are becoming increasingly utilised in the winter, as well as annual ryegrass and forage brassicas. In the summer, forage sorghum is often used, as well as millet and legume options of cow peas and lablab.

For the purposes of this report, beef cattle production will be the focus enterprise. Beef production on the North-West Slopes consists of both breeding and backgrounding cattle, with many businesses having a combination of the two and fluidity depending on seasonal conditions and market drivers. With feedlots located within the region and within relative proximity in neighbouring areas, it is common for cattle to be sold at feeder weight into this market. As this report will assume a grassfed or grain assisted production system, the challenge in this region exists to maintain production across the year. The research for this Scholarship has been undertaken with the assumption that feed is required year-round and the breeding or trading system isn't going to be altered to mitigate this. The approach has been from primarily an agronomic perspective, with the focus on using agronomic principles to support the production and utilisation of feed, with ruminant nutritional principles accounted for as assumed knowledge.

1.2 Filling the feed gap in a transitional environment

A “transitional climate environment” is a term used to describe a geographical region characterised by highly variable weather patterns and ecological communities that are adapted to fluctuating conditions (The Intergovernmental Panel on Climate Change, 2022). Figure 3 highlights the North-West Slopes of NSW and shows that the region covers an area classified as both temperate (no dry season, hot summer) and subtropical (no dry season). Characteristics of these two classifications manifest in summer dominant rainfall, but cool winters with adequate rainfall for pasture growth. In practical terms, the region has both a summer and winter growing season, which presents opportunities and challenges in feed production.

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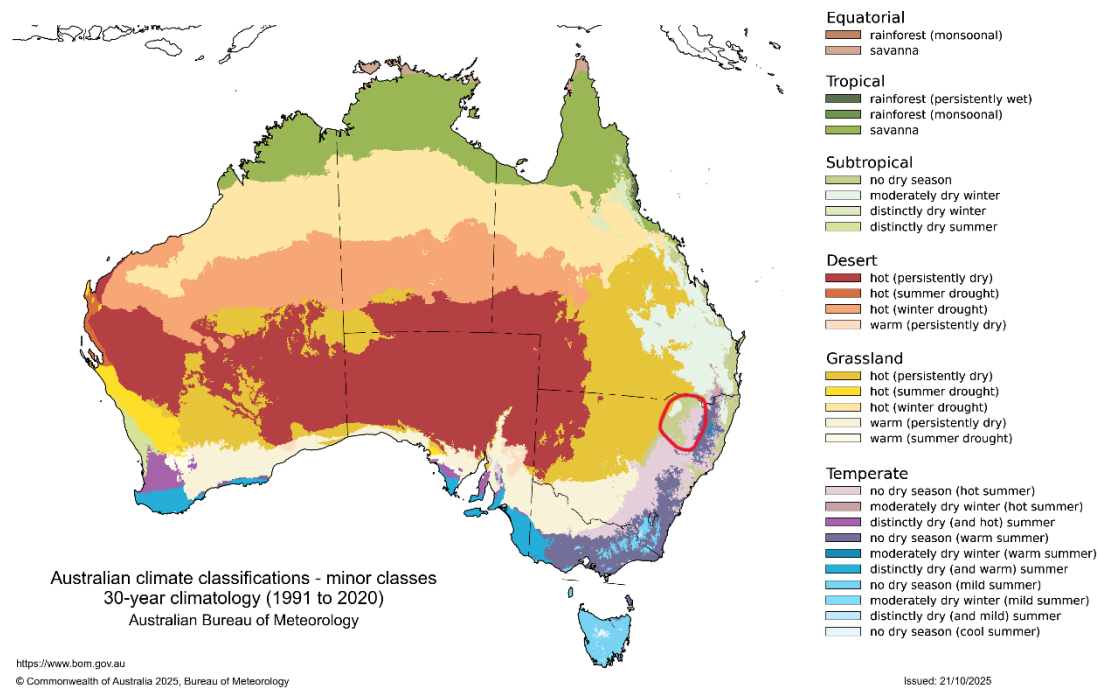


Figure 3 - Koppen minor zones (Australian Government - Bureau of Meteorology, 2026) showing the North-West Slopes of NSW outlined in red.

The traditional system for beef production on the North-West Slopes is an annual fodder crop (usually oats) in the winter and into spring, and either native or improved sub-tropical pastures in the summer and autumn. Native grasses are generally C4 grasses, which are actively growing in the summer and not tolerant to frost. Native medics and clovers are common however they are season dependent in terms of their productivity and can pose risks of bloat in their most productive seasons. Native pastures are productive in the summer, but for high production or fattening of livestock, many producers incorporate annual fodder such as forage sorghum into their summer feed program. The introduction of sub-tropical perennial grass species over the last 20 to 30 years has proven largely very successful in the area. These improved pastures provide high quality feed, do not require resowing annually, are responsive to fertiliser applications and can also provide dry feed and under-sown legumes for continued production into the autumn and winter. These deep-rooted perennial species are also typically far better placed to extract moisture from lower soil profiles during dry periods than shallow-rooted annuals, giving the system more resilience to exactly the kind of rainfall variability that characterises this region.

Winter on the North-West Slopes is milder than the Northern Tablelands further to the east, which as shown in Figure 3 has a temperate climate with again no dry season but a warm, as opposed to hot summer. Temperate perennial pastures based around grass species such as *Phalaris spp*, cocksfoot (*Dactylis glomerata*), tall fescue (*Festuca arundinacea*) and Italian, hybrid or perennial ryegrass (*Lolium spp*) are common on the Northern Tablelands. They often also include a mix of brassicas, herbs and legumes for additional protein and soil fertility benefits. These pasture mixes are actively growing from late summer, early autumn right through to late spring. Whilst growth rates slow in winter, the key to persistence with temperate species is a mild summer, which is typical of the Northern Tablelands and in contrast to the higher temperatures of the North-West Slopes.

Extensive research, plant breeding and variety development has been undertaken in temperate pasture species by Universities, Government departments and seed companies. This information has been widely disseminated and is freely available. However, much of this research has been undertaken in Southern NSW and Victoria where rainfall is more winter dominant. Whilst these areas can also experience hot summers, the drier conditions tend to mean that grasses are dormant at this time. By contrast, the North-West Slopes receive more rainfall in the summer, which allows the grasses to continue actively growing, but are then met with summer temperatures which are too high and many individuals will be lost. Ultimately, this affects the persistence of such pasture mixes and has made it difficult to achieve lasting results from the investment made in temperate pastures. Herein lies the problem; can producers successfully fill the winter feed gap without annual fodder crops on the North-West Slopes of NSW? And if they can, are the strategies employed to achieve this transferable to other regions that may also not fit neatly in a classified, more consistent climatic zone?

In selecting locations to visit to undertake the research, the author endeavoured to prioritise places with a similar latitude and climatic environment. This highlighted that it was challenging to find locations with similar climatic conditions, in particular rainfall averages and patterns. Nonetheless, the locations that were visited presented relevant learnings and perhaps even highlighted how unique Australia is in regard to rainfall variability and the impact that this has on agronomic decision making.

Chapter 2. Are there improvements to be made by transitioning away from annual fodder crops to perennial pastures?

2.1 The feed value of perennial pasture versus annual fodder

Whilst the focus of this research is on the agronomics of feed production and how to best grow temperate perennial pastures in a transitional environment, the decision to make the change firstly needs to consider the feed value of pasture and annual fodder options, as beef is ultimately the commodity being produced. The realised value and success of these options will of course depend on how effectively they can be grown and managed, but Table 2 provides a comparison on average expected feed quality for the most common temperate pasture species and winter fodder crops on the North-West Slopes of NSW. These values represent the vegetative phases when grazing should most commonly occur.

The productivity of a pasture is determined by the nutritive values of crude protein (CP) and metabolizable energy (ME). Fibre content is also important but is secondary to CP and ME in terms of weight gain. Understanding these values allows the producer to anticipate weight gain and plan grazing according to their animal's growth requirements at any given life stage (Meat & Livestock Australia, 2026).

Table 2: Average feed quality of temperate pasture species and common annual fodder crops. Adapted from (Fulkerson, et al., 2007) (Harris & Lowein, 2007) (Agriculture Victoria, 2024) using Claude AI.

Species	Crude Protein (%DM)	ME (MJ ME/kg DM)	Notes
Phalaris	10-25	10-11.5	High ME when leafy; declines with maturity and summer dormancy
Perennial ryegrass	18-28	10.5-12	Among the highest ME of temperate grasses; quality drops sharply once it seeds
Annual/Italian ryegrass	12-22	10.5-12.5	Fast-growing, very high quality when young; often matches or slightly exceeds perennial ryegrass early on, but quality falls quickly once it heads
Tall fescue	14-22	9.5-11	Slightly lower ME than ryegrass; more persistent through heat/drought, quality declines less in summer
Cocksfoot	12-20	9.5-10.5	Generally lower ME/CP than ryegrass; becomes stemmy and less digestible quickly if not grazed early
White clover	15-30	9.5-12	Very high CP, especially leaf; ME can dip in summer-autumn; leaf:stem ratio strongly drives protein content
Red clover	16-20	10-12	High CP and ME, especially at young leafy stage; more rumen-undegradable protein

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			than white clover; suits silage/hay as well as grazing
Plantain	15-22	11-12.5	Very high ME, often exceeds grasses; digestibility stays high even as it matures
Chicory	18-28	11.5-13	Among the highest ME and CP of all these species; deep-rooted, high quality through summer
Forage oats	15-25	10-12	High quality at vegetative/early boot stage; declines fast once stem elongation/heading starts
Forage barley	13-20	9.5-11.5	Similar pattern to oats; slightly lower ME typically; good early bulk
Forage wheat	12-20	9-11	Generally lower ME/CP than oats at comparable stage; more winter-hardy
Forage brassica	18-28	11-13	Very high ME and CP, especially leaf component; stems are lower quality, so whole-plant value drops with maturity

The comparisons between grass species demonstrate that perennial ryegrass provides the most feed value. However, the moderate rainfall and hot summers of the North-West Slopes means that perennial ryegrass does not perform well and is generally excluded in this environment as a viable option (Milne, 2024). Tall fescue or Phalaris are the next best options, with Phalaris anecdotally the most commonly used in this transitional environment, with (at least perceived) increased persistence. Farmer experience in Argentina and Uruguay suggested that cattle will preferentially graze tall fescue over Phalaris. There isn't the same general consensus in Australia, with some producers agreeing whilst others maintain that cattle much prefer Phalaris over fescue. The distinction should also be made between Continental tall fescue which is summer-active and winter-dormant, and Mediterranean tall fescue which is winter-active and summer-dormant. The Continental type was dominant in South America, similarly to Southern NSW and Victoria, but Mediterranean would better fit the North-West Slopes region, filling the winter feed gap which is the goal, whilst also protecting the persistence by being dormant during the hot summers.

White and red clover offer good quality feed, but this must be managed for the risk of bloat, which can quickly prove deadly to cattle. Plantain and chicory also boast good nutritive qualities but have traditionally more commonly been used in sheep or Southern Australian beef and dairy systems. One agronomic drawback of these two herbs is that their incorporation into a pasture will remove many herbicide options for weed control so this must be a consideration in their selection.

Of particular note in this table, is the comparison to the forage oats, barley, wheat and brassica. There is not a significant amount of difference in the feed quality of these crops with the perennial pastures. Depending on the sward mix of pasture, or even a mixed annual forage for that matter, both annual and perennial will provide good quality cattle feed when grazed at the appropriate times. The following questions must then be asked when assessing the options:

- For how long is each species in its most productive phase?
- At what time of the year and how quickly is feed available?

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- What is the resourcing cost (sowing, spraying, fertilising, labour etc) to achieve production from each species and how does this balance against productivity and/or persistence?

This research also highlighted that when it comes to species mix and diversity, more is not always better. Rather, it is best to ensure that different plant species within a sward complement each other rather than compete. Whilst some advice will suggest that as much diversity as possible will encourage diversity in soil biology (which granted, is important), a quote that stood out to the author came that from a reputable source within the pasture seed industry was,

“The only people who make money from multi-species cover crops are seed companies.”

It is food for thought in terms of focusing on the pasture species that are most valuable in a producer's own system.

2.2 Cost of production

The cash (or input) costs to Australian farms are often broken down to the “Four Fs”; fertiliser, fodder, fuel (including oil and grease) and freight. Meat and Livestock Australia report that fodder and freight are the dominant pressures for Australian cattle farmers, whereas for cropping enterprises this flips to fertiliser and fuel (Meat & Livestock Australia, 2026). However, as an industry wide assessment, this statement would likely be skewed by less intensive systems, rather than those typical of the North-West Slopes where a cropping system (and improved pastures) require higher inputs of fertiliser and fuel and may be more exposed to price rises. Nonetheless, the four F's account for around 23% of total costs in cattle businesses, and 32% in cropping businesses. This means that any rise in input costs are likely to have significant impact on profitability. If there are input cost savings to be made by switching from an annual fodder system to perennial pastures, then this could be an important driver.

Table 3 breaks down the approximate current (2026) costs of producing both systems of feed in one year. In an annual fodder system, these costs will be incurred each year, whereas the initial establishment year for a perennial pasture will be higher than subsequent years. Assuming the perennial pasture has a productive lifespan of five years, this averages out to approximately \$230/ha/year. Using industry standard data on overall dry matter production for both feed types (EverGraze, 2013), the following can be determined:

- Forage cereal total dry matter production per hectare per year = 12 tonne
 - Cost of production = 5.2c/kg/ha
- Perennial temperate pasture total dry matter per hectare per year = 6.5 tonne
 - Cost of production = 3.5c/kg/ha

Determining the average total dry matter production per hectare per year is dependent on several variables, such as season, soil type, location and variety, but the above estimates are indicative of expected yields on the North-West Slopes. Increasing the persistence of the perennial pasture will lower this cost per year, but this must be balanced with the agronomic limitations of maintaining productivity over a longer

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period. The cost of production will be dependent on the total dry matter production that can be achieved for both feed types. Whilst offering a lower cost of production, the perennials are also lower production in this environment, so in order to be the preferred choice for overall productivity, agronomic and grazing management techniques need to be employed to increase the dry matter production of the perennials. The other tool available is to refine the annuals to be even more productive, thus needing less land dedicated to this part of the system, allowing for a higher proportion of perennials.

The above numbers are worth contemplating when the argument is made that utilising annual fodder crops requires higher input costs. Whilst this may be true from a crude cashflow standpoint, the cost of actually producing relative feed may not be significantly higher.

Table 3 Cost of production figures for annual fodder crop versus perennial pasture

Annual Fodder (forage cereal)			
Activity	Unit Cost/ha	Number of applications	Total cost/ha
Summer fallow spraying	\$10	3	\$30
Summer fallow herbicide	\$25	3	\$75
Sowing	\$80	1	\$80
Seed	\$90	1	\$90
Starter fertiliser	\$112	1	\$112
In-crop fertiliser	\$90	2	\$180
In-crop fertiliser application	\$10	1	\$10
In-crop herbicide	\$35	1	\$35
In-crop herbicide application	\$10	1	\$10
Total			\$622
Perennial Temperate Pasture Year One			
Activity	Unit Cost/ha	Number of applications	Total cost/ha
Knockdown spraying	\$10	2	\$20
Knockdown herbicide	\$25	2	\$50
Sowing	\$80	1	\$80
Seed	\$200	1	\$200
Starter fertiliser	\$112	1	\$112
In-crop fertiliser	\$90	1	\$90
Total			\$552
Perennial Temperate Pasture Once Established			
Activity	Unit Cost/ha	Number of applications	Total cost/ha
In-crop fertiliser	\$140	1	\$140
In-crop fertiliser application	\$10	1	\$10
Total			\$150

2.3 Social influence on the current system

There are several factors that may be driving beef producers to look at perennial alternatives in their feedbase, even though the annual system has served reasonably

well in the past. An important factor is not agronomic at all, but rather social pressure and changing market expectations. The Australian beef industry, like most other sectors of agriculture, is operating under closer public and market scrutiny of its environmental credentials than it has in the past. The Australian Beef Sustainability Framework Annual Update (Meat & Livestock Australia, 2025) outlines that as demand for environmentally responsible products increases, beef producers and retailers are expected to substantiate claims about emissions, land use and animal welfare, and that vague or misleading sustainability statements now carry real reputational and legal risk as global standards tighten and third-party certification becomes more prominent. This reflects a broader shift where customers and consumers increasingly align their purchases with their personal values.

The emissions profile of annual fodder crops is going to be higher than perennial pastures due to the activities required such as sowing and spraying, as well as potentially bare ground in a fallow period, so this could be a factor to consider. The “grassfed” market does not differentiate between the two feedbase systems, but if this is a market a producer is wishing to enter, supplementary feeding with grain is restricted so the importance of maintaining feed availability throughout the year becomes even more critical.

The “regenerative agriculture” movement could also be an influencing factor, though it seemed to be more established from the author’s travels throughout the USA. Producers there have access to certifications that can provide premiums in the market, but this system is not yet widely available in Australia. With increased social pressure for sustainability putting pressure on suppliers, this could potentially be an area of opportunity for Australian producers.

2.4 Soil carbon

The conversion of land from cropping to permanent pasture has been identified by the Australian Government Clean Energy Regulator as an approved Eligible Management Activity under the “Estimation of soil organic carbon sequestration using measurement and models method 2021”. This means that if a landholder enters into a soil carbon project under this methodology, they have the potential to be issued with Australian Carbon Credit Units (ACCUs) which they can trade for financial gain, if they successfully sequester an increase in soil carbon after a baseline period (Australian Government DCCEEW, 2026). This presents an opportunity for producers who are considering making the transition, as it could become an additional source of income.

The Australian carbon market system is unique in that it is a government supported program and has a reputation of being arguably the most rigorous scheme globally – a fact which makes it attractive to emitters seeking to purchase carbon offsets. It was not uncommon to learn that a farm visited during this research was involved in some sort of carbon market program or similar. Some examples included:

- El Coraje in Uruguay – the Savory Institute’s Pampa Oriental for CO₂ capture and carbon credit bonuses in the native, unimproved grassland
- JD Hudgins in Texas, USA – Grassroots Carbon programs for payments throughout a five year period

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- White Oak Pastures in Georgia USA – features as a Savory Institute hub and has undertaken Life Cycle Assessment research into carbon sequestration on the ranch
- Noble Research Institute ranches – collaborative projects with the Savory Institute

Much research has been conducted on deep-rooted perennial grasses and legumes in terms of the benefits they provide for soil carbon sequestration. It is this research which has allowed the practice change to be included in the aforementioned methodology. Apart from the opportunity to receive ACCUs in a soil carbon project, increased soil carbon has production benefits that are also well documented, including improving the nutrient uptake of plants. These benefits were commonly cited at many farms visited during this research.

Chapter 3. How can temperate pasture species be better managed in a transitional climate?

3.1 Pasture case studies

One of the key objectives of this research was to investigate how to better manage temperate pastures in a challenging and non-traditional growing environment, visiting operations and learning from producers who are successfully doing so. The following case studies capture three operators (or groups of operators) who are taking an intensive approach to managing their pastures, particularly in regard to their agronomic decision making. Importantly, both sites in Uruguay feature a similar climatic zone to the North-West Slopes of NSW.

3.1.1 Case Study – Daryl Cleave, Texas Qld, Australia

Daryl Cleave runs a mixed irrigated and dryland pasture system for beef production on alluvial loam soils, with water supplied from a combination of river allocation and bores, applied via overhead pivots. The irrigated country carries a significant cropping history; at least ten years of back-to-back cotton preceded the current pasture, and before that the paddocks had a rotation of lucerne, corn, and peanuts. This drastic change in business and production system was not driven necessarily by financial incentive, but rather Daryl wanted to farm a system that he enjoyed. He decided to utilise his resource base to produce beef rather than cotton or other cash crops, primarily because this was a farming system he enjoys.

On the irrigated country, Daryl has established a temperate pasture mix of continental fescue, Phalaris, plantain, chicory, and red, white and arrowleaf clover. His guiding principle in selecting this mix is to choose species that complement rather than compete with one another. Daryl has deliberately moved away from including lucerne in this mix. He explained this is for two reasons two reasons; first is that when the lucerne is actively growing and needs to be grazed (in the summer months), the temperate pasture species are dormant and need rest from grazing. Second, and more significant agronomically, lucerne draws on deep soil moisture through summer, depleting the profile ahead of the autumn period when the grasses are trying to come into active growth. Bloat risk from the clover content of the pasture is managed by dosing stock water with a detergent additive, made possible because Daryl controls all water access on the improved pasture country and stock have no alternative water source.

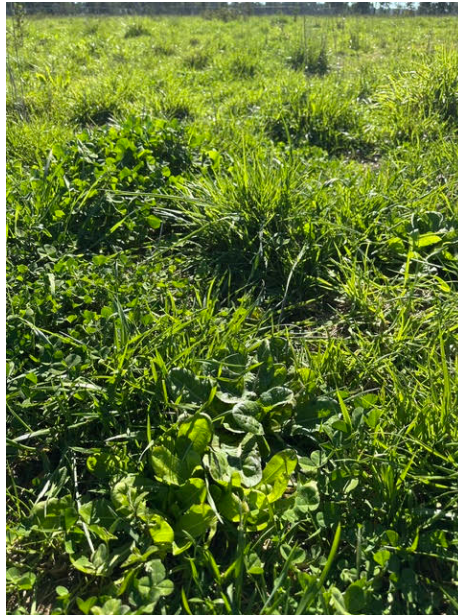


Figure 4 Temperate pasture mix at Daryl Cleave's property, Texas QLD (Source: Author)

Daryl's irrigated pasture is managed in small paddock cells of around 8 hectares, stocked at a density of 600–800 head at roughly 400kg liveweight. Stock are moved daily, with rest periods of around 28 days in winter and 12 days in spring when pasture growth is at its optimum. This density-driven approach is central to his pasture management strategy; where grazing density is not high enough, the grasses will dominate the sward, at the expense of the legumes and hence limit the protein available for the cattle and the benefits of nitrogen fixation. Pasture is spelled completely from December through to the end of February, then grazed hard in March. This heavy March grazing is a deliberate management step, used to remove standing dry matter and encourage fresh growth heading into the following season.

On the improved dryland country, Daryl has established a summer active sub-tropical pasture consisting of Premier digit (*Digitaria eriantha*), Rhodes grass and arrowleaf clover. He is running an active on-farm trial in his dryland sub-tropical pastures, spreading five different clover species in combination with three rates of single superphosphate (100, 200, and 300 kg/ha) to determine which clover varieties will successfully establish and persist within an existing tropical grass base.

At the establishment phase of any perennial pasture, Daryl notes that the weed burden is significant, however his approach is to use no herbicides and instead allow competition to be the management strategy. Daryl uses no starter fertiliser at sowing, nor any nitrogen fertiliser once the pasture is under the grazing system. Rather the legume content of the sward provides a balanced source of nitrogen for the grasses and perhaps even manages the growth of the grass and herbs so that they don't become dominant to the legumes. In terms of other nutrients, whilst limited soil testing has been undertaken, it's likely that residual levels of phosphorus and sulphur are being utilised from the historic high input cropping system. This is another reason why the trial work is critical for ongoing sustainability of the pasture.

With an attitude of continual improvement, Daryl's next step is to subdivide his larger paddocks further, to increase grazing density and extend rest periods. The obvious

advantage in Daryl's system is reliable irrigation water. This has allowed the temperate pastures to withstand the stress of high summer temperatures and ensure feed availability to shoulder the potential early summer and autumn feed gap when the sub-tropical pastures may not be at their optimum. Ultimately as Daryl points out though,

“The most important factor in establishing a good pasture, is rainfall.”

3.1.2 Case Study – ‘La Reserva’ Colonia, Uruguay

'La Reserva' is a family business near Colonia, run by Sergio together with his son and daughter, on country the family has leased for 30 years. The enterprise is a genuinely mixed operation, combining cattle finishing, forage seed production, and cash cropping with pasture functioning as one phase within a broader cropping rotation rather than a permanent, separate part of the farm. There is no native grassland on the property, all country is within the cultivation rotation.

The livestock system is a Holstein calf finishing operation. Calves are purchased at around 200 kg and finished on pasture through to a 500 kg sale weight, a process that takes roughly 18 months. Rather than buying in a single seasonal batch, Sergio purchases calves year-round, timing intake to match feed availability as it fluctuates through the rotation. Younger calves are backgrounded on self-feeders in the paddock before moving onto pasture to finish. Overall stocking sits at around two animals per hectare, tapering back somewhat over winter as pasture growth slows.

Pasture at 'La Reserva' is not a fixed paddock-by-paddock system but a phase in a four-year rotation between cropping and pasture. When paddocks come into the pasture phase, they are sown either to lucerne, or to a mix of lucerne with cocksfoot and brome grasses. Lucerne is utilised for grazing, hay and seed production and a deliberate choice has been made to select non-dormant lucerne varieties (all Group 9), specifically because the operation wants active winter growth for grazing. The trade-off here is persistence is affected, but Sergio is willing to sacrifice this for winter performance and willing to resow after three to four years. New lucerne-based pasture is established at a first-year sowing rate of 12 kg/ha lucerne, 6 kg/ha cocksfoot and 5 kg/ha brome, with lucerne alone typically seeded at 18–20 kg/ha where sown as a straight stand.



Figure 5 Lucerne-based pasture and rotational grazing (Source: Author)

Grazing is managed on a rotational basis, moving stock through paddocks on a half-day rotation. Water is reticulated with outlets spaced every 100 metres through the pasture paddocks, giving Sergio flexibility in how tightly he can subdivide grazing. Bloat risk from the lucerne-heavy pasture is managed through a bloat product delivered via the water system, with the concentration able to be adjusted as needed.

The cropping side of the rotation is intensive and closely sequenced, built around avoiding fallow wherever possible. The typical rotation is forage oats or soybean, then canola, a second-crop soybean, malting barley, soybean, wheat, and a second-crop maize before the paddock is returned to the lucerne/cocksfoot pasture phase that follows maize. Where a crop such as grazing oats is sprayed out and the following soybean is planted before the previous crop has technically been harvested, it's classified on the operation as a "first crop." The only real gap in the sequence occurs after a late maize harvest in July, with soybean going back in around November; as close to a true fallow as the rotation allows, and even then, not a deliberate rest period.

In 2024 Sergio substituted Camelina, a short-season oilseed brassica grown for biofuel, in place of maize in the rotation. He considered a cover crop but ruled it out because cover crops don't generate cash return. Camelina's appeal lies in its flexibility within the rotation; it can be planted late and harvested early, and it contributes useful grass control. It's also a low-water-demand option, needing only around 250mm of rain during the crop, and Sergio noted that ALS-tolerant varieties are currently being developed, which would add a further herbicide tool to the crop's management. All cropping is done with disc machinery, and fertiliser is applied at variable rates across paddocks rather than a flat rate. Soil pH sits at 5.5–6 on the operation's black soil.

Alongside the cattle and cropping enterprises, Sergio produces lucerne seed under a supply arrangement with PGG Wrightson. This seed production runs in parallel with the grazing and hay functions of the same lucerne stands, making the pasture phase of the rotation a genuinely multi-purpose one; feed, hay, seed income, and a soil-building break from continuous cropping.

The 'La Reserva' system illustrates a tightly integrated approach to mixed farming. Pasture is not treated as a separate enterprise from cropping, but as a deliberately timed phase within a single four-year rotation, chosen and managed to deliver multiple income streams of grazing, hay, and seed. Variety selection (non-dormant lucerne), herbicide strategy, and even the choice of break crop (camelina over maize or a cover crop) are all made with consideration of profitability and fit within the broader rotation, rather than being treated as isolated agronomic decisions.

3.1.3 Case Study – 'San Ramon' Apeo, Trinidad, Uruguay

At 'San Ramon', pasture and grazing management sit within a clearly stated overall objective; taking care of the land and increasing its value over time. Financial performance is tracked accordingly, with the operation measuring gross profit minus direct costs, deliberately excluding land cost from that calculation, which keeps the focus on the productivity of the grazing and cropping system itself rather than on land value appreciation.

San Ramon runs a genuinely data-driven approach to grazing management. Animal rotations are planned 90 days ahead, and the entire herd is weighed every three months to track performance against that plan. Rather than manually recording paddock movements for every mob, GPS trackers are fitted to two or three animals within each mob, which is enough to track the number of days spent in each paddock without the administrative burden of logging every movement by hand, or the cost of having collars on every animal.

Water is provided to all grazing areas on the property, both the intensively managed sown pastures and the native grassland country. This ensures stock distribution and grazing pressure can be actively managed across the whole property rather than just the improved pasture areas. San Ramon employs adaptive grazing techniques, monitoring the amount of dry matter available in a pasture and making dynamic decisions to move stock based on these measurements. Even with this degree of seasonal flexibility, spring pasture growth can still outstrip what the herd is able to graze. When that happens, the surplus area is either sprayed out and planted to soybeans, or set aside for seed production, providing an additional income source.

San Ramon runs a structured multi-year rotation between perennial pasture and annual fodder crop phases. A three-year-old perennial pasture is sprayed out in summer and sown to a tetraploid annual ryegrass. That ryegrass is then sprayed out and the paddock planted to soybean, with an Italian annual ryegrass broadcast in front of the soybean harvest for early establishment. The Italian ryegrass is sprayed out the following January, and a new perennial pasture is sown in March. That perennial stand is then held for four years, with the paddock sprayed out again in December of year four ahead of ryegrass going back in the following March, restarting the cycle.

Three pasture mixes that were present at the time of the author's visit were:

- Continental tall fescue with red and white clover: In this mix, red clover typically persists for around two years, while white clover reseeds and carries the stand

further, though by year three, relatively little of either clover type remains. This pasture is planted in March and grazed from June. Grazing on this pasture stops in early December, and from late October the operation shifts to using higher residual grass heights as the stand moves toward its summer rest.

- Mediterranean tall fescue with lucerne and cocksfoot: This mix includes both winter-dormant and non-winter-dormant lucerne types within the system and were in this case sown side-by-side to investigate the advantages and management requirements of both.
- Phalaris, cocksfoot, and red and white clover. This mix is sown in March and, at the time of the visit (August), had received one grazing.



Figure 6 Winter active lucerne-based pasture on left, winter dormant lucerne-based pasture on right (Source: Author)

San Ramon's pasture system has a strong depth of monitoring behind it; 90-day rotation planning, regular whole-herd weighing, and GPS-tracked mobs all feed into decisions that are made and adjusted through the season rather than set once and left. The structured four-year perennial-to-annual rotation, combined with deliberate seasonal stocking rate changes and a clear plan for spring surplus, reflects a system built to extract maximum value from pasture growth as it happens, while the "gross profit minus direct costs, excluding land" framing keeps the operation's focus explicitly on improving the productive value of the land itself.

3.1.4 Case Study – Pasture management in East Texas, USA

East Texas forage-livestock operations are built around bermudagrass (*Cynodon dactylon*), a warm-season (C4) perennial that dominates the region's improved pastures. Typical operations in this system run 250-500 acres (approx. 100-200 ha), and even well-managed enterprises are described as being only marginally profitable. This highlights how tightly forage costs and quality are tied to overall enterprise viability.

Bermudagrass is valued for its drought tolerance and autumn quality retention, maintaining reasonable feed quality into the autumn after it has browned off. It is established via vegetative propagation rather than seed, which raises the cost and effort of establishing new stands compared to sowing. It does, however, have excellent persistence. There are two main varieties grown in this region:

- Coastal bermudagrass — a finer-stemmed variety associated with better feed quality.
- Common bermudagrass — a coarser type that will take over a pasture if it is not actively managed, displacing improved varieties like Coastal over time.

Since bermudagrass is a warm-season species, it goes dormant over winter, creating a feed gap. The primary strategy used to address this in the region is oversowing cool-season annuals directly into dormant or senescing bermudagrass (and bahiagrass) stands. Oversowing is typically carried out in September to October, while the bermudagrass base is still active enough to compete with the establishing annuals but early enough for the annuals to get a foothold before winter. This timing window is explicitly described as risky; sow too early and the annuals compete poorly against actively growing bermudagrass; sow too late and there isn't enough time for establishment before cold weather limits growth. Rainfall variability at this time of year adds a further layer of establishment risk.

Species used in oversowing include grasses such as annual ryegrass (the predominant choice), with cereal rye used to a lesser extent, and oats and wheat used less commonly still. Legumes such as arrowleaf clover, red clover, white clover and vetch are also oversown, with the commonly acidic soils preventing the extensive use of lucerne. The legume component is particularly important in a bermudagrass system, since it fixes nitrogen and lifts the crude protein content of the winter feed base well above what bermudagrass residue alone would provide.

Given the risk and cost of oversowing, many producers instead rely on conserved hay through winter. Bermudagrass hay quality often fails to meet livestock requirements without supplementation. Some producers will supplement with corn to fill energy gaps left by the lower-quality winter hay.

Soil pH across the region's pastures ranges from below 4 up to 5.5, which is acidic relative to the requirements of some improved varieties. Tifton 85 is a higher quality bermudagrass cultivar grown for its improved digestibility and yield, but it requires a pH of around 5.8, meaning substantial lime application is a routine input cost for producers running this variety. As a side, lime is also difficult to procure as much is tied up in the extensive construction of roads in this part of the USA.

Bermudagrass is also a heavy potassium (K) user, drawing down soil K at a rate almost comparable to its nitrogen (N) demand. This has direct implications for fertiliser

programs, as K is often under-prioritised relative to N in general pasture fertility planning.

3.2 Key agronomic considerations of perennial pasture production

3.2.1 Persistence

One of the main advantages of transitioning from an annual fodder crop to a perennial pasture is just that – the perennial nature of the system. The persistence of a pasture species and of the sward generally is an important factor for Australian producers, as it removes the need to resow each year. The generally accepted advice is that a temperate perennial pasture will persist with full production from year two to around year six to ten, when it needs to be rotated and eventually resown (NSW Government, 2016). A distinct contrast was identified by the author between the expectation of persistence in Australia versus this expectation in Uruguay (as demonstrated in the above case studies) and Argentina. In the Uruguayan and Argentinian systems, producers are expecting to rotate their pastures back to cropping every three to four years at the most. In contrast, in the Australian case study above the producer is optimistic that they will not need to resow for at least ten years, perhaps even longer.

Australian producers are experienced with extensive persistence in the sub-tropical pastures, which if managed appropriately will still be productive after 10 to 20 years. They will however, change their species composition in this time, with some grass species becoming more dominant and the legume content diminishing or converting to perhaps a native medic. The grasses can also experience “pasture rundown” as the plant available nutrients decline over time, particularly nitrogen without good legume content (Barenbrug, 2024). The same phenomenon can be seen in temperate pastures, but what can be learned from the Uruguayan and Argentinian temperate system, is that if the expectation of persistence is reduced, then the productivity and percentage of desirable species can be maintained for the three to four years. If this is the case, then the feed value across this shorter period could be more comparable to that of annual fodder crops, whilst still not needing to be resown every year.

3.2.2 Grazing management and rest

Of note throughout the author’s travels in Uruguay, was the lack of improved summer active pastures in a climatic region where sub-tropical pastures could be expected to perform well. Instead, cattle are grazed on native grasses over the summer period, though these are not of high feed value and cattle weight gains decline significantly (Lago, 2025). This appears to be a commercial issue rather than a system one, with seed companies having not successfully brought sub-tropical species into the country in a breeding program. An opportunity exists in this space, however the constraints of biosecurity and ownership of genetic material would need to be navigated. This leads into the issue of pasture recovery and how to determine the appropriate period of rest to optimise production from a particular pasture, whilst also maintain production throughout the year.

It would be fair to say that gone are the days of set stocking, and it would be difficult to find a successful Australian beef producer who doesn't understand the benefits of rotational grazing. But ask two producers what their ideal grazing and rest periods are and you're unlikely to get the same answer. The author explored this concept with Hugh Aljoe at the Noble Research Institute in Oklahoma, USA. A centre for research and extension in regenerative grazing (ranch) systems, the philosophy that Noble employs is that adaptive grazing should be a mindset shift and that whilst actively managing pasture rest and recovery can involve moving stock once or more per day, it shouldn't be a set schedule. Instead, the key attribute is actively managing rest and recovery periods based on season and soil moisture conditions, rather than following a fixed pattern (Noble Research Institute, 2026). This was visible in several side-by-side comparisons on Noble ranches, where grazing days were consistently found to be up to 50% higher on the adaptive versus prescriptively managed paddocks, with more residual present after grazing as well (Aljoe, 2025).

At the JD Hudgins ranch in Hungerford, Texas USA, John Locke explained that on their paddocks, which are largely dominated by Tifton 85 bermudagrass, rest and recovery periods ranged from 14 to 40 days. Whilst this is dependent on the types of attributes described at the Noble Research Institute, determining the period comes down to looking at the grass. John will assess a pasture for plants that haven't yet recovered, indicating that the rest period has not been long enough. He also uses the Pasture Map app and has recently installed the Halter virtual fencing system, but for him it ultimately comes down to the plants themselves and adapting his management in response to how they're growing. Technology in the form of satellite imagery and pasture growth algorithms are useful tools, in John's opinion, they need to still be ground-truthed by actually looking at how the plants are growing.

Adaptive management is critical in a transitional environment such as the North-West Slopes of NSW. Rainfall variability will mean that even once stock have been rotated out of a paddock, the pasture may not begin recovering until it receives a rainfall event, making a prescribed number of days irrelevant. Designing a system that allows for adaptive management therefore must consider different pasture or fodder types.

The advantage of a transitional environment is both a summer and winter growing period, so by incorporating both temperate and sub-tropical pastures into the system, this provides more room for extended rest periods when either pasture is not actively growing, as well as when the species are actively growing in anticipation of the next grazing event. There has been some research conducted into incorporating temperate and warm season species in a mix in the one paddock but plant competition will generally affect the sward composition and timing the rest period becomes problematic with continually actively growing species.

3.2.3 Pasture cropping

In one respect, the East Texas system is similar to the North-West Slopes of NSW in that it generally utilises warm season perennials during the summer growth period and largely annual fodder to fill the winter feed gap. However, the glaring difference is that in East Texas (and other similar part of the Southern USA) the winter annuals are sown directly into the dormant summer perennial sward. This practice has been trialled and to some extent utilised in Australia under the term "pasture cropping"; albeit on a smaller scale and to arguably less success. The production quality of pasture cropping

is influenced largely by summer-autumn rainfall, cropping frequency and pasture composition (Millar & Badgery, 2009). The Australian experience also suggests that timing matters for grazing value, in that winter forage crops must be sown early in the season or the bulk of the forage growth shifts to spring, when it's often not needed. The No Kill Cropping trials also showed mixed results, with one site having no additional biomass over the perennial pasture alone, whilst another saw a 42% increase in total biomass (Millar & Badgery, 2009). The question of timing is then largely dependent on rainfall for a sowing event – if there is a delay in an autumn break the opportunity for pasture cropping is likely to be missed.

Whilst the rainfall patterns are similar, the average annual rainfall in East Texas is roughly double (Texas A&M, 2026) that on the North-West Slopes (Australian Government BOM, 2026). It is likely this is a key factor in the success of pasture cropping in this part of the USA (and others), and also the key factor in why the practice hasn't gained a great deal of traction in Australia.

3.2.4 Nutrient management

Fertiliser rates

The fertiliser program of an annual fodder crop is generally determined by pre-season soil testing and/or by commonly utilised “rules of thumb” or established programs that are repeated each year. It is also determined by the amount of feed required across a season, as cereal fodder crops directly responsive to fertiliser rates (in particular nitrogen-based fertiliser) for dry matter production, both at sowing and for second or third applications after grazing (Laycock, 2017). So, an annual fodder crop system could be as high or low input as the producer wishes, depending on their dry matter yield targets. This potentially high input system is one of the reasons that producers might move toward a perennial pasture, to reduce their annual fertiliser inputs, however it is not as simple as this being the case. Particularly when the goal is to maintain or improve the productivity of an annual fodder crop.

In an annual cropping system for grain, a nutrition and fertiliser program can be determined to a reasonable level of accuracy by using a combination soil testing and setting target yields. In a grazing system, it is not as clear cut because the “yield” is harvested more than once and nutrients are recycled back into the paddock via livestock (Watson, McDonald, & Bourke, 2000). Soil testing is still a useful strategy to manage nutrition throughout the life of the pasture, but perhaps even more importantly at sowing time to ensure the best establishment is achieved.

The nutrition requirements of a temperate perennial pasture will vary, depending on the existing nutrient profile of the soil at sowing, the intensity of grazing and required dry matter production across the season and importantly, the species mix – whether the sward consists of grasses, herbs or legumes or a combination of these. Different fertiliser strategies were viewed by the author throughout this research. For example, in Bolivar, Argentina, Alfredo and Maria Alzueta fatten steers off a lucerne-fescue pasture and will apply 100 kg/ha of Urea (equating to approximately 46 kg N/ha) after each grazing event, having determined that 1 kg N will produce 12 kg/DM. At ‘El Coraje’ in Uruguay, the system included dual purpose pastures, with seed production following grazing. One example of this was a paddock of tall fescue – due to the dual-purpose nature, the grass was the only species in this paddock. The fertiliser regime here consisted of phosphorus, nitrogen and potassium being applied in April, July and

August (throughout the growing season). This included 200-300 kg/ha of single superphosphate (9% P, 11% S, 19% Calcium) and approximately 300 kg/ha of Urea (46% N). Other farms in Uruguay visited throughout this research utilised variable rate technology to address specific nutrition constraints. The goal was always optimising dry matter production, ensuring that the nutrition program was not a limiting factor, even if this meant applying significant rates of nitrogen fertiliser to legume-based pastures.

The role of legumes

Legumes fix nitrogen from the atmosphere to the soil through *Rhizobium* bacteria in nodules on the roots. The symbiotic nodules formed on legume roots with *Rhizobia* fix atmospheric N_2 , with bacteria reducing it to NH_4^+ , which is then assimilated into amino acids by the plant, and in return, the plant provides photosynthates to fuel the symbiotic nitrogen fixation (Lepetit & Brouquisse, 2023). Peoples and Baldock (2001) conducted work to quantify the amount of nitrogen fixed in this process and reported 20-25 kg N fixed per tonne of legume dry matter produced, with total fixation commonly in the 25-250 kg N/ha/year range depending on legume type and productivity. The process of nitrogen fixation will also depend on the existing mineral nitrogen in the soil, as the legume fixation will be reduced when this is higher. The presence of grasses in the mix can counter this however, as they will readily take up this mineral N, resulting in the reduction of legume-fixation not being suppressed the way that it might be in a purely legume stand (Unkovich, 2026). The actual amount transferred to grasses in the mix has been studied but proved difficult to quantify. However, a French rhizodeposition study compared lucerne-fescue and white clover-ryegrass mixtures and found lucerne fixed roughly twice as much total nitrogen as white clover but transferred less to the companion grass (59 kg N/ha over three years for lucerne-fescue versus 147 kg N/ha for white clover-ryegrass) showing legume species choice matters as much for transfer efficiency as for total fixation (Louarn, et al., 2015).

As outlined in the Case Study at Texas Queensland, a well-functioning mixed species pasture sward with appropriate legume content can drastically reduce fertiliser requirements. In this case, the producer was not applying any nitrogen fertiliser and was instead relying on the nitrogen fixation of the legumes. Ensuring the optimum production of the legumes is therefore critical for the system to work effectively. Legumes require phosphorus, sulphur and potassium, however quantifying the actual amounts required specifically for legume production has proven difficult. From a practical perspective, producers should utilise industry guidelines for critical soil levels of these nutrients, ensuring that capital applications are made to maintain this over time as the pasture is utilised (Sandra, et al., 2019).

It's important to also consider the other nutrient requirements of the grass species apart from nitrogen. For example, studies have shown that *Phalaris* has high phosphorus requirements (Hill, Simpson, Wood, Moore, & Chapman, 2005) and this needs to be accounted for alongside the fertiliser requirements of the legumes.

Other nutrition considerations

The incorporation of chicory and plantain into a pasture sward can result in higher nitrogen requirements than the legumes can provide. Sources suggest nitrogen rates of 20-30 kg N/ha are required initially at sowing, with similar applications beneficial after grazing events (NSW Government, 2026) (Agricom NZ, 2026). Again, it is not just the nitrogen requirements that are important to consider though. At the Noble Research Institute, the use of small ruminants (such as goats) in the grazing system

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has allowed the improved utilisation of herbs and forbs in the pasture (albeit native pasture). Trials conducted on their ranches have hypothesised that these tap rooted herb and forb species are accessing nutrients such as phosphorus from deeper in the profile and cycling this back to higher in the profile, to make it more available for the shallower rooted species.

Chapter 4. Is it viable to replace annual fodder crops with improved perennial pasture in a beef cattle system and maintain productivity and profitability?

4.1 What kind of business do you want to run?

This is perhaps the most important question a producer can ask themselves when considering a shift in their system – what kind of business do I want to run? For the purpose of this research, we are focusing on beef cattle production, but there are several business decisions that need to be made beyond this such as:

- Breeding versus trading or backgrounding, or a combination of both
- Which breed/s do I prefer and which suit the environment that I'm farming and have a market
- Commercial versus seed stock or a combination of both
- Incorporating grain or hay production for additional income streams and drought preparedness
- Conventional versus regenerative versus organic system

In established businesses, these questions will often already be decided, largely by the land available and the system that it best lends itself to. For example, less productive country may be useful in supporting a breeding operation but would offer little value to a trading enterprise. The enterprise that is in place will influence the feedbase production that is needed and vice versa. It is not simply a question of what will grow well on my farm, rather what do I need to be able to grow to support the business that I wish to operate? In some cases, a philosophical position will have significant influence over the direction of a business. Research undertaken in the USA saw the author visit several farms who identify as practicing “regenerative agriculture”. Whilst a definition of regenerative agriculture could be an entire research topic alone, it was important to investigate this movement and the motivations of the producers who have gone down this path. Transitioning from annual fodder crops to perennial pastures fits under a broad approach to regenerative agriculture, and so whilst not necessarily the goal in this research, there are some examples of producers who have done so with what they believe to be great success.

4.1.1 Case Study – White Oak Pastures, Georgia USA

White Oak Pastures is a family farm in Bluffton, Georgia, continuously operated by the Harris family since Will Harris's great-grandfather settled the land in 1866. For most of the 20th century it followed the trajectory of mainstream American agriculture. Will Harris's father took over after World War II, the point at which chemical fertilisers and pesticides were introduced to the operation and slaughtering became centralised off-farm and from 1946 until 2003 the family applied ammonium nitrate to every acre of the farm every year.

Will Harris, a fourth-generation Harris, graduated from the University of Georgia's College of Agriculture in 1976 and initially continued in this conventional, input-

intensive mould, rising to regional manager for a large industrial beef operation before returning home. By the mid-1990s, however, he had grown disillusioned with the commodity system; he described his mindset at the time as focused purely on maximising pounds of beef at the lowest possible cost, without regard for animal welfare or land condition, and became troubled by practices such as cattle spending up to 30 hours on trucks to reach distant processing facilities.

The shift away from conventional practice began around 1995 and was explicitly gradual rather than a single dramatic change. The sequence was explained by Will Harris as follows:

- 1995: He began adopting holistic management practices, including ending the use of growth hormones in cattle.
- Early 2000s: He began developing a grazing system deliberately modelled on the way bison historically moved across North American plains, aiming to keep cattle on pasture for their entire lives rather than finishing them in a feedlot.
- 2000/2003: The farm discontinued chemical fertiliser use entirely, ending the multi-generational ammonium nitrate program.
- 2006: White Oak Pastures began selling meat through Whole Foods Market, and shortly after into Publix, giving the business a viable retail channel for its regeneratively raised product — a critical step, since the farm had started as a wholesale operation with no established local market for its output.

The core of White Oak Pastures' grazing management is very high-frequency rotation; cattle are moved to a new section of pasture every day, a practice Will designed to mimic the grazing-and-moving-on pattern of historic bison herds and to prevent any one area of pasture from being over-utilised. Grazed pasture is currently rested for approximately 60 days before being grazed again, though Will expressed a preference for extending this to 80 days where possible. This indicates an ongoing effort to lengthen recovery time further as the system matures, balanced against stocking pressure and land availability.

Rather than running a single class of livestock, White Oak Pastures rotates multiple species through the same land in a complementary sequence; cattle graze the grass, sheep and goats browse weeds and shrubs, and chickens follow behind to peck at grubs and insects. All species contributing manure and natural fertility as they move through. At scale, this multi-species system supports a herd composition including roughly 700 beef cows, 1,100 nanny goats, a 1,000 ewe flock, 150 breeding rabbits, 30 sows, and around 320,000 head of poultry (chickens, turkeys, and other birds) across the farm's pastures. Targeted mineral supplementation is practiced, with several minerals available to livestock at all times, allowing them to self-supplement as required.



Figure 7 Cattle have a choice of mineral supplements as they're required (Source: Author)

The farm's permanent pasture base consists of warm-season perennial forage. Because this base goes dormant over winter, Will uses a no-till overseeding system to introduce cool-season annuals including ryegrass, cereal rye and clover, carried out in October. The process for doing this is that the pasture is grazed very short ahead of sowing, annual forage seed is broadcast over the pasture by truck, a modified harrow is dragged behind to work seed into the soil surface without significant disturbance, and livestock are then run through the pasture to help tread the seed into the ground.

To maintain a consistent, year-round supply of finished animals for the farm's on-site processing operation, cattle are joined across two seasons (autumn and spring) over roughly four-month breeding windows each. This staggered breeding calendar is a direct response to the farm's need to have animals ready for slaughter twelve months of the year, rather than facing the seasonal gluts and gaps that a single annual calving window would create.

In place of the synthetic fertiliser program the farm abandoned around 2000–2003, fertility is now managed through on-farm composting. Waste material from the farm's own USDA-inspected processing plants, including bones, is composted on site and returned to the land as organic fertiliser. Compost is left to mature for approximately one year, and the process is deliberately managed to shift the resulting compost toward a more fungal-dominant, less bacterial-dominant profile.

Interestingly, Will expressed a preference for acquiring former plantation country over other available farmland, despite it commanding a higher purchase price, because its underlying soil condition is better. He therefore finds the return on investment is ultimately more favourable, since the farm starts from stronger natural soil fertility rather than needing to rebuild degraded soil from scratch.



Figure 8 Will Harris with the author (Source: Author)

4.2 How much grass do you need and when do you need it?

Before comparing the two systems of annual fodder crops and perennial pastures, the starting point has to be a liveweight gain (LWG) curve for the target market. For the purpose of this research, the assumption is made that high quality feed is required throughout the year. An autumn and spring calving program which is common on the North-West Slopes of NSW does not result in one period with an intensive feed requirement, it is more distributed throughout the year. In this type of production system, the forage program needs to be diversified to support this feed availability.

4.2.1 Pasture Growth Curve

The feed value in terms of crude protein and metabolisable energy of different fodder and pasture species were discussed earlier in this report. However, the amount of dry matter production from different fodder or pasture types is also critical to compare. Figure 9 shows a typical pasture growth curve for the North-West Slopes of NSW, highlighting dips in overall production in March-April and again in September-October. What is interesting here, is that these two periods align with the two peaks in dry matter production of the *Phalaris* and clover pasture. This may suggest that improved management and perhaps higher proportional incorporation into a feedbase system of this perennial pasture, could potentially raise these peaks and improve overall feed production at these two times of the year. This being said, the overall dry matter production of forage oats (approximately 12 tonne/ha) far exceeds that of the perennial alternative (approximately 6.5 tonne/ha) across the year (EverGraze, 2013).

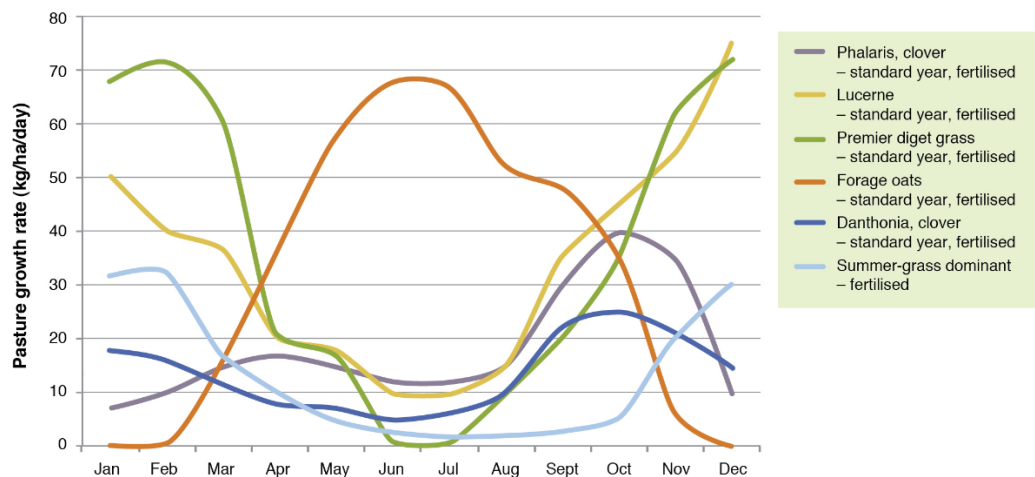


Figure 9 Typical pasture growth curve for the North-West Slopes of NSW (EverGraze, 2013)

4.2.2 Immediate moisture utilisation

One farm visit which demonstrated the advantages of having a system with a combination of both annual fodder crops and perennial pasture didn't require any travel, as the scenario presented itself on the author's own farm. A very dry start to 2026 was experienced across the North-West Slopes, which impacted the sub-tropical pastures significantly and as a result early autumn feed was limited. Sowing of annual forage cereals usually occurs from early February onwards but no planting rain was received until mid-May. This event provided the opportunity for dry-sown fodder crops to establish and further planting to take place, but the delay to feed was still another six to eight weeks away. Phalaris paddocks that had been rested over the summer months responded quickly to the May rain and provided the first quality feed as little as three weeks later. This highlighted the advantage that perennial pastures can have over annuals in a system, particularly in an environment with significant seasonal variability.

With very little follow up rain however, the Phalaris plants did not show signs of recovery following grazing. By eight weeks after the initial rain event, forage oat crops were ready to be grazed and so cattle could be moved to these paddocks to allow the pasture to recover. This scenario demonstrated the advantage of having both forage types in the system.



Figure 10 Phalaris pasture three weeks after first rain event in five months (Source: Author)

4.2.3 Fallowing

Whilst visiting farms all over the world, including as part of the Global Focus Program, the author observed a similar response to the concept of fallow. A common practice in Australian cropping systems to conserve and build soil moisture and to an extent nutrient profiles through mineralisation, the practice of fallowing was a foreign concept in most other countries. When questioned on this, the response was often,

“Why have land without a crop growing at any one time?”

Moisture was rarely limiting enough to justify a fallow period. In annual fodder cropping systems in Australia, a fallow period in the season prior to sowing is common. Opportunistic double (or sometimes even triple) cropping can happen in good seasons, but generally the biomass yield production will decrease without a fallow period. Conversely, depending on soil type and depth, a full moisture profile following a fallow period can provide enough moisture to sustain an annual fodder crop during a dry period.

At a rudimentary level however, a fallow period can create a (at least temporary) feed gap. In Daryl Cleave’s system at Texas, Queensland, the rest of the temperate pastures from December to March essentially forms a fallow period (minus any weed control being necessary) as the pasture isn’t being grazed during this time. But plants and roots are still in situ, and some will be growing depending on the season, so the soil biology is still maintained and active. The opportunity is also still there to graze the perennial pasture if the conditions and circumstance require it, whilst a well-maintained fallow will have little feed value if it is needed.

Maintaining actively growing plants year-round, particularly deep-rooted legumes, is often considered best practice for optimizing soil health and biology. But in a transitional climate, this can come at a cost to moisture. Another very close-to-home case study on the author’s own farm in the winter 2026 season demonstrated this clearly. An annual fodder paddock had been under-sown to lucerne in autumn 2024,

with the intention for this to be straight lucerne for the following few years. A patchy germination saw oats over-sown in 2025 to increase production between the lucerne plants. The same paddock was over-sown with forage barley in 2026, with the plan to terminate the poor lucerne stand and re-establish it later. However, marginal conditions were amplified by the actively growing lucerne over the summer and autumn, leaving minimal moisture available as the barley was sown. Two paddocks over, on the same soil type with the same rainfall, the same variety of barley was sown within one week into a paddock that had been fallowed over the summer with 100% ground cover from oats stubble the previous year. The photos below show the difference between the resulting barley in these two paddocks.



Figure 11 Left: barley with lucerne, Right: barley with summer fallow (Source: Author)

4.2.4 Optimising fodder crops

Much of the research undertaken to explore the concept of annual fodder crops versus perennial pastures in a transitional environment has focused on improving the agronomic management of the latter. But improvements made in the productive capacity of annual fodder crops can in turn take some pressure off the existing or newly established pastures. It may also mean that the area of a farm used for crop production can be reduced, allowing for a mix of annuals and perennials in the system.

Whilst a region may have a “go-to” fodder option, such as oats in the North-West Slopes, it can be helpful to explore incorporating alternatives that may be more productive. Tetraploid annual ryegrass for example is grown extensively in Southern Australian systems. These areas have higher winter rainfall which annual ryegrass responds well to, but incorporating it into a mix with oats in the transitional environments could be a viable option. The annual ryegrass will be more productive during the colder months when oats slow their growth rate down, but if conditions turn dry and the annual ryegrass becomes stressed, the deeper-rooted oats in the mix will maintain productivity for longer.

In Argentina and Uruguay, the lucerne varieties of choice were generally the most winter active varieties available. On the North-West Slopes of NSW, many producers opt for winter dormant varieties, as if there is excess feed available it is difficult to cut for hay in the winter. The author observed in the South American countries that silage production was very common for storage of fodder. An investment in the machinery required to make silage (particularly wrapped) could allow producers to opt for a winter active lucerne variety in a mix with a cereal which would improve the feed value of the fodder crop and incorporate a legume into the annual cereal, whilst giving the option to store fodder when it is not needed for grazing. This could be repeated for three to four years before being rotated back to pasture.

Conclusions

Becoming good grass managers is more than just understanding agronomic principles. It is also more than having an eye for cattle and how they graze, when they're starting to lose condition or might need to be moved to a new paddock. A good grass manager looks at all of these principles together and makes decisions based on what will optimise the production of their herd, whilst ensuring the land is cared for and the business remains sustainable into the future.

Throughout this scholarship process, I have had the privilege to meet and learn from many good grass managers around the world. Whilst they all have slightly different strengths and motivations, the common thread was a real enjoyment in producing beef from grass, and solving the jigsaw puzzle that comes with variable seasons and climates. A philosophy of continual improvement was also held by all of these producers, with pasture systems that can always be adapted and changed as new lessons are learned or markets require new focuses.

The conclusion I draw for my family's farm and for other farmers in the region, is that in order to respond to a variable climate in a transitional zone, we need to have a patchwork system feedbase. I do not believe it is viable to replace annual fodder cropping entirely with temperate pastures for the winter feed gap, as I still see a fit for having both in the system. I have concluded that the annual crops can be improved, with the introduction of different crops and where suitable, companion crops in the one field. I have learned that temperate pastures can play more of a role in this environment, as long as the expectation of persistence and productivity is relative to the location.

A mixed farming environment offers opportunities for hedging your bets. For a transitional environment where rainfall is variable and largely unreliable, having options available becomes critical. Having both sub-tropical and temperate perennial pastures in a system means that when rainfall does come, at any time of the year, there are plants ready to utilise the moisture immediately. But a well-managed annual fodder crop remains an effective and importantly, reliable way to optimise weight-gain. Exploring agricultural systems throughout the world only works to reinforce the fact that in Australia, rainfall will always be the major limiting factor in production, so we must design our systems around optimising the rainfall to in this case, continue producing beef from grass.

Recommendations

For producers in a transitional environment:

- Think outside the box of what species are considered suitable for a region.
- Implement a patchwork of annual fodder crops as well as both sub-tropical and temperate pastures, don't rely on just one or two of these.
- Adjust expectations of persistence – acknowledge that a harsher environment may reduce the longevity of a pasture, but it is more important to maintain productive value.
- Trial new varieties and non-traditional phenotypes – for example winter versus summer dormancy.
- Optimise the utilisation of feed when it is available through making hay and silage to store for drier times – this is not revolutionary, but by tweaking varieties this could be undertaken more effectively.
- Always have some parts of the feedbase system that can utilise moisture as soon as it is available, regardless of the time of year.
- Utilise technology as tools, but calibrate with actually assessing how plants are growing.
- Ensure adequate nutrition is available for plant growth and adjust fertiliser programs to the species mix, the season and to dry matter requirements.
- Adopt an adaptive, rather than prescriptive rotational grazing system.

For advisors:

- Gain a sound understanding of the production system you're advising on – when is feed required and is there a gap that needs filling.
- Develop strong relationships with seed company representatives to maintain currency on new and non-traditional varieties.
- Challenge industry standards and recommendations on what will work in a region – manage expectations but push the boundaries.

References

- ABARES. (2026). *Insights - Snapshot of Australian Agriculture 2026*. Australian Government Department of Agriculture, Fisheries and Forestry. Retrieved from <https://www.agriculture.gov.au/abares/products/insights/snapshot-of-australian-agriculture>
- Agricom NZ. (2026). *Forage herbs - chicory*. Retrieved from Agricom: <https://www.dpi.nsw.gov.au/agriculture/pastures-and-rangelands/species-varieties/pf/factsheets/chicory/part-c>
- Agriculture Victoria. (2024). *Specialist forages for opportunistic summer feed*. Retrieved from Agriculture Victoria: <https://agriculture.vic.gov.au/support-and-resources/newsletters/sheep-notes-newsletter/spring-2024/specialist-forages-for-opportunistic-summer-feed>
- Aljoe, H. (2025, August). Director of Ranches, Outreach and Partnerships - Noble Research Institute. (A. Jorgensen, Interviewer)
- Australian Government DCCEEW. (2026). *ACCU method tracker*. Retrieved from Climate Change: <https://www.dcceew.gov.au/climate-change/emissions-reduction/accu-scheme/methods/current>
- Australian Government - Bureau of Meteorology. (2026). *Climate classification maps*. Retrieved from Bureau of Meteorology: https://www.bom.gov.au/climate/maps/averages/climate-classification/?maptype=koppen_minor_AGCDv2_&period=1991-2020
- Australian Government BOM. (2026). *Climate statistics for Australian locations*. Retrieved from Bureau of Meteorology: https://www.bom.gov.au/climate/averages/tables/cw_055054.shtml
- Barenbrug. (2024). *Tropical Pasture Production Guide*. Retrieved from Barenbrug: https://www.barenbrug.com.au/sites/australia/files/2024-08/Barenbrug%20Tropical%20Pasture%20Guide_2024_Digital.pdf
- EverGraze. (2013). *Regional pasture growth rates*. Retrieved from EverGraze - More livestock from perennials: <https://www.evergraze.com.au/library-content/regional-pasture-growth-rates/index.html>
- Fulkerson, W. J., Neal, J. S., Clark, C. F., Horadagoda, A., Nandra, K. S., & Barchia, I. (2007). Nutritive value of forage species grown in the warm temperate climate of Australia for dairy cows: Grasses and legumes. *Livestock Science*, 107(2-3), 253-264.
- Harris, C., & Lowein, G. (2007). *Pastures Australia*. Retrieved from Lucid Central: <https://keys.lucidcentral.org/keys/v3/pastures/Html/>
- Hill, J. O., Simpson, R. J., Wood, J. T., Moore, A. D., & Chapman, D. F. (2005). The phosphorus and nitrogen requirements of temperate pasture species and their influence on grassland botanical composition. *Australian Journal of Agricultural Research*, 56(10), 1027-1039.
- Isbell, R. F. (2021). *The Australian Soil Classification* (3 ed.). Canberra: CSIRO Publishing.

- Lago, J. E. (2025, August). Director of Research and Development - Pasture Genetics Uruguay. (A. Jorgensen, Interviewer)
- Laycock, J. (2017). *Nitrogen for grain and graze crops*. Retrieved from Nutrient Advantage: <https://www.nutrientadvantage.com.au/news-listing-page/latest-publications/agronomic-insights/winter-crop/nitrogen-for-grain-and-graze-crops/>
- Lepetit, M., & Brouquisse, R. (2023). Control of the rhizobium-legume symbiosis by the plant nitrogen demand is tightly integrated at the whole plant level and requires inter-organ systemic signaling. *Frontiers in Plant Science*, 14.
- Louarn, G., Pereira-Lopes, E., Fustec, J., Mary, B., Voisin, A., Carvalho, P., & Gastal, F. (2015). The amounts and dynamics of nitrogen transfer to grasses differ in alfalfa and white clover-based grass-legume mixtures as a result of rooting strategies and rhizodeposit quality. *Plant and Soil*, 389, 289-305.
- Meat & Livestock Australia. (2025). Retrieved from Sustainable Australian Beef: https://www.sustainableaustralianbeef.com.au/contentassets/2a79018bd82a42bbb4bd6e32c8a279fd/absf-2025-annual-update_web.pdf
- Meat & Livestock Australia. (2026). *Understand livestock nutritional requirements*. Retrieved from More beef from pastures: <https://mbfp-pastoral.mla.com.au/managing-your-feedbase/understand-livestock-nutritional-requirements/>
- Meat & Livestock Australia. (2026, May 1). *What impact will increased input costs have on Australian cattle farms?* Retrieved from Meat & Livestock Australia: <https://www.mla.com.au/news-and-events/industry-news/what-impact-will-increased-input-costs-have-on-australian-cattle-farms/>
- Millar, G. D., & Badgery, W. B. (2009). Pasture cropping: a new approach to integrate crop and livestock farming systems. *Animal Production Science*, 49, 777-787.
- Milne, G. (2024). Technical Manager, AlfaGen Seeds Australia. (A. Jorgensen, Interviewer)
- Noble Research Institute. (2026). *Grazing Management*. Retrieved from Noble Research Institutes: <https://www.noble.org/grazing-management/>
- NSW DPI. (2014). *North West Slopes NSW - Overview*. Retrieved from EverGraze - More livestock from perennials: <https://www.evergraze.com.au/library-content/northwest-slopes-nsw-overview/index.html>
- NSW Government. (2016). *Temperate perennial pasture establishment guide*. Retrieved from NSW DPIRD: <https://www.dpiird.nsw.gov.au/agriculture>
- NSW Government. (2026). *Establishment of chicory in pasture*. Retrieved from NSW DPIRD Agriculture: <https://www.dpiird.nsw.gov.au/agriculture/pastures-and-rangelands/species-varieties/pf/factsheets/chicory/part-c>
- Peoples, M. B., & Baldock, J. A. (2001). Nitrogen dynamics of pastures: nitrogen fixation inputs, the impact of legumes in soil nitrogen fertility, and the contributions of fixed nitrogen to Australian farming systems. *Animal Production Science*, 41(3), 327-346.

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- Sandral, G., Price, A., Hildebrand, S., Fuller, C., Haling, R., Setfanski, A., . . . Simpson, R. (2019). Field benchmarking of the critical external phosphorus requirements of pasture legumes for southern Australia. *Crop & Pasture Science*, 70(12).
- Texas A&M. (2026). *Weather*. Retrieved from AgriLife Extension: <https://etweather.tamu.edu/rainhistory/>
- The Intergovernmental Panel on Climate Change. (2022). *Climate Chnage 2022 - Mitigation of Climate Change*. Retrieved from <https://www.ipcc.ch/report/ar6/wg3/chapter/chapter-17/>
- Unkovich, M. (2026). *Fact Sheet - Legumes and Nitrogen Fixation SA*. Retrieved from Soil Quality: <https://www.soilquality.org.au/factsheets/legumes-and-nitrogen-fixation-south-australia>
- Watson, R. W., McDonald, W. J., & Bourke, C. A. (2000). *NSW DPIRD*. Retrieved from AgFacts.