Resilient pastures

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Pasture-based livestock systems experiencing significant change

High value animal products from New Zealand's pasture-based livestock systems have consistently earned $25-$30B in export earnings per year for the country over the past 5 years (Ministry for Primary Industries 2021). Total earnings from dairy and meat of $30.5B in 2020 equate to 35% of New Zealand's total goods and services export earnings of $86.4B. The importance of this revenue to the national economy has been shown in stark relief recently with the Covid-19 pandemic substantially reducing the earnings generated by other key export sectors such as tourism and international education.

While our pasture-based livestock industries have ridden the coronavirus wave well compared with other sectors of the economy, they are facing change at a scale and pace not seen since the far-reaching reforms to the economic settings for agriculture introduced by the Lange Government in the early 1980s. Locally, the ramping-up of government environmental policies beginning c. 2011 has resulted in stringent regulations controlling the amounts of nitrogen (N), phosphorus (P) and sediment that can be discharged into freshwater from farm systems. The most recent iteration in this policy sequence includes new National Environmental Standards for Freshwater, and the new National Policy Statement for Freshwater Management (NPS-FW), which came into force in September 2020.

These policies reverse the trends of the past two decades when agricultural productivity grew substantially in the virtual absence of regulation to control the environmental externalities of systems intensification. While the initial impacts on land use and farming practices have been localised (e.g., in the lake districts of Rotorua and Taupo), disruption to the farm systems that have emerged over the past two decades, especially intensive dairy systems, will be widespread in the future. For example, Doole et al. (2021) estimated that the new standards introduced in 2020 will require about 40% of New Zealand's 11400 dairy farms to reduce nitrate leaching by an average of around 42% relative to requirements in previous iterations of the NPS-FW.

The most significant global force driving change in New Zealand agriculture is climate change, via New Zealand's commitment to the Paris Agreement to reduce carbon (C) emissions to net zero by 2050, C-neutral strategies being implemented by some of our largest customers (e.g., Nestle 2020), and the physical impacts of climate change on conditions for plant growth (e.g., Keller et al. 2021). Of direct and significant relevance to the livestock industries are the methane emission reduction targets proposed by government, of between 27% and 47% below 2017 levels by 2050. Meanwhile our international competitors have been steadily closing the gap in costs of production with New Zealand, and now have other fields on which to out-compete us (e.g., in C footprint) unless we can keep pace.

Resilience

The local and global trends briefly described above have brought a much sharper critical focus on the resilience of our primary industries, along with calls for transformation to products and services that unlock higher-value markets (Primary Sector Council 2019). Transformation is the longer, more speculative game. Its success will depend on a truly resilient base of traditional industries that can weather the incipient challenges and increase investor confidence in the future of New Zealand's land-based industries. While the traditional pasture-based livestock industries have become deeply unfashionable in some quarters in New Zealand, they remain a bedrock of the New Zealand economy.

Many definitions of resilience in the context of agriculture have been proposed in the literature. Most of these include reference to the ability of a farming system to rebound from disturbances or shocks without losing any of its critical capabilities and functions (or words to that effect). While an over-arching definition of 'resilience' was not adopted for this Symposium, the programme of invited papers, plus the offered papers that were accepted for inclusion, reflects the organising committee's view that environmental, productivity/profitability and competitiveness functions are all firmly and equally in scope. One critical element not directly included in the programme is the resilience of the people who operate and manage the sheep, beef, dairy, deer and goat farms across the ~10M ha of New Zealand pastoral land. Its omission is not intended to devalue its importance: indeed, the papers presented by farmers during the event poignantly described the high stress load and the consequent effects on the well-

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being of farm owners and staff created by rapid change in directions that are often uncertain, hard to plan for, and costly.

Typically, the resilience of pasture-based livestock systems has been framed using economic analyses that seek to maximise that probability of maintaining strong positive operating margins and minimise financial risk amid fluctuating and uncertain prices for products. For example, in an analysis of New Zealand dairy farm business physical and financial information, Neal & Roche (2020) concluded that "maximising pasture harvested, minimising reliance on supplementary feed, and effective cost control (minimising expenditure) as the key factors that lead to profitable businesses that are also resilient to the low milk prices that occur in volatile markets." It is therefore obvious that resilient pastures are an indispensable component of resilient dairy farm businesses. This conclusion holds across all livestock sectors in New Zealand, as explicated by Stevens et al. (2021). 'Resilience' in the context of pastures includes mitigating the effects of: increased climate variability and the underlying drying and warming trends predicted by climate change models (e.g., Keller et al. 2021); higher pest, weed and disease burdens, also related to changes in climate (e.g., Mansfield et al. 2021); and lower inputs of fertiliser, herbicides and other synthetic products that are subject to changes in regulation and/or customer demands.

The beauty of New Zealand's pasture-based farming systems is the ability to directly harvest, via the grazing animal, substantial quantities of generally high-quality feed cheaply even when the opportunity cost of owning land is accounted for (Journeaux 2021). Importantly, this means farmers can control the overall cost of feed and related expenses, and the top pasture farmers in New Zealand do this exceptionally well. The question is, can they continue to generate the cash surpluses critical to their financial resilience while simultaneously meeting the stringent nutrient emissions and freshwater targets being implemented by government policy; dealing with the physical effects of climate change; reducing methane and other greenhouse gas (GHG) emissions; meeting likely higher expectations for animal welfare/care; and managing for better biodiversity outcomes? Pastures are integral to the solutions to all of these challenges.

Expectations of pastures

Thirty years ago, a symposium focussed on resilient pastures would likely have attracted little interest. There were few regulatory constraints on production. Publicly funded research, development and extension (RD&E) organisations were active and focussed on physical constraints to productivity such as improving soil fertility and grazing management particularly on hill land. The New Zealand Grassland Association (NZGA) annual conference and other similar events covered the topical issues well (Casey et al. 2018). Twenty years ago, the focus was still very firmly on increasing production. There were no environmental regulations to curb systems intensification through, for example, increased use of cheap N fertiliser (Rys et al. 2021). The NZGA annual conference continued to provide a forum for information exchange, while specialist events such as the Ryegrass Endophyte Symposium (Woodfield & Matthew 1999) and Legumes for Dryland Pastures (Moot 2003) met specific needs.

The Pasture Persistence Symposium held ten years ago (Mercer 2011) signalled all was not well: concerns about the longevity of newly sown pastures, especially in the upper North Island, were mounting and were the primary motivation for that event. Initial stirrings regarding future environmental regulations and what they might mean for pasture production and management were also evident.

Ten years on from the Pasture Persistence Symposium, it is abundantly clear that the persistence problem has not been solved – and that this issue is but one of many emerging challenges for the management of pasture-based systems. Hence the broader scope of the Resilient Pastures Symposium, addressing multiple expectations of pasture performance.

So what are our expectations, and what are the prospects?

Performance review of pastures

One way to bring perspective to the scale of the challenges is to undertake a performance review of New Zealand pastures. A performance review, which we have all encountered in our jobs (for better or worse!), should be based on a clear job description, with attendant terms and conditions, placed in the context of organisational objectives, identifying strengths and weaknesses, and setting future goals. The organisational context is described briefly in the sections above. Here are some potential markers for the other steps in the performance review.

1. **Job description**
   a) Feed ~ 6.5M dairy cattle, 4M beef cattle, 27M sheep and 1M deer (Rys et al. 2021)
   b) Process most of the water, C and N flowing through ~ 10M ha of New Zealand agricultural land
   c) Assimilate net 30M t C/yr, and maintain net zero soil C balance (preferably achieve net positive C balance, Wall et al. 2021)
   d) Assimilate ~ 1.5M t N/yr through biological N fixation (Caradus et al. 1996; note, based on 13.5M ha and an estimated 3 t clover DM/ha/yr grown on flat/rolling higher productivity land

– clover yields have likely declined in recent decades due to the marked increase in N fertiliser use)

e) Support ~$30B in export earnings for New Zealand
f) Contribute towards ~10-20% price premiums paid for New Zealand's animal protein products
g) Maintain international competitiveness of our dairy, red meat and deer industries

This list of roles and responsibilities is analogous to the 'critical capabilities and functions' that might be included in a definition of pasture resilience. Most of those listed are self-evident, although the central role of pastures in mediating the mass balance of water, C and N cycling through New Zealand's agro-ecosystems is perhaps given insufficient recognition and illustrates just how critical pasture management and performance are for environmental resilience.

2. **Terms and conditions**

a) Hours of work: 24/7 × 365 days/yr
b) Sick leave: nil. Ailing pastures will be immediately replaced
c) Payment:
    i ~ 450000 t N fertiliser/yr
    ii ~ 150000 t P fertiliser/yr
    iii ~ 120000 t K fertiliser/yr
d) Dispute resolution procedures: nil. See b), above
e) Medical insurance: endophytes, pesticides and herbicides are available at cost. Some remedies such as bio-control agents are publicly funded and largely free
f) Learning and development (L&D) allowance: $7/ha/yr
g) Job security: there are two clauses.
    i Long-term contracts are preferred, but in some regions (notably on certain soil types in the upper North Island) only short-term contracts can be issued to ryegrass-based pastures due to pasture failure within 2 or 3 years post-sowing (Lee et al. 2017; McCahon et al. 2021). Other contractors may be deployed without notice as required.
    ii <u>All</u> pasture contracts may be terminated without notice if alternative local land uses surpass profitability of pastures and/or are required under Head Office policy. Note in particular the strong prospect of replacement by forestry contractors if the market price for C moves >~$75/t in emissions trading scheme.

3. **Strengths, weaknesses and goals**

Some of the strengths of pastures have been touched on above, and described in more detail by others (e.g., Clark et al. 1997). There are some emerging weaknesses that imply performance needs to lift.

Relative to job description

There are clear concerns in two areas.

a) Feeding and international competitiveness: Chapman et al. (2020) and Mills & Neal (2021) reported that pasture eaten/ha/yr on New Zealand dairy farms has been static (and in some cases declining) for the past 15 years. Beca (2020) reached the same conclusion, and noted that, among a group of other countries/regions where pasture-based dairying is practised, New Zealand has the lowest rate of increase in pasture eaten/ha at 0.1% compound annual gain (Table 1). International competitiveness is under threat.
b) Response to organisational change, specifically:
    - more work is needed on reducing nutrient and sediment losses
    - an action plan for methane reductions is urgently needed
    - climate change preparedness is seriously under-developed

Relative to terms and conditions

c) A wage freeze (or, in some cases, a pay cut) will be implemented in 2021, in the form of a cap on the total amount of N fertiliser that can be applied: 190 kg N/ha/yr. Adjustments are required in some cases, and more restrictions can be expected.
d) Some medical remedies will no longer be available, such as insecticides in the neonicotinoid family and, potentially, glyphosate herbicides. More restrictions can be expected.
e) Learning and development spend: it should be noted that the current L&D spend is viewed unfavourably in some quarters and reductions can be expected. New approaches to attracting and managing investment will be required.

These strengths and weaknesses touch on examples of the perturbations that pasture and pasture-based systems will need to absorb to achieve true resilience. More could be added, though even this short list highlights how much there is to deal with, quickly, and with limited (and potentially declining) management options.

Table 1 Compound average growth rate (CAGR) in pasture harvest (t DM/ha/yr) in pasture-based dairy regions from 2003 to 2019 (from Beca 2020).

	Tasmania	Victoria	New Zealand	Argentina	Uruguay	South Africa
CAGR %	1.3	0.7	0.1	0.7	0.2	2.2

Learning and development spend

'Learning and development' in the performance review above refers to investment in research and development (R&D) for the improvement of pastures. The L&D allowance cited in 2f is based on a best estimate of ~ $70M/yr total spend on pasture related RD&E in New Zealand (Pers. comm. J Morrison, Morrison Consulting Ltd.) servicing 10M ha. About one-third of the total spend is in the commercial sector (mainly private plant breeding companies), leaving ~ $50M/yr of 'discretionary' public and industry good investment. Each of those 10M ha generates, on average, ~$3000/ha in export income from milk and meat products, equating to an investment rate of ~ 0.23% of the value of income earned.

It is difficult to gauge how the number of 0.23% compares with other New Zealand business sectors or to agricultural sectors in other countries. For the former, total government and business R&D spend in the New Zealand 'primary' sector (defined as encompassing 'plant, animal and minerals') was $680M in 2018 (Stats NZ 2019), equating to 1.6% of total export earnings from the entire primary sector (Ministry for Primary Industries 2021) in that year. Thus, pasture is receiving around 10% of the combined government and private R&D investment in the primary industries, while contributing to about two-thirds of primary sector export earnings.

As an international comparison, R&D intensity in agriculture and food reported by the Organisation for Economic Co-operation and Development (OECD 2019) for 15 countries (not including New Zealand) averaged 1.37% of total Gross Domestic Product (GDP) for government investment (range 0.2% in Turkey to 2.5% in Switzerland; Australia 1.4%) and 1.52% (0.5% in Turkey, 2.4% in Switzerland; Australia 1.0%) for business investment (a total of nearly 3% of GDP). By these admittedly crude comparisons, the investment intensity in New Zealand pasture R&D sits well below what other countries are prepared to invest in innovation and development.

Job security: pasture persistence, adaptation and resilience

This Symposium marks the 10-year anniversary of the Pasture Persistence Symposium (Mercer 2011). It was initially conceived as an opportunity to review progress on solving the persistence problem in the intervening 10 years. As noted above, the scope of the 2021 event was broadened so that the numerous large-scale and fast-moving changes that farmers are now confronting could be considered in the context of long-term resilience. It follows that pasture persistence and pasture resilience are not the same thing. A highly persistent pasture does not necessarily confer resilience when the full suite of systems capabilities and functions are considered. For example, lowland pastures dominated by *Poa annua* and hill country pastures dominated by browntop (*Agrostis capillaris*) should be very persistent, but the low nutrient use efficiency of the former will likely lead to high nitrate leaching rates and the low nutritive value of the latter would likely lead to high methane emissions intensity. Thus, neither are 'resilient' to the more-stringent limits on environmental emissions imposed by regulation, nor would they produce sufficient feed to support high rates of animal production and profitability.

This does not mean persistence is unimportant: there is no doubt that productive pasture species that are able to persist for long periods (e.g., >10 years) tick many of the boxes for resilience. Hence, it is important to note that, despite several new R&D initiatives arising from the 2011 event, the problem of perennial ryegrass persistence failure has not gone away, despite indications in the early 2010s that tactical management responses such as reducing summer grazing intensity might be alleviating the issue (Reynolds 2013).

It is now indisputable that some combinations of local climate and soil type, often exacerbated by insect pest damage, present environments that are beyond the adaptive range of current perennial ryegrass cultivars (Lee et al. 2017; Jagger 2021; McCahon et al. 2021). The specific environmental combinations, and the lethal factors operating, are still poorly defined although simulation tools are being developed to help address this knowledge gap (e.g., Beukes et al. 2021). Perennial ryegrass is generally able to withstand, and recover from, single stress events like a drought, over-grazing, or insect damage (Chapman et al. 2011) but multiple simultaneous stresses can collectively exceed thresholds of plant survival (Cullen et al. 2006; Tozer et al. 2017; Moot et al. 2021). Soil physical (Houlbrooke et al. 2021) and biological (Shi et al. 2021) properties are significant contributors and require further attention. Whilst short-term annual or Italian ryegrasses can be used to, in effect, avoid the persistence problem, this strategy involves frequent soil disturbance and carries increased risk of soil organic matter depletion (Wall et al. 2021) and therefore may not result in true resilience.

Climate change projections indicate that temperate pasture species will experience increased abiotic growth stresses across much of the North Island (Keller et al. 2021), while damaging levels of several key insect pests will be exceeded more often (Mansfield et al. 2021). Recent trends toward hotter, drier summers/autumns in Waikato have been highlighted by Glassey et al. (2021), including the observation that six out of the last 10 years in Waikato have brought significant summer/autumn droughts. This closely mirrors trends in south-eastern Australia where the key lesson has been

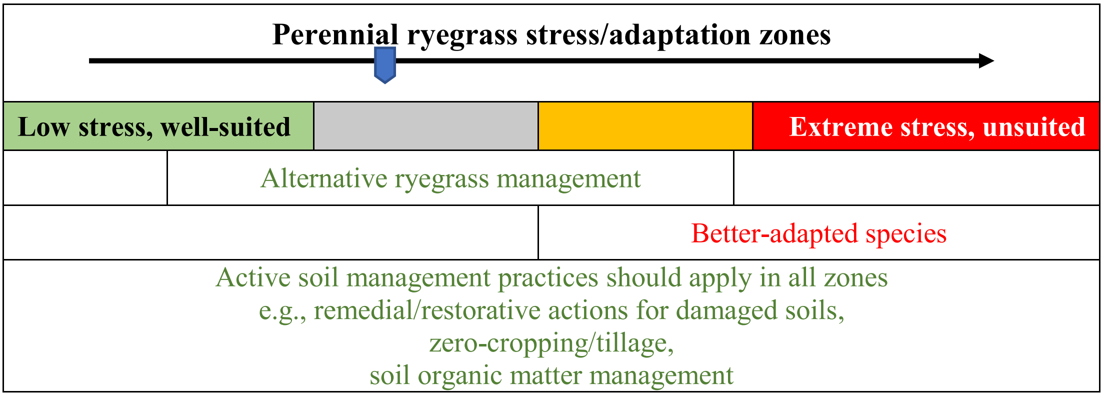

Figure 1 Conceptual framework for determining the most effective pasture management responses (examples shown below the coloured bar) across the spectrum of perennial ryegrass suitability zones. Note there is overlap and cross-over between zones: there will be localised areas within mega-regions (e.g., Northland, Bay of Plenty, Waikato) that represent all zones due to spatial variability in climate, soils, and pest populations. In general, increased abiotic and biotic stresses resulting from climate change are expected to push the slider toward the right in more regions.

that resilience to extreme climatic events is paramount (Cullen et al. 2021).

Farmers in affected areas, especially in Northland, are responding by moving away from perennial ryegrass (Glassey et al. 2021; Jagger 2021; McCahon et al. 2021). Simple conceptual models such as depicted in Figure 1 help guide the direction of change, but much better definition of what constitutes 'low' or 'high' stress, 'suited' or 'unsuited', 'alternative management' and 'better adapted' is needed to help decision-making at the individual farm level. Currently, farmers are left largely to their own devices when considering their options, a situation that is not helped by fragmented and incomplete information resources.

Conclusions

New Zealand's pasture-based livestock systems have been shaped by a unique set of climate, topography, soil and market factors. The dominant perennial ryegrass-white clover pasture communities that have proven productive and resilient in the past are, on closer analysis, ecologically vulnerable as described by Goldson et al. (2020) in the case of insect pest-predator relationships. As the climate changes, those vulnerabilities may be magnified as forecast by e.g., Mansfield et al. (2021, also in the case of insect pest population biology). Importantly, New Zealand's maritime, humid climate spanning ~ 15 degrees range of latitude and shaped by our geography does not 'map across' to any obvious and substantive analogue regions of the globe from which pasture solutions could be readily adapted. Climate analogues in Australia for the upper North Island of New Zealand are limited to pockets on the south-eastern coastal margin of the continent (Garcia et al. 2021) which have already been heavily prospected for promising organisms and management practices.

These points highlight how solutions to the challenges facing New Zealand pastures and pasture-based farm systems must be largely homegrown. Our pasture-based farming businesses are entering a period of rapid and deep change where simultaneous solutions will be needed on multiple fronts: production, profit, nutrients, GHGs, animal care, and customer/consumer demands/trends being among the headline issues. Importantly, solutions to any one of these challenges cannot result in poorer outcomes for others. Whereas it was a relatively simple matter to increase pasture productivity in the 1990s/2000s by using more N fertiliser, this management shift resulted (mostly indirectly) in increased nitrate leaching and nitrous oxide emissions and is no longer an option under emerging environmental emissions limits.

Pastures are pivotal to the successful navigation of most of the big changes ahead. This Symposium sought to bring to the fore the broad range of issues facing our pasture-based farmers, assess what technologies and management options will be needed to address those issues and how we are positioned currently, and help catalyse collaboration among farmers, rural professionals, agribusinesses and the R&D community. There is a long 'to-do' list. The aspiration of the Symposium Organising Committee was that the next performance review of pastures will record strong progress against the job description, supported by a better integrated and resourced R&D system in which farmers themselves play a pivotal role in finding solutions.

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