Challenges and opportunities impacting New Zealand's economic foundation – pastoral agriculture

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Highlights
New Zealand is unique amongst OECD countries in its reliance on pastoral agriculture for generating export revenue that underpin its economy. However, this agriculturally based production system is open to an unprecedented level of challenge which includes maintaining a high level of productivity to ensure international competitiveness, the impact of regulations and compliance, a social license to operate, the development and uptake of new technologies, competition from non-animal sourced foods, ensuring an adequate and well directed level of R&D investment, acceptable impacts on the environment and conversely having mitigation strategies to ensure adaptation to changes in climate, farming continuity through supply of adequate skilled labour, land use change, biosecurity breaches, and enabling added value opportunities to be developed. The aim here is to review these challenges and identify options for alleviating, managing or mitigating them.

Keywords biosecurity, environment, productivity, R&D investment, social license

Background
New Zealand's export earnings are largely based on free-range grazing of pastures. This incorporates both introduced pasture species and introduced ruminants which provide milk, meat and fibre (Caradus et al. 2023). About 90% of agricultural production is exported generating new wealth for the New Zealand economy valued at over $38 billion or 42% of total annual exports of goods and services (MFAT 2022; MPI 2023a). New Zealand's economic reliance on pasture-based agriculture is almost unique amongst Organisation for Economic Co-operation and Development (OECD) member countries (Lees 2014; Oenema et al 2014; Wreford et al 2019; IPES-Food 2022). New Zealand with a temperate climate, good natural resources and a reputation for producing high quality food products, efficiently and sustainably is positioned well for the future (MPI 2023b). However, the extent and intensity of challenges currently facing the pastoral sector are unprecedented (Dalziel et al. 2018). The aim here is to review the main challenges faced by the pastoral agricultural sector and identify options for alleviating, managing or mitigating those challenges.

Challenges confronting the New Zealand pastoral sector
Challenges facing the pastoral sector are many and varied. However, challenges also present opportunities and that is the approach New Zealand must take to ensure the wealth creating foundation of its economy, the pastoral sector, is supported and maintained at the very least.

1. Productivity
Productivity is a measure of how efficiently inputs are being used in an economy to produce outputs. The importance of productivity is that for a country to improve its standard of living over time almost entirely depends on its ability to raise its output per worker (Krugman 1997). Changes in productivity can result from either movement in the 'best practice' production technology, or a change in the level of efficiency (Rogers 1998).

Whole country productivity
Whole country productivity is routinely measured by dividing Gross Domestic Product (GDP) by the total number of hours worked. On this measure New Zealand is ranked 31st out of the 47 OECD countries (OECD 2024) with annual labour productivity growth averaging 1.4% since 1996 but slowed to 1% between 2008 and 2018 (Nolan et al. 2019). New Zealand's output growth is lower than that of Australia. From 1996 to 2022, the average annual growth in labour productivity in New Zealand was 1.3%, compared with 1.9% in Australia (Stats NZ 2023). New Zealand is one of a small number of OECD countries that includes Mexico, Greece, Portugal, Israel, and Japan with both a low level of labour productivity and low productivity growth (Nolan et al. 2019). However, using an alternative measure of 'per capita Real Adjusted Net National Income' (pcRANNI) (which is a measure of per capita net income that is available for consumption leaving the aggregate capital stock intact) then New Zealand had approximately zero pcRANNI growth from 1970 to the early 1990s. But since then, New Zealand's performance using this measure has been stronger than most, being ranked 8th out of 22 developed countries (Grimes and Wu 2023). Therefore, in terms of income available for consumption by a country's residents while consumption is sustainably maintained then New

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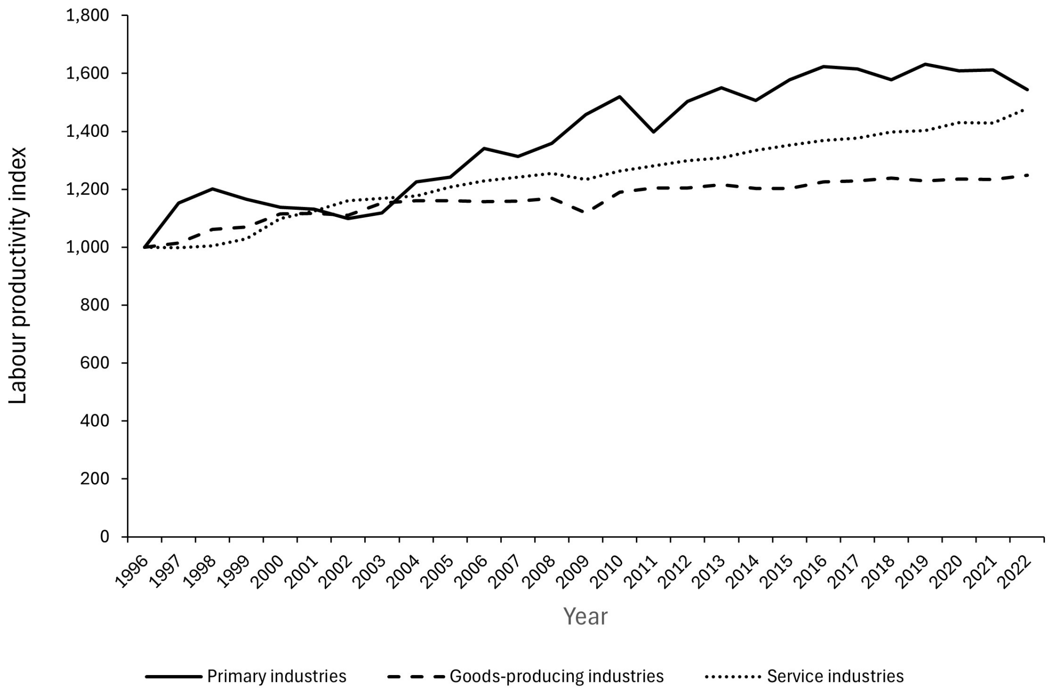

Figure 1 Labour productivity indices for industry groups from 1996 to 2022; base year was 1996 +1000. (Derived from Stats NZ 2023). Labour productivity divides the produce outputs of goods and services by the hours people work.

Zealand is apparently well placed. Despite that New Zealand's economic position still needs to seek options to improve and that will theoretically eventuate through reforms in competition policy, infrastructure, science and innovation, education, and the labour market (Nolan et al. 2019).

Another factor to consider when evaluating productivity measures is to distinguish between technical efficiency (i.e. producing more from the same or less inputs) and allocative efficiency (i.e. producing things someone wants to buy) (Grimes 2020; Grimes and Wu 2023). For New Zealand, economic prosperity has been linked irrevocably to providing food that the world wants, even if much is supplied into the commodity (low value) market (MPI 2023b).

Pastoral agriculture productivity

Labour productivity captures how output relates to changes in labour inputs. Estimates of labour productivity in 2022 compared with 1996 (index rated at 100) (Figure 1) indicated that:

- primary industries workers produced 154 goods and services per hour;
- service industries workers produced 148 goods and services per hour; and
- goods-producing industries workers produced 125 goods and services per hour (Stats NZ 2023).

While there has been a decline in employment within the primary sector (agriculture, forestry and fisheries) the annualised average labour productivity growth increased by over 2%, higher than most other occupation classes including manufacturing, accommodation and food services and administration and support services (Figure 2).

Measuring improvements in pasture production due to plant breeding

An important part of improving on-farm productivity is increasing feed supply from pasture for animal consumption. However, examination of long-term annual net herbage accumulation of pastures across New Zealand has indicated slower than predicted pasture growth rates based on climate change growth models (Mackay et al. 2023). These models had predicted a neutral or slightly positive impact on net herbage accumulation in pastoral systems attributable to warming and CO_2 enrichment of the atmosphere (Keller et al. 2014; Lieffering et al. 2016; Ausseil et al. 2019; Keller et al. 2021; Newton et al. 2022).

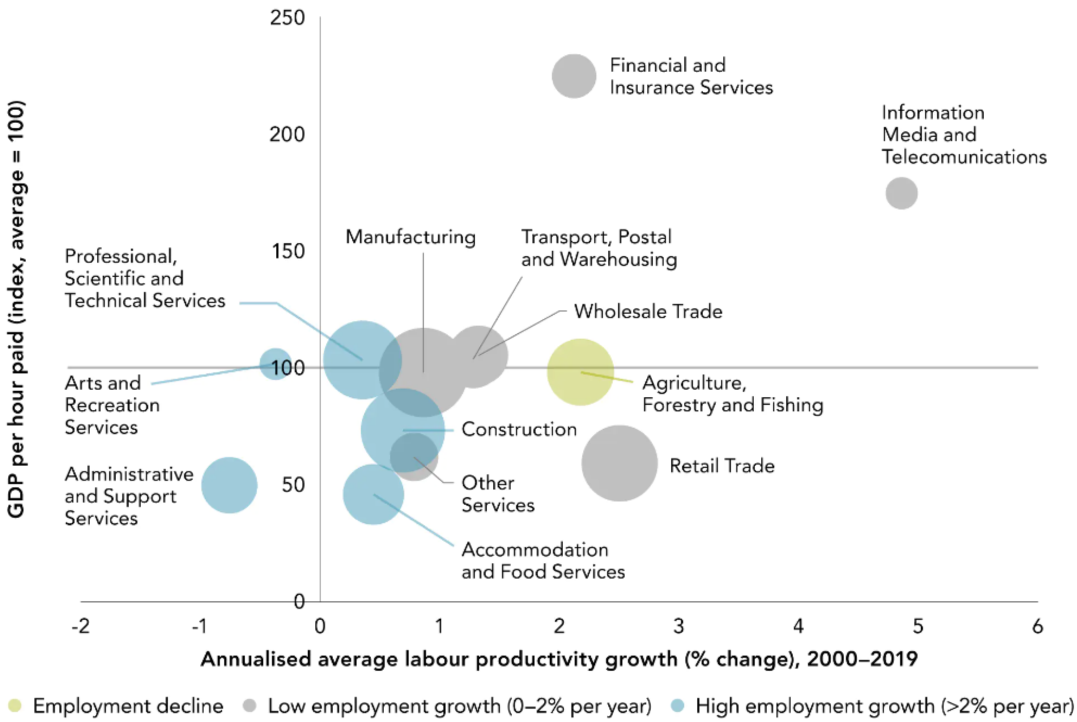

Figure 2 Relationship between annualised average labour productivity growth between 2000 and 2019 for various industry groups and indexed GDP paid per hour. Taken from NZ Productivity Commission (2023a) based on Stats NZ Productivity statistics: 1978–2022 (Stats NZ, 2023) and Stats NZ, National accounts (industry production and investment).

While increasing feed supply from pasture for animal consumption can be a significant challenge it is largely driven by a combination of plant genetics both in terms of plant breeding and use of appropriate species, astute management decisions, and increasing levels of inputs such as fertiliser, pesticides, fungicides and/or the use of irrigation. The focus here will be to understand the value created by plant breeding and how that might be evaluated.

In some countries it is a legislated requirement to evaluate new forage cultivars, using a centralised testing agency, to determine if they are distinct and add value over and above existing cultivars (Foletto 2008). This process is used in a number of countries including amongst others Europe and the UK (Kiewiet 2005; Foletto 2008; Van Waes 2008; Gov.UK 2024), Norway (Norwegian Food Safety Authority 2024), and Canada (Government of Canada 2020). However, it is not a system that is used in USA (Blaustein 2016), New Zealand, and Australia, although in New Zealand (PBRA 2024) and Australia (MLA 2024) there are national variety testing trials for forages which rank the agronomic performance of cultivars in a range of environments but have no influence on whether they can be marketed or sold. That is a decision made by the owner and commercial producer of the cultivar, relying solely on market forces and demand to determine the extent of acceptance and uptake. The New Zealand national variety testing trials cover only perennial ryegrass (*Lolium perenne*), hybrid ryegrass (*L. hybridum*), Italian and annual ryegrasses (*L. multiflorum*), while the Australian system monitors annual, Italian and perennial ryegrasses, brome (*Bromus*), cocksfoot (*Dactylis glomerata*), Phalaris (*Phalaris arundinacea*), tall fescue (*Festuca arundinacea*), chicory (*Cichorium intybus*), lucerne (*Medicago sativa*) and sub clover (*Trifolium subterraneum*).

In terms of assessing forage cultivars for improved animal performance there are three examples where data from herbage production trials is used with modelling to determine the economic value of each cultivar evaluated. This has predominantly focused on the value of ryegrass cultivars with the traits evaluated being dry matter yield and metabolizable energy concentration (Chapman et al. 2023). Persistence is a desirable trait to include but is challenging to define and quantify. In Ireland the Pasture Profit Index (PPI) (McEvoy et al. 2011) is used, and independently in Australia and New Zealand the Forage Value Index (FVI) (Leddin et al. 2018, and Chapman et al. 2017, respectively).

A recent analysis has concluded that in the dairy sector "lifting the pasture renewal rate from 8% of pasture area per year to 15% per year increased profit by $40/ha, or 1.3%" resulting in a Net Present Value (NPV) of $198/ha/year and an Internal Rate of Return of 56% (Journeaux 2021). This benefit was directly related to the percentage of the extra feed grown and assumes it is all consumed. Several other studies have also identified the economic benefit of pasture renewal (Sanderson and Webster 2009; Glassey et al. 2010; McLean 2011). However, many of these studies involved the renewal of the worst paddocks (Stevens and Knowles 2011 and Kerr et al. 2015), so the value of new plant genetics (as compared to any unelected or older genetics) is often hidden or not obvious. The use of the Forage Value Index in New Zealand was halted in 2024 due to results from a trial to validate the FVI rankings through using a farm systems trial not differentiating between higher and lower ranking cultivars, based on yield in small plots, for predicted milksolids production and operating profit expected from ryegrass dry matter yield measured at the plot scale (DairyNZ 2024). Reasons for the inability to differentiate between higher and lower ranking cultivars possibly related to a failure to either transfer yields from small plots to paddock scale or to use management systems that capture the yield difference in milk yields.

2. Regulations, compliance, bureaucracy and cost of operating

In a recent survey of rural professionals "42% of respondents indicated that 'compliance and regulation' will be the biggest challenge facing the industry over the next three to five years" (Macaulay 2021). As a producer of food products New Zealand must have a robust regulatory system and be an active participant in international standard-setting bodies associated with food safety and the protection of human, plant and animal health (MPI 2020). The Ministry for Primary Industries (MPI) is responsible for setting and enforcing standards and regulations for New Zealand's food safety, biosecurity, primary production and animal welfare systems. A bill to improve the quality and efficiency of regulations affecting the primary industries is currently being put into place with cross-party support (New Zealand Parliament 2024).

However, in addition to regulations and compliance for export of primary sector products several other regulations requiring on-farm compliance have been proposed recently - He Waka Eke Noa, which threatened to make New Zealand farmers the first in the world to pay a greenhouse gas emissions tax; the Natural Built and Environments Act to replace the Resource Management Act which would continue the compliance burden and adds complexity of co-governance; Significant Natural Areas that infringe on property rights; and the National Policy Statement for Freshwater Management which has the potential to create huge compliance issues. Undeniably farming today is beset by an increasing amount of "red tape' which can result in confusion and general uncertainty around long term production, productivity and profit (Keenan 2019). No one is arguing that New Zealand farmers should not strive for clean air, clean water, unpolluted seas and thriving native biodiversity, it is the process towards achieving that outcome which is causing the concern and at times frustration. Indeed, securing premium prices for exports based on an acknowledged brand is compelling and achievable. Compliance can be reached through effective communication and trust between all parties from central government to the farmer (Keenan 2019). There is evidence that overbearing regulatory systems can both stifle (Chataway et al. 2007) and promote (Abbas et al. 2024) innovation and impacts that should come from innovation depending on the type and focus of the regulation. Interestingly, deregulation and the removal of subsidies in the mid-1980s stimulated increased mechanisation, R&D investment and innovation within the primary sector, resulting in productivity gains (Eckhold 2024).

3. Customer dynamics, perceptions and demands – social license to operate

"Social license to operate" is a relatively recent term that is being used in New Zealand to identify community-initiated issues of concern about the impact of, and resulting reputation of, a range of industries, including the mining, aquaculture, dairy and forest industries (Ruckstuhl et al. 2014). It has arisen as a result of societal concern about how the country's resources are developed and used, and the need to balance risk against benefit resulting from operations within an industry (Morrison 2014). Requirements for obtaining a social license to operate include perceptions of legitimacy, credibility, trustworthiness, the scale of the business or operation, perceived procedural fairness and impacts on social infrastructure, ensuring organisational values and processes meet community expectations, and communication that incorporates engagement, partnership, openness and transparency, (Boutilier 2014; Dare et al. 2014; Edwards and Trafford 2016; Beban et al. 2023). It is important to realise that 'regulation and societal expectations operate quite independently of each other' (Edwards and Trafford 2016).

As with any business that seeks to sell something it is paramount to understand what your customers and your customers' customers value, and then deliver that at a sufficiently low cost that still allows a good profit or return. New Zealand is unique in the OECD through being a 'small' economy and being geographically distant from its customer base (Vitalis 2007). And yet trade is a necessary and critical component of any growth strategy for an economy such as New Zealand's. A survey across five export markets (China, India, Indonesia, Japan and the United Kingdom) was undertaken to examine how consumers of New Zealand food and fibre products perceive and value credence attributes such as food safety, animal welfare, environmental protection and cultural authenticity (Dalziel et al. 2018). It indicated that quality and food safety are the most important attributes. However, other credence attributes are also important, with some differences in how these are ranked in different markets. Consumers in China, India and Indonesia rated credence attributes more highly than consumers in Japan and the United Kingdom.

Consumer driven opportunities out to 2050 have been reviewed (MPI 2023b) and may need to consider:

- Future reputation through advancing the New Zealand brand to sustainability-plus, developing improved mechanisms to build trust with end-consumers and being proactive about planning for shocks to our reputation.
- Future exports that pursue both traditional and new innovative exports including alternative proteins and animal proteins which may be both natural and genetically modified food. New information and capabilities to encourage development of innovative products and services for future consumers will be needed.
- Future markets that balance traditional markets and potential growth markets (especially Asia) better while understanding emerging markets and building an appropriate reputation with them.

4. New technologies

New Zealand farmers excel at adopting science to drive production, productivity and both environmental and social outcomes (Caradus et al. 2013). Today, most dairy sheds have a computer in them allowing farmers to track and analyse data to improve decision making and productivity (Dela Rue et al 2020). Emerging wearable technologies on dairy farms such as collars on cows measure a multitude of factors - including whether or not a cow is in heat, level of feed intake, aspects of an animal's behaviour and other key insights (e.g. lameness) which have potential to save time and deliver benefits (DairyNZ 2023). Precision agriculture provides the opportunity to deal with the complexities of land use change and monitoring to assist in achieving environmental expectations associated with reducing greenhouse gases emission (Yule and Eastwood 2012; Finger et al 2019). Other advances in automation, sensors, analytical testing, supply chain management, pest and biocontrol, waste management, genetics and breeding, management system technologies, and nutritional understanding are predicted to significantly improve productivity on-farm (MBIE 2020; Caradus et al. 2023).

Genetic modification and gene editing methods have been used in many countries, many of which New Zealand trades with, and yet this technology while not banned is essentially regulated to a point where it is only used in PC2 contained laboratory and glasshouses for research purposes. Examples of the application of GM technologies towards providing solutions to either issues currently facing the New Zealand pastoral sector, or opportunities that deliver a competitive advantage have been previously described (Caradus 2023). Targeted gene editing is being promoted as a method "to deliver on a promise to quickly create crops with traits that withstand a changing climate, resist aggressive pests and reinvigorate healthy soils" (Klein 2024).

In New Zealand, much of the success of pastoral farming has been due to the willingness and ability of farmers to use, adapt, adopt, and integrate new ideas and technologies into their farming systems (Caradus et al. 2023). That review concluded that "the farming community will clearly continue to use new technologies and systems for profitable and sustainable farming systems, but a question remains as to whether the existing research structures and funding systems will be capable of delivering them".

5. Meat protein alternatives

Meat protein alternatives can come from a variety of plant-based sources, fungi, insects and as laboratory grown cultured meat (Wild et al. 2014; Kumar et al. 2017; Ismail et al. 2020; Hefferon et al. 2023). The recent increase in the consumption of plant-based and mycoprotein-based meat alternatives is due to their perceived benign environmental impacts, although perceived lack of naturalness and poor cultural acceptance could impact on widespread acceptance (Thavamani et al. 2020). Additionally, barriers to the rapid transition away from animal-sourced protein include political, regulatory, and cultural factors (Mylan et al. 2023). Indeed, there is a view that for "a majority of consumers, meat seems to be too attractive to be substituted by plant proteins, cultured meat, or insects" and these will simply become niche markets and that worldwide meat consumption is still likely to grow in the future (Siegrist and Hartmann 2023). Evidence for the superior nutritional quality of animal-sourced food such as meat, milk, and eggs, compared with plant-based foods, indicates that consumption of animal-sourced food should and will continue (Caradus et al. 2024a). Indeed, meat protein alternatives maybe no healthier than animal-sourced meat, and might be less healthy if the higher salt, and lower vitamin content are considered (van Vliet et al. 2020; Swing et al. 2021; Caradus et al. 2024a). Possibly, benefits to human nutrition and health and to climate outcomes may be best achieved through "partially substituting red and processed meat with plant protein foods" (Auclair et al. 2024). Currently, a world trend for lower animal-source meat consumption in developed countries is offset by increasing consumption in developing countries, such that animal-sourced meat consumption globally is increasing (Blaustein-Rejto and Smith 2020). Indeed, this review suggests that meat replacements can only take us so far and that it needs to be supported by low environmental impact livestock farming (Caradus et al. 2024b), such that there is a clear place for both plant- and animal-sourced foods in future sustainable food systems (Smith et al. 2022).

6. R&D investment and capability

Innovation and technological change, which require appropriate investment efforts, are critical to productivity growth (NZ Productivity Commission 2023b). However, New Zealand's R&D investment into the primary sector both from government and commercial organisations is low considering the importance of the sector to the New Zealand economy (Foley 2022). Gross domestic spending on R&D, defined as the total expenditure (current and capital) on R&D carried out by all resident companies, research institutes, universities and government laboratories, was 1.47% of GDP for New Zealand in 2021, compared with the OECD average of 2.72% (OECD 2022). A bottom-up analysis of investment into pasture R&D in New Zealand indicated that from government, industry good and commercial sources $92 million was invested per year (Warren King and David Hume, pers. comm). Government investment made up about 37% of that total investment into pastures-related R&D in NZ. Further to that New Zealand's agricultural innovation system has three issues which will block co-innovation and impact - (i) competitive science in silos, (ii) laissez faire innovation, and (iii) science centred innovation (Turner et al 2016).

An insightful review of New Zealand science system concluded that "NZ is doing the invention well, it's the innovation– the repurposing of existing technologies and science into new/novel uses, that is difficult in the current science landscape" (Foley 2022). Here invention was defined as "the creation of new knowledge, new ideas and new technologies" and innovation as "taking existing knowledge and technologies and repurposing them for uses in other ways". Foley also correctly observed that "we have a funder-facing science environment where countless hours are spent on funding applications instead of using this resource for improving society or innovations that makes NZ a wealthier country". New Zealand is not alone and there has been a call in the USA for research programmes to focus on delivering tangible benefits rather than building a research pipeline that venerates prizes and papers above all else (Flagg 2022). As often happens in New Zealand, after a researcher finishes a project and publishes the results in a paper, they simply go on to the next proposal — the next big, new idea, constantly chasing novelty, which Flagg (2022) described as a 'waste'. However, delivering tangible benefits and peer reviewed publications are not mutually exclusive.

Nearly 20 years ago it was estimated that investment in domestic agricultural R&D has generated an annual rate of return of 17% (Hall and Scobie 2006). They also concluded that while foreign knowledge was important in driving productivity, having a domestic capability that can receive and process the spill-ins is vital to capturing the benefits. However, below OECD-average investment in research and development and a fledgling venture capital market means New Zealand continues to fail to reach its full potential through embracing widespread entrepreneurship (Sawyer 2022).

7. Environmental impacts

Environmental factors that need to be considered include land, water and air sustainability, energy use and supply, food miles impacts, reduced use of synthetic chemistry and increased reliance on microbial bioprotectants (e.g. biopesticides and biofungicides). Consumers are increasingly expecting that sustainable environmental standards are maintained in the production, processing and distribution of food and fibre products (Dalziel et al. 2018). While New Zealand has a long-standing international reputation as a 'green' country more recently there has been an acknowledgement that there will need to be "trade-offs between continued reliance on exporting primary products and environmental and climate change mitigation goals" (OECD 2017). It is also now accepted that growing the value of land-based production, and consequently exports should not occur at the expense of social, cultural and environmental well-being. New Zealand must continue to invest in and deliver value from research efforts to find solutions that reduce the environmental impacts of agriculture.

New Zealand responded to the Paris Agreement Long Term Global Goal (LTGG) to limit temperature rise to below two degrees, with further aspirations towards 1.5 (UNFCCC, 2015) by passing the Climate Change Response (Zero Carbon) Amendment Act 2019, the establishment of the Climate Change Commission, and the subsequent first Emissions Reduction Plan in 2021, preceded by the Climate Change Response Act 2002 (NZTech 2024). However, despite those initiatives it is considered that the country will miss its 2025 Emissions Budget target (EB1) (NZ Herald 2023). The issue for pastoral agriculture is that it alone contributes more than half of greenhouse emission for New Zealand (Ausseil et al. 2013). The other main environmental impact from pastoral agriculture is nitrogen loss resulting in water contamination.

Agriculture has been identified as the single largest contributor (53%), followed by the energy sector (37%) to New Zealand's total greenhouse gas emissions (Mfe 2024a). Between 1990 and 2022, emissions from the agriculture sector increased by 12% primarily due to a 78 per cent increase in the national dairy herd and a 465 per cent increase in the application of synthetic nitrogen fertiliser since 1990 (Mfe 2023a). However, there has been a small decline of 1.4% in agriculture's carbon dioxide equivalent emissions from 2021 to 2022 that has been attributed to the fall in the numbers of sheep, and reduced nitrogen fertiliser use. Opportunities to further reduce greenhouse gas emissions from pastoral agriculture may include:

- Improving the nutritive value of the grazed feed through replacing low-quality pasture with improved higher-quality pasture (Alcock and Hegarty 2006; Smith et al. 2022). While this may increase the enteric methane emission (g/day) produced by ruminants it is likely to reduce the methane yield per unit of meat or wool produced.
- Incorporation of forage plants containing compounds that reduce greenhouse gas emissions when consumed by ruminants (Patra and Saxena 2010). This would include plants expressing condensed tannins which protect protein in the rumen and have been demonstrated to reduce methane emission [Min et al. 2020; Roldan et al 2022].
- Dietary additives such as oils, microalgae, macroalgae, encapsulated nitrogen, ionophores, protozoal control, phytochemicals from plant extracts, and 3-nitrooxypropanol have shown differing levels of efficacy in reducing methane production per kg dry matter consumed (Almeida et al. 2021; Honan et al. 2021).
- The breeding of animals with higher growth rates and increased fecundity and/or lower methane production (Cruickshank et al 2009; Fennessy et al 2019; Rowe et al. 2021).
- Rumen microbial manipulations through the use of broad specificity vaccines (Wedlock et al. 2013; Baca-González et al. 2020).
- Pasture management, which ensures grazing occurs when fibre content is low (Waghorn et al. 2002).
- Animal management that reduces age at first breeding [Cruickshank et al. 2009] and age to slaughter (Rolfe 2010).
- Soil management to reduce N_2O emissions including reducing tillage (Mutegi et al. 2010) but at the same time reducing soil compaction (Hernandez-Ramirez et al. 2021) and incorporation of nitrification inhibitors with nitrogen fertiliser (Luo et al. 2010; Harty et al. 2016)

Pastoral agriculture can impact nitrogen levels in waterways including ground water. Reducing this impact may require:

- N fertilizer used in conjunction with urease inhibitors.
- Supplementary feed formulations including essential oils.
- The use of nitrification inhibitors.
- Plant breeding to exploit genetic variation among and within species in traits that have the potential to improve nutrient use efficiency (such as condensed tannin content).
- Animal breeding to select for animals with lower methane per unit of dry matter intake.
- Combining traits in complementary forage species mixtures and including a herb that inhibits nitrification in the soil and/or dilutes the N concentration of urine (e.g., plantain).

8. Climate change adaptation

Assuming climate change policies are unchanged globally, studies have shown that mean temperatures in New Zealand in 2090 could be as much as 4.6°C higher than pre-2005 levels (Mfe 2023b). Modelling using a mid-range Intergovernmental Panel on Climate Change scenario predicts that in New Zealand average air temperature will increase by 2.1°C by 2090, with increased rainfall in the west, and reduced rainfall in the east (Lindquist et al. 2011). This will coincide with more intense rainfall events which will amplify rates of disturbance, erosion and sedimentation into aquatic, estuarine and coastal ecosystems, while areas with low rainfall will experience lost production from seasonal drought. and possibly increased fire risk. So, in addition to ensuring that pastoral agriculture continues to seek ways to reduce its direct environmental impact it must also learn to adapt to these predicted changes in climate. This can be achieved through changes in management systems, change of forage species, or selection and breeding for improved adaptation within existing forage and animal species to predicted changes in climate. Understanding impacts that an elevated CO_2 environment might have on pasture production and processes has been determined in field trials using CO_2 fertilisation (Newton et al. 2022).

Elevated CO_2 levels may have a substantial negative impact on plant-available P (Olsen P) in the soil which may reduce clover growth and subsequent nitrogen fixation (Watanabe et al. 2013; Keane et al. 2023). There also appears to be direct positive effects of elevated CO_2 on nitrogen fixation (Soussana and

Hartwig 1995; Brooks and Szeto 2024) associated with the link between an increase in the atmospheric CO_2 concentration increasing the C:N ratio of plant residues and exudates, assuming that nitrogen is available which it is in nitrogen fixing legumes (Roger et al. 2009). However, neither elevated CO_2 nor its interaction with legumes affected net N mineralization (Wei et al. 2019). Lower intake of herbage by animals grazing forage grown under elevated CO_2 suggests that "a future high-CO_2 world seems destined to reduce individual animal performance." (Owensby et al. 1996). Plantain (*Plantago lanceolata*) can reduce N_2O emissions by nearly 40% compared with perennial ryegrass alone when grown under elevated CO_2 conditions (Chibuike et al., 2024).

9. Lifestyle and farming continuity – labour supply and skills

Farming in New Zealand has been and still is largely characterised by the prevalence of family owned and operated farms, but equity partnerships have become an increasingly popular response to the trend towards larger farms and the rising cost of land (Mclead 2012). Population dynamics in New Zealand are leading to an older demographic, with fewer children, increased urbanisation particularly in the Auckland region and a declining population in the rural regions (Spoonley 2020). This has led to a skill shortage in the farming community even though only 6% of the workforce is active in the agricultural sector (Statistica 2024). This has partially been solved by employing immigrants into these roles, although the workforce is still primarily New Zealand citizens and residents. Artificial Intelligence (AI) is viewed a promising option for enhancing productivity and could be used to predict required water or fertiliser application to maximise production and minimise waste/emissions/runoff, predict and respond instantly to disruptions, and navigating complex and overwhelming requirements around policies and compliance (Deloitte 2024).

10. Land use change - availability of land and capital

In New Zealand, "land is an asset and resource that our prosperity depends on, and it is also a source of meaning and value" (Mfe 2024b). Pastoral farming will continue to be a significant part of the economy because New Zealand's landscape is best suited to livestock in the dairy and red meat sectors. Change will be driven by opportunity and need based on consumer preferences. Over the last past few decades land use changes have resulted in the growth of the wine and kiwifruit industries, dairy and forestry, with a decrease in sheep and beef farmed land, but concomitantly with the expansion of urban areas into highly productive land. External drivers that may influence decision-making on land use include commodity prices, both in New Zealand and internationally; market demands which are influenced by economic and population growth as well as government policy; regional and territorial government policy, primarily driven by the Resource Management Act in New Zealand; community preferences; technological changes; land value; and climate change (Britton and Fenton 2007). Additionally, regulatory obligations, driven by the likes of the Resource Management Act (1991) and the National Policy Statement for Freshwater Management (2014) will also drive change in the way that land can be used for primary production (AgFirst 2017).

11. Biosecurity

The major threat to any biological economy, such as that found in New Zealand, is a biosecurity breach which impacts directly on primary sector production or constrains exports (MPI 2016). Biosecurity is defined by MPI as the exclusion, eradication or management of pests and diseases that pose a risk to the economy, environment, cultural and social values, including human health. Where possible, biosecurity risks are identified and managed at the earliest intervention point, in many cases before reaching New Zealand, and everyone has part to play. Despite that biosecurity remains an ever-present risk as demonstrated by the statistic that "a new plant species establishes in the wild in New Zealand every 39 days (MPI 2016).

Harnessing science and technology is important in transforming and improving biosecurity outcomes. Science also provides the foundation for an evidence-based approach to risk-management (MPI 2016).

12. Added value opportunities

The majority of agricultural exports from New Zealand are commodities, the price of which is driven by world demand balanced against supply. There is a view that "instead of continually chasing higher production per unit of input, the emphasis can instead be on increasing the value of the product" (Lees 2014). For decades it has been recognised that to increase returns on our agricultural products we need to add value to them. Value-add products in the dairy industry for example, are of two types, either "fast moving consumer goods" (FMCGs) such as yoghurts, dairy desserts, and ice cream, or sophisticated ingredients that range from infant formula feeds through to binding agents that hold muesli bars together (Thain and Bradley 2014). For New Zealand the distance from markets constrains the development of FMCGs. Therefore "creating value requires moving beyond meeting minimum standards for sustainability, animal welfare and food safety to leading the market in these standards. These need no longer be seen as compliance problems but as providing a valuable competitive advantage. Value creation also involves building collaborative supply chain partnerships beyond the farm gate with distribution channels which give access to these selected customers" (Lees 2014). There are sections of the primary sector who have transformed a commodity into a high-value product, such as the success shown by New Zealand Merino who have linked "socially conscious consumers … to the land, families and communities that produce the wool and with a value-set that enables them to feel like they are contributing to a more natural, sustainable and better world" (Mayes et al. 2020). Adding value to primary sector produce before it leaves New Zealand is a strategy that should be a major focus for innovation.

Conclusions

Export of produce from the primary sector underpins New Zealand's new wealth generation and the economy as a whole. The most significant part of this wealth generation comes from grazed pasture, and in this regard, New Zealand is relatively unique because of its temperate climate and good soils which allows year-round grazing and a low requirement for additional feed over and above forage grasses, legumes and herbs which do not feature as direct source of food for humans. However, this biological economy is potentially fragile and open to many external (e.g. biosecurity breaches, international competition for both production of and prices for commodities, tariffs) and internal challenges (e.g., available labour, environmental integrity, social license to operate, availability of suitable land). Recognising the extent and impact of these risks and concomitantly preparing appropriate mitigation strategies to cope with them will hold New Zealand in good stead and ensure its future economic security.

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