White Paper

Pasture-fed livestock production and products: Science behind the narrative

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Overview Summary

Livestock farming is a 'lightning rod' globally for perceived negative impacts on climate change, land degradation, biodiversity loss, deteriorating water quality, and animal welfare and human health issues. However, there is a large continuum of livestock systems, from highly intensive housed systems to extensive low intensity systems, and the negative impacts of each varies. At the same time, 'grass-fed' ruminant livestock products are marketed for their superior nutritional and taste properties, their improved animal welfare including enabling natural animal behaviour, and their perceived 'naturalness' in general.

While this narrative about 'grass-fed' (most appropriately termed 'pasture-fed' to account for the presence of important non-grass species, including legumes and herbs) is being promulgated, the substance behind it are less clear. Thus, it is important that the science evidence behind this narrative is scrutinised, with the real benefits or disadvantages defined so that any claims are scientifically robust.

The aim of this paper is to evaluate the science evidence behind this narrative by comparing the benefits or disadvantages of New Zealand's pasture-based grazing system with crop-based housing/feedlot systems. It covers animal product quality, animal health and welfare, pastures and plant biodiversity, soil health, resource use, and environmental impacts to air and water (see Figure i). This paper represents a first working document that draws on expertise of AgResearch scientists across the range of relevant science disciplines as an important first step in discussions with agricultural and government sector groups.

Animal product quality

Meat and dairy products from pasture-fed systems differ from those from crop grain-based systems in having more favourable nutritional composition, including higher proportions of beneficial fatty acids. They also contain carotenoids, which are anti-oxidants enhancing the preservation of meat and dairy products, are precursors of vitamin A1 (retinol, important for good eyesight) and provide the yellow colour in butter and cheeses. Milk from grass-fed cows contains more protein and fat, and gives rise to dairy products of higher eating quality and notably different flavour. Such flavours, often described as 'pastoral' are also reported for meat products.

While such intrinsic benefits are recognised, results from product quality studies are often confounded and a better understanding of mechanisms involved is needed, preferably so it can be linked to biomarkers as proof of pasture-based products. Implications of level of partial supplementation with crop-based feeds on product quality characteristics and functional attributes are also unclear.

Animal health and welfare

It is well recognised that ruminant animals grazing pasture generally have fewer health and welfare issues than housed/feedlot animals (e.g. fewer reproductive, metabolic and lameness issues), with a good indicator being the higher longevity of breeding animals. However, exposure to inclement weather conditions and poorer quality pasture can lead to impaired welfare, such as heat stress and poor body condition. In addition, winter grazing can be associated with mud and reduced animal lying behaviour and hygiene, while some seasonal diseases associated with pasture occur (e.g. facial eczema, ryegrass staggers).

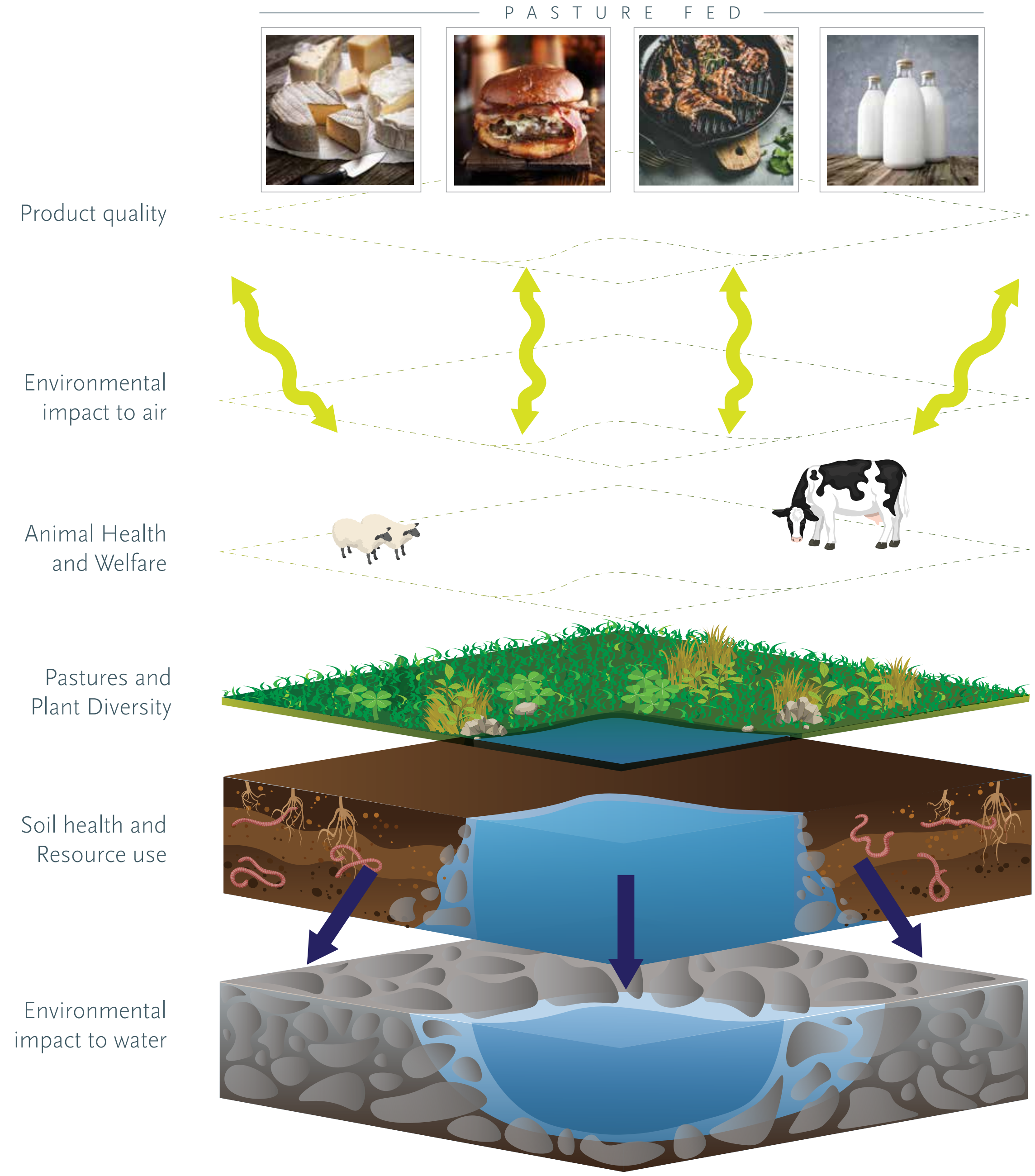
Management solutions to these challenges include providing shade and shelter, and automated precision livestock technologies to track the animals' health status. Research suggests dairy cattle favour outdoor access to pasture over housing, but more animal behaviour research is needed to understand drivers of any preference to pastures over crop-based housing systems.

Pastures and plant diversity

New Zealand's pasture systems typically contain perennial grasses and legumes for natural N_2 fixation, while crops are typically grown as annual monocultures. These pasture systems are amongst the most highly productive grassland systems globally, resulting in high land use efficiency for animal production.

Pasture species diversity is lower in more intensive grazing systems and various component research studies indicate the potential for greater pasture diversity to benefit a range of environmental and animal health factors. However, pasture-based systems provide fewer opportunities to balance diets for optimum animal nutrition. Longer-term research will be required to determine whether these potential benefits are demonstrated at a whole farm systems level.

Figure 1: Illustration of the key interconnecting system components that influence production of high-quality pasture-fed (or 'grass-fed') livestock products



Soil health

Soil organic matter content, biological activity and infiltration capacity are key measures of soil health. The scientific evidence suggests pasture soils have higher levels of organic matter and carbon than cropping soils. Further, many subsequent benefits for soil function arise, including improved water and nutrient retention, higher biological activity and diversity, and reduced sediment loss.

Currently, intensive winter-spring grazing imposes the greatest risk of soil damage, with flow-on effects for decreased water quality. In addition, maintaining (let alone increasing) soil organic matter in intensively grazed pasture soils is challenging. Some research evidence exists on how soil damage can be minimised, but there is very limited New Zealand research on practices to increase soil organic matter. Flow-on effects of benefits from soil health and pasture biodiversity to wider ecosystem services are not well defined and modelling at different scales is required to quantify benefits and compare grazed pasture and crop-based housed/feedlot systems.

Resource use

All livestock production systems require inputs of land, energy, water and nutrients. It is well established that, per unit of animal product output, farm system inputs of fossil energy and water are lower for grazed pasture systems compared to crop-based housing/feedlot systems, while animal drinking water needs are lower due to the high water content of pasture. Furthermore, resource footprint estimates for fossil energy and water scarcity for New Zealand livestock products are low compared to crop-based housed/feedlot systems, while land use per unit of product is generally similar for the two types of systems.

In contrast, non-nitrogen nutrient use is relatively high in pasture-fed systems, as pasture has a relatively high nutrient demand, resulting in nutrient contents that generally exceed animal requirements. However, it is less clear whether this leads to poorer nutrient efficiency at a farm system level and comparative research data for current pasture and crop-based systems is lacking.

Environmental impacts to air

The on-farm greenhouse gas emissions and carbon footprint of New Zealand livestock products are similar to or lower than those from crop-fed systems. This is associated with low carbon dioxide emissions due to low fossil fuel use.

Grazing also results in excreta returned directly to pasture soil, resulting in lower ammonia and methane losses than from manure collected in housed systems. However, it is countered by relatively high animal enteric methane emissions.

Some human health indicators, such as respiratory health (driven by fine-particulates and ammonia emissions to air), are likely to be lower for pasture-based grazing systems, but research data on these other indicators is lacking.

Environmental impacts to water

Nutrient losses to water from intensively grazed pastures appear to be similar to or higher than that from crop-based housed/feedlot systems. Lightly grazed pastures typical of New Zealand exhibit mild erosion compared to cropped and arable systems. However, year-round grazing systems and winter forage cropping in New Zealand exacerbate the risk of loss of nutrients and faecal microorganisms to waterways compared to that for housed systems where manure management can optimise the timing and use of nutrients on crops from animal excreta (assuming good practice is implemented). However, whole-system data is sparse for water quality, eutrophication footprint and other impact indicators for grazed pasture systems relative to crop-based housed/feedlot systems.

A summary of the benefits and challenges from NZ pasture-based grazing systems relative to crop-based housed/feedlot systems is presented below.

Clear benefits from NZ pasture-based grazing systems compared to confined (feedlot) systems (with strong science evidence)

- Pastures include legumes (particularly white clover) for high feed quality and natural nitrogen inputs from fixation of atmospheric N2
- Soils with high organic matter and carbon contents, providing benefits for soil structure and many ecosystem services
- Reduced risk of soil erosion
- Lower or similar carbon footprint than confined/ feedlot systems
- Lower water use and water scarcity footprint
- Higher longevity of breeding animals as a key indicator of good animal health
- Improved general animal welfare
- Meat and dairy products from pasture-fed livestock contain a higher proportion of beneficial fats and carotenoids

Key challenges from NZ pasture-based grazing systems

- Higher plant requirements for non-nitrogen nutrients which increase costs and risk of losses to waterways
- Higher animal enteric methane emissions per kg feed intake
- Increased risk of some animal health issues (e.g. intestinal parasites, facial eczema)
- Increased risk of compromised animal welfare due to nutritional challenges and climate
- Increased risk of nutrient and faecal microbial losses to waterways during winter-spring

Future research needs to address key challenges from NZ pasture-based grazing systems

- Better understanding of the whole-system nutrient use and efficiency for current farm systems, compared to crop-based systems
- Evidence on methane emissions from non-ryegrass forages, as well as continued research on practical methane mitigations, including studies on additivity of effects
- Systems research evidence of benefits of greater pasture biodiversity on multiple factors

- Better understanding of the agronomy and ecology of 'minor' pasture species and addressing issues of seed supply, and management of biodiverse pastures
- Comparative assessment of multiple environment and human health indicators, and trade-offs between them, for pasture-fed and crop-fed systems
- Comparative analysis of ecosystem services provided by grazed pasture and crop-based housing/feedlot systems
- Better understanding of animal welfare/behaviour factors associated with pasture including preference and opportunities for positive welfare
- Development of biomarkers for high meat and milk quality attributes and for product verification
- Knowledge on ability to manipulate pasture systems for bioactive compounds and improved nutritional quality of animal products

Table 1: Summary of benefits and challenges from NZ pasture-based grazing systems relative to crop-based housed/feedlot systems, for each system component identified in Figure 1.

	Implications for NZ pasture-based grazing systems	Ranking [1=low to 5=high]	Research Gaps
Animal product quality			
Benefits	Higher proportion of beneficial fats and carotenoids, contributing to anti-oxidants, retinol for improved eyesight and some other functional constituents. Milk also has less unfavourable saturated and trans fatty acids, better processability and higher consumer appeal.	4	Better understanding of effects of supplementation with non-pasture feeds on product quality attributes
Challenges	Having confidence about consistent presence of positive pasture-related product functional attributes due to lack of clarity on driving mechanisms and temporal variability in animal feeding. Flavour of milk and meat from pasture have distinctive notes, some of which may not be appealing in some markets.	2	Need to understand driving mechanisms of beneficial meat and milk product quality attributes and identify biomarkers for product verification.
Animal health and welfare			
Benefits	Higher longevity of breeding animals as key indicator of good animal health	4	Research proof of greater animal welfare and positive affective state with longevity would be valuable
	Grazing animals have ability to behave 'naturally' and are motivated to access pasture	4	Need to better understand animal welfare/behaviour factors and preferences for pasture
	Fewer disorders such as ruminal acidosis, respiratory disease and lameness	4	Implications for highly intensive grazing systems are less clear
Challenges	Increased risk of some animal health and welfare issues with pasture grazing (e.g. intestinal parasites, facial eczema) and exposure to climate (e.g. heat stress, mud)	4	Mitigation practices are well recognised for many areas but understanding of risks and management options for some (e.g. parasites and climate change impacts) is inadequate
	Risk of ill-thrift and higher mortality losses of young animals in extensive grazing systems	4	Change in management practices needed to mitigate these risks. Determine the barriers to implementing change in attitudes regarding the value of young animals.

Table 1: Summary of benefits and challenges from NZ pasture-based grazing systems relative to crop-based housed/feedlot systems, for each system component identified in Figure 1 cont.

	Implications for NZ pasture-based grazing systems	Ranking [1=low to 5=high]	Research Gaps
Pastures and plant biodiversity			
Benefits	Inclusion of legumes as a key component of biodiversity in NZ pastures captures the benefits of natural N_2 fixation.	5	Optimisation of species (and functional) diversity for whole farm systems not well understood for current and future environments.
	Biodiversity may convey functional benefits, such as to enhance pastoral system resilience, to reduce environmental footprint, and enhance animal health and nutrition.	3	Research evidence needed on whether there are functional benefits from increasing pasture biodiversity in longer term whole farm systems context.
Challenges	Difficulties in managing diverse pastures – especially to maintain desirable species.	5	Knowledge on how to manage diverse pastures.
	Minor species in limited supply and expensive.	5	Need better understanding of the agronomy and ecology of 'minor' pasture species and addressing issues of seed supply.
Soil health			
Benefits	Pasture soils have high organic matter and carbon contents, providing benefits for many ecosystem services	4	Knowledge of how to increase soil carbon (e.g. via additions or greater pasture diversity) is limited; flow-on benefits are poorly understood.
	Pasture soils have greater earthworm and microbial activity for improved soil function	5	Flow-on benefits to soil function are only weakly defined
Challenges	Some grazing practices (e.g. in wet winters) can degrade soil, decrease soil function, increase erosion and lead to greater contaminant loss to waterways	4	While mitigation practices are well-known, the cost implications and flow-on effects are less well defined
Ecosystem			
Benefits	Potentially wider range of ecosystem services from pasture-based systems, but are site dependent	2	
Challenges	Flow-on benefits (including from soil health and biodiversity) to multiple ecosystem services occur but are poorly defined for different systems and need quantification	2	There is a need to develop models to account for ecosystem services and compare grazed pasture & housed/ feedlot crop-based systems
Resource Use			
Benefits	Lower fossil energy use, animal drinking water use and water scarcity footprint, while land use is similar per kg product output	2-4	Comparative system analyses are required (otherwise based on data across countries and systems)
Challenges	Higher requirement for nutrients (other than nitrogen) by mixed pastures	4	Better understanding of the whole-system nutrient use and efficiency for current pasture farm systems is needed, compared to crop-based systems

Table 1: Summary of benefits and challenges from NZ pasture-based grazing systems relative to crop-based housed/feedlot systems, for each system component identified in Figure 1 cont.

	Implications for NZ pasture-based grazing systems	Ranking [1=low to 5=high]	Research Gaps
Environmental impacts to air			
Benefits	Carbon footprint of products is less than or similar to that for crop-based housed/feedlot systems	4	Limited comparative research under same soil/climate conditions (otherwise based on studies across countries and systems)
	Grazing of pasture leads to lower ammonia and methane emissions from excreta than from manure from housing/feedlot systems	3	
	Some other impacts (e.g. respiratory disease; ozone depletion) likely to be less due to lower other emissions (e.g. ammonia)	2	Requires comparative modelling to confirm, as well as check for trade-offs across multiple other environmental and health impact categories
Challenge:	Higher animal enteric methane emissions per kg dry matter intake from ryegrass pastures than high-starch crop-feeds, and this is exacerbated with poorer quality pasture, particularly in terms of emissions per unit of animal product.	4	Lack of evidence on methane emissions from non-ryegrass forages, and need for continued research on methane mitigations than can be readily implemented in grazing systems
Environmental impacts to water			
Benefits	Low-intensity grazing systems can have less impacts than intensive crop-based systems	5	
Challenges	Year-round grazing systems have risk of higher losses of nitrogen, phosphorus, sediment and faecal microorganisms	4	Lack of directly comparable research studies of pasture versus crop-based systems for system impacts on water quality and trade-offs to other impacts

Background

Livestock farming is acting as a lightning rod globally for negative impacts on climate change, environmental degradation of land, biodiversity and water, animal welfare and human nutrition. This is manifested in recent articles recommending the reduction in red meat and dairy product consumption and comparisons indicating a reduced environmental footprint of dairy and meat substitutes and plant-based foods. What has not been conveyed well to society is the large continuum of ruminant systems in existence from highly intensive housed and feed lot systems through to extensive nomadic low intensity low efficiency grazing systems. New Zealand grassland systems have a unique niche within that continuum with the ability, due to climate, soil and management, to harness sunlight by grass harvested by grazing ruminants and converted to nutritious food for human consumption in a highly efficient way. Topics such as regenerative agriculture and Adaptive Multi-Paddock grazing have piqued the public interest in providing new options for livestock using pasture in their contribution to carbon sequestration and biodiversity. This unique niche provides opportunities for positioning New Zealand as a market-leader for livestock produce with a point of difference.

Definition of “Grass-fed” or “Pasture-fed”

Internationally, some livestock products are being promoted as coming from “grass-fed” systems. There are several definitions around the term “grass fed” used at different scales including the national scale, companies and individual farms. Details are below but in general grass-fed is referring to pasture-based grazing systems where animals spend most of their time on pasture. The term pasture is used to cover the wider species present besides grass species, the inclusion of legume species, as well as others such as herbs.

The pasture-based livestock feeding regime must not include grains but various marketing initiatives allow inclusion of green-feed crops to cover nutrition of animals in times of feed deficit such as winter or drought.

Grass-fed systems also trade on several other attributes associated with grazing such as the “free range” concept that allows animals to exert their natural grazing behaviours. The prohibition of hormone use and responsible use of antibiotics is another key part to grass-fed narratives. All the narratives around grass-fed product include the human nutritional properties gained from products grown from grazed pastures. Many of the companies also include the family in the narrative. Typically, it is a family run farm with several generations involved and has some form of cultural aspect e.g. Gaucho, Cowboy, rancher etc.

Along with the definition of grass-fed used by some companies, there are standards and associated accreditation schemes that farmers must sign up to if they want to use the “grass-fed” label.

National Initiatives

USA

The USDA had a definition (now not used) adopted by the American Grass- fed Association (AGA). Grazed pasture must provide 60% of grass- fed ruminant dry matter (DM) average throughout the grazing season of not less than 150 days per year. Grain or grain-based products cannot be fed. The area of land must have 75% forage cover. The plants classified within a “grass- fed” diet are: a) Grass (annual and perennial), b) Forbs (e.g. legumes, brassicas), c) Browse, d) Cereal grain crops harvested in the pre-dough stage and e) Harvested forages. This definition then forms a standard that is used to certify farms that follow the practices. The marketing narrative of AGA-Certified “Grass fed” states that: ruminant animals are born, raised, and finished on open grass pastures where perennial and annual grasses, forbs, legumes, brassicas, browse and post-harvest crop residue without grain are the sole energy sources, with the exception of mother’s milk, from birth to harvest. Hay, haylage, silage, and ensilage from any of the above sources may be fed to animals while on pasture during periods of inclement weather or low forage quality. Associated with this grass-fed approach is the assumption that animals can always fulfil their natural behaviours and basic instincts. Use of antibiotics and growth hormone is prohibited and if an animal requires antibiotics it is removed from the herd and the product is sold under another label.

Ireland

Origin Green is Ireland’s food and drink sustainability programme operating on a national scale, uniting government, the private sector, farmers and food producers. Independent accreditation and verification are built into every stage of the supply chain.

Ireland’s temperate climate, abundant rainfall and tradition of family farming have resulted in a grass-fed system with cows grazing outdoors for most of the year. Dairy cows and beef herds have the freedom to graze on lush pastures up to 300 days a year.

The harsher winter months are the only time animals are taken off grass. During this time, they are housed to ensure animal welfare and to avoid damage to pastures. While housed, the grass diet is supplemented with grain feed to ensure optimal nutrition. As soon as the weather becomes milder, cattle are free to graze in open fields again.

Origin Green note that: i. research has shown that grass-fed dairy has superior nutritional properties, appearance, flavour and colour (Profiling Milk from Grass, 2016); ii. Grass-fed beef offers a fuller, meatier flavour as a result of time spent grazing, and iii. Grass fed has more evenly distributed fat and marbling, a deep burgundy colour, high levels of vitamins and a high ratio of omega-3 fatty acids.

Uruguay

INAC is the Uruguay National Institute of Meat (carne). It is the national marketing arm like MLA in Australia. They market on animals living in the open air all year round, raised based on a rich variety of natural pastures, under the most updated practices of respect and animal welfare. They underpin this marketing with state-of-the-art traceability systems where consumers purchasing meat from a supermarket can scan the bar code and see the farm the meat was produced. They also link pasture-based cattle feeding, to human nutritional requirements, "Uruguayan meat is recommended for healthy diets because of low levels of saturated fats, proper ratio of Omega 6 and Omega 3 and high doses of conjugated linoleic acid, iron and vitamin E (antioxidants)".

New Zealand

Beef and Lamb NZ's "Taste Pure Nature" origin brand is used as a global brand platform to underpin exporters' marketing programmes and enhance the positioning of New Zealand red meat. It has been developed in partnership with meat processors and farmers. The brand is based on developing a culture and story around food that is uniquely New Zealand, including reflecting the quality of land and farming techniques as there is little international knowledge of New Zealand's grass-fed hormone-free and antibiotic-free practices. The following quote is from B+LNZ:

> *"Our research showed that there is currently low consumer awareness of New Zealand's natural production systems. At the same time, there is growing consumer distrust of meat globally because it is associated with more industrialised production systems. It is therefore imperative we tell our story to avoid being affected by these trends.*
>
> *Our research also showed definitive payoffs from telling our story. There is growing demand for grass-fed hormone free, antibiotic free red meat that consumers are willing to pay a premium for. Our farming naturally fits in this category, but we are currently not capitalising on the opportunity."*

The brand relies heavily on the image of animals grazing pasture-based systems. Beef and Lamb NZ are building a national sustainability standard aligned with regenerative practices. Only meat from farms that are part of the NZ Farm Assurance Plan, or a processor equivalent, will be eligible to use the "Taste Pure Nature" origin brand. Underpinning the brand is also B+LNZ's environmental strategy.

Company use of "grass-fed" in marketing by New Zealand

In New Zealand different processors of livestock product define grass-fed:

Fonterra

Grass/pasture is classified as grass, grass silage, hay and forage crops, and the above figures are calculated on a 'wet' (or 'as-fed') basis. Fonterra's New Zealand cows consume on average 96 percent of their diet as grass, and cows spend on average 97% of their non-milking time outside on pasture.

The Fonterra Grass and Pasture Fed Standard assesses and verifies the farming practises across all Fonterra New Zealand farms, focusing on use of supplementary feed and cows' ability to have access to pasture. Products carrying the Certified Grass Fed claim have been certified by Assure Quality, an independent Conformity Assessment Body.

Synlait

Synlait notes that it is the only formula in the world made with certified 100% grass fed milk from New Zealand. The narrative includes links to human health: Grass Fed milk provides high levels of Vitamin A & E and a proper balance of Omega 3 to Omega 6 fatty acids. In addition, milk is GMO free, rBGH free, grain free, and antibiotic free.

Grassfedmilk.com.au

Although this is an Australian web site it cites New Zealand as the source of product. Their narrative is as follows. "OUR BELIEF - WE'RE BIG ON GRASS FED. 100% GRASS FED. We believe that 'every' child deserves the best nutrition it can receive in its formative years. The early years of a child's life are when cognitive (intellectual), social, emotional and physical development of a child are formed, and the right nutrition plays a huge part in this development. The primary ingredient for most formulas is milk. So that is where we started. However, we didn't start looking for the best cows, we started looking for the best place to grow lush, green grass year round, because if you have the best pastures and environment to raise cows of course you'll end up with the best cows, the best milk and the highest quality dairy based nutrition for your child. That place was New Zealand. With its year-round grass, regular rainfall and rolling pastures the cows can produce the world's best milk. Oh, and they also get to live longer, healthier lives".

McDonalds

Beef is an iconic ingredient for McDonalds, but they note there is little research to evaluate and quantify best practice related to sustainability practices of pasture-based systems. This is true for regenerative farm practices with a focus on pasture based grazing systems where herds are moved quickly in rotational grazing with long pasture recovery phases. In March 2020, McDonalds launched in Australia, a brand-new certified Grass-Fed Beef Burger within their premium burger range using meat sourced only from Australian farmers.

First Light

"Grass-fed wagyu cattle thrive on a diet of rye and white clover, with specialist green feed crops occasionally used on those farms that experience particularly dry summers or cold winters"

Silver Fern Farms

What does grass-fed mean in New Zealand?

> *"Here, the climate, clean air and plentiful pure water fuels year-round growth of lush, green pastures. The animals are raised year-round, on this pasture, with access if needed to conserved forages like hay and silage. It also means that they have been raised with the ability to wander and graze freely. The animals can eat and live as they would naturally – reducing stress and promoting better animal welfare".*

Any price premiums?

The Red Meat Sector Strategy Report (2011) identified several challenges for the industry including a lack of differentiation and New Zealand owned brands in export markets. The opportunity is to market the New Zealand product story through a connected value chain.

The Marbled grass-fed beef PGP project notes the following:

> *"Increased premiums - Sustained premiums have been delivered for calves and finished animals; In 2019 dairy breeders are receiving between $180 and $280 per calf (minimum pick-up age 10-days old) compared to $30 for a 'bobby' calf. For finished animals the price being achieved is consistently more stable than commodity prices and for First Light Wagyu NZ's (FLWNZ) last financial year the return to farmers was a 22% premium over commodity beef".*

While the programme has delivered sustained premiums to farmers over the price of Prime Steer, achieving an average premium of $1.18/kg in 2018, the aspirational programme target of $2.12/kg over the prime schedule remains a long-term goal.

Beef and Lamb NZ developed their "Taste of Pure Nature" brand based on their research showing that consumers will pay a premium for naturally raised, grass-fed, hormone-free and antibiotic-free red meat.

A meta-analysis study conducted through Our Land and Water National Science Challenge looking at credence attributes and willingness-to-pay a premium included grass-fed in the attributes assessed and showed that the greatest gains were for pasture-fed (increase of 36% to 49%) dairy products while on average, consumers would pay 25% more for grass-based. It should be noted that some other credence attributes such as environment-friendly and animal welfare friendly also showed similar premiums.

National Initiatives

The aim of this paper is to evaluate the science evidence behind factors underlying many of the statements evident in the various national initiatives by comparing New Zealand's pasture-based grazing system with crop-based housing/feedlot systems. It covers animal product quality, animal health and welfare, pastures and plant biodiversity, soil health, resource use, and environmental impacts to air and water (see Figure 1). This paper represents a first working document that draws on expertise of AgResearch scientists across the range of relevant science disciplines as an important first step in discussions with agricultural and government sector groups.

Animal product quality - C. Craigie and S.M. Loveday

Key Messages

- Pasture-fed meat and dairy products are different to those from intensive crop-based production systems
- The eating quality (e.g. flavour and texture) of pasture-fed meat and dairy products is generally perceived favourably by consumers, although certain flavour notes can be perceived as less desirable in some markets
- Pasture-fed meat and milk have improved nutritional status via more favourable fatty acid composition
- Pasture-fed meat and milk contain carotenoids, which give butter, cheeses and fats its yellow colour, inhibit the development of rancid flavours and contribute to healthy eyesight
- Methods to test and verify that meat and dairy products come from pasture-based production systems require research and development
- The impacts of supplementary feeding in an extensive pasture-based system on meat and dairy product quality are not well understood

On a global scale, meat and dairy products derived from livestock raised solely in extensive pasture-based production systems (i.e. without feed supplements) are produced in very low volumes. As a result, exclusively pasture-fed meat and dairy products are much rarer than products produced from more conventionally raised livestock in systems that use supplementary feeds (e.g. grain) and/or feed livestock a total-mixed-ration (TMR) in a confined space.

Benefits

Pasture-based meat and dairy products are perhaps best known for nutritional differences in their fatty acid content and composition. Compared to products from grain-fed systems, the pasture-fed meat products contain less fat, and higher proportions of more beneficial fats such as α-linolenic acid which are building blocks of omega-3 essential fatty acids (Wood and Enser, 1997; Wood et al., 2008). Pasture-based products also contain carotenoids which are anti-oxidants enhancing the preservation of meat products, and are also precursors of vitamin A1 (retinol) which plays an important role in eyesight. Besides fats and vitamin A, flavonoids, condensed tannins derived from pasture-based finishing systems, may influence meat product functional attributes.

Compared with milk from TMR feeding systems, milk from pasture-fed cows is noted for having higher omega-3 and conjugated linolenic acid, as well as lower omega-6, saturated fat and trans fatty acids, and much higher carotenoid levels (Elgersma, 2015; Alothman et al., 2019). This fat profile is healthier, but also contributes to better processability and eating quality of dairy products made from pasture-fed milks. Butter made from pasture-fed milks is more spreadable, with lower rancidity (due to antioxidant vitamins A and E) and more appealing yellow colour and creamy flavour (Silva et al., 2019). Cheese from pasture-derived milk has better texture, colour and flavour (Carpino et al., 2004; Esposito et al., 2014), and the effect of feeding system on the cheese flavour and aroma is clearly distinguishable due to feed-related volatile organic compounds (Faulkner et al., 2018). In addition to health and product quality benefits, milk from pasture-fed cows has higher fat and protein content and proportionally lower lactose levels (Alothman et al., 2019).

Challenges and how to mitigate them

Beneficial attributes of pastoral products have been investigated and demonstrated on numerous occasions, however many of these investigations are highly confounded, and/or are of limited practical relevance to the extensive, pasture-based production systems found in NZ, Ireland and South America. For example, in the comparison between forage and concentrate diets by Koch et al. (2019) the pasture diet contained no clover which is an important component of NZ pastures. Management of livestock over their lifetime is complex and dynamic, and one size does not fit all producers. Assuming an exclusively ryegrass/clover pasture-based system is the default, the growth rates, type, amount, and timing of pasture and/or supplementary feeding as well as the temperature and housing of livestock add additional complexities. Understanding the benefits of a pasture-based system on product attributes presents a significant challenge. Increasing our understanding of the biological mechanisms, both in the animal and the forage plant species, are very relevant because they identify several biological systems at play that could potentially be harnessed to improve meat product quality and consumer acceptability of pastoral food products.

This also applies to the dairy sector where there is wide variation in feeding systems, farm inputs and level of non-pasture feed supplementation. For example, feeding brassicas can adversely affect milk flavour, and palm kernel expeller contains fats that lower the melting point of milkfat and contribute to overly soft butter. Also, herbage with a high content of protein can cause an increase in metabolites that can give off-flavour notes to milk and meat (Lane et al, 2002; Schreurs et al.,2008). Milkfat from pasture-fed cows contains higher levels of unsaturated fatty acids, which are more susceptible to oxidation, but carotenoids and tocopherols from pasture have antioxidant effects, and oxidative rancidity is generally lower in milk from pasture-fed animals (Alothman et al., 2019).

With meat, there is greater difficulty in achieving consistency of quality due to variation in feeding through pasture grazing and time for animals to reach finishing weights. Older animals usually have greater levels of connective tissue in muscles affecting meat texture, furthermore, meat colour tends to darken as animals age due to increased levels of myoglobin. In markets where animals are processed at a younger age, this phenomenon can easily be mistaken for dark cutting - a quality defect arising from pre-slaughter stress. Considering the requirements of certain demographics (e.g. active aging and sports people), pasture-fed meat products from older animals may confer desirable increases in nutrients collagen and iron contents.

A further challenge is how to effectively measure and market the distinctive quality attributes of pastoral food products. As a result, value chains struggle to differentiate their products based on the intrinsic benefits and an opportunity to capture additional value is lost. World-wide, value chains tend to rely on "Grass-Fed" branding, with no standard definition or shared understanding of what "Grass-Fed" actually means, or how it is perceived by consumers. The key challenge here, is that the lack of information and standardisation means that products resulting from intensive production systems (possibly with only a small proportion of pasture-feeding) could easily be branded as grass-fed thus misleading consumers.

Strength of research evidence and research requirements

The evidence that pasture-fed livestock products are different to products from crop-based housed/feedlot systems is clear. However, the evidence for which system is better or best for certain attributes is less clear. This becomes more obvious because consumers of animal products consider product quality to comprise of extrinsic quality attributes (how a product was produced) as well as intrinsic product quality attributes (like taste and texture etc.) (Grunert, 1997; Bello Acebrón and Calvo Dopico, 2000). To enable producers and value-chains to capture value from their pasture-based animal products, they need to be able to differentiate in the market based on intrinsic quality attributes, and to have a verifiable provenance that consumers trust. Research is required to understand the range and variation in product quality attributes at both macro and micro levels to identify biomarkers that relate both to how a product was produced, but also to the consumer demand for that product.

Another important consideration is that pasture-based production systems are subject to seasonal variation, and weather events, such as drought, where producers may need to give livestock alternative supplementary feeds such as grain. The impact of sporadic or small amounts of supplementary feed on meat and dairy products is not well characterised or understood.

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Animal health and welfare - K. Schütz and D. Pacheco

Key Messages

- Natural living is an important consideration of animal welfare
- Pasture access is in general associated with health and welfare benefits, however, there are challenges associated with meeting nutritional needs and exposure to climate
- The type and prevalence of animal health issues are different between confinement and pastoral systems, but indicators such as longevity suggest an advantage in animal health for pastured livestock
- There are opportunities to promote NZ outdoor systems as more natural and ethical compared to more intensive systems
- Potential effects of climate change will need to be considered when designing future farming systems

Introduction

Societal ethical concerns regarding the welfare of animals can be divided into three overlapping categories: 1. physical functioning, meaning that animals should function well in the sense of good health, normal growth and development, 2. affective state, which describes how the animal is feeling, and 3. naturalness, meaning that the animals should have the ability to express normal behaviours that they are strongly motivated to perform in an environment with some natural elements (Fraser, 2008). Physical function (e.g. health and production) and negative affective states (e.g. pain and hunger) have historically been the main focus in welfare assessments. It is now, however, generally agreed that welfare assessments also need to take into consideration positive affective states, such as pleasure, and the ability to perform behaviours that are important to the animals. The concept of natural living is a major component in modern-day animal welfare discussions and is a significant concern for consumers. Most people would likely agree that grazing animals on pasture represent a more natural life compared to intensive systems. Pasture is a more complex environment compared to many other systems and provides plenty of space and opportunities to graze, explore, and engage in social activities. It also provides animals with a certain degree of control and choice over their lives, or 'agency', something that is increasingly considered important to animals (Webster, 2016).

Benefits from pasture-fed livestock systems

It is well recognised that pasture systems are associated with several health and welfare benefits. For example, dairy cattle with pasture access have improved health, such as less lameness (Wells et al., 1999; Somers et al., 2003; Hernandez-Mendo et al., 2007), and fewer reproductive and metabolic issues (Washburn et al., 2002) compared to some indoor systems; however, lameness is still an issue in New Zealand sheep and dairy cattle, which can be exacerbated by for example long walking distances and long periods standing on unsuitable surfaces (e.g. dairy cattle on concrete; Chesterton et al., 1989). Pastured cattle also have a lower incidence of disorders such as ruminal acidosis and respiratory disease compared to more intensive systems, due to the lower content of rapidly fermentable starch and less crowding and dust, respectively (Church and Rodostits, 1981; Dunn et al., 1995; Nagaraja and Lechtenberg, 2007). The management of respiratory disease involves dosing of prophylactic antibiotics in feedlots, with the corresponding concerns over the development of antibiotic resistance (Drouillard, 2018).

While there are different types of health issues prevalent in confined vs. pasture-feed cattle, the longevity of dairy cattle could be used as a proxy to conclude that pasture-fed cattle are 'healthier' than their counterparts in feedlot systems. It has been reported that 70-80% of the cullings in a dairy farm are involuntary and related to lameness, mastitis, fertility and metabolic health problems, the latter particularly during early lactation (Rushen and Passillé, 2013, DeVries, 2013). In New Zealand, some of these health issues are also a cause of involuntary culling (DairyNZ, 2020). However, the longevity of dairy cows in the US is 4.8 years, or 2.6 years of productive life (lactation) (De Vries, 2013). By comparison, in New Zealand, 85% of dairy cows of 4-5 years survive to the next lactation, >60% of cows of 8-9 years of age survive to the next lactation (LIC, 2019) and the average number of lactations is 4.8 (DairyNZ, 2020).

Access to pasture provides cattle and sheep with opportunities to move around freely and graze/forage and select their diet (in particular extensive beef and sheep systems) (Rutter, 2006; Tuomisto et al., 2008) and to engage in positive social interactions. There is now good evidence that cattle are highly motivated to access pasture, particularly at night (Charlton et al., 2013; von Keyserlingk et al., 2017), which suggests that the animals perceive pasture as an attractive surface to lie down and rest on (Schütz et al., 2020). However, more research is needed to determine what aspects of pasture are attractive and important to livestock, e.g. abundant space, comfortable lying/walking surface, foraging/grazing/exploration opportunities, and/or fresh air etc. This information would not only increase our understanding of positive welfare and affective state, but would also strengthen New Zealand's reputation as a world leader in animal welfare.

Challenges and how to mitigate them

While New Zealand sheep and cattle kept on pastures have the opportunity to express natural behaviours, by being managed outdoors, they are exposed to seasonal challenges, mainly related to nutrition and climate (Hemsworth et al., 1995; Fisher et al., 2003; Hernandez-Mendo et al., 2007; Roche et al., 2009). For example, seasonal variation in pasture growth and quality at times can result in the provision of feed being sub-optimal and lead to hunger, poor body condition and undue competition. The nature of the feed provided (grazed pasture) also has an influence on the type and incidence of animal health issues. So, while the incidence of infectious respiratory disease and acidosis is much less in pasture-fed ruminants, pasture-fed animals are exposed to a different type of health issues. A predominantly pasture-based diet can lead to mineral imbalances (e.g. hypomagnesemia) (Roche et al., 2017) and exposure to internal parasites and fungal related diseases such as facial eczema and ryegrass staggers (Smith and Towers, 2002). The nature of the grazing system means that opportunities to correct mineral imbalances are not as straightforward as with balanced rations in feedlots (Roche et al.,2017).

Access to shade and shelter in summer and winter is important to enhance the welfare and productivity of livestock (Pollard, 2006; Fisher, 2007). For example, cattle seek protection from inclement weather both in windy, rainy (Vandenheede et al., 1996; Tucker et al., 2007; Schütz et al., 2010a), and warm conditions (Tucker et al., 2008; Schütz et al., 2009). Ambient weather conditions will also influence the surface quality of pasture and thus the available, comfortable space for lying and walking. When managed on pasture, underfoot conditions can quickly become muddy in wet weather and impose constraints on animals' ability to move and find a comfortable place to lie down, which in turn may lead to chronic stress (Fisher et al., 2002). Several studies of dairy cows have reported severely reduced lying times on wet and muddy surfaces by 50 to 75% compared to dry surfaces (Fisher et al., 2003; Chen et al., 2016; Schütz et al., 2019). The negative effects of mud might be even more evident at colder temperatures (Muller et al., 1996; Fisher et al., 2003), possibly due to thermoregulatory challenges associated with cold, wet surfaces (Morrison et al., 1970; Holmes et al., 1978) which in turn will increase metabolic requirements (Degen and Young, 1993; Tucker et al., 2007). Newborn and young animals are particularly vulnerable to cold/wet/windy weather, and both calf and lamb mortality in New Zealand can be high which in turn poses a high risk both to the welfare of the animals and to our reputation as a nation with high welfare standards. The seasonal nature of the pastoral systems results in concentrated calving and lambing seasons, which imposes challenges in terms of ability to properly care for animals. This, together with exposure to outdoor conditions impacts the ability to properly care for young stock. The resulting wastage and treatment of dairy calves is also a significant risk to the New Zealand dairy industry which has gained attention lately. As mentioned earlier, the extensive nature of New Zealand beef and sheep systems has many benefits, but extensive systems also impose a risk of lack of supervision where animals with injuries, disease challenge and/or ill thrift may not receive timely treatment. Improved management systems and tools (e.g. using automated precision livestock technologies) and research surrounding these are critical to mitigate some of these issues.

It is likely that climate change will significantly impact animal agriculture worldwide and one major concern is the ability of livestock to cope with climatic extremes (Lees et al., 2019). Globally, various climate change models are predicting a 1.1°C to 6.4°C increase in temperature by the end of this century (Nardone et al., 2010) and global warming is likely to have a considerable impact on the stability and sustainability of livestock production in New Zealand. Climate change will increase the risk of heat stress and influence soil fertility and degradation, water availability, forage yield, quality and availability, and spread of diseases/pathogens that may potentially impact the welfare and productivity of animals (Nardone et al., 2010; Henry et al., 2012). Warm and humid climate could also lead to increased risk of disease, such as facial eczema, ryegrass staggers, other mycotoxins and external and internal parasites including fly nuisance (Anyamba et al., 2014). Changes in climate conditions can also increase the risk of exotic diseased becoming endemic in New Zealand, which in turn puts the status of NZ as a 'disease free, healthy producer' at risk. This is exemplified by the occurrence of theileriosis outbreaks, a disease caused by a blood-borne parasite transmitted by cattle ticks (Watts et al., 2016), which population increases in warmer weather. Increased standing behaviour as a response to heat load (Tucker et al., 2008; Schütz et al., 2010b) may increase the risk of lameness. Heat load has also been associated with an increased frequency and incidence of clinical mastitis in cattle (Morse et al., 1988). Climate change needs to be taken into consideration when planning for the future of livestock production and agriculture to safeguard the welfare of animals.

Animal health and welfare: Strength of research evidence and research needs

There is abundant evidence of health and welfare benefits and challenges of providing pasture access to livestock, in particular to dairy cattle; the confidence about this research evidence is approximately 4 on a scale of 1-5 (very-low to very-high). However, there is a lack of research comparing pasture and more intensive systems for beef and sheep. There is an opportunity for our animal industries to promote the relative naturalness and impact on positive welfare of NZ systems, but more research is needed to show these possible benefits as well as strategies and initiatives to overcome challenges associated with outdoor living (e.g. nutritional and climate). Overall, there is also a lack of research on how climate change will impact the health and welfare of NZ livestock, which are particularly sensitive to changes in climate due to the outdoor nature of NZ farming.

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Pastures and plant diversity - W.M. King, M.B. Dodd, K.N. Tozer and D.E. Hume

Key Messages

- NZ pastoral systems contain multiple plant species, in contrast to crop-based animal production systems
- Pasture legumes are important for feed quality and natural fixation of atmospheric nitrogen
- Biodiversity may convey functional benefits, such as to enhance pastoral system resilience, to reduce environmental footprint, and enhance animal health and nutrition
- Component studies with increasing pasture biodiversity have shown some evidence for these benefits but they need confirming in whole farm system studies over the long term
- Selecting the best species to sow may be affected by insufficient agronomic / ecological understanding of many 'minor' species, along with their inconsistent availability and relatively high cost
- There are challenges in managing diverse pastures – especially to maintain desirable species within the sward

In New Zealand, in situ grazing of multi-species pastures provides over 80% of all livestock feed. These pastures are typically dominated by perennial grasses introduced from Europe in the 19th century, such as Lolium and Agrostis, with a legume component (e.g. Trifolium spp). Native grasses and forbs are a minor component, except where Rytidosperma, Chiononchloa, Poa and Festuca species dominate in higher-altitude settings. Most pastoral area is in permanent pasture, with up to approximately 10% of the cultivatable area renewed by drilling or broadcasting in any given year. The pasture renewal activity is dominantly on lowland intensive dairy and livestock finishing systems, as much of the pastoral area is too steep for cultivation.

New Zealand pastures contain a legume component that supports biological nitrogen fixation and enhanced forage quality for high animal productivity (e.g. Harris et al., 1997). As noted in the Resource Use section, NZ's sheep and beef farms rely on nitrogen fixation and have low use of fertiliser-N, while on dairy farms it is also an important source of farm N inputs.

There is a clear difference between the effective biodiversity of land used to grow crops (usually grown as monocultures) for feeding in housed animal systems, and land in multi-species pastures. However, at a system level, housed animals are typically fed a mix of different feed types sourced from a wide area and this can represent a greater diversity in animal intake of forage types and species than animals solely grazing on pasture.

In less extensive grazing systems on rolling to steeper land in NZ there can be a wide diversity in species, which can be enhanced by localised differences in climate, soil moisture and fertility. However, in intensive grazing systems on flat-rolling land that receive high N fertiliser inputs, the pasture biodiversity may be low and the diet is often dominated by ryegrass.

Functional benefits of greater pasture biodiversity

To support the notion of "pasture-fed", discussion of biodiversity needs to focus on the functional benefits of forage biodiversity in animal feeding production systems. Increased plant biodiversity could potentially benefit animal health and product nutrition (scored to indicate confidence, 1 -low to 5 -high):

1. More diverse pasture plant communities may provide better nutrition to grazing animals year-round, since the animals are able to selectively graze from a broader range of species. This could potentially lead to healthier animals, with reduced animal health costs. Animals could also 'self-medicate' and reduce parasite load (Provenza et al. 2015). **3**
2. Better quality products, especially meat and milk. There also may be opportunities to deliberately manipulate pasture composition to deliver specific product attributes (e.g. flavour; see Product Quality section) (Crush et al. 2020). **2**

More diverse pasture plant communities may also be more resilient and sustainable, given the inclusion of well-adapted species. This is manifested through a range of effects including flow-on to other soil properties, invertebrate diversity and environmental impacts described in other sections of this paper. These include (scored to indicate confidence, 1 -low to 5 -high):

1. More reliable intra- and inter-year plant production and, therefore, a more consistent output of animal products (Sanderson et al., 2004; Pembleton et al., 2015). **2**
2. Greater richness of above-ground invertebrates (Milcu et al., 2008). **5**
3. More diverse below-ground microbial and invertebrate communities, driving more efficient cycling of nutrients and regulation of soil-borne pests **5** and diseases **2** (Milcu et al., 2010; Tozer et al., 2016; Goldson et al., 2020)
4. Better use of available nutrients and ability to withstand climatic extremes. Studies show potential benefits for pasture performance through mitigating the impact of drought stress (Sanderson et al., 2007) **5**, increased N uptake (Vibart et al., 2016) **3**, reduced N losses (Bryant et al. 2017; Romera et al., 2017) **3**, reduced C losses and increased root C inputs (McNally et al., 2015; Rutledge et al., 2017) **3**

5. Greater resistance to pest and weed invasion, leading to lower costs through less frequent re-sowing (Dodd et al., 2004; Tracy and Sanderson, 2004; Tozer et al., 2010) 4

Most studies on these various effects of increased pasture biodiversity have been in component research. Thus, the flow-on effects, in terms of longer-term benefits to soil properties (e.g. increased soil C) and reduced environmental emissions (including from effects on N cycling), at a farm system level over time have not been studied and represent an area of research need.

Challenges with high biodiversity pastures

The typical pattern for newly established pastures is an increase in biodiversity over time, following sowing of relatively few species and cultivars. The low sowing diversity is driven by an understanding of best fit of improved genetics to environment and management. However, the ingress of volunteer species, including resident naturalised species and new weeds is inevitable. This is a combination of both persistence failure in the sown species and natural community re-assembly processes (Tozer et al., 2011).

There are many challenges associated with establishing and maintaining biodiverse pastures. These include:

1. While biodiverse pasture communities have the potential to equal or exceed the pasture production of traditional ryegrass/white clover pastures, the complexity of managing biodiverse communities means this is difficult to achieve. For example, some species may have conflicting optimum grazing and soil fertility requirements.
2. Selecting the best species to sow may be affected by insufficient agronomic / ecological understanding of many ‘minor’ species, their inconsistent availability and relatively high cost. Research to improve this broader species understanding is needed.
3. Pasture composition is inherently dynamic so that the original species mixture will not be stable for prolonged periods and the ‘trajectory’ of the pasture community may be unpredictable.
4. Grazing management and fertilisation of biodiverse pastures will inevitably favour some species over others, accelerating pasture composition change.

Wider context

There is evidence from contingent valuation studies that consumers value biodiversity conservation (Martin-López et al., 2008). However, the connection to differing aspects of biodiversity within farm systems (such as forage biodiversity) has not been specifically studied. These benefits of biodiversity should be noted in addition to aspects mentioned above but are not further considered here.

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Soil health - M. Donovan, D.J. Houlbrooke and S.F. Ledgard

Key Messages

- Soil organic matter and carbon levels are higher in pastoral soils than cropping soils, which has many benefits for ecosystem services
- These benefits include more developed soil structure with increased solute and air transmission, greater water holding capacity and greater cation exchange capacity
- Soils with good structure and cohesion, undamaged by compaction and pugging, generate less surface runoff and derived losses of contaminants, especially sediment, phosphorus and faecal microorganisms (FMOs)
- Earthworm and soil microbial diversity and activity are greater under pastoral soils compared to arable soils

Soil health reflects the ability of the soil to provide optimum conditions for plant growth, soil biological activity and below-ground biomass, while minimising risk of contaminant loss and providing valuable ecosystem services. Pasture grazing has the potential to serve as a multi-functional land use by providing economic benefits, high-quality food and soil rehabilitation if managed well and grazed sustainably. On the other hand, with overgrazing and/or poor management, pastoral grazing can degrade soil physical quality, disturb soil nutrient cycling, increase contaminant loss and incur significant economic losses that impact local communities. The range of positive and negative outcomes for soil health demonstrate that pasture-raised cattle and sheep simultaneously represent an opportunity and a risk for the health of NZ's soils.

Benefits from pasture-fed livestock systems

A key driver of soil function is the soil organic matter status and a dominant component of this is carbon (C), which typically comprises about 60% of soil organic matter in top-soils. Soil C is directly responsible for increasing soil cation exchange capacity (a measure of the ability of soil to retain nutrients), water holding capacity and building good soil structure. Soils under perennial pasture systems generally contain higher levels of organic matter and C than soils under cropping and/or trees. For example, the NZ Greenhouse Gas Inventory reports average steady-state soil organic C stocks of 105 t C/ha for pasture-land, whereas for perennial cropland it is 88 t C/ha and forests 92 t C/ha (MfE, 2019). Thus, shifting from exported crop-fed livestock to perennial pasture-fed grazing can lead to significant sequestration of C in soil that eventually reaches a steady-state. Research across numerous sites in NZ indicated that soil C stocks are increasing on hill pasture land (Schipper et al., 2010), although other hill country studies have shown inconsistent changes with greater pasture productivity (Mackay et al., 2018).

New Zealand pastures often experience light to moderate rotational grazing, which has been shown to maintain or even improve soil health with minimal evidence of pugging or compaction (Nie et al., 2001), especially when compared to long-term cropped soils. Immediately following grazing, NZ pastures typically retain 45-60% groundcover (Pande et al., 2000), which helps to increase the ability of soils to intercept and reduce the force of raindrops from disaggregating surface soils. This means that NZ pasture soils retain significant root mass and organic content that are known to increase soil cohesion, resist degradation and increase water retention. These attributes are important soil functions that help minimise the loss of soil structure and cohesion. In turn, these promote retention of topsoil and reduced erosion rates.

Pasture soils show improved function with greater earthworm and microbial activity. Earthworm abundance and, to a lesser extent, microbial biomass, were greater under permanent pasture in comparison to arable management in Canterbury (Fraser et al., 1996). Soil disturbance due to cultivation also reduces microbial species diversity, functional diversity and enzyme activity (Zuber and Villamil, 2016; Briones and Schmidt, 2017). Although changing cultivation to direct drilling benefits earthworm abundance, under both practices, earthworms were less abundant than under permanent pasture (Springett, 1992). The decline in soil biology under arable management largely reflects physical disturbance from cultivation. Other factors such as depth of cultivation and access to organic matter for the soil food web can also have important effects on the soil microbial community (Briones and Schmidt, 2017).

Challenges and how to mitigate them

While typical pasture grazing demonstrates numerous benefits to the health of New Zealand's soils, challenges remain in cases where poor land management practices degrade soil physical quality. The largest challenge is found when intensive overgrazing of pastures during wet conditions compromises soil health (Merten and Minella, 2013; Pimentel and Burgess, 2013; Trimble and Mendel, 1995). This is a significant challenge for steep hillslopes (Silburn et al., 2011) and naturally poorly drained soils that can remain wet throughout winter and much of spring (Burkitt et al., 2017). While winter grazing represents a significant challenge, many soils exhibit some degree of recovery within weeks to months following intensive grazing (Cournane et al., 2011; Greenwood and McKenzie, 2001; Nie et al., 2001). In addition, much research has demonstrated numerous active and passive strategies that can mitigate soil degradation and reduce sediment eroded to waterways (Houlbrooke et al., 2009; Daniel et al., 2006; Laurenson et al., 2016; McDowell and Houlbrooke, 2009; McIvor et al., 1995). For example, avoiding or reducing grazing during and after rainfall events significantly reduces soil damage (Herbin et al., 2011) due to improved soil cohesion and strength found in unsaturated soils. As such, pasture management and proactive strategies are the key to maintaining and improving the suite of physical, chemical, and biological components that make up soil health. If proper management of NZ pastures continues and winter grazing management improves, soil health of grazed pastures will continue to exceed cropped lands supporting housed systems.

Strength of research evidence and research requirements

On a scale of 1-5 (very-low to very-high), the confidence about this research evidence relating to soil properties and soil health is 4. Despite clear evidence of greater soil organic matter and C contents in pasture soils, there is a lack of research in NZ on our ability to increase these levels via greater inputs of plant material, the implementation of novel grazing practices or increasing sward diversity.

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Benefits of pastoral systems beyond food and fibre

The benefits or ecosystem services we obtain from our pasture grazed ruminant systems, beyond the provision of food and fibre, are rarely captured, quantified or valued (e.g. Dominati et al., 2104, 2019, Maseyk et al.,2017, 2019,). This is where an ecosystems approach to pasture grazed ruminant systems can be useful. The stocks and flows from the pasture grazed ruminant systems listed in Figure 1 are not exhaustive, but include the major underlying stocks (resources), the processes that are likely to degrade or sustain those stocks and the flows of ecosystem services coming from the use of those stocks in the farm system. It goes someway to capture the elements described in the picture of the pasture grazed ruminant system.

The equivalent figure for a crop based housed/feed lot product would have a different suite of stocks, would include the use of more built capital, and the flow of services beyond food would be different and less exhaustive.

What are the challenges and how might these be mitigated?

To our knowledge attempts at describing, capturing, quantifying the differences between a pasture grazed ruminant product with a crop based housed/feed lot product has not be undertaken. There are still many challenges in quantifying stocks and ecosystem services listed in Figure 1.

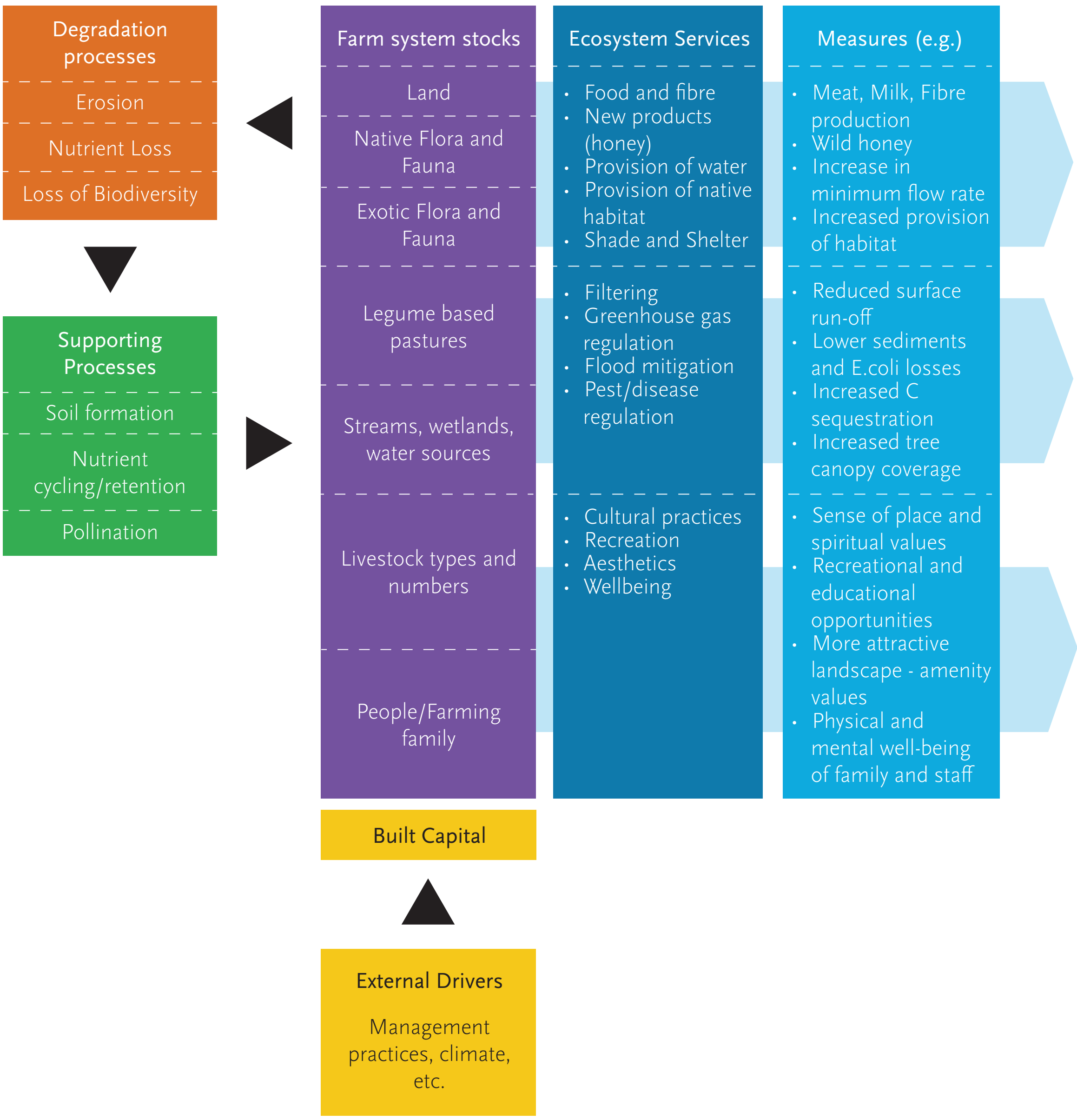

Figure 1. The stocks and flows of ecosystem services from pasture grazed ruminant systems. Adapted from Dominati et al., (2010) and Dominati et al., (2020)

Despite the wide range of farm scale simulation models available (Bryant and Snow, 2008) none of them can adequately examine the flows of ecosystem services across different areas of pasture grazed ruminant farm, including woodlots, hedgerows and waterways, to fully capture the trade-offs associated with having a diversity of ecosystems on the farm. In comparison, modelling monoculture/feedlot systems is a lot easier. Extending the capability of farm scale models to predict the provision of multiple ecosystem services across productive and non-productive areas of the farm and beyond the farm is still to come. Unfortunately, the tools available to model the non-pastoral areas of a farm, which include wetlands, riparian margins, restored native remnants or newly planted biodiversity enhancement areas, are very limited in their capacity to capture the functions, processes and ecosystem services these ecosystems deliver to the farm and wider environment (Turner et al., 2015). Models also have limited functionality to explore the interactions between adjacent ecosystems as they influence the flow of ecosystem services across landscapes (Maseyk et al., 2018). Combining the capabilities of catchment scale ecosystem service models (Crossman et al., 2013; Sharps et al., 2017) with farm system models might offer the kind of insight into the flows of ecosystem services across pasture grazed ruminant farms.

This is one of the challenges being tackled by all the countries represented in the Strategic Partnership (INIA [Uruguay], Teagasc [Ireland], SRUC [Scotland], IRTA [Catalonia] and AgResearch [New Zealand]) in agri-food production, competitiveness and sustainability.

Strength of research evidence and research requirements

On a scale of 1-5 (very-low to very-high), the confidence about research evidence from an ecosystems approach to pasture grazed ruminant systems is 2 (low), primarily because it is an emerging science that is still in its infancy particularly in its application in agricultural systems. This is in stark contrast to the research investment in deepening our understanding of the flow of services from natural ecosystems such as forests or water ecosystems. There are still major challenges surrounding the capture and quantification of a number of stock and ecosystem services from complex agro-ecosystems such as grazed ruminant systems. That said the approach has huge potential to demonstrate all the benefits of diverse grazed ruminant systems compared to crop based housed/feed lot systems and monoculture plant-based systems.

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Resource use - S.F. Ledgard and A. Mazzetto

Key Messages

- All livestock production systems require basic inputs of land (for growing animal feed), energy, water and nutrients
- Land use for NZ pasture is similar to that for crops for livestock under similar climate
- Fossil energy use for NZ pasture-based grazing livestock production is low compared to crop-based housed/feed-lot livestock production [e.g. by about two-thirds]
- Drinking water requirements are lower for pasture due to its higher water content than crop-feed. The water scarcity footprint of NZ livestock products is low
- Non-nitrogen nutrient requirements for pasture growth are higher than for crops, while NZ clover-based pastures fix atmospheric nitrogen and generally use less fertiliser-nitrogen than crops. However, at a whole-system livestock product level, nutrient use efficiency can be similar to that for crop-based livestock products

Key resources for livestock agriculture are land, energy, water and nutrients. The NZ farm system of year-round grazing of pastures could be considered as highly efficient from an energy and water use perspective, while being moderately efficient for land use and relatively inefficient for nutrient use compared to that for livestock systems relying on animal housing/feedlots and brought-in crop feeds.

Land use

The land use requirements (land occupation) for NZ livestock production on grazed pasture is broadly similar to that for crop-based housed/feedlot livestock production. However, at a global and regional level the pasture and crop production, and therefore land requirements for livestock production, vary widely depending on climatic and site characteristics.

Benefits from pasture-fed livestock systems

The land use requirements (land occupation) for NZ livestock production on grazed pasture is broadly similar to that for crop-based housed/feedlot livestock production. However, at a global and regional level the pasture and crop production, and therefore land requirements for livestock production, vary widely depending on climatic and site characteristics.

The average NZ dairy farm land use is approximately 0.9 m2/kg fat-and-protein-corrected milk (FPCM) (estimated using data from Ledgard et al., 2020). This is similar to the average from 16 published studies (mostly from Europe; using the same methodology) of approximately 1.0 m2/kg FPCM (Baldini et al., 2017). The low NZ value can be attributed to the relatively high pasture production, due to NZ's temperate climate. For sheep, land use was also similar for NZ and for French crop-based partial-housing systems (Ledgard, 2017), while traditional beef cattle production in NZ was similar or higher than that for a simulated EU suckler cow/calf system with productive grassland for grazing and crops for indoor feeding (Nguyen et al., 2010).

Challenges and how to mitigate them

In general, the amount of land required for total livestock production decreases with increased intensification, and housing systems that use productive crops can have a relatively low land use. Conversely, extensive livestock production may occupy a relatively large area. In recent years, the discussion around land occupation has been extended to account for land used for human-edible versus human-inedible plant production. Within NZ, many areas under pasture-based livestock production are unsuitable for growth of crops for animals or humans due to site limitations.

Energy use

Fossil energy use on farms comprises direct use of fuels and the fossil energy component of electricity used, as well as well as indirect use for production, transport and use of farm inputs (e.g. fertilisers or brought-in feeds).

Benefits from pasture-fed livestock systems

For all NZ livestock pasture-fed grazing systems, the direct fossil energy use is very low, largely due to reliance on grazing for 'harvesting' of pasture with limited use of brought-in feeds and feed conservation for silage or hay. Most fossil energy use on NZ dairy farms is from indirect sources, predominantly from fertilisers and brought-in feeds (covering their production, transportation and use). Estimates for NZ dairy, sheep and beef production all showed that the total (direct+indirect) fossil energy use was only 20-40% of that for crop-based housing/feedlot systems (Nguyen et al., 2010; Vigne et al., 2012; Ledgard and Falconer, 2019; Rotz et al., 2019).

Challenges and how to mitigate them

While fossil energy use on NZ farms is low, there are significant fossil energy requirements in getting produce to NZ's many distant markets and therefore it is important that our farm energy use is low. One study indicated that even when fossil energy use for shipping milk product to China was included the total was still less than half of that from Chinese dairy farms only (Ledgard and Falconer, 2019). The corresponding assessment of NZ sheep meat to UK indicated that energy use for shipping was similar to that for on-farm energy use, but still giving a small overall advantage.

Water use

Water use is best examined from the perspective of "blue water", i.e. water extracted from surface or ground-water sources. Current water footprinting methods more commonly refer to a water scarcity footprint, which importantly accounts for the scarcity of blue water, i.e. the availability relative to the demand for use (Pfister et al., 2009). In practice, the water scarcity factor for NZ regions is low compared to that for many other countries, particularly those with drier heavily-populated countries/regions. This is due to the moderate-high rainfall and lower competition for water use in NZ than in many countries.

Drinking water requirements by livestock will generally be lower when grazed on pasture than crop feeds due to high water intake from pasture associated with its high water content (c. 70-90%), compared to that for cereal grains and concentrates (c. 10% water).

Benefits from pasture-fed livestock systems

For most NZ livestock pasture-fed grazing systems, the water scarcity footprint of products from NZ farms is low compared to that from many overseas countries, particularly those from drier climates. For example, Huang et al. (2014) estimated the water footprint of milk from California, China and NZ at 461, 11 and 0.01 L H_2O-equivalents/kg FPCM.

A study of the water scarcity footprint of NZ beef and sheep meat showed lower values than corresponding estimates for Australian beef (by 9-60 fold) or UK sheep meat (by 30-90 fold) (Zonderland-Thomassen et al., 2014). In USA, the blue water withdrawal was 2.5- to 35-fold higher (highest in regions with irrigation) than for NZ beef and this didn't account for their higher water scarcity factor (Rotz et al., 2019).

Challenges and how to mitigate them

Irrigation of pastures has a dominant effect on water use, competition with other sources and on the NZ average water scarcity footprint. The water scarcity footprint for milk from an average irrigated Canterbury dairy farms was approximately 70-fold higher than that for milk from an average non-irrigated Waikato farm (Payen et al., 2018). Irrigated Canterbury dairy farms were similar to that for the overseas irrigated crop-based housed-cow systems.

Some reports still refer to the Water Footprint Network method (which includes blue, green and grey water) and results from global analyses indicated a similar or higher water footprint from grazing systems than industrial milk production systems (mainly due to lower green water use, which makes up over 80% of the total water footprint) (Mekonnen and Hoekstra, 2010). Fortunately, the folly of using green water in water footprint calculations is becoming accepted and recent publications now focus on the more-appropriate water scarcity footprint indicator.

Nutrient use

Benefits from pasture-fed livestock systems

For nitrogen (N) fertiliser use, the inputs per hectare on NZ pastures are generally less than those used on feed crops. Pastures in NZ have traditionally relied on a legume fixation of atmospheric N_2 by legumes and N fertiliser use on NZ sheep and beef farms is only about 10-15 kg N/ha/year (B+LNZ statistics). Conversely, N fertiliser use on dairy farms has increased over time to currently average approximately 140 kg N/ha/year (Ledgard et al., 2020), with additional inputs from clover N_2 fixation at about 100 kg N/ha/year. Estimates of dairy whole-farm N use efficiency for NZ pasture systems were generally similar or lower than that for crop-based systems at 20-40% compared to 20-60% range for Europe and USA (de Klein et al., 2017).

Challenges and how to mitigate them

In contrast to N, inputs of non-N fertiliser nutrients on NZ pastures are relatively high. In general, the efficiency of use of added fertiliser-nutrients by crops is higher than that for legume/grass pastures. Most crops (excluding legume crops) have lower nutrient concentrations and use of a mixture of crops can be used to match animal nutrient requirements, whereas temperate pastures generally have nutrient concentrations that exceed animal nutrient requirements. This means that the amounts of nutrients (including N) voided in excreta and manure by grazing animals is relatively high, which increases the risk of environmental emissions (see Water Quality section).

For example, studies in the Netherlands have shown typical phosphorus use efficiency for arable crops or grass of 65-73% or 43-48%, respectively (van den Broek et al., 2007). However, in whole farm systems the nutrient use efficiency is also influenced by the efficiency of recycling of nutrients via excreta during grazing or via manure collection and subsequent application to crops. The NZ average P use efficiency (i.e. outputs-P/inputs-P) for the average NZ dairy farm in 2107/18 was approximately 55% (estimated from data in Ledgard et al., 2020), whereas Dutch dairy farm data for mixed crop-fed housed cows is over 60% (Mu et al., 2016). In some countries, the recycling of manure from housed cows may be relatively poor, such as in China where 20-40% of manure-nutrients are discharged to waterways (Bai et al., 2017).

The high P fertiliser use for NZ pasture-fed livestock was highlighted in a recent paper, which noted NZ as the most highly-compromised country globally for P-fertiliser exceedance (Li et al., 2019). The P fertiliser use on NZ dairy farms has decreased over the past 10-15 years (Ledgard et al., 2020) but further efficiencies could be made. Plant breeding research is testing for lower P-requiring clovers.

Strength of research evidence on resource use and research needs

There are few published data on resource use on NZ farms, although studies have been comprehensive, so that for land, energy and water use indicators, the confidence about this research evidence is 3 on a scale of 1-5 (very-low to very-high). An exception is efficiency of use of non-N nutrients for current farm systems (but with much data for farms of 20+ years ago). Thus, there is a lack of data for comparing current NZ pasture-based farms and crop-based housed/feedlot farms at a whole-system level. This is important, since limited information suggests lower efficiency from pasture-based systems.

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Environmental impacts to air - A. Mazzetto, C.A.M. de Klein and D. Pacheco

Key Messages

- The carbon footprint (total greenhouse gas emissions [GHG] per kg product) of NZ livestock products from grazed pasture is lower or similar to that for products from crop-based housed/feedlot systems
- Manure management results in emissions of ammonia, methane and nitrous oxide, and these are generally lower from grazed pasture systems than from housed/feedlot livestock systems
- Animal enteric methane emissions are the largest contributor to total GHG emissions and this source is usually a larger contributor to the carbon footprint of livestock from pasture-based diets
- Lower ammonia and fine particulate emissions from grazed pasture systems means less risk from respiratory diseases for animals and humans

General introduction

Various contaminants are emitted to air from agriculture. In New Zealand, the main contaminants of concern are greenhouse gas (GHG) emissions and their effects on climate change. The government has set ambitious targets for the reduction of GHG emissions from all sectors, especially agriculture, since it represents about one-half of NZ's total GHG emissions (MfE, 2019). Typically, the main source of GHG emissions (and contribution to the carbon footprint) from livestock systems is enteric methane (CH4). Nitrous oxide (N2O) from manure and application of nitrogen (N) fertilisers are also important sources, followed by the emission of carbon dioxide (CO2) from the production of inputs (e.g. fertilisers, pesticides, brought-in feed). This section is sub-divided into areas covering carbon footprint of livestock products, manure management and enteric methane emissions.

Carbon footprint

Life Cycle Assessment (LCA) is the methodology used to provide a holistic approach to evaluate the environmental performance of a production system. It achieves this by considering the potential impacts from all life cycle stages of a product or system, such as the manufacture of inputs into the system, the product use and end-of-life. NZ is well known for its efficiency in the production of milk and meat, and this efficiency is shown in the total GHG emissions of NZ's products (i.e. their carbon footprint).

The carbon footprint of NZ milk (0.73 to 0.77 kgCO2equivalents / kg FPCM; Ledgard et al., 2020) is lower than for other regions of the world (0.80 to 1.13 kgCO2e / kg FPCM; Baldini et al., 2017; Lorenz et al., 2020), especially when compared with housed systems (1.1 to 1.2 kgCO2e / kg FPCM; O'Brien et al., 2015) and when compared with the milk produced in developing countries, as Costa Rica (1.86 to 5.32 kgCO2e / kg FPCM; Mazzetto et al., 2020) and Kenya (2.19 to 3.13 kgCO2e / kg FPCM; Wilkes et al., 2020).

The same is true for lamb production, where the NZ average (5 to 8 kgCO2e /kg LW) is similar to published values for other grass-based systems, but much smaller than for housed systems (range 5 to 33 kgCO2e / kg LW, respectively; Ledgard, 2017). The carbon footprint of NZ beef (10 kgCO2e /kg LW [range 5-12 depending on source]; Ledgard and Falconer, 2019) is similar to that for USA beef (11-12 kgCO2e /kg LW; Rotz et al., 2019), but smaller when compared with other traditional-beef herds, such as in Brazil (18 to 42 kgCO2e /kg LW; Ruviaro et al., 2020).

Benefits of the pasture-based system for dairy, sheep and beef

Farms relying on grazing of pasture show less contribution of CO2 from fossil fuel due to efficient feed utilisation compared to housed systems where crops must be established, harvested, transported and fed to animals. However, pasture-based systems generally show a relatively high contribution from enteric CH4. In Ireland, O'Brien et al. (2016) showed that increasing sheep production by feeding more concentrate was less efficient and increased the carbon footprint compared to increased grass production. The use of concentrates requires significantly more resources, generating more pre-farm-gate (upstream) emissions.

In a meta-analysis of dairy systems globally, Lorenz et al. (2019) found that, when controlled for milk yield, pasture-based systems generally had a lower carbon footprint than other systems. They also noted that increases in dairy milk yield, pasture intake and feed efficiency resulted in a reduction of the carbon footprint of milk, independent of the dairy production system. However, the mitigation benefits from these practices were greatest on farms with low-to-average performance. For example, across a range of studies, a review of research by Lorenz et al. (2019) indicated that an increase in milk yield from 5,000 to 6,000 kg FPCM/ cow (which can be achieved in pasture systems) can reduce the carbon footprint by 0.12 kg CO2-e /kg FPCM, while an increase from 10,000 kg to 11,000 kg/cow leads to a reduction of only 0.06 kg CO2-e /kg FPCM.

Challenges and how it might be mitigated

One important factor to consider is the interaction between production systems, such as between dairy and beef farms. Less intensive (low input systems) with lower dairy milk production usually have more animals, which lead to more calves for beef production. Intensive systems with fewer but more productive animals can lead to less beef production. When the boundaries of the dairy farm are expanded for considering the beef system, less intensive farming results in a smaller carbon footprint per kg of milk plus beef, but still shows a larger land occupation footprint (m2) than intensive systems (Styles et al., 2018; Mazzetto et al., 2020 – under review). This also applies for increased dairy cow reproductive efficiency. One option for reducing the footprint of pasture-based systems is making greater use of surplus calves from the dairy herd, reducing the total beef GHG emissions due to less need for breeding beef cows.

Intensive pasture-based farms can have moderate-high N fertiliser use to get more pasture growth, which can increase the emission of N2O from the application of fertiliser on pasture and CO2 from the production of the inputs, thereby increasing the carbon footprint. Precision farming techniques and the use/development of controlled/slow release N fertilisers have the potential to reduce the N2O emissions from fertiliser use. The CO2 emissions from the production of fertiliser could be mitigated by using a renewable source of energy (solar, wind, geothermal) by the producer, reducing the dependency on fossil fuels.

Diversification of the land use can contribute to reducing the carbon footprint. Sheep and beef farms that integrate forestry, such as via spaced tree planting within pastures (Dodd et al., 2020), could increase vegetative carbon sequestration thereby reducing net emissions. When the carbon sequestration in soil from pasture-based system was considered, O'Brien et al. (2014) reported a lower carbon footprint for grass-based milk production than confinement systems (in USA and UK). However, excluding carbon sequestration resulted in grass-based and confinement systems having a similar carbon footprint per unit of FPCM.

The main challenge in reducing the carbon footprint of livestock products is in reducing methane-related emissions since they dominate the farm carbon footprint. This aspect is covered in section 5.6.4, along with feed options for decreasing methane emissions and potentially also decreasing the carbon footprint of the livestock products. This is also important since methane is a short-lived GHG compared to the other main anthropogenic GHGs (Reisinger et al. 2017).

Other resource use and environmental impact categories (land use, water, eutrophication, etc.) should also be evaluated to avoid burden-shifting (e.g. a positive mitigation measure for the carbon footprint can have a negative impact on the water footprint). It is likely that other impact categories will be also favourable for pasture-based production, as human health and ecotoxicity, due to lower contaminants like ammonia and pesticide use.

Strength of research evidence

The data cited for the comparisons of the carbon footprint is published in peer-reviewed journals, and over the years the results from NZ milk and sheep meat production have been consistently lower than (most) of other production systems in the world. The beef production still needs an update (currently being done by AgResearch) for comparison with the more recent studies.

Manure management

For this paper we define 'manure' as all livestock excreta. In grazed systems most of the excreta are deposited directly onto pasture as urine and dung (unmanaged manure), with typically less than 8% of the excreta being deposited on hard surfaces (Rollo et al., 2017). In contrast, in housed/feedlot systems, all livestock excreta are collected on hard surfaces and fully managed as manure. Manure can be managed in solid (e.g. bunker manure, deep litter) or liquid form (e.g. anaerobic lagoons, effluent; Schils et al. 2013). Livestock manure is a source of CH4, deriving from organic matter in faeces, and typically representing 5-35% of the total CH4 emissions from livestock systems (e.g. Phetteplace et al. 2001; van der Weerden et al. 2018). Nitrous oxide emissions from manure are derived from N contained in both urine and faeces. These N2O emissions can occur immediately following excretion/deposition (direct emissions) or from N that is initially lost via N leaching or ammonia (NH3) volatilisation, but subsequently emitted as N2O (indirect emissions).

Benefits of the pasture-based systems

In terms of GHG emissions from manure management, the main benefits from grazed systems are that CH4 emissions from dung deposited during grazing are estimated to be much lower, per unit of faecal dry matter produced, than emissions from faecal material excreted in housed systems (MPI 2019; IPCC 2019). Depending on the form in which the manure is stored, CH4 emission from manure can be anywhere between 10 and 100 times higher than from dung; e.g. CH4 from anaerobic lagoons are >100 times higher than from dung, while emissions from solid storage are ca. 10 times higher (IPCC 2006). Van der Weerden et al. (2017) estimated that changing NZ dairy systems from 100% to 0% grazing, by keeping animals off the paddock on stand-off pads and storing the manure as solids, increased manure CH4 emissions by on average 15%.

Another key benefit from grazed systems is that NH3 volatilisation (and the subsequent N2O emissions) from urine and dung deposited during grazing are estimated to be 3-5 times lower, per unit of N, than emissions from manure collection and storage (IPCC 2006). Direct N2O emissions from urine and dung deposited during grazing are similar to those from manure management systems, although it is estimated that some systems have negligible direct N2O emissions (e.g. uncovered anaerobic lagoons; IPCC 2019).

Finally, grazed systems have fewer issues with odour from manure management and/or human health respiratory problems, as fewer fine particulates are emitted.

Challenges and how it might be mitigated

During grazing, urine and dung are excreted directly on pasture in very concentrated patches that have much higher N concentrations than can be utilised by plants. As a result, the excess N is at risk of being lost as N2O, NH3 or through N leaching. This risk is lower for sheep systems, compared to dairy and beef systems, as N2O emissions from sheep urine are lower than for dairy & beef cattle (van der Weerden et al. 2020).

The key management options for reducing N2O emissions from urine include reducing N inputs from fertiliser, reducing the N content in the diet, and the use of biological or chemical compounds that inhibit nitrification. Options for reducing the N content of the diet are limited in pasture-based systems, especially in clover-based pastures that can have higher N contents and thus higher total N excreted than non-clover pastures. However, the use of diverse pastures (especially including plantain) has been suggested as a potential option to reduce total N excreted and associated N losses (e.g. Box et al. 2016; de Klein et al. 2020; Di et al. 2016). As N2O emissions are generally higher under wet conditions, off-paddock practices to limit urine deposition at certain times of the year may also reduce N2O emissions (de Klein et al. 2006; Schils et al. 2006; Luo et al. 2007). Such practices can be especially beneficial on poorly drained soils when reductions in N2O emissions are large and not entirely offset by increased GHG emissions associated with housing or stand-off pads (van der Weerden et al., 2017). Nevertheless, a recent study comparing GHG emissions from NZ dairy systems that were designed to reduce N leaching found that total GHG emissions from systems that included a barn or standoff pad could potentially have lower total GHG emissions, provided these systems also included other improvements (e.g. using animals with higher genetic merit, optimised N fertiliser use, avoiding winter grazing on crop; van der Weerden et al. 2018).

Because only a small fraction of the livestock manure is collected and managed, pasture-based systems have limited opportunity to recover and recycle the nutrients and energy contained in the manure (Petersen et al. 2013). For example, a biogas system that has been operational in Southland for three seasons, produces enough biogas on average to create 30 kWh for the dairy shed (https://www.waterfordpress.co.nz/business/glenarlea-farms/). Further challenges of grazed systems could include their ability to adapt to a changing climate. For example, warmer and wetter conditions will increase N2O and NH3 from urine and dung (de Klein et al. 2014), but, compared to housed systems, there are fewer options to manipulate the timing of manure deposition onto land. On the other hand, high temperatures can result in higher CH4 from housing and storage. However, manure collection and storage provide more opportunities for capturing the nutrient and/or energy benefits contained in the manure and the development of options for reducing GHG emissions from manure management continues to be a focus of research in countries that rely on housed or part-housed systems (Petersen et al. 2013).

On balance, GHG emissions from manure management from grazed systems are lower than those from housed systems.

Strength of research evidence

Although the principles of GHG emissions from manure are well understood, quantification of the emissions is challenging and many studies rely on modelling approaches to assess differences between pasture-based and housed system. The recent revision of the IPCC guidelines for estimating GHG emissions from manure stated that the methane conversion factor from manure remains uncertain (IPCC, 2019). Similarly, many of the N2O emission factors from manure management systems are based on 'expert judgement'. Compared with the evidence on CH4 and direct N2O emissions, the current knowledge on NH3 emissions from housed systems is more advanced, as efforts to reduce NH3 emissions from livestock systems has been a focus for many European countries for many decades.

Overall, the strength of the evidence summarised here is about 3 (where 1 is very-low and 5 very-high).

Enteric methane

Benefits from pasture-fed livestock systems

Methane is formed by rumen methanogens (domain Archaea) when they utilise hydrogen produced from the fermentation of feed by other inhabitants of this ecosystem. Different feeds result in different combinations of microbial end-products, which in turn define the amount of hydrogen available to the methanogenic Archaea for methane production. High quality pasture has a relatively high metabolisable energy concentration, similar to that for many quality crop feeds, and the enteric methane emissions per MJ gross energy are generally similar (Niu et al. 2018), except for high-starch feeds.

Challenges and how it might be mitigated

In general terms, feeding concentrates containing starch results in less methane per unit of dry matter intake or per unit of feed digested, compared to roughage diets (see Janssen 2010 for review).

Although many methane mitigation approaches have been proposed and discussed extensively in numerous reviews (Hristov et al. 2013; see Pacheco et al. 2014 for references to reviews), nutritional management is still considered one of the most practical and reliable approaches to mitigate methane (Hristov et al. 2013). However, the opportunities for diet formulation (or inclusion of additives to mitigate methane) are limited in pastoral systems (Buddle et al. 2011; Pacheco et al. 2014).

The methane emissions from ruminants fed perennial ryegrass-based pastures have been extensively studied (e.g. Hammond et al. 2013; Pacheco et al. 2014; Jonker et al. 2017; Jonker et al. 2018) because this pasture species plays a prominent role in improved pastures for intensively managed pastoral land in the country. However, there is less information on the methane emissions from ruminants fed other grasses such as those common to hill country farms. The NZ research indicates that variation in the chemical composition of ryegrass explains only a minor proportion of the variation in methane yield (g CH4/kg DMI) (Hammond et al. 2009; Jonker et al. 2016). These results are in contrast with research that has demonstrated that forage composition, specifically its neutral detergent fibre content, determines the methane yield from forages when diverse forage types are considered (Archimède et al. 2011; Zhao et al. 2016). Pacheco et al. (2014) suggested that, although the chemical composition of ryegrass has little effect on the yield of methane per unit of DM intake, the yield of methane per unit of digested organic matter (OM) reduces as the quality of the forage increases. Whether this finding applies to other grasses and forages species is unknown. The provision of high-quality swards will have benefits in terms of the amount of methane produced per unit of animal product (also known as 'emission intensity'). However, proper quantification of the effect of pasture composition on emission intensity has not been undertaken.

Beyond forage quality, the implementation of other well-studied dietary mitigation approaches is challenging in pastoral systems. For example, oil supplementation has been identified as a dietary methane mitigation approach (Grainger and Beauchemin 2011). Following that premise, a study in New Zealand demonstrated that it is possible to reduce methane emissions from cattle by spraying the pasture with oil before the animals grazed it (Pinares-Patiño et al. 2016). However, the practical application of this methods poses technical issues and may prove wasteful. The development of genetically-modified grasses with increased content of lipid (Winichayakul et al. 2013; Winichayakul et al. 2020) provides a pathway for incorporation of dietary lipids as a methane mitigation tool in grasses, but the technology has yet to be proven effective in vivo. Chemical compounds developed to reduce methane formation in the rumen have shown promise (up to 30% reduction of methane per unit of feed eaten) when mixed in the diet of beef cattle in feedlots (e.g. 3-nitrooxypropanol: 3-NOP; Romero-Perez et al. 2014; Hristov et al. 2015; Duin et al. 2016; Van Wesemael et al. 2019). However, there is evidence that the response to 3-NOP in pasture-based diets is not as profound because the ruminant is not consuming the inhibitor in each mouthful of feed during grazing (Muetzel et al. 2019). The development of long-acting formulation is underway to overcome this issue. Alternatively, in a similar way to the oil example, attempts could be made to incorporate into the forage (via breeding of divergent populations or through genetic engineering) naturally occurring methane inhibitors, either already known such as saponins (Hristov et al. 2013; Wang et al. 2019) or condensed tannins (Tavendale et al. 2005; Moate et al. 2014). Reports on identification of specific secondary plant metabolites (Ghamkar et al. 2018) encourages the discovery of methane inhibitors from the secondary metabolite repertoire of common pasture species (Subbaraj et al. 2019).

A vaccine against methanogens could be a technology able to be implemented widely in pastoral systems, given that farmers routinely vaccinate their animals for protection against infectious diseases (Leahy et al. 2013; Wedlock et al. 2013).

As discussed previously, the diet that is consumed by grazing ruminants is not closely tailored to meet all the requirements without nutrient excesses or imbalances. Therefore, potential 'tension' may exist between dietary goals. Ultimately, for a feed to be considered a 'low GHG' option, it has to result in a net reduction of total GHG compared to any current alternative, and it should not have a negative impact on productivity and product quality. There are cases of forage crops that result in lower methane emissions compared to 'traditional' pastures (ryegrass/white clover). Such is the case of forage rape, a brassica crop, which shows consistent methane-related benefits when fed to ruminants as shown from the integrated evidence (Sun et al. 2016). However, the feeding of this crop in winter, at high animal densities relative to a pasture-based diet, has been highlighted as a risk for increased nitrous oxide emission, causing 'pollution-swapping'. To-date, seven trials have been conducted to examine the effect of forage rape on the N2O emission factor for animal urine. (Thomson et al. 2016; Simon et al. 2019). Most of these studies showed that there is indeed a risk of pollution-swapping with N2O emissions from urine patches on forage rape being higher than urine deposited on ryegrass/white clover pasture. However, an initial assessment of the overall impact of forage rape use on total GHG emissions suggested that there was an average net reduction of about 2% per cow (Simon et al. 2019). These challenges can be mitigated through integrated predictions of GHG based on dietary and animal factors (Van Lingen et al. 2018), or if possible, as in the case of forage rape, the development of grazing management strategies to mitigate risk of trade-offs.

Strength of research evidence

The strength of the evidence regarding the difference in methane emissions generated from the digestion of forages compared to feedlot diets is strong (5). There is also a large body of evidence regarding the quantification of methane emissions from ryegrass pasture (5), but other forages and crops are less studied (1 to 5). Most of the evidence is based on quantification of methane emissions per unit of dry matter eaten (5, strong), but there is less quantification regarding the effect of different forages on emissions intensity (1-2).

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Environmental impacts to water - M. Donovan and D.J. Houlbrooke

Key Messages

- The four main contaminants of concern are nitrogen (N), phosphorus (P), sediment and faecal microorganisms (FMOs)
- Losses of N to waterways are greater from year-round grazed pastures than from housed/feedlot systems, requiring mitigations or improved management practices in catchments with water quality concerns
- Losses of FMOs, as indicated by E. coli, are less controlled and more widespread from grazed pastures than from cropped/housed systems. The actual difference between systems depends on the effectiveness of manure management practices
- Soil erosion and sediment losses from low intensity pasture grazing are significantly less than from intensively grazed or arable systems
- Losses of sediment, P and FMO can be considerable from intensively grazed winter forage crops
- Housed cow systems often have large P surpluses due to the importation of large amounts of animal feeds. Most of this P is excreted, collected in manure and then applied to crops

Water quality is primarily influenced N, P, sediments and FMOs. Regional water quality regulations have mainly focused on N because it has increased in many intensive agricultural catchments. Research has focused on contaminant losses from livestock cascading impacts to receiving waters including eutrophication. Published studies comparing pasture-grazing and housing systems have variable results, although many indicate an advantage to the latter. An exception is soil erosion from grazing on pasture and rangeland, which are typically significantly less than systems supplemented or fully dependent on crop feed (Modernel et al., 2013; Tsutsumi et al., 2014).

Benefits from pasture-fed livestock systems

Extensive grazing systems have relatively low contaminant losses to waterways (McDowell and Wilcock, 2008). Typically, soil erosion from low-intensity grazing on pasture and rangeland are significantly less than systems supplemented or fully dependent on feed (Modernel et al., 2013) and only exhibit low to moderate increases (5-25%) relative to background/natural rates (Cournane et al., 2011; Donovan & Monaghan, 2020; McDowell et al., 2003). For example, O'Brien et al. (2016) showed that intensification of sheep farm systems using feed concentrates in Ireland had a greater environmental impact (including eutrophication) compared to increasing pasture productivity, due to emissions from land and production of crops for concentrates.

Under current management practices, soil losses from pastures were < 5 tonnes/ha per year (Hancock et al., 2020), reflecting the combined effect of rotational grazing and year-round ground cover retained on perennial pastures. These proactive management practices of New Zealand pastures result in higher rainfall interception, improved root cohesion to armour surface soils, and less overland flow, which all contribute to reduced surface runoff of sediment and particulate P. The majority of NZ pastures also benefit from rotational grazing that allows soils to recover and retain 45-60% ground cover (Pande et al., 2000). The effectiveness of crop/vegetation cover in reducing erosion will vary with changes in the height, density, and fraction of cover. However, increased water infiltration that results from reduced overland flow generally conveys much less benefit for N loss risk unless pasture species provide adequate N-uptake.

Housed dairy cow systems often have large P surpluses due to the importation of relatively large amounts of feeds. Much of this imported P is excreted, collected in manure and then applied to crops (McDowell and Kleinman, 2011). In Europe, this has often led to the accumulation of P in topsoil and an associated greater risk of loss to waterways. In contrast, P surpluses in pasture systems are relatively low, although runoff losses of P can occur from sources such as fertiliser, dung and soil. Soils with a high P fertility status result in greater losses of dissolved P and fertilisation with high soluble P products increases the risk of direct fertiliser P losses. Both systems have resulted in relatively large losses of P to water (McDowell and Kleinman, 2011). A global review found increasing surpluses of N and P with increased use of brought-in feeds; significantly greater losses of N and P were inferred for a given runoff event (Modernel et al., 2013).

Challenges and how to mitigate them

In grazed systems, 'feed gaps' often exist in which farmers must rely on supplemented supplies of grain. Such feed gaps often have the highest erosion risk (Moore et al., 2009) and are a challenge for managing multiple contaminant losses to waterways (Drewry et al., 2008; Laurenson et al., 2018; McDowell et al., 2003; Monaghan et al., 2017). In New Zealand, such feed gaps during winter months are the source of much soil and P losses due to their exacerbated impacts on ground cover and soil permeability (Elliott & Carlson, 2004; McDowell & Houlbrooke, 2009). The effects on soil and nutrient loss are also amplified on poorly drained soils and steep hill-country soils lacking residual ground cover (Burkitt et al., 2017). Ongoing research has highlighted multiple management practices and grazing strategies that can mitigate sediment runoff and nutrient leaching (Hancock et al., 2020; McDowell et al., 2005; Monaghan et al., 2017). Such practices include retaining ground cover, avoiding steep hill-country terrain and poorly drained soils, and deferring grazing to periods when soils are unsaturated. However, current intensive winter grazing practices still poses the greatest challenge for losses of sediment, N and particulate P despite representing a relatively small proportion of the farmed landscape (Hancock et al., 2020; McDowell et al., 2005; McDowell & Houlbrooke, 2009; Monaghan et al., 2017).

NZ farm systems generally involve year-round grazing and therefore have significant additions of excreta to soil from animals in autumn and winter. Year-round grazing systems can lead to significant P losses, particularly on farms with high soil P fertility levels. Where soils suffer from the effects of treading damage and bare/exposed soils, this can accelerate losses of N, P, sediment and FMOs to waterways, especially in steep hill-country terrain. In contrast, livestock housing/feedlot systems allow for the collection of animal excreta and the opportunity to apply it to land during periods when the risks of leaching or runoff are lower (assuming similar farming intensities). NZ studies have shown that removal of grazing animals off pasture onto stand-off or housing areas with manure management systems reduced N leaching losses by 20-25% (Ledgard et al., 2006; Monaghan and De Klein, 2014). However, this practice can lead to pollution swapping via increased gaseous losses, particularly ammonia.

Particulate P losses are most highly correlated to the magnitude of runoff due to the lack of vegetation cover and reduced infiltration rate (Elliott & Carlson, 2004; McCaskill et al., 2003; Melland et al., 2008). This highlights that soluble P losses to waterways are best managed by retaining ground cover after grazing and reducing P inputs, especially prior to rainfall events. Once ground cover is removed, slope and the parent material have the next most significant influences on the rate of erosion (Silburn et al., 2011). Work has shown that P losses can be mitigated by grazing management, sometimes down to levels of lightly grazed pastures (McDowell et al., 2005; McDowell & Houlbrooke, 2009; Monaghan et al., 2017). Much research in New Zealand is focused on continuing to evaluate which active and passive practices successfully mitigate erosion and contaminant losses reaching waterways (Houlbrooke et al., 2009; Daniel et al., 2006; Laurenson et al., 2016; McDowell & Houlbrooke, 2009; McIvor et al., 1995). Practices include planting vegetation along adjacent hillslopes and gullies, grazing away from hillslopes, avoiding critical source areas, and reducing or halting grazing during and after winter rainfall events.

A grazed pasture system has an uncontrolled risk of spread of FMOs due to the spread of animal excreta around the farm and catchment. While well-managed housed/feedlot systems have the potential to containand control this risk, it is often not well managed due to poor adherence to the necessary manure management practices that are required to safely return animal manures to land (Oliver et al. 2017). Limited studies in beef farming systems using Life Cycle Assessment methods to estimate Eutrophication Potential per kg beef have shown differing results for grazed versus housed beef production systems, with more showing an advantage to housing systems (de Vries et al., 2015). However, the latter were based on extensive low-producing grazing systems, so that there were relatively large differences in cattle productivity between the systems. Almost all studies have shown reduced environmental impacts from systems where cattle were derived from dairy farms than from traditional beef and sheep farms, including an NZ study (Payen et al., 2020). Additional overseas studies with beef cattle showed that pasture grazing reduced rates of eutrophication, which are offset when supplemental feed is brought onto farm (Tsutsumi et al., 2014).

Strength of research evidence

On a scale of 1-5 (very-low to very-high), the confidence about this research evidence is 4. However, while comparisons between countries can be implied from published research, there have been no systematic comparisons (desk-top or field) of pasture-fed versus crop-fed housed/feedlot systems under the same climatic/site conditions that recognise some important management aspects of NZ's productive pasture systems.

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