Report to the Ministry for Business, Innovation and Employment

Current land based farming systems research and future challenges

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Executive summary

Two key questions motivated this enquiry:

- What 'mega-trends' are likely to be paradigm-shifting for New Zealand land-based farm systems?
- What is New Zealand's research capacity and capability regarding these 'mega-trends' and how well placed is New Zealand's science and innovation system to respond to these trends?

To explore these questions we interviewed international experts, and triangulated those findings with a literature scan. We then used an organising framework developed specifically for this project to determine what trends might be paradigm-shifting.

We identified three key trends, each with underlying dimensions. In descending order these trends are:

- *Enhanced environmental consciousness*- including dimensions relating to environmental sustainability and measurement of effects.
- *Transformational science*- predominantly developments in genomics, and alternative proteins.
- *Changing consumer views and preferences*- not only are consumers demanding more evidence of ethical production, environmental effects and provenance/traceability, they also have faster and more pervasive mediums through which to communicate their views.

Other less significant trends were noted around robotics and vertical farming, changes in investor interest, the rise of precision and digital agriculture and international trade and regulatory settings. We observed that the trends were often interlinked, and would have impacts in multiple areas.

We then tested our findings from the international experts with New Zealand stakeholders in land-based farm systems. Agreement with the significant trends was evident, and it was clear that the trends had been considered widely by New Zealand organisations.

The primary implication of the trends is that a change in research areas is required. Consideration of wider goals beyond the farm gate, and greater focus on the customer will be required to respond to the challenges posed by the trends.

It was clear the current capability of research organisations in land-based farm systems will need to be enhanced and augmented, with a change in focus from primarily production maximisation to production under constraints. Integration of existing scientific capability with other, so-called 'softer' scientific skills to look at the full value chain of food production will increase.

A particular challenge facing science investors (and researchers), is the inherent uncertainty associated with funding decisions made at a point in time. Research results are not always guaranteed and may not manifest until some time in the future. There is no certainty the trends identified will continue, or have a significant impact on New Zealand. However, the basis for research direction should be an assessment of the risk to New Zealand of not having mitigation strategies in place if particular trends outturn. For example, should alternative proteins substitute for dairy and meat proteins, or climate change mitigation render greenhouse gas emitting farm processes unsustainable, it would be critical for New Zealand to have considered strategies to ameliorate the impacts on the economy.

Science or agricultural policy should then consider the highest levels of risk and opportunity and influence scientific research to mitigate the risk or capture the opportunities. In other words decisions made on science investment are expectations-based, combining estimates of both the magnitude and likelihood of impacts. Utilising the best available evidence will assist in making such decisions, but there will always be a speculative element.

1. Approach to establishing trends

We set out to establish whether land-based farm systems research is fit for purpose in light of future challenges. We approached this question by, first understanding future trends and set out how we did that in this section. We later talk about the current research base and the challenges identified to us.

This question addresses a wide scope of land-based farming practices. The scope covers the types of production undertaken (e.g. dairy, sheep and beef, cropping) as well as the interactions along the entire food production value chain (i.e. on-farm and beyond the farm gate activities). The only major exclusion is marine farming.[1]

1.1 Interviews with international experts

We sought the views of a range of overseas experts with relevant knowledge and experience of land-based farm systems. We conducted 19 telephone interviews in total with experts in fields such as agriculture, farm systems, genetics/genomics, China, and agribusiness (see Appendix 1).

The interview questions were structured around the following areas of interest:

(a) *Purview*- the particular experience and expertise that the interviewee brings to bear and the degree to which new or emerging trends feature in their thinking.

(b) *Primary understanding*-thoughts in relation to existing land-based farm systems, prevailing attitudes and paradigms in place, and issues facing land-based farm systems.

(c) *Change potential*- trends, ideas and changes likely to be influential to land-based farm systems and their basis.

(d) *Bringing about change*- what actions or investments could be made to elicit change in response to the identified trends and who has what role in terms of such change?

(e) *Paradigm shifts*- the nature and extent of likely paradigm changes, the areas where the greatest shifts would occur, drivers of such change and the possible magnitude and length of impacts.

(f) *Relevance to New Zealand*- knowledge of New Zealand land-based farm systems and how trends would impact on New Zealand.

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1 We note that marine farming can take place on land, but such activities were not a major consideration for the project, and were not upper most in the minds of interviewees.

1.2 Literature scan

We supplemented the expert interviews with insights from published literature. That is, we scanned available literature as a means of better understanding and 'triangulating' the views of international experts.

We focussed on identifying material that is credible, reputable, and has currency, rather than limiting the search to a country or countries of publication. The search terms used are shown in Table 1. Any search process necessarily involves trade-offs between coverage and tractability and not all possible terms can be included, especially terminology that combines other terms or areas (e.g. AgroForestry).

Table 1 Search terms used for literature scan

Farming	
Pastoral	Farm/farming/farmland
Land-based	Productive land
Agriculture	Pasture
Horticulture/viticulture	Food production
Land-based aquaculture	Land use models
Crop/cropland	Agri-business
Livestock	Future foods
Arable	Robotics (agri-related)
Primary production	Precision agriculture
AgriTech	Agroecosystems/agroecology
Synthetic foods / beverages	GMO
Climate change (agri-related)	
Agroeconomics	
Future	
Trends	Transformation
Prediction	Change
Innovation	Adaptability
Emerging	Outlook
Opportunity	Forecast
Factors	
Technology/agri-technology	Consumer preferences
Impact (economic/social/environmental)	Consumption
Workforce capacity & capability	Scientific/science system

Farming	
Investment	
Land-use suitability	
Social license	
Environmental barriers	
Regulations (environmental and other)	

Peer reviewed literature sources included:

- PubMed
- ABI Inform
- Index New Zealand
- Proquest Research Library
- Business Source Premier
- MasterFILE Complete
- Google Scholar

Grey literature and data sources included:

- Key governmental & research entities such as Lincoln and Massey universities, UC Davis, Wageningen University and others, USDA and the EC European Agricultural Research Services, Teagasc Ireland and others.
- Recognised quasi and non-governmental organisations such as the OECD, AgNIC, FAO, CSIRO and Rabobank.
- A scan of sources such as futurist commentary, and information repositories such as WorldWideScience.org and the Economist Intelligence Unit.
- Reports by NZ agencies: Beef&Lamb Synthetic meat report, DairyNZ documents, etc.

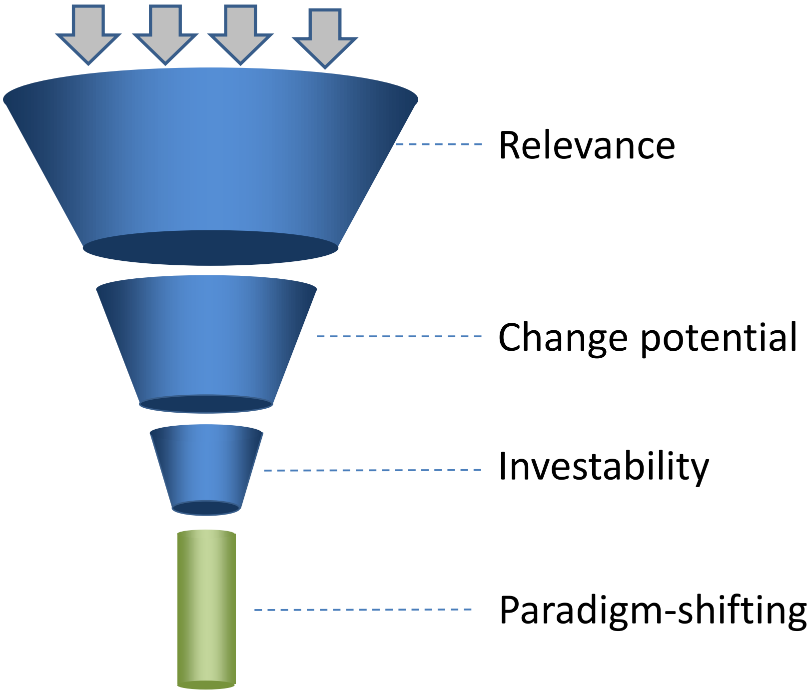
1.3 Organising framework

The organising framework we used has two uses: as a high-level sorting device as well as informing the analytical component of the work. The sorting element applies to both the literature review (in terms of selection of articles) as well as the stakeholder interviews (in terms of the topic areas to be discussed).

Figure 1 shows the four assessment 'tests' that we applied. The first three are used to determine the range of written material to be considered further while the fourth step is used to consider the materiality of the idea/trend. The paradigm-change test requires specific consideration in its own right, rather than featuring as part of the initial tests. It may not be immediately obvious that the idea or trend will result in fundamental change so to avoid 'false negatives' (i.e. excluding a potentially game-changing idea or trend early in the piece) the framework allows for a distinct and detailed test of the paradigm-shifting nature of the idea/trend.

All four assessment 'tests' also provided structure to the interviews.

Figure 1 High-level framework



1.3.1 Relevance

Relevance is the first broad filter and concerns the degree to which identified literature and/or ideas are within the parameters of the study. We used the inclusions and exclusions contained in the project plan to determine relevance. In addition, an initial assessment was made of the relevance to New Zealand land-based farm systems.

1.3.2 Change potential

Change potential is about assessing the relationship between land-based farm systems and the idea or trend. While there may be trends that could influence land-based farm systems (e.g. changes in financing arrangements brought about by crypto-currencies, changes in lending practices/risk assessments), land-based farm systems are not necessarily strong drivers of change for those trends.

The trends identified would occur with or without changes in land-based farming systems (equivalently, very few pathways or opportunities to change behaviours or activities in land-based farm systems to capitalise on new or emerging trends exist). While we list some of these trends later in this report, we did not analyse them further.

1.3.3 Investability

Investability means that there is a scientific component that is amenable to intervention/investment. That is, there is scope for policy (through science investments) to be effective. Further, such investments should be efficient in an economic sense. For instance, such investments should have payoffs that are risky but not uncertain (unknown probability), have clear intervention logic and make use of known or easily understood funding streams.

1.3.4 Paradigm-shifting

Having met these 'tests' the focus then turns to the extent to which the idea or trend could be paradigm-shifting: likely to fundamentally alter the 'rules of the game' and/or the 'play of the game.' By this we refer to explicit factors such as regulation as well as tacit factors that are accepted norms, beliefs, and practices associated with land-based farming systems. Both are equally important from the perspective of paradigm change as it is possible that the way people play the game, (i.e. behaviour), can lead the way the game is governed as much as the more traditional direction of causality from rule changes to behavioural changes.

General paradigm shifts that could be usefully applied include changes relating to systems and natural resources, and the interplay between them (e.g. climatic disasters and biosecurity threats).:[2] As mentioned above, the potential for paradigm shifts is sufficiently material to warrant detailed assessment and analysis in its own right.

Linear to complex is the shift from independent and predictable systems to interdependent adaptive systems. The transition is from seeing the world in a linear way, in which small causes have small effects and large causes have large effects, towards realising that it's perfectly possible for seemingly large changes to have almost no result, while seemingly small things go viral and alter perceptions with significant impact. When moving from a predictable world to a world that is unpredictable in principle, a similar shift in strategy is needed, from *planning* to *preparing* (including development of resilience in response to the range and quantum of future change).

Scarcity to abundance is the shift from scarce natural resources to using natural abundance. Where a specific situation may have had a limited set of choices, it now specialises on an abundance of renewable resources.

Conceptually, assessment of potential for paradigm change is best viewed as a constrained optimisation problem. In very simple terms, the objective function for farming systems could be to maximise output, which is subject to constraints relating to resource availability, available budgets, limits on productive capacity (e.g. climate and soil restrained), environmental impacts, the state of existing knowledge, and the freedom to operate. Broadly then, a paradigm-shifting trend is one that could lead to a change in the objective and/or reduce or eliminate the constraints.

Paradigm change may also come about because of trends that result in one or more of the constraints becoming the objective function. For instance, the prevailing approach may have been to maximise output while minimising environmental harms. A change in paradigm could see the objective function of maximising the avoidance of environmental harms, subject to a minimum level of production to remain viable. That change of view would likely have significant effects on land-based farming systems.

2 THNK Strategies (2015) *"The Golden opportunity of Paradigm Shifts."* www.InnovationManagement.se.

In assessing the identified trends in terms of their potential for paradigm change, we considered the:

- *binding nature of any constraints*- how likely are they to change and the potential magnitude of the change
- *level of inherent irreversibility*- is the trend likely to endure once established, or be more ephemeral in nature
- *extent of interdependence and additivity/multiplicity*- a paradigm change is best characterised as a series or system of often complementary trends that operate together to alter the fundamental ways people (and consequently systems) think and act, rather than a single or unique trend
- *ubiquity and 'reach' of the idea/trend*- how pervasive the trend is or is likely to be, where trends with universal 'reach' and that are largely unavoidable, (e.g. climate change), are expected to change paradigms more than sector-specific or avoidable trends
- *possible payoffs and incentives*- is the idea or trend problem-based or opportunities-based, where the former relates to a more narrow conception of solutions to known problems (with predictable returns to investment, but uncertain adaptability) while the latter involves potentially unbounded returns and general purpose application
- *degree of novelty*- while paradigm change is likely driven strongly by newness, this may not always be the case. Obliquity and serendipity can influence change unexpectedly (e.g. Newton developed calculus as a means to an end to describe motion and gravity, but changed mathematical paradigms in the process).[3]

Taken together, these assessment factors confirm the speculative nature of enquiries of this nature. It is inherently difficult to be precise or definitive about the future. Nevertheless, the framework does provide for ordered thinking.

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3 It would not be true to describe the development as accidental, but it seems at least to be incidental.

2. Our findings on influential trends

This chapter sets out our findings in relation to identifying emerging and future trends with paradigm-shifting potential for land-based farm systems.

2.1 Influences are interlinked

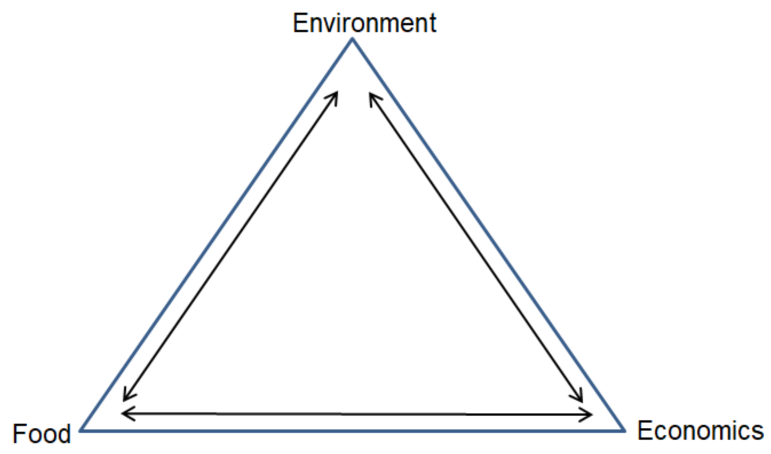
The first finding that the interviews revealed is that trends are interrelated, in general. That is, it is difficult to conceive of an idea or trend that acts in isolation of others. This observation is largely due to what has been characterised as the 'breakdown of linearity' in the underlying relationships relevant to farm systems and food production. In the past, food production was the ultimate goal and overriding consideration. Other factors were somewhat subordinate to the production goal. However, in more recent times the relationships between food production and other factors are now more intertwined.

Figure 2 below shows the relationships that experts have indicated as best representing food production now and into the future. Rather than food production being the most important goal, subject to some limitations around environmental effects and consumer tastes and preferences (particularly in relation to price), the system now explicitly factors in environmental concerns and the role of consumers in more than just a price sense.

For instance, changes in consumer tastes and preferences around ethics and/or consumption of meat products can spur trends in technology. Similarly, advances in technology (e.g. better measurement of environmental impacts or animal welfare) can drive changes in consumer tastes and preferences.

In summary, the relationships are multi-directional and thus trends are more likely to have more than a single, stand-alone dimension as a result.

Figure 2 Food production relationships diagram



In addition, identified trends also tend to operate on the supply (production) and demand (consumption) side. The interactions between suppliers (and their farm systems) and demanders are more complex and demanding than previously. The previous examples highlighted the importance of the entire supply and value chain in food production.

The role of large retailers has also grown such that they now have requirements around demonstrating that the ethical and environmental practices employed on-farm meet certain standards in order to be sold through their outlets.

2.2 Enhanced environmental consciousness: a major trend

Issues related to the environment were not only the most frequently cited, but also elicited the strongest reactions for most of the experts. Moreover, environmental considerations were mentioned as drivers of other trends (e.g. technology) in interviews and relevant literature.[4] Environmental factors matter to land-based farm systems from both production and consumption perspectives and we see two elements to environmental consciousness relevant to this study. Again, these two elements are best considered alongside each other, rather than as distinct or separate.

4 TEAGASC (2016) *"Technology Transforming Irish Agri-Food and Bioeconomy 2035."* TEAGASC Technology Foresight, March.

2.2.1 Environmental sustainability

Sustainability is relevant to land-based farm systems on both the supply (production) side and demand (consumption) side.

Sustainability places pressure on production

The literature is clear that adaptation in farm systems is needed in the face of higher temperatures, droughts and floods. In the absence of such adaptation, yields will be reduced and considerable year-on-year variability is forecast.

Consensus is emerging that in the face of climate change significant mitigation measures will be needed to maintain and enhance the natural capital needed to ensure the delivery of the productive capacity of global agriculture.[5] Developing systems that can simultaneously expand food production while also hitting environmental targets (i.e. Sustainable Intensification) has been described as the challenges of scientific careers and the world more generally.[6]

Such adaptations take place in the context of greater disquiet in relation to resource quality and quantity. Scarcities and the declining quality of natural capital, such as air, water, soils, nutrients and biodiversity are a continuing source of concern for agricultural production, at least in western (developed) nations. This concern arises from both the reliance of land-based farm systems production on such resources and the effects they may have on ecosystems. That is, land-based farm systems use land and water in production, and the process of production can impact the resulting quality of water, land and air.

At a more tangible level, agriculture is the world's largest user of freshwater, accounting for around 70% of global freshwater use[7] although there is considerable variation across regions and farming systems. Agriculture occupies 38% of the world's land surface and competes for space with other land uses. These include ecological habitats as well as urban and infrastructural land use.

Fossil fuel resources, which are a major input in agri-food production and processing around the world, are considered uncertain in the longer term. In light of the significance of energy in agricultural production costs (both related to energy as a direct input and as a driver for other input markets, such as equipment, fertilisers and chemicals), and the increased use of agricultural biomass for fuel generation, such uncertainty is transmitted into the food and agriculture system.

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5 *Ibid.*

6 Hunter M, R Smith, M Schipanski, L Atwood and D Mortensen (2017) *"Agriculture in 2050: Recalibrating Targets for Sustainable Intensification."* BioScience 67 (4) pp.386-391.

FAO (2003) *"World Agriculture: Towards 2015/2030. An FAO Perspective."* J Bruinsma (ed), Earthscan Publications Ltd. London.

UK Government Office for Science (2011) *"The Future of Food and Farming: Challenges and Choices for Global Sustainability."* Foresight report looking at the increasing pressures on the global food system between now and 2050.

7 Evans A (2009) *"The Feeding of the Nine Billion: Global Food Security for the 21st Century. A Chatham House Report."* London. The Royal Institute of International Affairs.

Furthermore, direct emissions from agriculture make up almost half of New Zealand's greenhouse gas emissions. While further productivity increases will reduce future emissions per unit of product, absolute emissions will continue to rise in the absence of significant policy change or permanent depression of commodity prices, such that animal numbers do not increase.

Exploration of alternative land uses, and taking into account climate change and carbon constraints as well as other economic, social and environmental objectives (e.g. water quality and contaminants), is thought to be a major impact in reducing emissions in the long term, with potential paradigm-changing effects.[8]

In terms of interviewee views, the need to adapt to a changing physical environment was not seen as new or necessarily novel. One interviewee commented that (relevant) industry bodies in New Zealand had been aware of the issue of climate change for at least 15 years.

However, they went on to say that there has been much less action than awareness. In part, this may reflect the different area of food production involved, where New Zealand is less involved in crop production (e.g. maize, wheat), which is thought to suffer the consequences of climate extremes in a more direct manner than animal-based agriculture. In addition, it may also be related to the moderate effects of climate change that New Zealand has experienced to date. Finally, it may be an attitudinal thing, whereby New Zealander farmers see themselves as adaptable and able to deal adequately with the consequences of environmental change that is likely to occur over a relatively long timeframe, and that they consider they have been dealing with on a regular basis.

Regardless of what has happened in the past, environmental sustainability is tipped to continue to exert pressure production-wise, particularly extreme events, on land-based farm systems in future. At the farm level, the challenge will be determining what practices should be followed in order to meet environmental sustainability goals, when evidence is nascent and separating fact from fiction can be difficult.

Sustainability pressures from consumption may be more material

The driver for any real change in paradigm from environmental consciousness/sustainability is likely to be consumers. Global consumers, particularly those in developed markets and the growing middle classes in emerging markets, are increasingly demanding products that fulfil a growing range of functional needs. Amongst these needs is food that can be shown to be sustainably produced.

Increasingly, this aspect is framed in terms of agriculture's licence to operate. In particular, such licence is no longer guaranteed. The basis for consumer and community views around social licence, specifically as it relates to environmental sustainability, is less relevant than the fact such views are held.

Thus, irrespective of what science and/or logic provides by way of defence or rationale for practices that the wider community considers indefensible, the debate has been settled:

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8 The Royal Society of New Zealand (2016) *"Transition to a Low-Carbon Economy for New Zealand."* Available at: https://royalsociety.org.nz/assets/documents/Report-Transition-to-Low-Carbon-Economy-for-NZ.pdf

'…sustainability must be first in everything that every organisation in the agri-sector does every day.'[9]

The majority of interviewees spoke of their belief that consumers are increasingly moving away from a pure price focus and more towards a wider value focus. That is, the costs consumers have in mind when purchasing food products comprises more than its monetary price. They are interested in the degree to which products deliver benefits outside of immediate consumption satisfaction such as minimal environmental harm.

This shift, which experts considered is highly likely to continue in future, raises the bar in terms of farmers and farm systems being able to transparently demonstrate that environmental concerns are at the heart of the food production system, rather than a necessary and unavoidable by-product. Moreover, such pressures are likely to be exerted on behalf of consumers, through major retail chains as well as directly from consumers.

By way of summary, KPMG (2017) claim that New Zealand's future ability to supply premium markets relies on sustainability: Without that sustainability, there will be no customers, and with no customers comes no business. This is especially the case for European markets, where a so-called anti-meat lobby is increasing in influence and scale.

2.2.2 Understanding environmental effects

The experts interviewed were clear in their view that the increased requirement to consider and factor environmental effects into food production means there is a clear need to better understand and articulate the nexus between farm systems and the environment. In their view, it is no longer sufficient for the industry to use imagery (e.g. 'a picture of an animal in a lush paddock on a sunny day next to a flowing stream') or oblique references to being 'clean and green' to convince consumers of environmental *bona fides*.

It follows that enhanced measurement, monitoring and reporting of environmental factors is needed. Relevant factors mentioned were:

- Nutrient levels in water.
- Use of pesticides and fertilisers on land and in the air.
- GHGs.
- Water takes and uses (soil moisture levels).
- Nutrient use/contamination on land.
- Soil carbon levels.

Experts believe a combination of science (e.g. regarding use of fertilisers and herbicides) as well as technology (e.g. sensors, drones) is needed to firstly understand the nature of the relevant environmental effects as well as to accurately measure the extent of such effects in a quantitative sense. The experts conceded that farmers in general, and New Zealand farmers in particular, are already aware of and are using such technology. However, the focus of

9 KPMG (2017) "*Agribusiness Agenda 2017. The Recipe for Action"* p.41.

technology use, in their view, has been to increase yield rather than examine environmental effects.

In some respects the issue is to what extent resource depletion (equivalently waste) is taken into consideration by land-based farm systems, and how it is captured in attitudes towards a circular bio-economy, which is a variant of the circular economy concept. Whereas the traditional economy is a linear model, where valuable resources pass along a value chain to produce goods that are consumed with various streams of waste being produced all along the way, a circular economy involves value chains with waste streams as inputs for other businesses or activities. Nothing is discarded.

The same prospect can be applied to value chains for bio-products. Moving to that state requires changes to value chains, from product design to new business and market models, and to turning waste into a re-usable resource. However, in order to transition to that model it is necessary to accept that waste is created in the linear model, with that acknowledgement leading to developments in measuring such waste and ultimately creating markets for bio-based products, etc.[10]

In line with insights from literature, experts suggested that application of big data in agriculture could contribute to both economic gain and to reduction of environmental impact.[11] According to the experts we spoke to, the challenge around big data in agriculture is less about recognising the value of collecting data and more to do with analysis of that data into an easily usable form to aid decision making. Processing capability is lagging the technology around generating and collecting data, so that is the next step towards paradigm change motivated by environmental considerations.

The speed and manner by which the environmental measures are communicated was also seen as important. In a world where communication is instantaneous and wide reaching, farmers will likely need to increase not only the quality and volume of environmental information provided, but also alter the channels through which measures are expressed.

Greater use of social media and associated 'influencers' to deliver information and enhanced participation in online forums and platforms is likely to be required in future, as opposed to traditional media and published articles. Transparency and trust in the data is the key, and may take some time for farmers to get used to, according to the experts.

While there may be a need for transparency of measurement and immediacy of communications, the climate change aspect of environmental concerns is recognised as relatively slow moving, with the possible exception of extreme events and their impact. Experts acknowledge that farm systems are adaptable, that farmers are natural experimenters, and much has changed in farm systems over the years.

Some experts believe that, while environmental concerns are the major trend and will continue to be so, the previous adaptations in land-based farm systems show that there is less need for urgency than is commonly called for. Most experts, however, do not believe

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10 TEAGASC (2016).

11 Sonka S (2016) *"Big Data: Fuelling the Next Evolution of Agricultural Innovation."* Journal of Innovation Management 4 (1), pp. 114-136.

these are decisions that farmers alone make; consumers and the wider community are making the choice for them. That is, the consumer side of the market (including retailers and other distributors) drive the speed of change required and land-based farm systems need to react in a timely manner or risk being 'left behind'.

2.3 Transformational science

Experts agreed that science has always played a role in the evolution of land-based farm systems. They also agreed that this is unlikely to change in future. However, there was some disagreement among our interviewees about the extent to which science will radically transform food production and land-based farm systems.

Notwithstanding those dissenting views about how major the science-based changes are likely to be, the interviews suggested two areas of science had strong potential to be paradigm-changing: genomics and alternative proteins. The former follows the more traditional scientific path of academic publications and a reasonably high degree of public investment, while the latter is seen as more private-sector oriented, with the potential for public involvement in future.

2.3.1 Genomics

Genomics are relevant to agriculture in terms of improving the productivity and sustainability of crop and livestock production.[12] The major motivation for the use of genomics in agriculture is a growing population (i.e. food security). Advances in the science of genomics offer the potential to speed up the process of developing crops and livestock with desirable and valuable traits that meet productivity, quality and environmental goals.

Both the consulted experts and the literature highlight gene editing techniques, such as CRISPR-Cas, presenting a broad range of opportunities for significant change worldwide. Gene editing causes targeted mutations in an organism's genome that can range in size from a 'tweak' to adding or removing whole genes. It is much more precise than traditional techniques used to cause mutations and may therefore be lower risk, and generally reduces the time needed for product development. In New Zealand, gene editing is currently regulated as genetic engineering, and a number of jurisdictions are considering whether and how to regulate it.

While most of the activity in this area relates to crops, there are also potential impacts on animal breeding.[13] In the case of plants, gene editing can, for instance:

- improve disease resistance
- delay flowering time
- increase oil content

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12 Wang W, X Cao, M Miclaus, J Xu and W Xiong (2017) *"The Promise of Agricultural Genomics."* International Journal of Genomics, Editorial, 2017 Volume.

13 Van Eenennaam A.(2017). *"Genetic Modification of Food Animals."* Current Opinion in Biotechnology, v44 pp.27-34.

- raise nutritional quality
- reduce nicotine content
- increase tolerance to drought.

For animals, gene editing can, for instance:

- increase muscle yield in cattle
- de-horn calves
- eliminate allergens from milk
- improve disease resistance (e.g. bovine tuberculosis)
- remove unwanted proteins.

In addition to food security motivations, some experts highlighted the potential for gene editing to contribute positively to environmental sustainability. The selection choices associated with gene editing could result in fewer inputs being used in production of crops and/or livestock. In addition, there would be a lower level of resource depletion and harm from such production. For example, disease resistance in plants would reduce the need for pesticides and eliminating factors that reduce growth could lead to less fertiliser being needed, with concomitant reductions in environmental damage as a result.

Interviewees suggested that the potential paradigm-shifting nature of advances in genomics has particular relevance to New Zealand given our position on genetic modification. In light of New Zealand's 'clean and green' branding some interviewees thought a continued reluctance to allow gene editing that could potentially reduce environmental impacts is somewhat incongruous. In addition, the advanced understanding associated with genomics (and gene editing in particular) may mean that New Zealand's position requires updating.

Given the focus to date on crop production (and rice in China and other parts of Asia) the relevance of genomics to New Zealand is probably muted, though there is a risk that New Zealand could find itself behind the pack if developments continue apace, as some interviewees considered they would (the number of academic publications focussed on a specific gene editing tool/technology, CRISPR, has risen from 80 in 2011 to over 1,300 in 2017).

The Royal Society of New Zealand has acknowledged the potential for gene editing to benefit New Zealand in a range of sectors, including agriculture and has recently published expert papers on the subject to stimulate further debate.[14] In part, the Royal Society enquiry was driven by the potentially revolutionary impact of gene editing for life science (essentially 'switching off' genetic elements that cause disease in humans), but the wide range of applications is another driver.

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[14] https://royalsociety.org.nz/what-we-do/our-expert-advice/all-expert-advice-papers/gene-editing-technologies

2.3.2 Alternative proteins

Interviewees discussed two major alternatives to protein contained in animals: plant-based protein and cellular agriculture.[15] The former involves the development of a meat substitute using plant material only. The latter is a process of cultivating meat and other agricultural products from cells in a bioreactor rather than harvested from livestock on a farm.

There are various motivations for the development of alternative proteins, from a desire to see far fewer animals used for food, to reducing the amount of land used for animal food production, to ensuring that the world has sufficient, nutritious food available in future for everyone to consume.

However, major players in the manufacture of plant-based protein are doing it for sustainability reasons. In their view, animal food production consumes too much land and other resources, and damages environments and ecosystems. In addition, animal food production systems are said to result in exploitation of labour through 'brutal' and dangerous working conditions, predominantly in the United States, that can often result in serious injury or death to its migrant work force. . Compared to a burger made from cows, Impossible Burger (a US firm) make a plant-based burger (meat patty) that claims to use about 1/20th the land, 1/4th the water, and produces 1/8th of the greenhouse gas emissions.

Another interviewee was firmly of the view that a move towards plant-based protein is a matter of not if, but when, given the increasing changes in consumer preferences away from consuming animal meat. This is not solely a matter of taste, as the existing provider of plant-based meat undertook considerable research and development with the sole goal of developing a product that looked, smelled, and tasted like meat and had the same texture.

Other interviewees were sceptical about the ability of alternative proteins to achieve their goals, or to change land-based farm systems to any significant degree. The experts doubted the scalability of current plant-based protein activities to meet food security issues in the future. They also questioned the claims that consumer preferences are shifting away from animal-based protein, considering that notion overblown. The combination of these factors led the interviewees to believe that the economics of alternative proteins do not stack up.

In relation to cellular agriculture/lab-grown meat, some interviewees tended to the view that as well as scalability issues, there is a question of priority. If the technology being used to culture meat is viable, the experts thought it would be applied to health-related priorities rather than for food production. The returns for healthcare are significantly greater than those for food, and the technology would more likely represent a breakthrough in the healthcare field, rather than an evolution in food production.

Further, the possibility exists where cellular agriculture would increase industrial energy consumption and, consequently, greenhouse gas emissions, as it replaces biological systems with chemical and mechanical ones.[16]

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15 While not mentioned in the interviews, we understand that insects and algae are increasingly being seen as third alternatives to traditional protein sources.

16 Mattick, C. S. (2018). *"Cellular agriculture: The coming revolution in food production."* Bulletin of the Atomic Scientists.

2.4 Consumer changes

Today's consumer has different tastes, preferences and concerns to the consumer of 30 years ago. Organic certification, free-range eggs, health labels, and fair trade logos were much harder to find in the supermarkets of 1985. Farmers' markets were relatively rare. Now, such labels are commonplace in supermarkets and farmers' markets occur at multiple locations on a weekly basis in most large cities.[17]

Most interviewees mentioned the potential for a continuation of the trend towards more demanding consumers. Consumers no longer care about 'getting full in the cheapest possible way'.

According to the experts, there has been a significant swing in consumer consciousness and communication, which will contribute to major change for land-based farm systems in the future. In addition to the environmental and animal welfare concerns mentioned in material above, experts think consumers will continue to raise demand for quality, food safety, healthiness, provenance, ethics and biosecurity.

Moreover, the means through which such preferences are expressed has changed. Social media is thought by experts to accelerate and magnify the role of provenance, traceability, ethics, and health in agricultural and food markets. Consumers will be able to access selective information about products at the point of sale, see rating scales for product quality based on customer reviews, and provide feedback immediately. There are examples of supermarket chains using applications that allows users to scan a code on fresh food (e.g. meat, fruit, vegetables) to instantly see where the produce originated and to view nutritional information.

Digital technology effectively opens up the entire food supply chain. Events (both positive and negative) are easily captured on film and rapidly disseminated to a wide audience.

Most interviewees agreed that the relationship between consumers and their food (and producers of that food) needs to mature. In New Zealand this has been expressed as a need to shift relationships with customers and consumers into partnerships, based on trust and open, frank communication.[18]

Overall, interviewees saw this trend leading to more empowered consumers and thus, more need for farmers (and associated farm systems) to understand and respond. Importantly, interviewees highlighted that consumer perceptions were the key change variable. The scientific and logical basis for consumer beliefs is less material than it is what consumers 'feel.'

This means that farmers will radically need to alter the way they deal with, or consider, consumers of their products and modify practices and communications to be much closer to said consumers than they may have been in the past, regardless of views around how knowledgeable or well-informed consumer perceptions are.

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17 Hajkowicz S and S Eady (2015) "*Rural Industry Futures. Megatrends Impacting Australian Agriculture Over the Coming Twenty Years.*" Report to Rural Industries and Development Corporation and CSIRO, July.

18 KPMG (2017) *Op.cit.*

2.5 Other influences

In addition to the four big trends discussed above, our interviews and a scan of the literature revealed other influences, which will affect land-based farm systems. These influences will not necessarily be paradigm-shifting because either they are not likely to be of sufficient import or they are too remote from land-based farm systems.

2.5.1 Robotics and vertical farming

Interviewees reported that robots are increasingly being used in farm systems the world over. They are labour saving and more efficient due to the ability to repeat processes without error and work long periods of time without fatigue. In addition, robots can reduce the potential for contamination of crops and/or livestock, as can occur through human contact. Particular areas where robotics could result in fundamental shifts are fruit picking and robotic dairy cow milking. The technology is closely tied to the concept of precision agriculture.

Robotics is also seen as possibly changing the economic model in farming. In particular, intelligent robots can make small-scale production viable again, following a move towards 'bigger is better' that seemed to dominate more recently. Again, there is also a sustainability dimension to the use of robotics, through better monitoring and management of soil and animal quality and elimination of pests and disease without resorting to indiscriminate use of agrichemicals.[19]

Vertical farming involves stacked layers of produce in an indoor, controlled environment. Such environments can be warehouses, factories or office buildings, and even disused bomb shelters in one case. This means farms can be found in urban areas and food may be produced in some of the least traditionally agrarian economies.[20]

The advantages of vertical farming are twofold. First, it enables precise control of environmental conditions to increase yields and maintain year-round production. In addition, vertical farming can reduce the distance crops have to travel to reach the end consumer and thereby increase consistency between crops.

While potentially impactful, vertical farming, and to a certain extent the use of robotics, are concentrated on crop production. This is not a prominent feature of relevant activity in New Zealand which is mostly pasture. Furthermore, the relative abundance of land in New Zealand means the impetus to investigate vertical farming is not major.

2.5.2 Investor changes

A small number of interviewees noted that more institutional and investment funds are now involved in farm ownership/food production. Given food security concerns, such investors see the potential for significant returns to be made. Interviewees thought that the involvement of such investors could create greater expectations of higher and more

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19 King A (2017) *"The Future of Agriculture."* Nature, v 54, April.

20 https://www.nzherald.co.nz/business/news/article.cfm?c_id=3&objectid=11892327

immediate financial returns and pressures to innovate, which would bring changes to traditional farm systems.

In our view, this development is largely productivity/yield-related rather than a fundamental shift that would alter the land-based farm system paradigm.

2.5.3 Other technology

The use of sensors, drones and other electronic devices is able to generate significant amounts of data, which can augment the intuition of farmers, regulators and consumers. Artificial intelligence and 'the internet of farm things' will also allow farmers to trial changes designed to enhance production while lowering the costs (including environmental) of doing so.[21]

King (2017)[*] described the use of sensors in helping to pick produce at the right time to improve efficiencies. Picking too early is wasteful as you miss out on growth, but picking too late means less storage time. Sensors can feed data into an algorithm to calculate when to pick and can be used on animals (e.g. smart collars) to detect early signs of illness or fertility.

King (2017) also described the use of drones to cut agrichemical use by spotting crop enemies earlier thereby allowing precise chemical application or pest removal. Drones and software that use close-up infrared images can map patches of unhealthy vegetation in large fields and these images can also reveal potential causes, such as pests or problems with irrigation. The market is demanding foods with less herbicides and pesticides, so this technology will help. According to researchers at the University of Sydney's Australian Centre for Field Robotics, targeted spraying of vegetables used 0.1% of the volume of herbicide used in conventional blanket spraying. Drones can also be used for smarter application of fertiliser.

Interviewees were of the view that these technologies are largely in play now, are likely to continue to be important, and in contrast to robotics, are labour augmenting (as opposed to replacing). A few interviewees suggested that New Zealand is already reasonably advanced in terms of precision agriculture, so the impact is likely to be more incremental in nature.

Development in cryptocurrencies (e.g. Bitcoin) and Blockchain were mentioned by a few interviewees. Bitcoin could potentially alter the way farm systems are financed and in general the availability of credit which might be relevant to farm investment, but in reality is quite some way removed from land-based farm systems to be paradigm-shifting. That is, land-based farm systems are not prominent in such developments and definitely unable to influence such developments in technology. Blockchain could have the potential to contribute to greater transparency through the supply and value chain as well as enhance the security of information being transmitted by farmers in relation to say, environmental effects. However, the technology is not well understood yet, and its use is as an enabler of other game-changing trends rather than the driver of change itself.

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21 TEAGASC (2016).

Overall, our view was that these other technologies largely represent a continuation of existing developments rather than a material shift, and at this stage were best thought of as improving existing practices, not fundamentally altering them.

2.5.4 Trade and regulatory issues

A small number of interviewees raised the prospect that trade wars and associated regulatory antagonism towards foreign-sourced products could be a trend that severely affects land-based farm systems in New Zealand. Market access and other trade barriers would see New Zealand able to sell less to the world than otherwise would be the case.

Interviewees did highlight potentially offsetting effects in that the demand for meat and dairy in China and other countries is not likely to recede. One interviewee did express the view that the trend towards greater middle-class numbers and concomitant food demand has already expressed itself, so there is not much by way of material growth likely in future.

Our view is that regulatory matters around trade have always been capricious and the kinds of actions mentioned have presented themselves in the past. While potentially very material to sales of food products overseas, we do not see trade and regulatory issues as being a so-called mega-trend, notwithstanding the need to avoid such things if possible. Perhaps the biggest risk in trade issues relates to biosecurity lapses which now have tourism dimensions as well as product movement implications.

3. Are research activities in New Zealand up for the challenge?

3.1 Interviews with national stakeholders

We undertook a further series of 22 interviews of key stakeholders in New Zealand's land-based farm systems research space. Where possible we undertook the interviews face to face, with the majority of interviews conducted in Wellington, Hamilton, and Lincoln. When we were unable to arrange a face-to-face session, the interviews were taken via either video or audio conference.

Key research questions

We conducted semi-structured interviews beginning with a brief introduction of our findings from Phase 1. Our questions were then as follows:

- What are the current areas of relevant research in New Zealand?
- What are your plans for research in the future?
- How well aligned are the current and future research activities in New Zealand to the trends identified by the international experts?
- To what extent are there gaps in the current and future research activities in New Zealand?

3.2 Key summary findings

There are higher level findings of some import:

1. *The trends identified internationally were confirmed as the relevant domestic trends.* These trends require new areas of research in a number of areas. The breadth and depth of research required creates new challenges for existing research providers, requiring additional science skills, and increasingly needing fusion with non-biological skill sets, such as market research and customer insight. The additional skills will need to be developed by research providers, or accessed via collaboration with other parties. In short, national organisations agree that trends exist and are important. They assert they have a good understanding of the skills that will be needed to meet the challenge presented by those trends.

2. *There is an increasing fusion of skills.* Knowledge and understanding of the customer will be important, and the combination of traditional land-based farm systems research with new techniques from social sciences such as economics will be required to deliver the change required to meet the challenges presented by the paradigm shifting trends. Technologists with an understanding of Blockchain may be needed to resolve food security challenges. Data analysts are needed both to assist with industry data standards and big data analysis is here today – but the workforce is scarce.

3. *There is an imperative to get on with things sooner rather than later.* Scientists commented that much of the research used today to meet the current challenges around the impact of land-based farm systems on the natural environment, was first conducted ten to twenty years ago. They comment the research to meet the challenge posed by future trends will need to be undertaken soon.

4. *Joined up thinking is lacking.* A range of strategies exist across the primary sector. These occur in individual organisations, in sectors, and in government departments yet, a single over-arching national strategy does not exist. Interviewees thought this lack of co-ordination was detrimental to New Zealand.

In the following sections, we explore five main themes that arose from the interviews:

- Alignment with international trends.
- Awareness of trends, with action required.
- New Zealand's place in the marketplace.
- Research delivery.
- Barriers to fulfilling the research need.

3.2.1 Alignment with international trends

There was a remarkable degree of agreement amongst science providers with the trends we had identified from Phase 1 of the study. The majority of those interviewed agreed strongly that the trends found were of importance for New Zealand land-based farm systems. However, some experts expressed the need for caution in reacting to all trends. There was, however, a minority view. Those that had been undertaking research for a significant period of time, primarily based in academia, suggested that a number of forecast trends in the past had not proved to be as paradigm-shifting as expected.

> 'Trends may not be dramatic in the New Zealand context.'

> 'Be wary of "flavour of the month" trends.'

Vision Mātauranga

Scientists referenced a key characteristic unique to New Zealand as being the need to consider Māori in science decision-making and research direction. MBIE's predecessor organisation (Ministry of Research, Science and Technology) developed the Vision Mātauranga policy to use the science and innovation system to help unlock the potential of Māori knowledge, people and resources for the benefit of New Zealand. There were a number of comments about the relevance of this policy and of Māori stakeholders.

> 'Important domestic trend is the Māori land dimension, Significant increase in Māori landholders and contribution to GDP.'

> 'The Māori aspect drives different thinking about land, sustainability – it is a national story that is unique in the world.'

New Zealand science providers are aware of the need to embody Vision Mātauranga into their future plans, and indeed it has formed a part of CRIs Statements of Core Purpose from 2011. However they acknowledge that there is a gap in their capability, with a range of organisations noting they need to do more to build their capability in Vision Mātauranga specifically and more generally engagement with Māori: The organisations did not specify the scale of their capability requirements however.

> 'We need to build capability in Vision Mātauranga.'

> 'We are short on Māori capability - drives different thinking about land, sustainability - national story that is unique in the world.'

> 'We need more in-house capability in engaging with Māori.'

New Zealand science providers will need to grow their own capability and capacity to meet these needs. This capacity is not available offshore and must be developed internally.

3.2.2 Aware of trends, with action required

Our key reflection from the interviews was that those we interviewed acknowledged the trends as important and critical to the future direction of land-based farm systems. Moreover, they all recognised that current efforts were insufficient to meet the challenges posed by the trends. More research effort was required to respond adequately to the trends, and, in some cases, there was a distinct lack of research being undertaken. This was succinctly summarised by an industry association:

> 'We have been thinking about the trends - now we have to do the research'

A number of trends were common to our interviews:

- The environment and environmental limits of traditional farming.
- Productivity.
- Alternative proteins.
- Farm systems beyond the farm.
- Genetics.
- Data, automation and other technology.
- The international food marketplace and changing consumer preferences.

We expand on our findings in these areas in the next sections.

Environmental issues were number one

The most prominent trend identified was that of the environment. The organisations interviewed had experience of issues requiring science input in the past, and recognised its importance in the future. There were a number of specific environmental factors that were observed as requiring further research:

> 'New Zealand needs to learn about how to manage sediments, e-coli bacteria and campylobacter.'

> 'We need meta data in order to understand greenhouse emissions.'

> 'We need to think about more than solely the environment, and need to include consideration of social and economic issues.'

> 'The environmental challenge is now about carbon, greenhouse gases, nutrients, and water interacting together.'

A subcomponent of the trend towards greater awareness of the environment has been the impact on the end goals of industry research. Production was previously solely about productivity, but organisations have recognised that the social licence has changed. The requirements for research and farming are now about maximising productivity within environmental constraints:

> 'Our focus has been on dairy systems, but not looking at whole environment.'
>
> 'We are now about producing more of the right milk for a lower environmental footprint.'
>
> 'Now we need to focus on productivity under constraints.'
>
> 'Most science has been focussing on production – now no longer the sole focus - need more on water quality.'

With the knowledge that the licence to operate has changed, there was some evidence that research is being directed towards the joint challenges of productivity and environmental constraints. The objectives of the Our Land and Water National Science Challenge are seen as well aligned to these environmental challenges. In addition, the New Zealand Agricultural Greenhouse Gas Research Centre is seen as focussing on mitigating greenhouse gas emissions from New Zealand's agricultural sector.

The emergence of alternative proteins

Alternative proteins were seen as important, though there were different opinions as to the scale of the trend, its relevance to New Zealand farm systems, and the required response. It was recognised that New Zealand would not be able to compete directly in the plant-based alternative protein market due to our limited potential scale, distance from market and the commodity nature of the product, for instance soy production.

> 'New Zealand can't compete on global scale with soya beans for alternative products.'
>
> 'New Zealand cannot shift to plant based protein.'

Some interviewees thought the challenge of alternative proteins could be managed by rebuttal with evidence. They felt this was analogous to challenge posed by food miles, which was countered by solid evidence and research.

> 'Alternative proteins are coming, but carbon footprints, nitrogen emissions and resource requirements are not as beneficial as expected.'
>
> 'The total system impact for synthetics is unknown.'

Others were more pessimistic, and thought we should prepare for the total substitution of animal-based protein for alternative proteins.

> 'We need to do scenario modelling, to prepare for a world without animal proteins.'

All interviewees felt research is needed to meet the challenges provided by alternative proteins. We note that Plant and Food Research have recently published a report 'Opportunities in plant based foods – Protein'. This report identified opportunities for New Zealand to expand and develop plant based protein. Specifically, the opportunities were identified as manufacturing high-value plant-based protein food; using New Zealand's sustainable production systems and delivering premium products to international customers. The report also noted a capability gap in the large industrial scale production of plant proteins.

Increased importance of data and technology

While data and the associated increasing levels of automation and measurement was seen as an trend of medium import by external commentators, domestic interviewees gave this range of issues a much higher priority. Organisations perceived advanced data analytics as providing opportunities to help farmers make the best decisions on their farms. They also noted that automation and robotics could solve the emerging labour shortages.

> 'Farmers will get swamped by data, will need to produce decision support systems to help them.'
>
> 'Artificial intelligence will help capture the data in a less than perfect environment, and help interpret and analyse results.'
>
> 'Automation could bridge a large barrier around shortage of pickers in New Zealand.'
>
> 'We need better technology for consumer and regulators to verify ethical, safe, and environmentally sustainable farms.'

The infrastructure and technology around making the best use of data was considered an important area of investment. For instance, if data monitoring and sensors are to apply across remote rural settings, then investment in infrastructure would also be required. If sensors are to be useful in remote (for example hill country) farm systems, then infrastructure to provide a rural internet of things would need to be developed in parallel. It was clear that the organisations interviewed had considered the increasing need for capability in this area and had identified a number of gaps in both their capability and that of other science providers. The skill deficits are in data architecture, big data skills such as machine learning, as well as the ability to implement sector wide infrastructure.

> 'Need data to drive decision making, if we can measure we can show footprint. Data and sensing is currently expensive, and we are not looking at it. It should be automated.'
>
> 'There are gaps in precision agriculture, including in expertise, capability, and not enough researchers.'
>
> 'Not good experience of in-house knowledge of machine learning or big data.'
>
> 'Our capability is light in tech development, sensing, managing mass amounts of data.'
>
> 'We talk a lot about big data, but we are not creating the data sets.'

Research providers had thought about how to solve the specific problems of the shortages of researchers and scientists with abilities in both farm systems and data analytics. The conclusion was, given the difficulty in procuring these people, it would be best to partner with other organisations or use capability developed in parallel sectors.

> 'Use more information from other sectors about Artificial Intelligence, use best practice developed in other sectors. We could partner with overseas organisations.'
>
> 'We can get capability in parallel sectors for Artificial Intelligence and sensing.'
>
> 'The best way is to leverage off Amazon and Google, as there are very few people with capability in the New Zealand context.'

For our interviews, it was clear that there was much to be done in developing the right capacity and capability in the data fields. Organisations recognised this as well, as they wished to grow their capability in this area.

Genetics research held back by policy settings

The issue of genetics, including gene editing and genetic modification was raised in response to the challenges presented by the trends. These techniques could produce more productive animals, or food with specific healthcare benefits, or could mitigate adverse environmental effects. New Zealand has a strong history in the use of genetics to improve the characteristics of livestock, and many scientists acknowledged that there existed a significant opportunity in the use of genetics. However, the specific nature of New Zealand and its relationship to genetic modification meant that the potential to maximise the opportunity in genetics may be limited inside New Zealand while current policy settings and political appetites remain constant.

There were mixed views around the desirability of genetic modification. The 'impossible burger' produced by Impossible Foods (https://www.impossiblefoods.com) was raised as an interesting development, where the presence of heme[22] would mean that the impossible burger would be classed as genetically modified. An interviewee posed the hypothetical trade-offs for consumers created by the impossible burger – one that saves the planet by lower ecological footprint, but is conflicted by the genetic modification properties.

Scientists questioned whether policy settings towards genetic factors should be revisited, as otherwise much work and research in this area would be of little future value in New Zealand. Commercial interviewees also observed the benefit that could be gained from marketing products with specific health properties, even if the products were developed with genetic modification.

Traceability and food safety

Another aspect of consumer desire is the ability to know where their food comes from, to fulfil the need for probity and provenance. This probity and provenance is about a number

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22 Heme (or haem) is a compound found in proteins such as myglobin in muscle, or leghemoglobin in plants, and contributes to the distinctive flavour of meat.

of issues ranging from food security to holistic concerns and the nature of its social licence. It was observed by interviewees that key export markets are already indicating that traceability is important to consumers:

> 'Food safety is important and it links with verification and traceability.'

> 'The Asian markets are more interested in food security and food safety, in particular China.'

> 'There is an increasing focus on verification and traceability systems.'

Organisations noted technology is available to provide traceability, but the implementation of the technology was not apparent. Therefore, despite the clear customer need to understand the provenance of their products, and the existence of the tools to deliver that need, organisations were not well equipped to meet consumers' requirements for traceability and food safety.

> 'Tracing technology is there, but we are not doing it. Weibo, for example, are much more advanced than we are.'

Interviewees, primarily from commercial organisations but also universities, asserted the importance of food safety to the international customer, in particular customers from Asia. They also observed the increase in value that could be captured if a safe product can be produced and marketed.

> 'Customers want and pay more for safe, high quality and trusted food.'

Animal welfare is to the fore

Animal welfare is a sub-component of the trend for consumers concerned about the ethics and environmental aspect of their food. There are concerns that there has been a reduction in capacity in scientists concerned with animal welfare, with scientists in animal welfare having left CRIs. Interviewees also recognised that the concept of animal welfare is expanding because of customer preferences. It is changing from the current areas of focus and that new strands of animal welfare research are required:

> 'The current research in animal welfare is around areas such as dehorning and foot rot. The new areas are recognising the happiness of the animal.'

> 'Animals are starting to be seen as sentient beings, a significant change from ten years ago.'

> 'People far more concerned about animal welfare.'

> 'Premium consumers want animals that are healthy and happy.'

Beyond the farm, a mosaic of activity in a catchment

An emerging area of research was touched upon by a number of organisations regarding the requirement to look beyond the farm. The beyond the farm concept is one of optimising agriculture at a larger scale than solely the farm, namely to the level of the catchment (for example a river catchment). The concept could see, for example, combinations of agriculture such as forestry, dairy and horticulture across a wider landscape. It would be designed to align with regional council areas of responsibility.

> 'We need to begin to look at catchment scale, beyond farm boundaries.'

> 'We could look at the scale of a regional council, or at a catchment level.'

Thought has been given to the requirements to develop a broad understanding of catchment 'mosaics'. However, interviewees indicate there is much work requiring expertise in multiple disciplines to implement the research.

> 'To undertake research into a catchment, a mix of chemists, physicists, computer experts is required in order to create a coherent information system.'

> 'Important to work out the characteristics and opportunities and risks of the land is.'

> 'Need understanding how landscapes work at scale.'

> 'We have gaps in landscape optimisation.'

Alternative perspectives were espoused particularly as moving to a mosaic of systems could mean significant impacts on economic performance, particularly if dairy farms are converted to other less profitable activities.

Some missing themes

While on the whole there was a good degree of alignment between what international experts considered were the major trends likely to be significant for land-based farm systems in New Zealand and the local interviews undertaken, some dimensions were not prominent in discussions.

For instance, the possibility of interactions between biosecurity and climate change adaptation was not mentioned as part of our discussion with local experts, but was raised by international interviewees. Perhaps this is due to New Zealand's incidence of major biosecurity threats that were raised, such as foot and mouth disease, being lower than that of overseas countries. Nevertheless, the path towards climate change adaptation could involve less of a focus on biosecurity risks, with potentially harmful consequences.

In addition, the risks of new technology, either in terms of the wider economy (e.g. displacement of labour) or in terms of the operating environment around alternative protein, were not frequently brought up in our interviews. Finally, the possibility that New Zealand has the opportunity to become a leader, rather than follower in relation to some trends did not feature prominently.

3.2.3 New Zealand's role in the international food marketplace

A direct consequence of the paradigm shifting trends for New Zealand is the increasing importance of positioning the production from land-based farm systems into a premium product space and the corresponding understanding of what is required to fulfil the premium. Many organisations agreed that New Zealand is best placed to focus on the premium end of the market and to avoid the commoditised products:

> 'New Zealand can only feed at most 50 million people. We want to feed the rich customers.'

> 'We should avoid high efficiency markets. It is hard to create value there.'

Clearly, New Zealand farmers will not be the only entities attempting to create opportunities in the premium end of the market, and therefore the ability to know and respond to customer needs in a timely fashion will prove integral to the success of New Zealand's farmers.

Know the customer

Many interviewees noted that it required coordination across the value chain for a product to sell at a premium, and observed the positive example of Zespri. However, it was acknowledged that many farmers are often significantly removed from their customers, with multiple steps in the chain between customers, supermarkets, distributors, manufacturers, cooperatives, agents, and farmers. There are examples of farmers interacting directly with customers (for example, by selling through farmers markets) but they may not have a scalable model. Interviewees noted the observed disconnect between customers and farmers was also reflected in the disconnect between science and farmers.

> 'NZ is not taking advantage of the ability to get close to consumers. Need direct relationships. Too far away from consumer.'

> 'Structures of research may not be right. Not enough connection between end users and the research.'

There was almost unanimous agreement amongst interviewees that customer knowledge is key, and the land-based farming sector requires support from the science system to validate consumer preferences. A number of interviewees provided evidence that they understood a method in which to understand customers, by integrating a product with science and research. The science could either prove a direct consumer benefit (via health or medicinal properties) or to provide quantifiable evidence to support an environmental story.

> 'We must create the story and the backing to the story. We could prototype a product, and then see if the market will pay for it. Once we have a story, we must consider how we prove it. Need science and technologies to do so.'

> 'People are looking for the connection back to real food. It's how it used to be produced. Going back to a natural farming system – slower less intensive system.'

> 'There is an opportunity for niche products that are sold with a back-story. We must also provide an evidence base to allow value to be captured.'

Even Plant and Food, who were noted by other parties at being good at understanding the customer, recognised that it needed to do more in understanding customers' preferences, as well as validating customers' propensities to buy and estimate customers' price elasticity. Plant and Food, and others, noted that insight research on customers was underinvested in New Zealand.

> 'Big gap in market validation. It is hard for firms starting up to get funding to test the market.'

> 'New Zealand is lacking skills in consumer insight, through to consumer strategy and how to action that knowledge.'

> 'We are missing information on consumer requirements, including provenance. There is a lack of data on the chain of custody.'

> 'A lot of science is needed on what customers are interested in - animal welfare, bio diversity, environmental impact.'

A number of organisations in addition to Plant and Food considered their internal capabilities were underdeveloped in the consumer knowledge space. These organisations ranged from industry bodies, to producers as well as Crown Research Institutes.

3.2.4 How could the necessary research be delivered?

Interviewees made a number of comments about delivery of research.

Research is not about disruption

The trends identified in Phase 1 of the work were concerned with observing shifts in paradigms. Interviewees noted there was direct conflict with the incentives faced by many levy based research providers, whose research is designed to assist their members. For instance, a number of scientists at AgResearch noted that the policy settings were conflicting:

> 'Science signals are confusing - for instance what is relevant to industry and is disruptive and transformative.'

This set of conflicting factors creates a barrier to undertaking disruptive research, as interviewees noted industry participants will be unwilling to undertake research that could significantly disrupt their own industry.

> 'Industry won't disrupt itself.'

> 'Don't look at disruptive change - industry happy to fund work that fit in the current paradigm.'

> 'Do not want to invest in research that might disrupt.'

Interviewees also commented the incentives for industry led research into land-based farm systems is to research immediate or current issues and to focus on research with short payback periods of <1 year.

> 'No one wants to fund long-term research - looking at short payback periods, 6 months to 1 year.'

> 'Land-based farm systems mainly research immediate current issues.'

> 'Industry collaboration is short term focussed.'

Maintain and expand existing research

Although much of the focus was on what needs to be done in new areas, there were observations that much of the existing research needs to be continued. Interviewees felt this existing research had relevance to the major trends.

They also felt this existing research base required a focus on fundamental research that might not already be being undertaken. For instance, research into soil and pastures' ability to lower nitrate leaching is highly relevant to environmental concerns. Similarly, research into lowering agriculture's footprint of emissions, such as carbon and other greenhouse gases, is motivated by the need for better environmental sustainability.

> 'There is a shortage of water quality data. We are very light on water monitoring data'.
>
> 'No one seems able to come up with efficient sampling, measuring, and reporting data for water quality.'
>
> 'There is not much work done on underpinning fundamental research. We do not have the people, infrastructure, and models to do that.'
>
> 'Lot of fundamental research is not happening. For example, we are not seeing good data collection, such as understanding alternatives to rye grass. The research we do have is out of date. It was covered 20 years ago, and has limitations based on measurement technologies of the time. It is a challenge, there is not enough detailed science being done.'

Our scientists have good international standing

The status of New Zealand scientists in an international context was viewed as positive, with a number of interviewees suggesting that New Zealand scientists in land-based farm systems were well regarded internationally.

A number of interviewees noted there is significant value to international co-operation, noting there are areas of research where it would not be necessary for New Zealand to be leading the way, such as climate change research that applies to global models, while noting that research relevant to the New Zealand context should be undertaken. This could include understanding the impacts of climate change in New Zealand, how to mitigate emissions and how to adapt to the impacts of climate change in New Zealand.

Concern was raised around the ability of New Zealand to compete with overseas counterparts. In particular, interviewees noted United States or the European Union research organisations were often beneficiaries of large grants or subsidies. The institutions are on a larger scale as is their funding and capacity was much greater. Access to these research institutions is critical; New Zealand science should look to collaborate to benefit from the large scale programmes.

The rate of change is a challenge

A common observation from scientists, producers, and marketers was that the speed of change in land-based farm systems is slow. The observations include:

- Changes in farm use potentially taking generations (though the increase in dairy conversions in the past decade does run slightly contrary).
- The amount of time it takes for scientific research to make its way onto farms. In a number of cases, the speed of adoption of research was thought to be in excess of fifteen years.
- The speed of science in Crown Research Institutes was slower than desired, and that it would have consequences for meeting consumer requirements in the future.

Here are some telling comments from interviewees.

> 'The pace of research is slow.'

> 'The adoption speed is slow – it can take 19 years for research to make it into New Zealand farm systems.'
>
> 'Research takes more than 15 years to get onto the farm.'
>
> 'Farm change happens generationally.'
>
> 'Overcome barriers of individual farm owners to optimising farm use.'

This observation, when also considering the potential for many of the paradigm shifting trends to occur rapidly, will be a significant barrier to New Zealand farm systems ability to react to trends. It is therefore imperative land based farm systems researchers understand and define the research required to equip New Zealand farmers and the associated farm systems with the tools to respond to the trends. Indeed Fonterra and AgResearch both observed the need to be forward looking in research:

> 'Farm systems take a long time to change, therefore how do we get ahead of the trends?'
>
> 'It can take ten to fifteen years to get science to market.'

To counter this assertion we note there have been examples in New Zealand of rapidly adopted technology, such as herringbone design milking sheds in the 1950s, and circular dairy sheds in the 1960s.

Scientists are of standing and we need more

An important factor in the capacity of the science system to deliver required research is the ability to have the right scientists available. Many organisations were complimentary of the quality of the current research scientists. However, we identified a strong theme that there were gaps in science resource and scientists able to address challenges posed by future trends. This covered the availability of scientists, concerns with succession, and a reduction in capability over time.

While the issues faced by organisations were not pervasive, they generally noted some degree of difficulty across all ranges of experience in the recruitment challenge. They observed that attracting staff domestically is a challenge:

> 'Unsure of pathway for younger scientists. The mid-tier scientists are most vulnerable'
>
> 'Other organisations struggle to recruit enough scientists.'
>
> 'We are not seeing enough quality people coming out of universities, especially those that are interested in coming to Waikato.'
>
> 'Two thirds of the new staff are recruited from overseas.'
>
> '50% of our company were not born in New Zealand.'

Succession planning was identified as a challenge, and further raises concern when coupled with the concerns with recruiting:

> 'A lot of scientists have been here a long time.'

> 'Our scientists are getting old.'

> 'We have problems with succession.'

Finally, organisations noted that there have been cuts in capability and infrastructure, mainly focussed in CRIs, which has had flow-on impacts to scientists and research capability:

> 'Animal welfare researchers were lost to the organisation when funding was pulled.'

> 'Uncertainty of funding has created uncertainty for people.'

> 'If capability is cut, then we observe that scientists go overseas.'

> 'We risk losing scientists to industry, and we are losing competencies due to programmes being pulled.'

> 'The scientists doing the fundamental research have gone.'

> 'Loss of capability when farms shut down, we lost a great deal of data on research farms when they were sold.'

Collaboration is needed to deliver research

With the upcoming trends, and the issues of resourcing the correct number and right type of scientists, inter-organisation and inter-industry collaboration will be necessary to best deliver integrated research outcomes. Collaboration between people in the 'softer sciences' like economists, market researchers, sociologists, psychologists, and those in the 'pure sciences' will continue to grow. However, research providers recognised there is more work to be done in integrating the multiple strands of science. Many parties noted collaboration was a useful part of the system and that it should continue to grow:

> 'It is useful to have a system with collaboration.'

> 'We would advocate for more collaboration, science is a team sport.'

An often-cited claim was that multi-disciplinary approaches were related more to funding mechanisms than to a desire to learn across disciplines. Interviewees felt current multi-disciplinary approaches are somewhat superficial. Once the funding had been received, different disciplines tended to retreat to their particular areas and focus on what they already knew.

We heard interactions between soil science, water science involving hydrologists, and ecologists was increasing. This interaction was seen as evidence of multi-disciplinary approaches to science. There were also a number of suggested collaborations that would be of use for forthcoming research challenges.

> 'We can get a better eye into consumer need by using science collaborations with market intelligence.'

> 'It would be useful to integrate pastoral research with knowledge of horticulture and carbon.'

> 'We need capability to connect with other research providers to incorporate tourism, evidence based land options.'

Interviewees noted there was significant value to New Zealand in collaborating with international groups. The aim of this collaboration is to apply the relevant findings into the New Zealand context. This international collaboration was most pertinent in areas where New Zealand would not be viewed as world leaders. Interviewees commented many of New Zealand's top scientists are frequent and well regarded contributors to international programmes.

An area of skill or focus that was observed to be required was those that could act as trans-disciplinary scientists or integrators of teams. It was noted that in some organisations, there exists the necessary skills in a broad range of subjects, but there were some issues in connecting the different skills in a meaningful manner. These integrators were regarded as particularly valuable.

> 'There is a disconnect between biophysical and credible economic and social analysts.'

> 'We have seen the CRIs shut market analysts, social scientists and economists out of the work programme.'

3.2.5 Barriers to undertaking research are substantial

A number of sectors, including arable and pastoral farming, noted that the current poor profitability meant there was not the money to pay to invest in game changing innovations:

> 'The problem with technology and the provenance story is the financial burden on farmer. The brand adds the mark-up; however, you need a strong ROI for someone to make the investment'

Interviewees identified New Zealand's risk averse nature as being another barrier, particularly as research projects can at times be risky in terms of both time and outcome.

> 'There is a perception of a distrust of large programmes and how they are run. There are bigger consequences if a large investment goes wrong.'

> 'A challenge for projects is the political environment is challenging. Failure would be a big criticism.'

Path dependence was also identified to us as an issue, as funding tended to be given to those with existing research records, thereby continuing already existing research areas. Thus, transformative research or innovation is less likely to be produced if the same people and groups continue to receive funding.

Barriers to research uptake were also noted. Scientists observed there was a shortage of personnel that were able to communicate across a range of stakeholders, in particular to farmers.

> 'We are lacking scientists that can understand multiple disciplines, and package science for the right audience, farmers, industry, and local, regional and national government.'

> 'Regional councils are struggling to get people that can communicate about farm systems to farmers.'

Capacity and capability gaps are substantial

Providers were grappling with resource availability and capability in core areas as well as those needed for truly collaborative research. There were very few people with the technical scientific expertise also able to understand consumer behaviour, preferences, and choices. Thus, looking forward, getting those capabilities in place will be a challenge, especially with an older workforce and a slim pipeline. An assessment of areas of capability that were missing or below requirements was wide reaching: While adding these capabilities to existing organisations may go part way to solving the issues, a cultural change or even a change in purpose would also be required to integrate the new skills into existing research practices.

> 'We need more economists, data analytics, and those scientists that are able to think about changes in the entire value chain.'
>
> 'We need to continue to develop knowledge of biological system and whole of life cycle.'
>
> 'We need to have scientists that understand economics and finance and people that understand animal and plant husbandry.'
>
> 'There is a need to understand the interaction of pollution control with CO2 concerns.'
>
> 'There are gaps in capability in human health side.'
>
> 'We need scientists who are trained in people, soils, and climate.'
>
> 'We need to build up our attribute research in the meat sphere, similar to what has been done with kiwifruit.'

There were also a number of broader observations about the capability and capacity of the science system.

> 'Don't think we have right parts of science capacity. The perception is that in the last few years capacity has been trimmed back.'
>
> 'Some Crown Research Institute infrastructure is run down.'
>
> 'The National Science Challenges do not hold capability.'

3.2.6 Funding and strategy issues

In the course of the interview process, a number of comments were made regarding the supporting mechanisms to the research sector, specifically the role of industry science strategies and the funding mechanisms. We include these comments noting they point to some possible areas of improvement in government funding and priority setting.

Agricultural strategies and a pan-industry strategy

Many interviewees had observed that while there was a proliferation of individual, sector-led strategies (such as dairy or meat) or governmental department science strategies, there is a lack of a pan-industry or national primary sector strategy. Interviewees felt this lack of a pan-industry strategy to be detrimental to New Zealand and would be best resolved by central co-ordination of a well thought through strategy.

> 'The government is displaying a lack of joined up thinking, the government should join with industry to develop a strategy.'

> 'Lots of science strategies, everyone has one so how do we get joined up thinking.'

> 'There is no New Zealand primary sector strategy, unlike in Australia, the United Kingdom or the Netherlands for example.'

> 'Need to work out what the societal goal is first - then you can sort out communities, industry, science and production.'

Compliance costs of funding regimes

Numerous research organisations cited the governance of funding regimes as a barrier to getting the best out of research at a system wide level.

> 'MBIE/Callaghan funding systems have an incredible amount of admin work.'

> 'The competitive funding environment is overly complicated and there are a lot of mechanisms, and a lot of different governance structures.'

> 'The compliance costs of funding are high, it is better to have larger projects given the level of overheads.'

> 'Collaborations take a lot of administration effort, i.e. a MBIE project needs 20% time to administer.'

The efficiency of having scientists involved in the governance regime was also questioned, and suggestions were made that employing administration specialists could be more efficient.

> 'I previously observed, while at a Crown Research Institute, that lead scientists spend lot of time on proposals or reporting. It produces very auditable results, but is a highly inefficient use of time.'

> 'There is a need to cultivate a management and admin resource for reporting against governance requirements.'

We note that these governance barriers were common observations, and are unlikely to be new revelations.

Government funding has co-ordination and incentive issues

The changing mix of funding between the private and public sector is creating issues and there is little industry appetite for funding scientific thinking that was a long way from commercialisation or where there are 'public good' benefits.

> 'We are seeing challenges in the funding model, with the government stepping away but industry are not stepping in to fill the gap.'

> 'There is a game of chicken on funding between industry and government.'

> 'Industry does not have the ability or the capacity of funds to pay for the fundamental thinking. For a 20-year timeframe it would be best funded as a public good.'

> 'Early stage science is difficult to pay for, particularly when we observe long time horizons for application.'

The method of funding could also lead to some unintended consequences. One organisation was pragmatic and stated that they were not necessarily strategic in their choice of research, and instead chose to follow the direction of the MBIE bids. Another organisation noted that the competitive funding model creates a lack of long term planning in Crown Research Institutes or universities.

Internal regulation

Phase 1 work suggested off-shore regulation against foreign sourced products could impact New Zealand farm systems. The internal regulation may also impact New Zealand farm systems. While policy is capricious by nature and often subject to election cycles, future land use in New Zealand could be influenced by government policy. For example, a range of government policies have come to light recently:

- Zero carbon Bill.
- 10 year plan for 1 billion trees.
- National Policy Statement (NPS) on Freshwater management.
- NPS on Forest management.
- Proposed NPS for versatile land and high-class soils.
- Climate Change Commission.

Each component will have implications for the future direction of land use. Constraints on existing uses of land or changes in land use may emerge, and in the absence of research into mitigation strategies, fewer land based farms, or fewer animals on farms.

Appendix 1 Phase 1 Interview participants

Table 2 International experts interviewed

Name	Organisation	Country
Andre le Gall	Institut d'elevage in Rennes	France
Tom Tomich	UCDavis	USA
Alison Van Eenenam	UCDavis	USA
James Murray	UCDavis	USA
Rosie Bosworth	Journalist	NZ
Patrick Brown	Impossible Foods	USA
Maggie Gill	Chair of the Independent Science and Partnership Council of the CGIAR	UK
Mark Post	Mosa Meats	USA
Brian McConkey	Agriculture and Agri-Food Canada's Science and Technology Branch	Canada
Edward McLaughlin	Cornell University	USA
Bruce Kefford	Chair of the Gardiner Foundation, former Deputy Secretary Department of Agriculture	Australia
Scott Rozelle	Stanford University	USA
Ann Stevenson Yang	Co-Founder and Research Director at J Capital Research Co. Ltd.	China
Catherine Milne	Farm Management Research Director, Scotland's Rural College	Scotland
Andrew Campbell	Australian Centre for International Agricultural Research	Australia
Michael Robertson	Science Director, CSIRO Food and Ag	Australia
Gerry Boyle	Director, TEAGASC	Ireland
Laurens Klerkx	Associate Prof, Knowledge, Technology and Innovation Group, Wageningen University	Netherlands
Jan Bebbington	University of St Andrews	UK

Appendix 2 Phase 2 Interview participants

Table 3 New Zealand organisations and participants interviewed

Organisation	Participant
AbacusBio	Anna Campbell, Chief Executive
AgResearch NZ	Tom Richardson, Chief Executive Liz Wedderburn, Assistant Research Director Alasdair Craig, Science Group Leader Farm Systems & Environment Mark Shepherd, Principal Scientist Cameron Craigie, Science Impact Leader Meat Products & Supply Robyn Dynes, Science Impact Leader Farm Systems Cecile DeKlein, Science Representative - Executive Team Greg Murison, Research Director Tony Hickmot, Chief Financial Officer
Beef and Lamb NZ	Suzi Keeling, Sector Science Strategy Manager Nick Beeby, GM Market Development
Callaghan Innovation	Jesse Keith, Group Manager - National Technology Networks
Dairy NZ	David McCall, General Manager Development and Extension Bruce Thorrold, Strategy and Investment Leader New Systems & Competitiveness
Federated Farmers	Sarah Crofoot, Meat and Wool Policy advisor Gavin Forrest, GM Policy and Advocacy
Fonterra	Andrew Fletcher, General Manager Science & Technology Bridget Maclean, General Manager - On-farm R&D

Organisation	Participant
Foundation for Arable Research	Alison Stewart, Chief Executive
Land Improvement Corporation	Wayne McNee, Chief Executive
Landcare Research	Richard Gordon, Chief Executive
Lincoln Agritech	Peter Barrowclough, Chief Executive
Lincoln Hub	Toni Laming, Chief Executive
Massey University	Peter Kemp, Head of School of Agriculture and Environment Janet Reid, Senior Lecturer in Agricultural Systems David Horne, Associate Professor in Soil Science Frank Scrimgeour, Professor of Environmental Economics
Meat Industry Association	Tim Ritchie, Chief Executive
Our Land and Water National Science Challenge	Rich McDowell, Chief Scientist
Plant and Food	David Hughes, Chief Executive
Rezare	Andrew Cooke, Chief Executive
Waikato Innovation Park	Stuart Gordon, Chief Executive