Using a co-innovation approach to accelerate the development of dairy sheep enterprises in New Zealand.

David Stevens[a], Linda Samuelsson[b], Sue McCoard[b], Li Day[b], Wayne Young[b], Natalie Bartlett[c] , William Konui[d], Peter Gatley[e], Nick Hammond[f], Thomas MacDonald[f], Miles King[g], and Jazz Hewittson[h]

[a]*AgResearch Ltd, Invermay Research Centre, Private Bag 50034, Mosgiel, New Zealand, David.Stevens@agresearch.co.nz*

[b]*AgResearch Ltd, Grassland Research Centre, Private Bag 11004, Palmerston North, New Zealand.*

[c]*AgResearch Ltd, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand*

[d]*Waituhi Kuratau Trust*

[e]*Maui Milk*

[f]*Spring Sheep Milk*

[g]*Kingsmeade Cheese Ltd*

[h]*Antara Ag Farms*

Abstract: *A research and development programme was initiated to assist in the establishment of a new value chain based on milk production from dairy sheep. A co-innovation approach created a partnership between scientists, milk processors and farmers in the development and delivery of that research programme. The programme continues to work as a partnership. The partners defined and prioritised the initial research questions. An oversight reference group continues to meet every six months to review progress and direct and refine the research work. The programme has 4 themes: milk composition, milk function, milk production from pasture and environmental impacts. Partners share knowledge on a regular basis, both through formal, facilitated channels and informal networks. Research projects incorporate knowledge and data from farm, processing and research facilities, and farmers are directly involved in delivering parts of the research. Significant improvements in milk production and processing have accompanied the development of new Asian markets for sheep milk powder, opening up non-traditional avenues for dairy sheep industry growth.*

Keywords: *Co-innovation, dairy sheep, milk composition, milk production, pastures, milk functional attributes*

Introduction

The New Zealand sheep industry has a long history of innovation, pioneering the first successful frozen meat shipments in 1882 (Hewland, 1958). Sheep milking, however, has not featured strongly in our past. Most recently, the importation of East Friesian sheep (Allison, 1995) has provided an entry point as an opportunity to enter the sheep milking industry. During the late 1990's some sheep milking flocks were formed though progress was slow due to limited marketing opportunities. Some recent developments are providing further impetus for expansion.

In 2013 the sheep milking flock numbered approximately 30,000 of the 21,000,000 breeding ewes in New Zealand (Agricultural Statistics, 2013). The industry had a range of scale of operation (Peterson and Pritchard, 2015), with several small enterprises (100-300 ewes), one medium enterprise (3000-6000 ewes) and one large enterprise (25,000 ewes). The East Friesian breed is the base of all of the milking flocks and average milk production is between 120 and 130 L/ewe/annum (Stevens and Bibiloni, 2014). One estimate of the potential of the

industry suggests that it may build to more than 2 million ewes (10% of the national flock) within 10 years (Anon, 2013).

The establishment of significant scale supply chains provided a base for the instigation of a research programme to support the further development of the industry. This research programme is jointly funded by Government and the industry enterprises to address industry-identified issues and opportunities. This paper describes the process of project development, implementation and success in the first 4 years of the 6 year programme.

Establishing a co-innovation based programme

The delivery of research to an emergent dairy sheep industry is an example of a complex system problem. This is embodied in the wide ranging needs of a start-up industry that has to solve many issues together. These issues are often inter-related, with little understanding of cause and effect. As an emerging industry there are many stakeholders, often with different world-views, and different needs. To accelerate the process of providing solutions, a co-innovation, trans-disciplinary approach was chosen for this research.

Co-innovation is the process of jointly developing new or different solutions to an agricultural problem through multi-participant research processes, and keeping these processes alive through-out the research (Boyce et al., 2016). The five principles are:

1. Involve partners and stakeholders
2. Take a problem focus
3. Assemble the right team
4. Front up early and often
5. Use the action learning cycle: Plan-Do-Observe-Reflect.

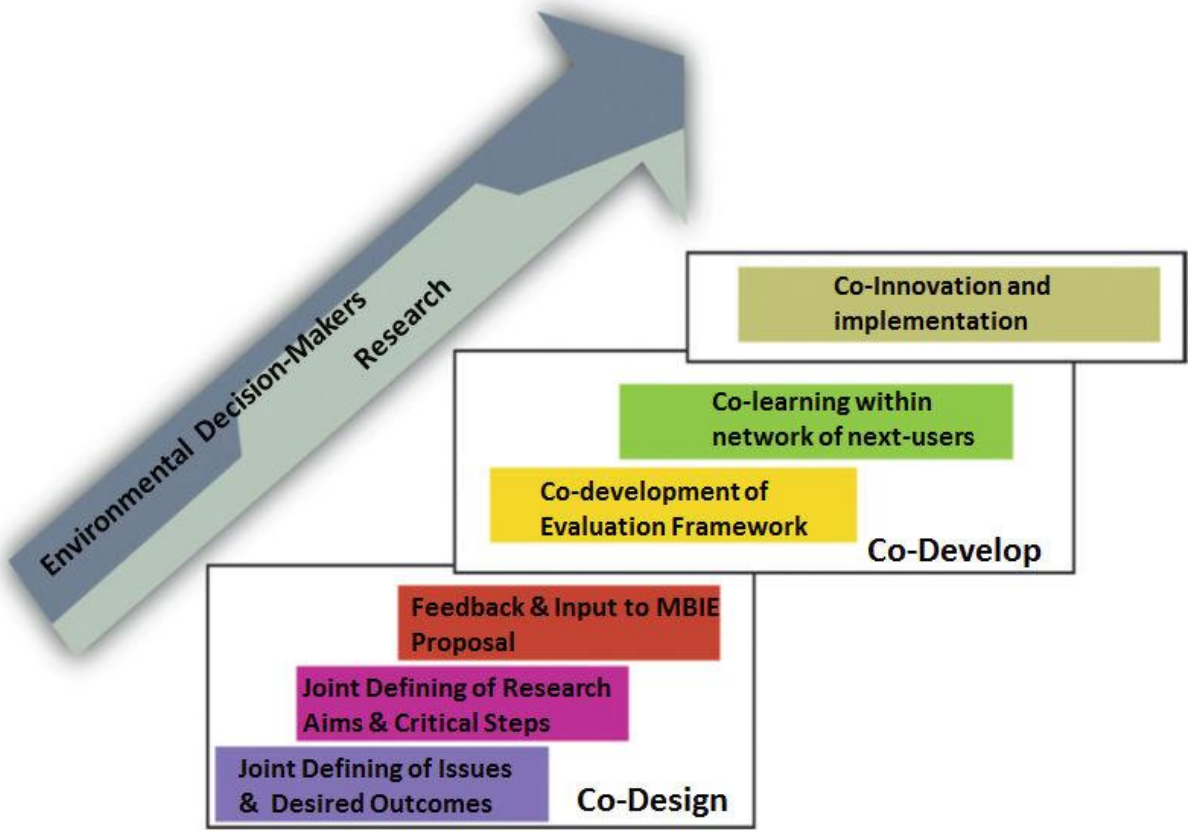

Figure 1: An indication of the steps in the co-innovation research process (Boyce et al., 2016)

With a signalling of government intention to support a research programme for the dairy sheep industry in New Zealand (Anon, 2013), a group of seven research and six industry representatives held a workshop in early March 2013 to identify the research needs of the industry. Of specific interest were the requirements to ensure the development of an industry that promoted the unique features of sheep milk produced from the blend of sheep genetics and pasture-based feeding systems found in New Zealand.

Methods

We explore the processes, outputs and outcomes from using a co-innovation framework (Figure 1) in designing and delivering a research programme to an emerging dairy sheep industry. Factors which were tested in this evaluation included world views, trust, science process, knowns and unknowns, commercial imperative and complexity.

Data from each step of the process was gathered using informal interview, review of annual reports, research plans and contracts. This provided a resource to document how the programme used a co-innovation approach to developing and delivering the research. Feedback from within the team was recorded to provide insight into the factors tested, and how they influenced the co-innovation process.

Results and Discussion

Research needs

From the initial workshop, Industry and research representatives identified four significant areas of research required to assist in the development of the New Zealand dairy sheep industry (Table 1).

Table 1. Research needs to assist in the further development of the New Zealand dairy sheep industry.

Topics	Sub-topic	Importance	Urgency
Understanding the raw product	Variation of composition/functionality due to feeding, seasonality, genetics and processing	High	High
	Composition and functionality of the products		
	Retention of functionality in final products		
More milk harvested per ewe	Impacts of sheep genetics on milk composition, volume, and ewe efficiency	Medium/High	Medium/High
	Impacts of feeding on milk volumes and composition		
	Animal welfare of housed and grazing systems		
Impacts of rearing and weaning practices on co-products of meat and wool	Cost-effective lamb rearing methods	Medium/High	Low
	Impacts of rearing on life-time performance		
Freedom to operate	Product handling and safety	Medium	Medium
	Trade regulations		
	Environmental footprint and regulatory requirements		
	Land use and impacts on local communities		

The results of the workshop were then pooled into three areas of research. Area one was further split between milk composition and processing, and product functionality.

1. Identify the nutritional and functional characteristics of sheep milk necessary for product development, marketing, and regulatory purposes.
2. Design optimal nutrition systems to increase net volume and value of harvested milk, and improved early weaning outcomes.
3. Develop criteria to ensure the environmental sustainability of sheep dairying in the New Zealand grazed pasture environment.

Co-innovation development

The following list documents the processes that were put in place to meet industry requirements for research.

Co-innovation principle	Activity
Joint defining of issues and outcomes	– Form group of industry and research participants.
Joint defining of research aims and critical steps	– Workshop research needs for developing industry. – Design research programmes that integrate commercial partners within the research programme.
Feedback and input into funding proposal	– Submit bid for funding. – Re-workshop research topics and prioritise and develop research plan.
Co-development of evaluation framework	– Form stakeholder reference group. – Meet twice a year to review progress. – Formal review mid-way through the project to test if outcomes are going to be met by science – Use international experts to assist in reviewing ideas
Co-learning within network of next users	– Hold workshops with industry to exchange information, pass on latest research findings, and develop implementation pathways for research findings. – Collaborate on organising a national dairy sheep conference.
Co-innovation and implementation	– Refine final research projects to meet programme outcomes. – Define new areas of research, and revisit those that have not been fully explored, to help design a continuing research programme for industry. – Use partner farms to provide samples and carry out experimental work

To further implement the co-innovation approach, a post-funding meeting of research and industry stakeholders was convened. At this meeting, the team was expanded to include 3 extra research partners, and one regulator. A final research plan design was agreed upon (Fig. 2). This included an industry aim, a research outcome, represented by an impact statement, and an integrated research outline. This outline included both on-farm and off-farm components, as well as the interactions between the two.

Underpinning the co-innovation approach was the formation of a research steering group. This consisted of the leaders of the four research objectives, six representatives of the industry partners, and a regulatory representative. This group met twice a year to review results, refine the programme objectives and guide further research implementation. This provided an on-going action learning process to ensure the research remained relevant to the industry needs and directions.

The research team designed the research programme to utilise the resources of the industry/commercial partners, as there was no dairy sheep research facility. This involved co-ordinating sample collection for milk, pasture and effluent. As the programme developed, further interactions saw the development of feeding, lamb-rearing and nitrogen leaching experiments on partner farms.

As the research information became available, workshops were held with partners and practical implementation approaches were co-developed between the research and commercial teams.

Information was spread to the wider industry and potential new entrants through the team's role in co-ordination and delivery of an annual national dairy sheep conference. The conference was co-organised with Massey University, and supported by the team through the supply of speakers from both within the science programme and from the commercial partners. Documentation of the findings were also published in the Food New Zealand

publication and in national pastoral industry-centric animal, grassland and environmental conference publications.

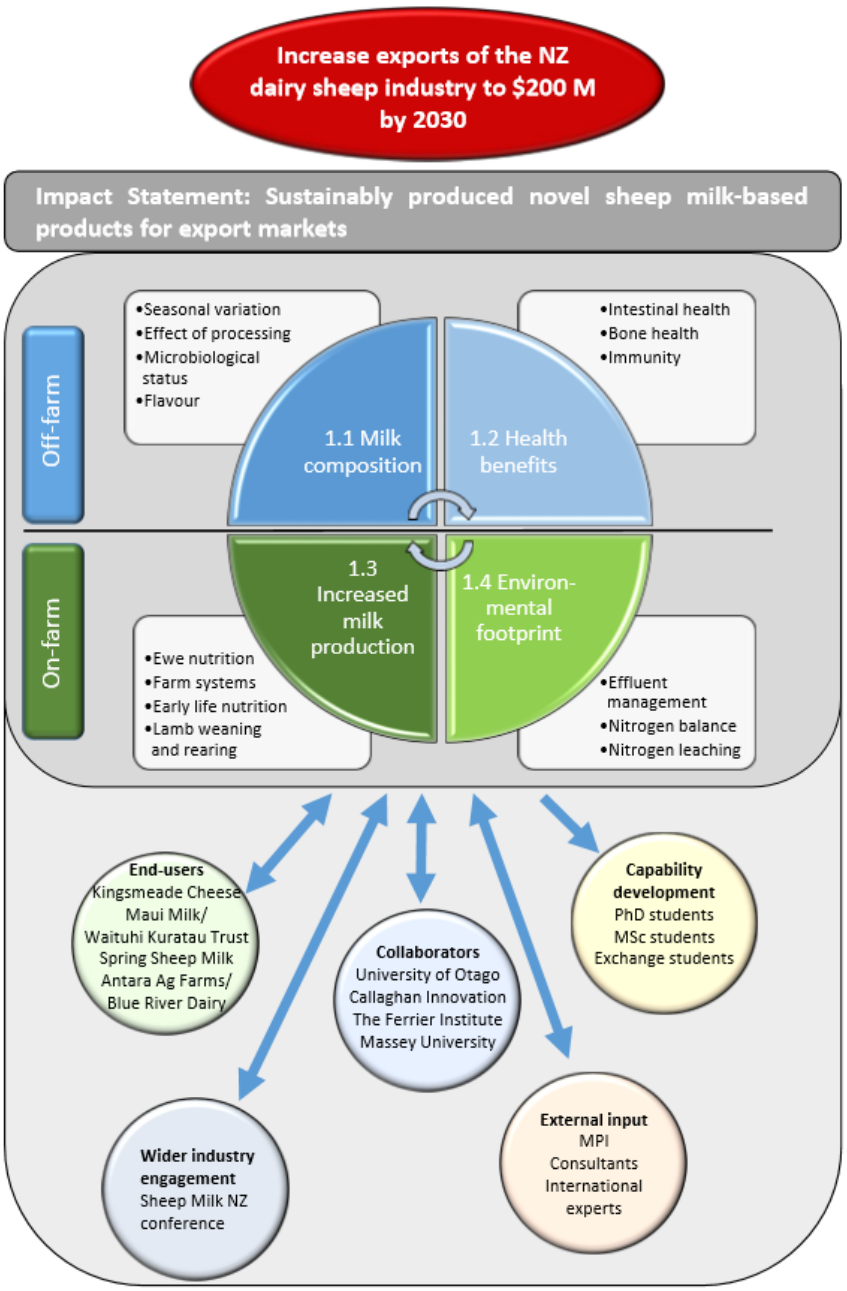

Figure 2: The research plan design for dairy sheep industry development in New Zealand

The underpinning methodologies, deployed across the value chain, integrated innovative farm systems research aimed at understanding feeding systems and environmental sustainability of sheep dairying, with analytical and functional food research designed to optimise milk production and processing, and substantiate claims for sheep milk-derived ingredients.

.

Table 2. Research outcomes during the first four years of a programme aimed to assist in the development of the New Zealand dairy sheep industry.

Research objective	Research question	Science progress
Understanding product characteristics	What are the effects of seasonality, ewe lactation status, farm of origin, and breed on the composition, physico-chemical properties, and nutritional value of NZ sheep milk and the consequent effects of processing, storage and desired product qualities?	Seasonal variation of NZ sheep milk composition characterised for the first time NZ sheep milk contains more total lipids and medium-chain triacylglycerols than European sheep milk. The microbiological status of NZ sheep milk was determined demonstrating safety to industry and regulators Spray drying was shown to increase the concentrations of these milk flavour-related compounds due to heat-induced lipolysis
Assessing functionality of sheep milk bioactives	What are the biological activities of ovine milk bioactives to warrant consideration for developing health-promoting functional foods?	Sheep milk induced increased the expression of genes associated with tissue organisation, gut barrier function and growth in large bowel microbiota and intestinal tissue than cows milk in in-vivo rate studies Sheep milk proteins were more easily digested than cow milk proteins in in vivo rat studies. The immunological properties of sheep, goat and cow milk showed potential differential effects on adaptive immunity when compared in a cell culture model and in an in vivo rat model indicating that all milks may not have the same immunological properties. Sheep milk had more beneficial effects on bone structure than cow milk even though there was no difference in mineral uptake in different organs.
Improving milk production through feeding	Can we improve ewe milk production and lamb growth and health in dairy sheep farming via improved nutrition?	New lamb rearing systems have been developed to suit the individual needs of end-users resulting in increased milk production and/or improved lamb survival and growth. A non-invasive method to study mammary gland development in young and adult sheep has been developed to provide insights into the effect of early life nutrition (pre- and early post-weaning) on the development of the mammary gland. A whole systems approach to integrating pasture and supplement feeding systems has highlighted the interacting issues of diet change, diet quality and daily activity when aiming to increase milk production per ewe to inform future farm system design and management practices.
Environmental impact	What is the environmental impact of sheep dairying?	The seasonal composition of NZ dairy sheep effluents sourced from three different farms has been determined and findings used to produce best practice guidelines for effluent management.

A nitrogen balance model for NZ dairy sheep farming systems has been established and has been used to estimate how efficiently dietary nitrogen is converted into milk, meat and wool, and how much is excreted in urine and dung.

An on-farm leaching study is underway to robustly measure N leaching losses from a case study dairy sheep grazing system.

Data requirements for inclusion of dairy sheep into the national regulatory nutrient budgeting model have been mapped.

Science outcomes

Outcomes of the science programme in the first four years are summarised in Table 2. The programme has provided several benefits to date.

The composition of New Zealand sheep milk, particularly lipids, is significantly different from that of European sheep milk (Bell et al., 2017; Burrow et al., 2016; Vyssotski et al., 2016). The implications of this include potential differences in functionality, and in processing requirements.

Variations in milk composition across the year and between producers (Day et al., 2016) may make accurate labelling a challenge, and may alter processing requirements. This variation is being addressed by industry in a variety of ways, including post-processing blending. As the industry expands to more flocks with a more uniform genetic base these issues may dissipate. However, understanding the variation across the season and from farm to farm, and feeding system to feeding system, will provide potential opportunities for product differentiation and specialisation.

The investigations into milk microbial safety across the range of farms and farming systems (Mros et al., 2016) has provided support to endorse the different types of milking environments in predominantly outdoor production systems based on pastures.

The greater understanding of the effects of storage and processing are unique to the value chains being developed for the New Zealand dairy sheep industry. The distance to market, and small local market for cheese has led to the development of dried power and infant formula as major products. Knowing how sheep milk changes and reacts to the drying process becomes important in ensuring product consistency for the consumer.

Potential health benefits from sheep milk are distinctly different from cow milk (Young et al., 2017). While present studies are restricted to rat and *in vivo* cell models, this area of research provides a basis for future investigations. While the research to date provides research direction, the near future of the industry is to generate enough milk to meet the demands of current consumers. The research provides some level of confidence to consumers, but does not provide definitive evidence for health claims or specific product differentiation at this stage.

Lamb rearing studies (Cristobal-Carballo et al., 2017; Jensen et al., 2017; McCoard et al., 2016; Nieper et al., 2017; Stevens et al., 2017) have concentrated on ensuring that both male and female progeny can be reared cost-effectively, and that a range of different rearing systems can be implemented in commercial settings. These have specifically been targeted at the large scale rearing operations that are currently undertaken, where up to 3-4000 lambs may be reared by a single producer each year. Uptake of these solutions has been rapid, with associated increases in lamb survival and decreases in rearing costs.

The impacts of pasture-based feeding systems on the onset of puberty and mammary gland development are part of an on-going study. During this process a non-invasive ultrasound technique has been developed (Molenaar et al., 2017) to provide an early screening technology to assist in research programmes and the selection of potential ewe replacements. This technology is under continuing development and calibration.

The large scale nature of dairy sheep production on pasture is unique to New Zealand. Flocks of 2-3,000 milking ewes are the current mainstay of the industry. This provides some unique challenges when dealing with environmental impacts. Best practice guidelines for dairy effluent management have been developed for the production systems that are being used (Smith et al., 2016). A nitrogen balance model has been developed for dairy sheep (Longhurst et al., 2017) and data requirements to calibrate the national nutrient budget and nitrogen leaching model have been developed to meet regulatory guidelines. This will enable dairy sheep enterprises to provide environmental impact data, and demonstrate the eco-efficiency of pasture-based dairy sheep systems.

Programme review

A formal review at the end of the fourth year of the project provided recommendations for the final directions of the programme, with the aim of meeting the original stated aims of the programme.

The panel concluded that the overall programme was delivering to the development and expansion of the industry. Specific areas contributing to short term progress were listed as the lamb rearing, feeding and environmental footprint research. It was recognised that other research, although generated useful data and information and provided a basis for the future of the industry in the development of new differentiated and high value products, it does not contribute significant to the industry's immediate needs.

The review also highlighted the role that the co-innovation programme had in providing a significant platform for industry collaboration. It recognised the fragile nature of an early developing industry, and identified the high regard that the programme had with industry.

Further work on processing characteristics, ewe feeding appropriate to New Zealand pasture-based systems and a wider environmental footprint (beyond groundwater nitrate) were recommended as opportunities to further support industry development.

Industry progress

Industry progress has also been registered. In 2013 there were five dairy sheep enterprises in New Zealand. By 2017 this had increased to 15 enterprises. While the total number of sheep milked had not changed significantly (being approximately 30,000), the number of exporting companies had increased from 2 to 3, and major markets have increased from 3 to 7. Products include milk powder, infant formula, cheese, gelato, yoghurt, liquid milk and milk tablets.

Success in lamb rearing has seen an increase in lamb survival and weaning weights. Production per ewe has increased from approximately 120-130 l/ewe (Stevens and Bibiloni 2014) to approximately 200 l/ewe (MacDonald pers. comm.). The first New Zealand dairy sheep breed has been registered (Dairymeade, based on East Friesian genetics) with production of between 300 and 500 l/ewe on a diet of >80% pasture. The genetic base has been expanded by the importation of European Lacaune and East Friesian embryos and semen (Hughes 2016).

Co-innovation impacts

The use of a co-innovation approach to designing and delivering research is a relatively recent concept (Klerkx et al., 2012). At the heart of the approach is the collaboration of both research and commercial partners. Often other parties, such as regulators, do not contribute significantly, but are potential gate-keepers (Rhodes et al., 2016) or disrupters of emerging enterprises. The interactions between these groups can affect the efficiency and impact of research programmes.

The programme described here has, to date, proved to be successful in assisting the New Zealand dairy sheep industry in its expansion. However, this is the third attempt at establishing a dairy sheep enterprise. The first, in the 1970's, used local genetics of Romney, Dorset and Corriedale breeds to provide milk for cheese making for the local market (Geenty, 2015). This was short-lived, in part because of the predominance of cheap bovine cheddar and a lack of sophistication in cheese consumption.

The second attempt came with the importation of East Friesian dairy genetics, aimed at improving the weaning weight of lambs for the sheep meat industry (Allison 1995). Again the attempt was based around cheese making, though this time for an export market. The withdrawal of the retail partner caused the enterprise to fail.

This latest attempt comes with the recognition that cheese making is a local activity and that the real expansion of the industry relies on the ability to meet growing consumer demand for differentiated dairy products with health benefits in the Asian markets. While this provides a ready outlet for product, it also requires a significant boost in scale to meet market demands.

Several features of co-innovation rely heavily on the relationships and understanding between partners. These factors can be tested on many levels. Factors which were tested in this project included world views, trust, science process, knowns and unknowns, commercial imperative, and complexity.

World views. This means that industry and research both have to share a common understanding of on another's business and skills to ensure a successful programme. This was addressed through the collaborative development of research questions, and the on-going review of progress.

Trust of science. The entrepreneurial nature of people in new enterprises, and the independent nature of New Zealanders engenders a sense of self-reliance and a general tendency to use trial and error to solve problems. The use of a formal science process, and a trust in those using that process is lacking in many areas of business (Stevens, 2018). Often the science community is seen as distant from commerce, and potentially there to fulfil needs of curiosity, rather than commercial imperative. This barrier was evident during the early part of the project, but dissipated as the findings of science were shared and implemented. Programmes like this need to focus significant energy and resources on relationship building early in the programme. An important part of ensuring that science has a trusted place in commerce is to have scientists available to provide on-going support, becoming part of the commercial community.

Science process. Science process is a specific systematic way of examining a problem. The benefits of this approach is to provide repeatable and transferable results that can be adapted to any situation. In this process, appropriate conditions must be met to ensure that. The need to work directly with commercial partners, on their farms and in their processing plants meant that scientists had to accommodate commercial processes, while industry partners had to adapt to fit science processes. Occasionally this did not achieve the requirements of either. The lessons learnt on both sides provided guidance for changes in process and expectations when designing the next steps.

Perhaps combining both trust and process are the different timelines that research and commerce follow. Research requires the in depth processing and analysis of results, while often commerce will make decisions based on incomplete data. This means that commerce moves more quickly in response to new information. Often science will require data to be repeated before making a final judgement. This may be a full year or more after commercial interests may have made a decision.

Knowns and unknowns. Working through known and unknown knowledge was a significant potential impediment to development of these programmes. The following example illustrates this effect. While much is known of the grazing conditions to maximise pasture quality and feed intake of grazing sheep, the application of this to dairy sheep is limited in international experience and literature. However, the principles still hold, an example of the transferability of science-based research. While the researchers knew of this knowledge, the experience and exposure of the industry partners was to concentrate feeding systems in dairy sheep. Therefore the request from industry was to understand concentrate-based feeding systems, even though the majority of diets were pasture-based. It was not until a workshop on nutrition and grazing management was held, in conjunction with a visit to a high performing pasture-based dairy sheep farm which confirmed the grazing management principles that progress was made in better management and utilisation of pastures. This resulted in a significant between seasons increase in milk production.

Commercial imperative. Issues pertaining to commercial imperative arose in two categories. The first was competing forces asserting themselves between partner commercial enterprises. This created tension when both deciding on specific research projects and when sharing results. One area of research that was specifically excluded from the programme was sheep genetics. This was deemed to be both proprietary, and a commercial opportunity for individuals. Follow-on outcomes from this were the registering of a New Zealand Dairy sheep breed, and the importation of European genetics.

The second area of tension was the changing nature of business. Regulatory constraints into the Chinese market saw a significant restructuring of one partner, and their withdrawal from the programme. However, another enterprise emerged which took their place. This meant that a continual relationship building had to be maintained. This also impacted on science delivery. The exit of one partner also meant the loss of access to lines of sheep which had specific nutritional histories, and so curtailed one promising area of research.

Complexity. Complexity of commercial partners farming operations did provide some issues when developing research projects, and interpreting results. Occasionally farm operations would change without notice, potentially affecting research outcomes. For example, an intensive leaching experiment was set up, and a change to more indoor feeding reduced the potential urinary inputs onto the land designated for the experiment. This then means that the results become applicable to a different set of management criteria than that set out at the beginning of the experiment.

Conclusions

Results from this co-innovation research programme have provided significant support to improve the emerging New Zealand sheep milking industry. Short term benefits will be accrued from milk safety, processing, lamb-rearing protocols, ewe nutrition and environmental footprint research. Milk composition and functionality results will provide a platform for further research to investigate the opportunities to develop differentiated, high value products for future value chains. On-farm benefits and associated profitability will assist existing farmers, and promote sheep milking as a compelling choice for new entrants to this industry. The program will contribute to the development of guidelines for sustainable dairy sheep farming to ensure that the industry can operate within the regulatory framework.

Lessons that have been learnt from the co-innovation approach include:

The time required to develop trusting relationships varies between participants. Sometimes trust may not be achieved and compromise must be accepted.

A common world view may not be necessary but participants must understand and respect the world view of others

Effort needs to be committed to ensuring all participants understand the specific requirements that make an investigation scientific. Concepts such as bias, sources of error, repeatability and significance need to be explained.

Transferring of know knowledge to participants to which it is unknown needs some priority to ensure that all participants become equally informed. This needs to take place early in the life of the project.

Recognising and accommodating commercial imperative is needed. This may alter experimental design and may improve either science outcomes or commercial application, and sometimes both.

Acknowledgments

Thanks to Antara Ag Farms, Waituhi Kuratau Trust, Maui Milk, Kingsmeade Cheese, and Spring Sheep Milk Co for support of this programme and the Ministry for Business, Industry and Employment for funding through contract C10X1305.

References

Agricultural Statistics. (2013) Agricultural Statistics: June 2013 (Provisional) – Tables. [Online] http://www.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry.aspx [accessed 20 January 2014].

Allison, A.J. (1995) Importing a sheep which offers more – the East Friesian. In: *Proceedings of the New Zealand Society of Animal Production*, 55, p. 321-323.

Anon. (2013) Briefing on the sheep milking industry. Report to the Primary Production Committee. [Online] http://www.parliament.nz/resource/0001603214 [Accessed on 20 January 2014].

Bell, T., Sims, I., Samuelsson, L. and Day, L. (2017) Oligosaccharides in New Zealand sheep milk. Food NZ.

Boyce, W., Percy, H., Turner, J., Fear, A., Mills, T. and Craven, C. (2016) Building co-innovation into your research proposal. http://apc/SuccessPrinciples/Documents/Guide%20to%20Co-innovation%20FINAL.pdf

Burrow, K., Bekhit, A., Broadhurst, M., Samuelsson, L. and Day, L. (2016) New Zealand sheep milk – mineral composition. Food NZ

Cristobal-Carballo, O., Khan, A., Knol, F., Lewis, S., Stevens, D. and McCoard, S. (2017) Impact of early weaning on rumen fermentation profiles of artificially reared lambs *Proceedings of the New Zealand* Society *of Animal Production* 77: 49-54.

Day, L., Broadhurst, M. and Samuelsson, L. (2016) New Zealand sheep milk – nutritional composition. Food NZ

Geenty, K. (2015) Important influences on sheep dairy milk production. *Proceedings of the New Zealand Society of Animal Production* 75: 279.

Hewland, PD. (1958) Davidson and Brydone founders of the New Zealand meat export industry. In: *Proceedings of the New Zealand Society of Animal Production* 18: 61-76.

Hughes, A. (2016) Breeding for sheep milks future. *Country-Wide*, November 2016: NZ Farm Life Media, Feilding, NZ. p. 52.

Jensen, A., Khan, A., Knol, F., Peterson, S., Morel, P., McKenzie, C., Stevens, D. and McCoard, S. (2017) How does feeding meal affect growth of artificially reared East Friesian-cross dairy lambs? *Proceedings of the New Zealand Society of Animal Production* 77: 13-17.

Klerkx, L., van Mierlo, B., and Leeuwis, C. (2012) Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions. In: *Farming Systems Research into the 21st Century.* Springer, Dordrecht, pp. 457-483.

Longhurst, B., Smith, C. and Bartlett, N. (2017) Nitrogen and the dairy sheep industry. *Proceedings of the New Zealand Society of Animal Production*

McCoard, S., Lowe, K., Kjestrup, H., Silvestre, T., Hennes, N., Cadars, V. and Stevens, D. (2016) Designing early weaning approaches to optimise lamb growth and milk harvesting. *Proceedings of the New Zealand Society of Animal Production* 76: 202.

Molenaar, A.J., Thompson, B., Wall, A., McCoard, S., Leath, S., McKenzie, C., Koolaard, J. and Stevens, D. (2017) The use of ultrasonography to examine mammary gland development in ewe lambs with different live weight–gain profiles between 12 and 20 weeks of age. *Journal of Animal Science* 95 (supplement 4): 368-369.

Mros, S., Broadhurst, M., Samuelsson, L., Day, L. and McConnell, M. (2016) The microbiological profile of New Zealand sheep milk. Food NZ

Nieper, B., Khan, A., Knol, F., Peterson, S., Stafford, K., Stevens, D. and McCoard, S. (2017) The effects of early access to meal on the behaviour of artificially reared dairy lambs. *Proceedings of the New Zealand Society of Animal Production* 77: 18-22.

Peterson, S.W. and Prichard, C. (2015) The sheep dairy industry in New Zealand: a review. *Proceedings of the New Zealand Society of Animal Production* 75: 119-126.

Rhodes, A.P., Casey, M.J., Payne, T.A. and Brown, M. (2016) Over the fence: understanding what people do and how they might change. *Grassland Research and Practice Series No. 16: Hill Country Symposium.* New Zealand Grassland Association, Mosgiel, NZ. pp. 39-46.

Smith, C., Longhurst, B. and Watkins, N. (2016) Fact sheet: Effluent management guidelines for dairy sheep

Stevens, D., Knol, F., Nieper, B. and McCoard, S. (2017) Post-weaning performance of East Friesian-cross ewe lambs grazing ryegrass or plantain-based pastures after rearing on two contrasting diets. *Journal of New Zealand Grasslands* 79: 55-60.

Stevens, D.R. (2018) Applied agricultural research: where is the future? *Journal of New Zealand Grasslands* 80. In prep.

Stevens, D.R. and Bibiloni, R. (2014) The emerging dairy sheep industry in New Zealand. *Options Mediterraneennes 109*, Series A: 741-744.

Vyssotski, M., Lagutin, K., Bloor, S., MacKenzie, A., Scott, D, Broadhurst, M., Day, L. and Samuelsson, L. (2016) Lipid profile of New Zealand sheep milk. Food NZ

Young, W., McConnell, M., Burrow, K., Bekhit, A. and Samuelsson, L. (2017) Nutritional and health properties of New Zealand sheep milk. Food NZ