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Inspiring Agriculture

Pasture For Humans

Think Piece Report for Our Land and Water National Science Challenges

December 2022

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OUR LAND AND WATER
Toitū te Whenua, Toiora te Wai
National SCIENCE Challenges

Think Piece Report

Pasture for Humans

Land-use change through harvested pasture proteins

Funded by: Our Land and Water (OLW) National Science Challenges

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EXECUTIVE SUMMARY | He whakarāpopototanga

To significantly lower the environmental footprint of Aotearoa dairy farms while looking after the wellbeing of mana whenua, an adoption of innovative farm practices is required. To achieve landscapes that are more resilient, healthy, and prosperous than today, our Think Piece looked at the implications of diverting pasture from ruminants to a direct harvest process that delivers a human-digestible protein.

Our Purpose | To Tātou Whāinga

A Think Piece is simply that. A piece of study that challenges our current views and knowledge. Our (BakerAg) investigation into how protein harvesting might change the way we farm has uncovered compelling ideas about land-use change. Our purpose is to share those ideas as a catalyst to change.

Pasture For Humans' is an advanced study by BakerAg on land-use change through harvested pasture proteins. An innovation developed by Plant & Food Research (Rangahau Ahumara Kai). Following preliminary work funded by Fonterra, Pāmu and Plant & Food Research. The work presented in this report looks to identify and test novel production systems to give farmers, growers, and mana whenua a greater choice of sustainable and profitable land-use options.

Working with case study dairy farms in different regions, the intention was to demonstrate how a farmer could integrate protein harvest technology into existing pastoral grazing systems and assess the potential economic and environmental consequences for both farm and region.

The project sought to validate that shifting a proportion of Aotearoa's pasture from ruminant grazing to direct recovery of plant protein will reduce pastoral farming's environmental footprint, particularly for water quality and greenhouse gases (GHG).

Why is this Issue Important? | He aha tēnei take hirahira ai?

The opportunity to develop a new plant protein industry in Aotearoa depends upon on-farm viability and farmer willingness to change. Without this we will not realise the opportunity to make pasture available for producing protein foods.

If farmers elected to direct a portion of their farm into protein harvesting this would require a change in the farm policy and operation that has the potential for positive implications on nutrient loss to land and water. With less livestock, farming emissions can reduce.

The protein produced on the land set aside for harvest would provide a revenue stream that would offset altered milk and livestock revenue. Farmers that de-intensify without land-use change might achieve similar emission reductions but at a level that is disruptive and costly to the business. Alternative land-use such as protein harvesting might demonstrate the potential to create a win-win outcome. Better for the farmer, better for the environment and better for the community.

What Did We Do? | I aha tātou

We identified three dairy farms as case study farms, located in the Hawke's Bay (Te Matu-a-Māui), Canterbury (Waitaha), and Southland (Murihiku) regions where the environmental impact of livestock farming needs to be reduced.

Alongside these farmers, a stakeholder group, including regional council, industry representatives and rural professionals, was engaged in three meetings during the course of the project. These meetings were an important forum to discuss the concept, the results, and draw out the unique features for the farm and community.

Using Farmax and Overseer, we modelled several pasture harvest scenarios for each case study farm, overlaying the implications of annually rotating a block of pasture for protein harvest and extraction. This was done with scope to include the unique features and thinking that comes with farming under different ownership/management structures, different regions (and therefore feasibility to meet regional environmental regulations), and different community expectations.

Through this process, we collated a summary of physical, financial, and environmental findings on the impact of protein harvest within a dairy farming system. Through a consultation process we also attempted to gauge the feasibility and appetite for this technology with end users/guardians of the land. These findings have informed our 'Think Piece' on how the concept of land-use change, in the form of pasture protein harvest, might impact on the farmer and the environment.

What Did We Find? | I ahatia e kimihia ai 6atou?

This study has given us greater clarity of the on-farm triple bottom line benefits of introducing the protein-from-pasture protocols. Protein harvesting has the potential to provide Aotearoa farmers with alternate land-use choice. For the farmer, the inclusion of protein harvesting has the potential to reduce the stocking rate without losing economic viability. It can, in conjunction with other mitigating actions, significantly reduce the environmental footprint while still producing food.

Farmers will need to individually investigate suitability of protein harvesting on the farm. Our findings highlighted existing economic performance, soil types, seasonality of pasture protein production, livestock wintering policies, facilities such as herd housing and composting barns, regional compliance requirements, and on-farm objectives can each influence the feasibility of setting an area of the farm aside for this land use. Common findings across all three case study farms included:

- Farm systems and management adaptation of the protein harvesting initiative will be significant. For example, we have identified that to set aside 30% of the farm for protein harvest would result in a 25% to 40% reduction in stocking rates. As the area in protein harvest increases the number of cows farmed reduces.
- With fewer cows, the nitrogen and phosphate losses to water reduces.
- Greenhouse gases will reduce, but not all technologies that reduce nutrient loss are favourable to GHG emissions. In this case, compost barns and cow housing are at best neutral.
- As the protein harvest area increases milk revenue reduces in step with reducing livestock numbers. It is the view of BakerAg that the payment for the harvested protein would have to exceed the lost milk revenue to prove attractive to farmers.

- For our case study farms, a protein price in the order of $3 to $6 per kg of protein harvested would generate an EBIT position equivalent to the baseline (i.e., current farm operating status). This does assume the processor meets all the protein harvest costs.
- Protein harvesting for human consumption does provide favourable environmental outcomes. As such this is a form of mitigation that will be of increasing value to farmers required to reduce their environmental footprint.
- However, our study indicated that only where a range of mitigations are stacked can we consistently see our case study farms in a position to meet future regional council expectations for nutrient loss to water.

In addition to the protein scenario modelling, a key part of this Think Piece was the consultation process of understanding how this technology would sit with end users and custodians of the land. It became very clear that the drivers for land-use change were varied and quite individual. The concept of Kaitiakitanga is embedded in a healthy fashion but there remained a concern for the unknown that is a common theme for farmer hesitancy around land-use change. It came through that adoption will be a function of confidence in the returns from the business of protein harvesting, clear understanding of the environmental advantages, and faith that de-intensifying the farm will mean the farm, farming family and community will be no worse for the change.

We identified that mana whenua will need to have awareness that changing land-use and de-intensifying farms would reduce emissions (broad definition of nutrients (N&P) and gross CO2 equivalents) to land, water and air by up to 60%, but this is also likely to reduce the number of people engaged in the day-to-day business of farming. This could be as high as a 20% reduction, or one person in five no longer required for the day-to-day running of the business. Note the calculation of "emissions" is at farm level only and excludes processor (milk or protein) harvest, transport and processing.

For mana whenua, this report flags the double-edged sword nature of de-stocking and diversifying land-use through protein harvesting. Improvement to the environment with reduced emissions and de-intensifying farms will be a strong positive. However, such changes come with the risk of reducing the number of people living off the land and contributing to the community.

What are the Next Steps? | He aha ngā hikoi ko atu?

For farmers considering land-use change, and more specifically protein harvesting, this report should provide insights into the implications of change. There are insights for the strategies and policies that need to be formed around protein harvesting.

The results presented here will also inform further investment in developing the processes, products, applications, and markets enabled by this technological revolution. More specifically, processors of harvested protein might use this report to better appreciate the implications for farmers around pricing and drivers for adoption.

From the farmer perspective, it was evident of the view that this technology could be seen as 'invasive' i.e., requiring significant system change. While being an innovative opportunity, farmers see the risk/uncertainty of the technology as a red flag for their business as protein harvest and processing through to sale as a food ingredient is yet to be proven. For protein harvesting to become an accepted practise worthy of adoption, farmers will need to see a successful commercial scale farmer-to-processor-to-market-to-consumer story that celebrates the physical, financial, and environmental outcomes. Along with support from all sectors of the community.

BakerAg is aware that full vertical integration is being researched for this initiative. Plant & Food along with other research groups are researching the requirements to scale-up and commercialise the process. With this commercialisation potential, processors are looking to find and build markets for this food ingredient which will take time but would appear to have global appeal. An end-to-end view of how protein harvesting will operate is needed to realise this opportunity. It will be an innovative food grown by innovative farmers utilising the initiative developed by pioneering researchers.

OUR PURPOSE | To Tātou Whāinga

Future Landscapes | Ngā Horanuku Anamata

Our Land and Water (OLW) is one of 11 National Science Challenges that focus on defined issues of national importance. One of the research themes is 'Future Landscapes', whereby in the future, landscapes will contain mosaics of land use that are more resilient, healthy and prosperous than today.

Aotearoa's agricultural landscape has seen the expansion of large farms that produce single products, on land classified according to its maximum capability. Over time this has resulted in undesirable environmental outcomes.

Within OLW Future Landscapes theme, the concept of "land-use suitability" describes not just the land's capability to grow a product, but also considers impacts on soil and waterways, and economic, social and cultural outcomes.

The environmental impact of food production is front of mind not only for farmers, but also for consumers, processors, retailers, and government. Issues with intensification of farming in some areas of Aotearoa has highlighted the need for a change in land-use that is sustainable. 'Pasture For Humans' is a next-stage project by BakerAg, following earlier work funded by Fonterra, Pāmu and Plant & Food Research on land-use change through harvested pasture proteins. The work presented here looks to identify and test novel production systems to give farmers, growers, and mana whenua a greater choice of profitable land-use options.

Objectives

Technology is progressing that can extract protein from pasture, to create a plant protein food ingredient for human consumption. The opportunity to develop a new plant protein industry in Aotearoa depends upon on-farm viability, or there will be no incentive to make pasture available for producing protein foods.

Our objectives were to explore sustainable and complementary alternatives to intensive dairy farming in Tararua - Hawke's Bay (Te Matu-a-Māui), Canterbury (Waitaha), and Southland (Murihiku). By working with three case study dairy farms, we wanted to:

- Validate that this alternative land-use opportunity will reduce the environmental footprint (greenhouse gas emissions (GHG) and water quality), compared with current use.
- Provide insights to the mitigation activities that might otherwise be (regionally) required to continue farming.
- Address the economic impacts and implications at the farm-level for commercial resilience.
- Demonstrate how a farmer would integrate pasture as a crop for protein harvest into existing pastoral grazing systems.

Why is this Issue Important?

The opportunity to develop a new plant protein industry in Aotearoa depends upon on-farm viability and farmer willingness to change. Without this we will not realise the opportunity to make pasture available for producing protein foods.

If farmers elected to direct a portion of their farm into protein harvesting this would require a change in the farm policy and operation that has the potential for positive implications on nutrient loss to land and water. With fewer livestock, farming emissions can reduce.

The protein produced on the land set aside for harvest would provide a revenue stream that would offset altered milk and livestock revenue. Farmers that de-intensify without land-use change might achieve similar emissions reductions but at a level that is disruptive and costly to the business. Alternative land-use such as protein harvesting might demonstrate the potential to create a win-win outcome. Better for the farmer, better for the environment and better for the community.

What are the Expectations?

Compliance expectations

For some, more intensive farmers, the National Policy Statement for Freshwater 2020 (Freshwater NPS, 2020) will require a reduction in nutrient loss to land and water. Accommodating such compliance requirements are unlike that proposed around GHG emissions where farms can pay a tax and continue existing farm practises. How feasible these compliance expectations (which differ across the regions) and their impact on the farming system (and business) continues to be a moving target. In saying this, we are interested in identifying the opportunities that land-use change in the form of protein harvesting might have in terms of mitigation strategies.

To enable reductions in nutrient loss to water, real physical change must occur on farms. Changing land-use in-sync with a reduction in livestock numbers, and/or change to farming systems needs to be a clearly managed process to mitigate loss in revenue, profitability, and sustainability.

Community expectations

We must be mindful that as we destock our farms, we reduce the number of people who work on these farms. A recently published report by BakerAg (Beetham & Garland, 2019) on East Coast North Island forestry expansion identified this. Subsequently, once the indirect consequences of forestry expansion were realised, there was strong community push back and raised concerns for impacts on rural communities.

Iwi expectations

Managers of the Māori trust (case study) property in Hawke's Bay clearly expressed an expectation for the future of the farm. This was about respect for natural resources and expectation that people will stay on the land to learn and enjoy the farming custodianship of the land, Kaitiakitanga.

In response to this need to retain people on the land, BakerAg altered the approach taken in farm system modelling on Farmax and in Overseer whereby we consciously sought outcomes that would deliver retention of people on the land but a much smaller environmental footprint.

WHAT DID WE DO? | I aha tātou?

This project tested the hypothetical concept that redirecting a proportion of Aotearoa's pastoral lands from grazing ruminants to direct recovery of plant protein for human consumption may provide significant improvements to the environment while having minimal impact on farm returns and on the social contribution from current pastoral farming.

Farm Case Studies

To test our hypothesis, our approach was to identify three dairy farms as case study farms.

The three farms selected were in Tararua - Hawke's Bay (Te Matu-a-Māui), Canterbury (Waitaha), and Southland (Murihiku) regions (**Figure *1***).

These regions were selected because they represent a range of climates but have challenges where intensive farming and environmental expectations do not align. All three farms shared common ground in that they were wanting an answer to the same question of "*where is the solution that enables sustainable food production from the land*?"

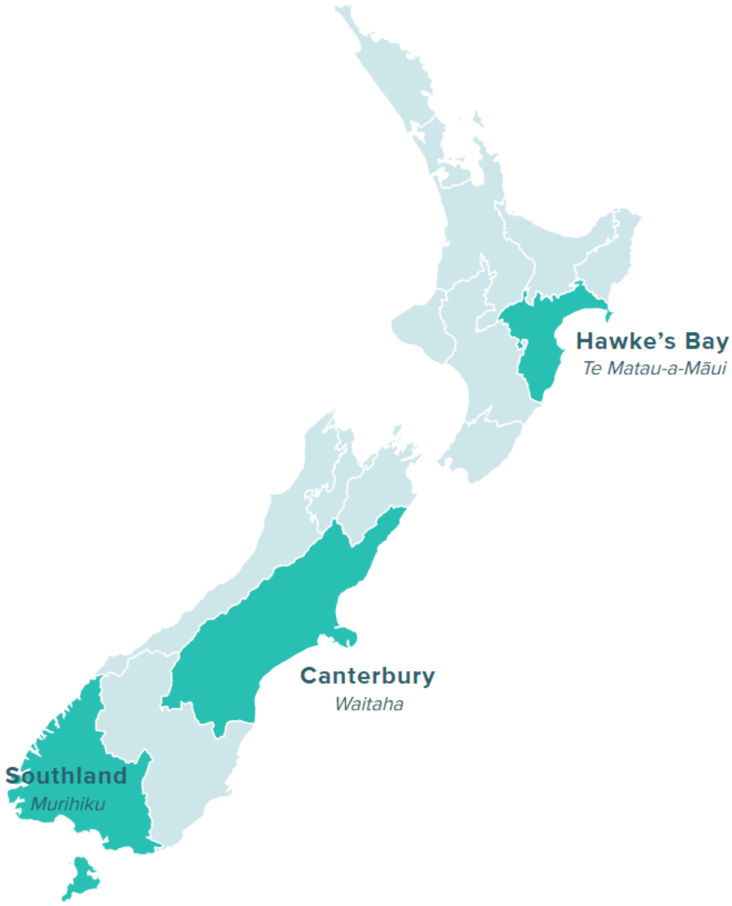


Figure 1. *Locations of case study farms for modelling and analysis.*

Southern Hawke's Bay (Tararua) | Te Matu-a-Māui

The Hawke's Bay case study farm is a Māori trust-owned farm operated by contract milkers who will be entering their third season. The farm is located on the south bank of the Manawatu River, north of Mangatainoka.

There are 430 cows peak milked on 158 ha, at 2.7 cows/ha. Average milk production is 165,000 kg MS/year, or 380 kg MS/cow. Approximately, 460 cows are wintered; 260 cows are wintered off, with 200 cows remaining on the milking platform. There is a feed pad which is utilised nine months of the year. There is no irrigation.

The diet consists of pasture, palm kernel extract (PKE), baylage and maize silage (made off the platform; 10 ha) and summer turnips (10 ha).

The Hawkes Bay farm is located in the Tararua district of the Horizons region. It is within the Mana_8 and Mana_9 target catchments, which is a priority catchment. Therefore, they are required to farm within the limits as set out in

Table 1, which uses the N leaching limits set out by Plan One for specific land classes (Horizons Regional Council, 2014). For this farm, given their Land-Use Capability (LUC) classes, this would require an average nitrogen (N) loss to water of 16 kg N/ha for the farm by 2034. However, Plan Change Two (Horizons Regional Council, 2021), while not yet fully legislated, will be in the coming years, and the N leaching limits as set by the One Plan (Horizons Regional Council, 2014) has been updated to match the Overseer updates. This is likely to lead to a N loss target of 25 kg N/ha by year 20 (2036). See

Table 1 below.

Table 1. *Nitrogen (N) leaching limits for The Tararua Farm, as defined by Table 14.2 of the Horizons Regional Council (2014) which calculates the cumulative N leaching maximum for the land used for intensive farming activities within each specified land-use capability (LUC) class.*

Original

Land Use Capability* (LUC)	LUC Areas (ha)			Table 14.2 N Leaching Limits (kgN/ha)			
	Total	Platform	Run-off	Year 1	Year 5	Year 10	Year 20
I	0.0	0.0	0.0	30	27	26	25
II	54.6	54.6	0.0	27	25	22	21
III	18.8	18.8	0.0	24	21	19	18
IV	65.2	65.2	0.0	18	16	14	13
V	0.0	0.0	0.0	16	13	13	12
VI	9.9	9.9	0.0	15	10	10	10
VII	0.0	0.0	0.0	8	6	6	6
VIII	0.0	0.0	0.0	2	2	2	2
Farm Area (ha)	**148.5**	**148.5**	**0.0**				
FARM LEACHING TARGET (kgN/ha)				**22**	**20**	**17**	**16**
Total Nitrogen (kg)				**3,248**	**2,902**	**2,570**	**2,432**

Proposed Revised

Land Use Capability* (LUC)	LUC Areas (ha)			Table 14.2 N Revised Leaching Limits (kgN/ha)			
	Total	Platform	Run-off	Year 1	Year 5	Year 10	Year 20
I	0.0	0.0	0.0	50	45	43	42
II	54.6	54.6	0.0	44	41	36	34
III	18.8	18.8	0.0	36	32	29	27
IV	65.2	65.2	0.0	26	23	20	19
V	0.0	0.0	0.0	23	19	19	17
VI	9.9	9.9	0.0	22	15	15	15
VII	0.0	0.0	0.0	11	8	8	8
VIII	0.0	0.0	0.0	3	3	3	3
Farm Area (ha)	**148.5**	**148.5**	**0.0**				
FARM LEACHING TARGET (kgN/ha)				**34**	**30**	**27**	**25**
Total Nitrogen (kg)				**4,992**	**4,488**	**3,963**	**3,751**

Canterbury | Waitaha

The Canterbury case study farm is a family-owned farming business located on the north side of the Waimakariri river, in South Eyre. The farm has light, free-draining stony Lismore soil. Any water which drains through the soils feeds the Silverstream Reserve, which has measured high nitrate levels above 10 mg/L.

This property peak milks 880 cows on 260 ha effective, at 3.4 cows/ha. Average production is 400,500 kg MS, or 450 kg MS/cow. Approximately, 900-920 cows are wintered, with all cows wintered off at a support block. The farm has in-shed feeding which is utilised throughout the milking season. The farm is fully irrigated, with pivot and sprinkler irrigation. The diet consists of pasture with barley fed in-shed throughout the season, molasses during spring, silage throughout spring and autumn as required, with no cropping on farm.

The farm is located in the Northern Waimakariri Tributaries Freshwater Management Unit (FMU), in nitrate priority catchment sub area C, which requires a 20% N reduction by 1st Jan 2030, a 30% reduction by 1st Jan 2040 (Environment Canterbury, 2021), with further reductions still under review. Nitrogen reductions are calculated against baseline Good Management Practices (GMP) N losses. Further reductions in N loss are likely to be required beyond that but are not yet legislated as they are under appeal. However, Environment Canterbury believes it is likely that this will go further due to the requirements set out in the Freshwater NPS (2020), to meet Te Mana O Te Wai (Anna Veltman, Environment Canterbury, Land Management Advisor, Pers. Comm.).

Southland | Murihiku

The Southland case study farm is a family-run lease farm, which is starting its second season of the lease from 2022/23. The property is located on the banks of the Mataura River, in the Mataura Catchment.

The Southland case study farm peak milks 730 cows, on 242 ha effective, at 3 cows/ha. Average production is 400,000 kg MS, or 547 kg MS/cow. Typically, all 760 cows are wintered off farm. There is no irrigation. Half the farm is heavy soil, and at risk of flooding when there are high river flows, and half the farm is a light stony soil, and not at risk of flooding. The farm has a feed pad which is used as a stand-off pad during calving, and for feeding through all spring, and again as a feed pad in autumn. There is in-shed feeding which is utilised year-round.

The diet consists of pasture plus PKE and a barley pellet fed through the shed, as well as silage fed on the feed pad in spring and autumn.

The Southland farm is located in the Mataura catchment. While currently there is no legislated required reduction in N and phosphorous (P) load, the Proposed Southland Water and Land Plan (Plan Change Tuatahi) is progressing through the courts, with the aim of becoming notified mid-2024.

A report by Snelder (2021) has been released which has indicated what the total reductions in both N and P loadings in the waterways within specific catchments need to reduce to achieve target water quality improvements. In the Mataura catchment, there is likely to be a reduction required of 79% (67-89% range) in total N, and 58% (37-70% range) reduction in total P (Snelder, 2021). Timeframes for these required reductions are unclear. This may not all fall on farmers to meet these reductions, with some improvements being sourced from interventions such as sediment traps/ dams, bio filters or other novel technologies. However, there is an expectation that there will be significant reductions required by farmers.

Modelling Scenarios

To identify how protein harvesting might influence farm systems for each of the three case studies, modelling was undertaken using Farmax and Overseer which overlayed the implications of rotating a block of pasture for protein harvest and extraction.

Through an on-farm meeting, baseline information (existing farm system, inputs, and performance) was captured for input into the Farmax and Overseer models.

Agreed standard/common scenarios to be modelled across all three case study farms were:

1. **Baseline** (existing farm system, inputs, and performance)
2. **10%** of farm area set aside for protein harvest
3. **20%** of farm area set aside for protein harvest.
4. **30%** of farm area set aside for protein harvest

Modelling with both Farmax and Overseer gave the physical, financial, and environmental outcomes of the described system change.

The vested interest group for each region were then presented with the results and asked for input on a further round of modelling. This then presented three further categories/scenarios of enquiry:

5. **SR Mitigation:** The cost and implications of a policy change (primarily lower stocking rate, SR) to mitigate N loss to water that would otherwise deliver the same N loss result as that achieved through protein harvesting at 30% of farm area.
6. **Unique:** What 'unique' feature for each case study farm should be considered and studied further? This was an add-on developed after consultation with the vested interest group used during the study element of this project.
7. **Stacked Mitigations:** What would a combined technology scenario deliver (with no specific physical or financial outcome targeted) where protein harvesting was coupled with other proven mitigations (such as reduced N use, change in cropping practises, standing off cows and/or herd housing, use of plantain crops, etc)?

The (vested interest group) agreed specifics for the Unique scenario of each case study were:

- Hawke's Bay/Tararua: no loss in farm staffing levels (connected to hapū expectations) and self-contained farming.
- Canterbury: the implications for environmental outcomes where cows are wintered off farm.
- Southland: the farm is on heavy and light soil terraces which have different nutrient loss properties and different pasture growth yields that influence farm management. What are the implications of protein harvesting if applied disproportionately across these terraces?

The Stacked Mitigations scenario was added into the analysis to address the question, which was if there were no constraints with the property, what would the farm system look like if we could stack several mitigation options? Using this concept, the specifics for the Stacked Mitigations scenario of each case study were:

- Hawke's Bay/Tararua: Approximately 30% of land set aside for protein harvest, a compost barn, plantain, and no N fertiliser on the grazed area.
- Canterbury: Approximately, 30% set aside for protein harvest, a compost barn with cows wintered on-farm, plantain, and no N fertiliser on the grazed area.
- Southland: Approximately, 20% set aside for protein harvest, all in-calf cows wintered at home, plantain, and no N fertiliser on the Light Soil grazed area. The peak cow numbers in this scenario reduced 18% against Baseline.

Farmer and Stakeholder Consultations

An important aspect of the project was engagement with the case study participants and stakeholders. This was not only to obtain accurate and relevant farm data for the modelling component, but also to get an understanding of the Māori principles of Kaitiakitanga regarding farming mainstream.

Initial consultations gave an understanding from our participants and stakeholders of how the concepts of Toitū te Whenua, Toiora te Wai and of Kaitiakitanga could be incorporated into all aspects of the project and most importantly into the recommendations for adoption and implementation of the work into future land-use discussions for all farming entities.

The initial consultations also shaped the different modelling scenarios to be used, specific to each case study. With each farm effectively modelled for its baseline position, the vested interest group of farmer, rural professionals and community representatives helped to shape the modelling scenarios best suited for determining the effect of setting land aside for protein harvest.

Once the modelling was complete, final outcomes were presented to the farmer and stakeholder panel. Feedback on the suitability (or not) of different protein harvest options and impacts on the farm system for each case study was gathered and reported here.

Analyses

For analysis of the different scenarios for each of the case studies, the modelled outputs included:

- Physical outcomes for area grazed, livestock numbers, milk production, pasture production, harvest protein, N use, and cropping.
- Financial performance as Earnings Before Interest and Tax (EBIT).
- Environmental outcomes as kilograms of N loss to water, kilograms of P loss to water, and tonnes of GHG per hectare.

Assumptions used for both Farmax and Overseer can be found in ***Appendix 1.*** Model output data has been summarised into results tables and analysis has been directed on providing greater clarity of the on-farm triple bottom line benefits of introducing the protein-from-pasture protocols to inform further investment in developing the processes, products, applications, and markets enabled by this technological revolution. Specifically, we have reported on:

- The economic impact of protein harvesting.
- The environmental impact of protein harvesting.
- The economic impact of alternate mitigations.
- Implications of combining technologies.
- Sensitivity analysis to help understand how milk price and protein price and yield might impact on adoption.
- Insights for discussion where further analysis is outside the scope of this report.

WHAT DID WE FIND? | I ahatia e kimihia ai tātou?

This section presents the modelling analysis for each of the case study farms individually, in addition with a collective analysis of all three farms, and feedback of the stakeholder consultation process.

Hawke's Bay | Te Matu-a-Māui

See ***Table 2*** which summarises the main outputs from the modelled scenarios for the Tararua case study farm.

Economic impact of protein harvesting (10, 20 and 30% Protein Harvest)

- As the proportion of land increased for protein harvest, the number of cows peak-milked reduced, physical milk production reduced, and EBIT reduced *(**Table 2**, **Figure 2**)*.
- As the area of protein harvested increased, there was an associated decrease in gross EBIT, where 10% protein harvest resulted in a 18% decrease in gross EBIT relative to Baseline, and a 30% protein harvest had a 43% reduction in EBIT (**Figure 2**).
- In the modelling of protein harvest, an associated effect was an impact on the number of Full Time Equivalents (FTE's) employed, which reduced. This triggered a useful conversation with the farmer who indicated that for part of their expectation as custodians of the land, it would look after and train the same number of people as Baseline. Therefore, subsequent scenarios modelled for this case study retained staffing levels, regardless of the stocking rate.
- For the 10%/20%/30% scenarios, the average breakeven protein price required to maintain baseline EBIT was $3.42/kg protein harvested at a $9/kg MS milk price.

Environmental impact of protein harvesting (10, 20 and 30% Protein Harvest)

- Where land-use change included protein harvesting; cow numbers reduced, and in step with this, the environmental footprint measures also reduced relative to the Baseline *(**Table 2Error! Reference source not found.**, **Figure 2**)*.
- Relative to Baseline, the greatest reduction in N loss to water was 30%, which occurred with 30% of the farm set aside for protein harvesting.
- Also at 30% protein harvest, P loss reduced by 23% and GHG emissions reduced by 20%, relative to Baseline.
- Under the SR Mitigation scenario, all case study farms were modelled to generate the same N loss to water outcome as the 30% protein harvest scenario, but without any protein harvest, where the primary driver was a reduction in stocking rate. For the Hawke's Bay case study, a 20% reduction in cow numbers at peak milk generated the same N loss reduction with a 10% reduction in P loss and a 25% reduction in GHG.

Impact of alternate mitigations (Unique Scenario)

- For the 'Unique' scenario, the farmer for this property requested (with support of the vested interest group) a scenario of being self-contained for all livestock grazing and supplements with full retention of baseline people on the land, and 20% of land set aside for protein harvesting. This scenario demonstrated, relative to Baseline, that a 26% reduction in stocking rate could deliver a 19% reduction in N loss to water, a 22% reduction in P loss, and a 22% reduction in GHG emissions.

- The Unique Scenario did result in a 42% reduction in gross EBIT, relative to Baseline. To generate the same Baseline EBIT, the Unique scenario would require a $4.64/kg protein price.

Stacking of mitigation technologies (Stacked Mitigations Scenario)

- The mitigations stacked to generate the Stacked Mitigations scenario included 30% set aside for protein harvest, a compost barn, plantain, and no N fertiliser on the grazed area.
- The Stacked Mitigations scenario generated the lowest environmental footprint but came at the greatest cost (in terms of EBIT) and required a protein price of $4.82 to breakeven with the Baseline.
- If the SR Mitigated scenario reflected a compliance-based standard, then the 'Stacked Mitigations' scenario would require a protein price of $3.44 per kg of protein harvested to breakeven.
- The Stacked Mitigations scenario is the only option that would proximate the regional council standard for N loss in this catchment.

Stakeholder scenario preferences

Farm contract milkers' preferences:

The contract milkers who were part of this Think Piece have strong values aligning around family, communities, education, animal health and welfare, and environmental stewardship. This directed our research in ways to try and maintain staffing levels, while also reducing environmental emissions.

For this farming business, given its location, currently there is no enforcement from the regional council requiring change to achieve reduced levels of environmental contaminants. This is coming in the future, but it is not in place yet. As such, the lack of enforcement (or requirement of action) to accommodate a reduced environmental footprint, has meant that the concept of protein harvesting as a form of alternative land-use, has less weighting (or priority) in relation to the numerous other issues farmers are currently dealing with on-farm.

The contract milkers had reservations around the pasture protein as an alternative land-use due to it being a new and novel concept. The technology is in its innovative stages and so has many uncertainties. In the current farming climate, where annual inflation is at 7.3%, a 32-year high, and costs (and therefore profit margins) are difficult to contain, we are in a situation where farmers are less inclined to take additional risks within their business. These contract milkers highlighted the importance of weighing up where the risk would fall in terms of milk production, protein sale prices and quantities, and market access etc. In regard to protein harvesting, they wanted to know where the production and price risk will lie; with the farming business, or with the processor.

A further reservation around the protein harvesting concept for land-use change was whether it would set a precedent with the regional council for reduced cow numbers, and if this could prevent the business from being able to return the land to dairy farming if they wanted to. It was discussed that farmers would want some certainty that they could "give it a go" for pasture protein farming, while also having the ability to go back to conventional dairy farming if they wished.

The contract milkers were not in favour of building additional infrastructure in the form of a composting barn (or any form of wintering barn on farm), as it is their belief that this does not align with optimum animal welfare. As such, their (contract milker) optimal scenario, would be the Stacked Mitigation scenario, but removing the composting barn.

Regional council:

Our Horizons Regional Council attendee was very open and excited by the opportunities offered by the pasture protein technology. From the participants personal perspective, it gives dairy farmers an option to remain financially viable, while also achieving the desired environmental outcomes.

Table 2. *Hawke's Bay (Tararua ccase study farm Farmax and Overseer outputs for modelled scenarios of '**Baseline'** (existing farm system, inputs, and performance), **'10%', '20%' or '30%' of farm area set aside for protein harvest**, **'SR Mitigation'** (use of a lower SR to mitigate N loss), **'Unique**' (specific scenario catered for this farm only), and '**Stacked Mitigations'** (stacking of mitigations to achieve low N).*

SCENARIO*	Baseline	10%	20%	30%	SR Mitigation	Unique	Stacked***
Description	*Current Status Quo System*	*10% of grazed area set aside for Protein Harvest*	*20% of grazed area set aside for Protein Harvest*	*30% of grazed area set aside for Protein Harvest*	*- Retain grazed area but de-stock to N loss = 30% - Plantain - ½ N fertiliser - Reduced supplement*	*- Self-contained operation with mitigants - Home grown feed - Same Baseline FTE - 20% Protein Harvest, Plantain*	*- Stacked mitigations incl Same Baseline FTE - 30% Protein Harvest - Plantain - Compost barn - No N fertiliser*
Total Area, ha	160	160	160	160	160	160	160
Grazed Area, ha	160	144	128	112	160	128	112
Protein Harvest Area, ha		16	32	48		32	48
Peak Cows	455	414	372	346	364	336	311
Staff, FTE	2.75	2.75	2.5	2.5	2.75	2.75	2.75
EBIT, $ per ha**	$3,798	$3,131	$2,701	$2,171	$3,089	$2,207	$1,324
EBIT, $/ MP ha**	$3,798	$3,479	$3,376	$3,101	$3,089	$2,759	$1,891
N Loss, kg/ha	43	38	34	30	30	34	17
N loss pasture protein	-	5	5	5	-	5	5
P Loss, kg/ha	0.9	0.8	0.7	0.7	0.8	0.7	0.6
GHG, kg/ha	11,602	10,784	9,969	9,228	8,648	9,076	7,688
Protein Harvested, T	-	27	55	82	-	55	82
Breakeven Protein**, $/kg protein**	-	$3.89	$3.20	$3.16	-	$4.37	$4.64

EBIT, Earnings Before Interest and Tax; GHG, Greenhouse Gas emission; MP, milking platform; N, nitrogen; P, phosphorus; SR, stocking rate.

*Milk price used $9/kgMS for all scenarios.

** EBIT is before any protein harvest payment, and EBIT/MP ha is calculated from the milking platform area.

*** 'Stacked' Scenario definition: the stacking of relevant mitigations but is not directed towards any specific optimal outcome physically or financially.

**** Protein Breakeven for Stacked versus SR Mitigation: $3.44/kg protein.

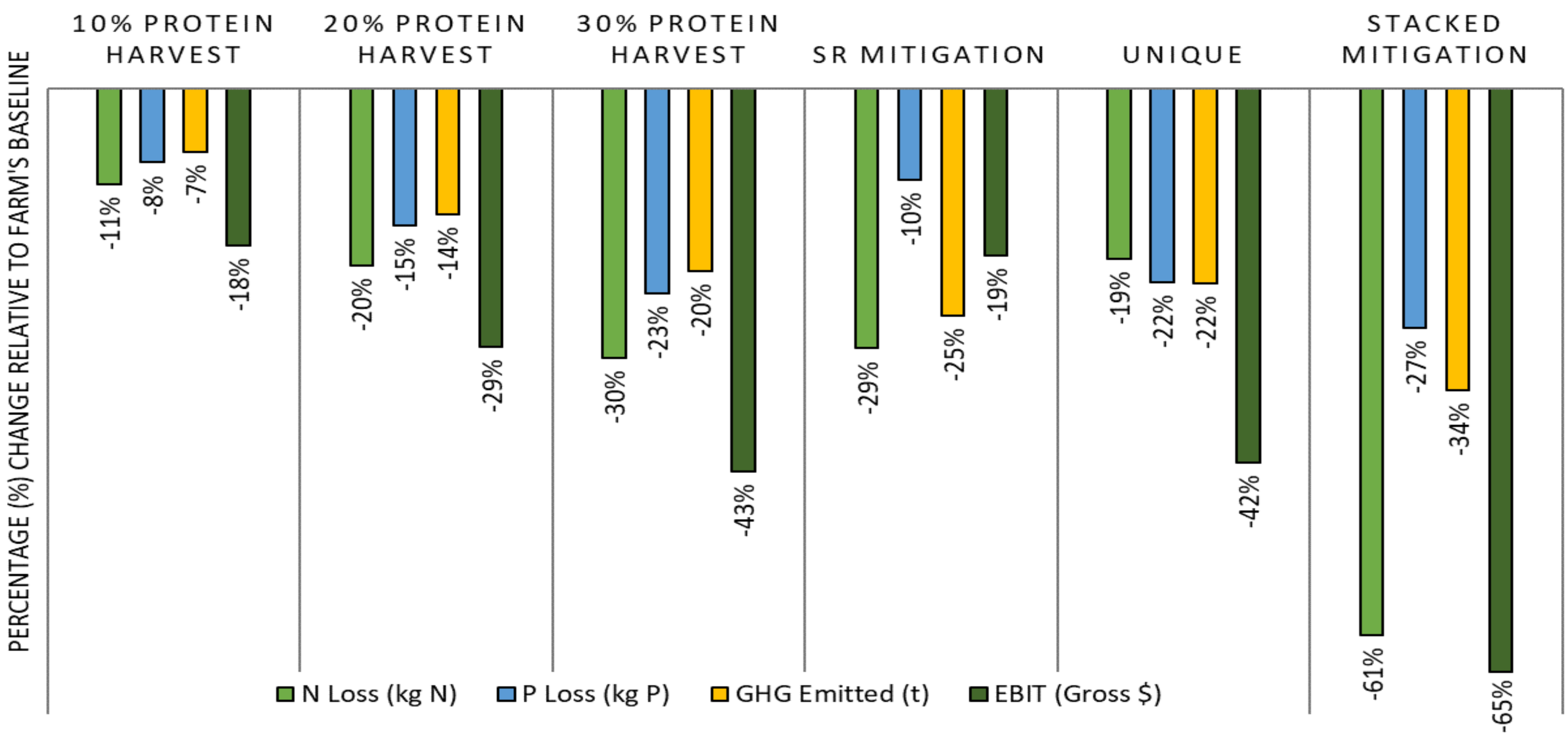


Figure 2. *Percentage (%) change, relative to the Hawke's Bay (Tararua) case study farm's baseline for total nitrogen (N) loss (kg N), phosphorus (P) loss (kg P), greenhouse gas (GHG) emissions (tonnes, t), and gross Earnings Before Interest and Tax (EBIT, $) for the different scenarios modelled using Farmax and Overseer. Scenarios included '**Baseline'** (existing farm system, inputs, and performance), '**10%', '20%' or '30%' of farm area set aside for protein harvest**, **'SR Mitigation'** (use of a lower stocking rate (SR) to mitigate N loss), **'Unique**' (specific scenario catered for this farm only), and '**Stacked Mitigations'** (stacking of mitigations to achieve low N).*

Canterbury | Waitaha

See ***Table 3*** which summarises the main outputs from the modelled scenarios for the Canterbury case study farm.

Economic impact of protein harvesting (10, 20 and 30% Protein Harvest)

- As the proportion of land increased for protein harvest, the number of cows peak milked reduced, physical milk production reduced, and EBIT reduced (***Table 3, Figure 3***).
- An associated effect of increasing land area for protein harvest was a decrease in FTE requirement. For this case study farm, a 20% reduction in staffing levels occurred with 20% of area set aside for protein harvest.
- As the area in protein harvest increased from 10 to 20 to 30%, there was a respective decrease in gross EBIT, relative to Baseline of 17%, 25% and 38%.
- For the 10%/20%/30% scenarios, the average breakeven protein price required to maintain baseline EBIT would be $3.54/kg protein harvested at a $9/kg MS milk price.

Environmental impact of protein harvesting (10, 20 and 30% Protein Harvest)

- Where land-use change included protein harvesting; cow numbers reduced, the physical milk production reduced, and EBIT reduced. In step with this, the environmental footprint measures also reduced relative to the Baseline (***Table 3, Figure 3***).
- Relative to Baseline, the greatest reduction in an N loss to water was 26% with 30% of the farm set aside for protein harvesting.
- Also at 30% protein harvest, P loss reduced by 29% and GHG emissions reduced by 20%, relative to Baseline.
- Under the 'SR Mitigation' scenario, all case study farms were modelled to generate the same N loss to water outcome as the 30% protein harvest scenario, but without any protein harvest and the primary driver being a reduction in stocking rate. For the Canterbury case study, a 13% reduction in cow numbers at peak milk generated a similar (28%) N loss reduction, with a 14% reduction in GHG emissions but no reduction in P loss relative to Baseline.

Impact of alternate mitigations (Unique Scenario)

- For the 'Unique' scenario, the farmer for this property sought to understand (with support of the vested interest group), what was the full environmental footprint taking into consideration the livestock grazing off-farm (mixed-age cows in winter and replacement dairy heifers year-round). Modelling indicated a further 104 ha of land would be required for this scenario, making the total grazed area 372 ha.
- This 'Unique' scenario set aside 30% for protein harvesting and had a reduction of 13% in peak cow numbers relative to Baseline.
- The Unique scenario generated a total N loss to water of 49 kg/ha (up 7% or 3 kg on Baseline), a 43% reduction in P loss, and a 25% reduction in GHG emissions.
- The Unique scenario resulted in a 38% reduction in gross EBIT, relative to Baseline. To generate the same Baseline EBIT the Unique scenario would require a $3.30/kg protein price.

Stacking of mitigation technologies (Stacked Mitigation Scenario)

- The mitigations for the Stacked Mitigations scenario included 30% set aside for protein harvest, a compost barn with cows wintered on-farm, plantain and no N fertiliser on the grazed area.
- The Stacked Mitigations scenario generated the lowest environmental footprint with a 59% reduction in N loss, 29% reduction in P loss, and a 19% reduction on GHG emissions. This also came at the greatest cost to gross EBIT, with a decrease of 49%, relative to Baseline. This required a protein price of $4.16 to breakeven with the Baseline.
- If the SR Mitigated scenario reflected a compliance-based standard, then the Stacked Mitigations scenario would require a protein price of $3.15 per kg of protein harvested to breakeven.
- The Stacked Mitigations scenario presented a substantial change in true N loss with the compost barn enabling nutrients to be captured and cows to be wintered on farm.

Stakeholder scenario preferences

Typically, in this region there was acceptance that environmental emissions must be reduced. Environment Canterbury has had legislation in place for several years for measuring and monitoring nitrogen and water quality in specific catchments and farm systems, with a view to implementing a sinking lid on emissions.

However, the common thread from most of the stakeholders was that the preferable scenario modelled was the SR Mitigation. The driver of this preference was due to the uncertainty and new system requirements of the pasture protein farm systems. There was considerable discussion around the increased risk to farm business's from integrating pasture protein into a farming system. Increased exposure to market, intangible diversification risk and most significantly the skills risk if it required a new learnt skill set that farmers might be currently lacking.

In the "Stacked Mitigation" model, there was the addition of a composting barn to the farm system, as well as the pasture protein harvesting. Composting barns are an incoming technology which show signs of significant positive outcomes in reducing nitrogen losses and improving water quality. But at this stage, composting barns are still not fully understood by all farmers and the correct management of them is critical to their success. Composting barns are expensive to construct, which adds additional capital requirements. These two key facts (new skill requirements and additional capital expenditure) were viewed as strong reasons to not invest at this time.

For these reasons, the SR Mitigation, which focused on known and understood mitigations was the preference, despite there being no potential for alternative incomes.

Interestingly, the farmers consultant expressed a preference for the 20% modelled scenario. This was because it fell into a "sweet spot" for farm systems with staffing levels and efficiencies within the dairy farming business, as well as offering the potential for an alternative income source, which the SR Mitigation alone did not offer. If legislation became more limiting for the farm, or over time when the 30% reduction from good management practises (GMP) is required to be met, then a combination of the 20% pasture protein, with additional stacked mitigations is the direction that could be seen as favourable for farmers. This would likely allow environmental compliance to be achieved and would offer the potential to remain profitable.

***Table 3**. Canterbury case study farm Farmax and Overseer outputs for modelled scenarios of '**Baseline**' (existing farm system, inputs, and performance), **'10%', '20%' or '30%' of farm area set aside for protein harvest**, **'SR Mitigation'** (use of a lower SR to mitigate N loss), **'Unique**' (specific scenario catered for this farm only), and **'Stacked Mitigations'** (stacking of mitigations to achieve low N).*

SCENARIO*	Baseline	10%	20%	30%	SR Mitigation	Unique	Stacked***
Description	*Current Status Quo System*	*10% of grazed area set aside for Protein Harvest*	*20% of grazed area set aside for Protein Harvest*	*30% of grazed area set aside for Protein Harvest*	*- Retain grazed area but de-stock to N loss = 30% incl plantain, N reduction.*	*Whole footprint i.e., includes: - 30% Protein Harvest - Winter off-farm - Youngstock grazing footprint.*	*Stacked mitigations incl: - 30% Protein Harvest - Plantain - Compost barn - No N fertiliser - Wintered on.*
Total Area, ha	266	266	266	266	266	372	266
Grazed Area, ha	266	239	213	186	266	292	186
Protein Harvest Area, ha		27	53	80	0	80	80
Peak Cows	896	807	739	679	793	679	638
Staff, FTE	5	5	4	4	5	4	4
EBIT, $ per ha**	$5,104	$4,246	$3,836	$3,141	$4,500	$3,141	$2,627
EBIT, $/MP ha**	$5,104	$4,726	$4,790	$4,492	$4,500	$4,002	$3,757
N Loss, kg/ha	46	42	38	34	33	49	19
N loss pasture protein	-	5	5	5	-	5	5
P Loss, kg/ha	0.7	0.7	0.6	0.5	0.7	0.4	0.5
GHG, kg/ha	14,950	13,653	12,826	11,988	12,832	11,172	12,140
Protein Harvested, T	0	53	111	158	0	158	158
Breakeven Protein**, $/kg protein**	--	$4.27	$3.04	$3.30	--	$3.30	$4.16

EBIT, Earnings Before Interest and Tax; GHG, Greenhouse Gas emission; MP, milking platform; N, nitrogen; P, phosphorus; SR, stocking rate.
*Milk price used $9/kgMS for all scenarios.
** EBIT is before any protein harvest payment, and EBIT/ MP ha is calculated from the milking platform area.
*** 'Stacked' Scenario definition: the stacking of relevant mitigations but is not directed towards any specific optimal outcome physically or financially.
**** Protein Breakeven for Stacked versus SR Mitigation: $3.15 per kg protein harvested

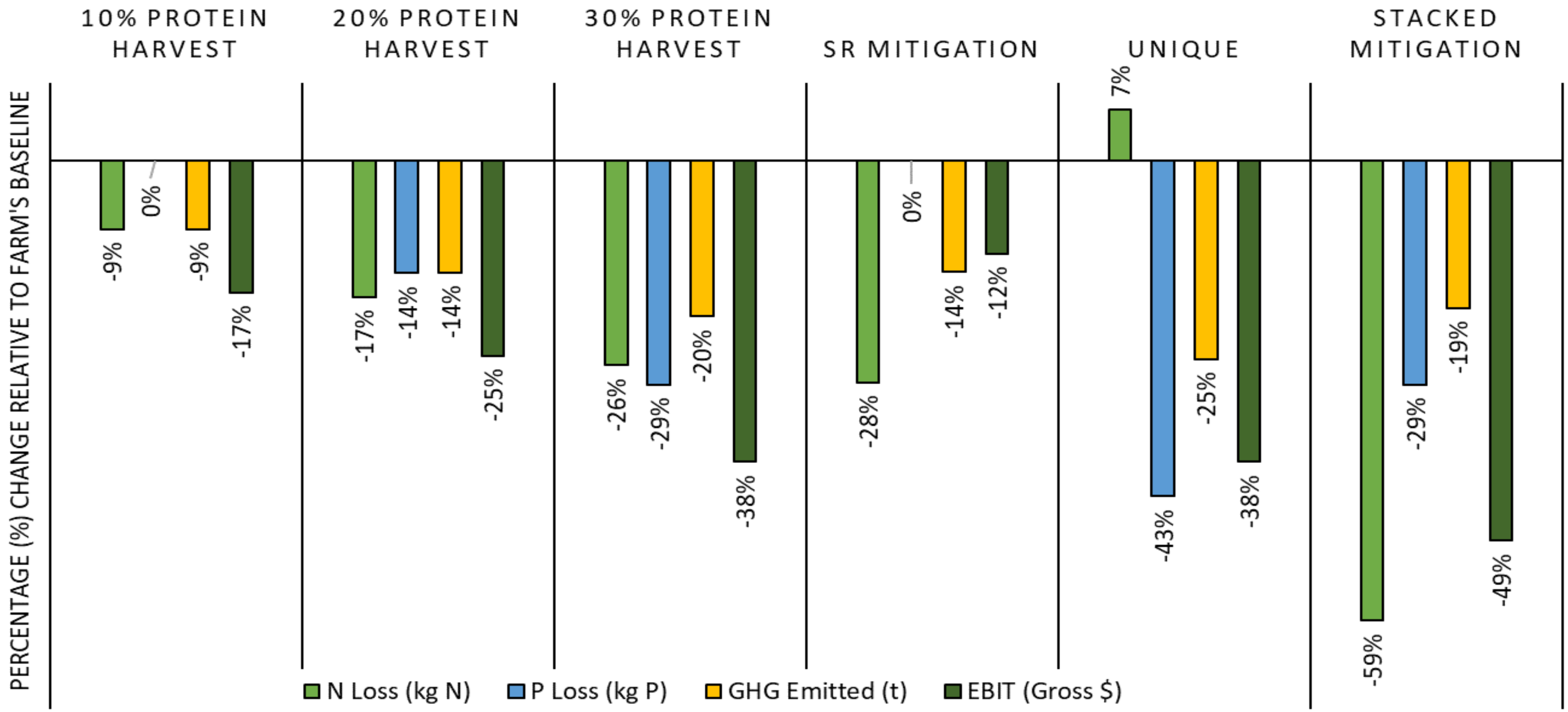


Figure 3. *Percentage (%) change, relative to the Canterbury case study farm's baseline for total nitrogen (N) loss (kg N), phosphorus (P) loss (kg P), greenhouse gas (GHG) emissions (tonnes, t), and gross Earnings Before Interest and Tax (EBIT, $) for the different scenarios modelled using Farmax and Overseer. Scenarios included '**Baseline'** (existing farm system, inputs, and performance), '**10%', '20%' or '30%' of farm area set aside for protein harvest**, **'SR Mitigation'** (use of a lower stocking rate (SR) to mitigate N loss), **'Unique**' (specific scenario catered for this farm only), and '**Stacked Mitigations'** (stacking of mitigations to achieve low N).*

Southland | Murihiku

See ***Table 4*** which summarises the main outputs from the modelled scenarios for the Southland case study farm.

Economic impact of protein harvesting (10, 20 and 30% Protein Harvest)

- As the proportion of land increased for protein harvest, the number of cows peak milked reduced, physical milk production reduced, and EBIT reduced (***Table 4*****, Figure 4**).
- In the modelling of protein harvest, an associated effect was an impact on the number of FTE employed, which reduced. At the point of 30% protein harvest, staffing reduced by 13%.
- For the 10%/20%/30% scenarios, the average breakeven protein price to maintain baseline EBIT would be $5.17/kg protein harvested at a $9/kg MS milk price. This case study has a noticeable higher breakeven point across all scenarios tested. This resulted from excellence in feed conversion efficiency and a high baseline EBIT. Reducing land area to produce an alternate "crop" would naturally drive up the breakeven price.

Environmental impact of protein harvesting (10, 20 and 30% Protein Harvest)

- Where land-use change changed to protein harvesting; cow numbers reduced, the physical milk production reduced, and EBIT reduced. In step with this the environmental footprint measures also reduced relative to the Baseline *(**Table 4Error! Reference source not found.**, **Figure 4***).
- For the SR Mitigation scenario, all case study farms were modelled to generate the same N loss to water outcome as the 30% Light Soil protein harvest scenario, but without any protein harvest and the primary driver being a reduction in stocking rate. For the Southland case study, a 32% reduction in cow numbers at peak milk generated a similar N loss reduction (48%) with a 13% reduction in P loss and a 38% reduction in GHG emissions.

Impact of alternate mitigations (Unique Scenario)

- The unique feature for this farm was to explore the differences between protein harvesting on the light and heavy soils. Significant differences were identified.
    - Protein harvesting on the light soils reduced the stocking of this soil block which delivered the largest change in N loss to water.
    - Where the heavy soils were protein harvested the impact on summer feeding levels was significant, most notably impacting on physical and financial performance at the 30% set aside for protein harvesting.
    - At 30% of light soil protein harvest the models indicated a 45% reduction from baseline in N loss, 25% reduction in P loss and 27% reduction in GHG emissions.
    - The breakeven protein price at 30% of light soils was $4.28/kg MS.

Stacking of mitigation technologies (Stacked Mitigation Scenario)

- The Stacked Mitigations scenario included 20% set aside for protein harvest, all in-calf cows wintered at home, plantain, and no N fertiliser on the Light Soil grazed area. The peak cow numbers in this scenario reduced 18% against the Baseline.

- The Stacked Mitigations scenario generated a similar environmental footprint to SR Mitigation at 49% reduction in N loss, but only a 9% reduction in GHG emissions, and no change in P loss when compared to the Baseline.
- While at 0.8 P loss could be acceptable for the farm, the catchment does have a focus on reducing P loss to water. The higher number of peak cows being one of the key drivers to this outcome. If P loss reduction was a priority, more work would be needed in the scenario.
- The Stacked Mitigations scenario had a reduction in gross EBIT, relative to Baseline, of 39%, and required a protein price of $5.66 to breakeven with the Baseline.
- If the SR Mitigated scenario reflected a compliance-based standard, then the Stacked Mitigations scenario would require a protein price of $1.71 per kg of protein harvested to breakeven.

Stakeholder scenario preferences

The farmer case study in Southland has a progressive and forward-thinking approach to the different alternative scenarios. His opinion was that the main driver for farmers would be "*how many cows do they want to milk*", and then retire the remaining farm into pasture protein production. His comment was that "*if there is an alternative land-use that drastically reduces environmental contaminants and makes money, why would you not change?*". As with all farming systems, there is often a "sweet spot" to be found where the most efficiencies are achieved, and so the farmer believed that if you could find a sweet spot, or balance point, with dairy farming and the pasture protein, that would be the target business system.

It is worth noting that out of all the catchments, Southland has the most uncertainty around future environmental legislation, but potentially the most significant required reductions in farm N and P emissions. This is likely to be helping create the growth/ early adopter mindset as it helps solve the problem.

This farmer felt that the risks or uncertainties around pasture protein supply/ demand and price were a non-issue, as it is something that the dairy industry already faces, and if you have two sources of income (pasture protein and milk) then you are reducing your risk through diversification. It was discussed that the more detail that can be provided to the farmer- modelling, finances, transparent supply chain relationships etc, the more willing a farmer would be. This would allow farmers to better understand any potential risks/ rewards and make educated decisions.

The farmer had the belief that tools like this provide the time and space for farmers to reduce current nutrient loss, while allowing for further tweaks and improvements in the dairy system and additional technology to become available in the environmental contaminants space. The pasture protein offered the potential for a "triple win":

- Environmental – N, P and GHG reductions
- Profitability- potential to keep farms financially viable
- Productivity – The farm produces both milk and pasture protein
    - Same or similar levels of total food produced (as seen in table 5)
    - Fewer cows required
    - Less work and staff required
    - Less stress
        - But without a loss in income as the pasture protein adds to EBIT

***Table 4**. Southland case study farm Farmax and Overseer outputs for modelled scenarios of '**Baseline'** (existing farm system, inputs, and performance), **'10%', '20%' or '30%' of farm area set aside for protein harvest**, **'SR Mitigation'** (use of a lower SR to mitigate N loss), **'Unique**' (specific scenario catered for this farm only), and '**Stacked Mitigations'** (stacking of mitigations to achieve low N).*

SCENARIO*	Baseline	10% Light	20% Light	30% Light	10% Heavy	20% Heavy	30% Heavy	SR Mitigation	Stacked***
Description	*Current Status Quo System*	*10% light soils for Protein Harvest*	*20% light soils for Protein Harvest*	*30% light soils for Protein Harvest*	*10% heavy soils for Protein Harvest*	*20% of heavy soils for Protein Harvest*	*30% of heavy soils for Protein Harvest*	*Decrease SR to point N loss = 30% Protein Harvest on Light Soil*	*Stacked mitigations: - Herd house - 20% light soil Protein Harvest - Winter on - No N on light soils - Plantain*
Total Area, ha	245	245	245	245	245	245	245	245	244
Grazed Area, ha	245	220.5	196	171.5	220.5	196	171.5	245	195
Protein Harvest Area, ha	-	24.5	49	73.5	24.5	49	73.5	-	49
Peak Cows	770	693	617	529	693	617	448	527	634
Staff, FTE	5.3	5.3	5.0	4.6	5.3	5.0	4.6	4.6	5.0
EBIT, $ per ha**	$5,587	$4,683	$3,933	$3,469	$4,638	$3,707	$1,994	$4,071	$3,428
N Loss, kg/ha	43	36	30	24	39	34	25	23	22
P Loss, kg/ha	0.8	0.8	0.7	0.6	0.8	0.7	0.6	0.7	0.8
GHG, kg/ha	14,683	13,501	12,199	10,648	13,344	12,166	9,503	9,110	13,310
Protein Harvested, T		40	81	121	47	93	140		94
Breakeven Protein****, $/kg protein		$5.48	$5.01	$4.28	$4.99	$4.95	$6.30		$5.66

EBIT, Earnings Before Interest and Tax; GHG, Greenhouse Gas emission; MP, milking platform; N, nitrogen; P, phosphorus; SR, stocking rate.

*Milk price used $9/kg MS for all scenarios.

** EBIT is before any protein harvest payment.

*** Stacked definition: the stacking of relevant mitigations but is not directed towards any specific optimal outcome physically or financially.

****Protein Breakeven for Stacked versus SR Mitigation: $1.67/kg protein.

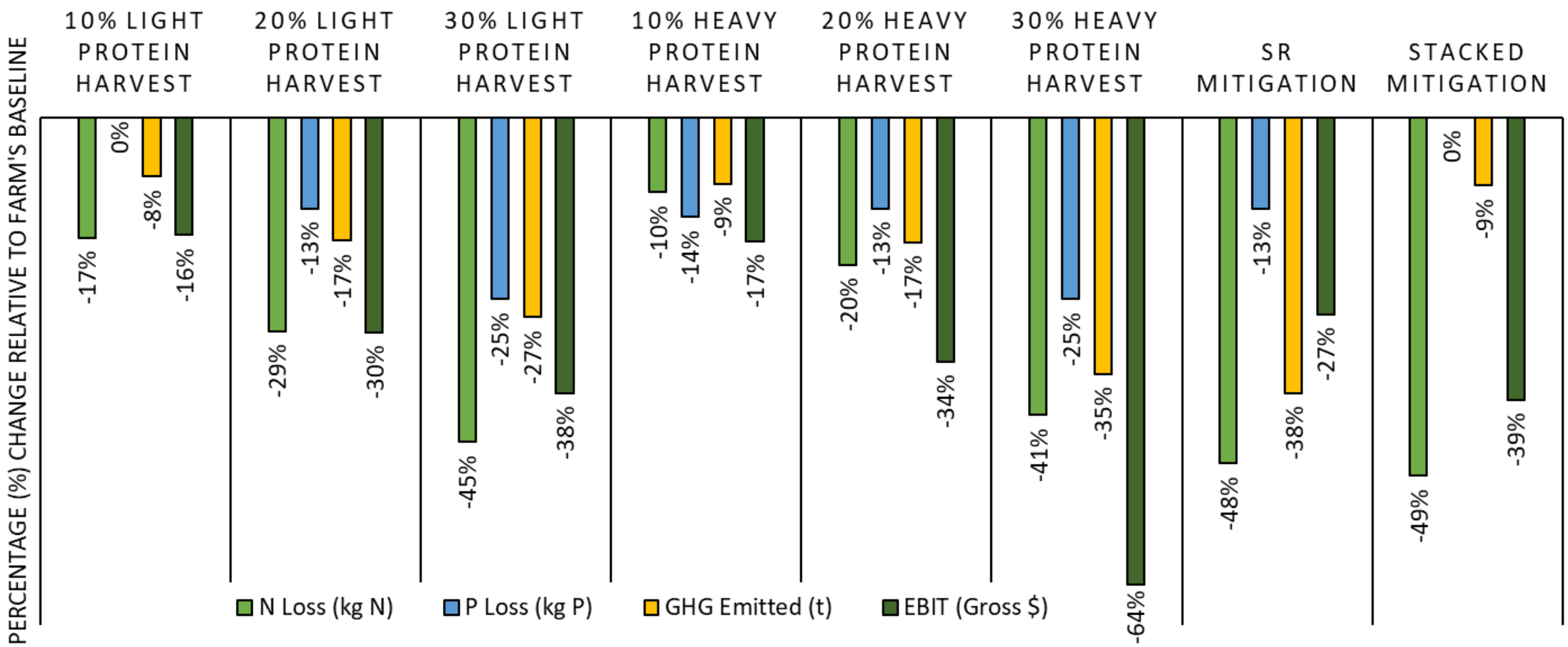


Figure 4. *Percentage (%) change, relative to the Southland case study farm's baseline for total nitrogen (N) loss (kg N), phosphorus (P) loss (kg P), greenhouse gas (GHG) emissions (tonnes, t), and gross Earnings Before Interest and Tax (EBIT, $) for the different scenarios modelled using Farmax and Overseer. Scenarios included '**Baseline'** (existing farm system, inputs, and performance), '**10%', '20%' or '30%' of farm area set aside for protein harvest**, **'SR Mitigation'** (use of a lower stocking rate (SR) to mitigate N loss), **'Unique**' (specific scenario catered for this farm only), and '**Stacked Mitigations'** (stacking of mitigations to achieve low N.*

Collective Farm Analysis

Common trends across all three case study farms included:

- Farm systems and management adaptation of the protein harvesting initiative will be significant. As an example of this, we have identified that to set aside 30% of the farm for protein harvest would result in a 25% to 40% reduction in stocking rates. As the area in protein harvest increased the number of cows farmed reduced.
- For N loss to water, as the area in protein harvest increased the N loss to water reduced. The modelled outcomes from the case study farms suggests:
    - 10% of the farm in protein harvest will reduce N loss by 9% to 17%.
    - 30% of the farm in protein harvest will reduce N loss by 26% to 45%.
    - Where farmers opted to stack mitigations (EBIT drivers being set aside), and including protein harvesting, the range in N loss reduction was 49% to 61%. It should be noted that stacked mitigations included the assumption of herd housing and compost barns. The combination of protein harvesting and compost barns had a substantive impact on nutrient loss to water.
- For P loss to water, as the area in protein harvest increased the P loss to water reduced. The modelled outcomes from the case study farms suggests:
    - 10% of the farm in protein harvest will reduce P loss by 0% to 14%.
    - 30% of the farm in protein harvest will reduce P loss by 23% to 29%.
    - Where farmers opted to stack mitigations (EBIT drivers being set aside), and including protein harvesting, the range in P loss reduction was 0% to 29%. The baseline level of P Loss being already below 1.0 on all three farms meant that small changes (0.1) in P loss could drive a high percentage change but not all scenarios actually changed their P loss.
- Greenhouse gases will reduce, but not all technologies that reduce nutrient loss reduce GHG emissions. In this case, compost barns and cow housing are at best neutral.
    - At 10% of farm in protein harvest the GHG emissions reduced 7% to 9%.
    - For 30% of the farm in protein harvest the GHG emissions reduced 20% to 35%.
    - The GHG emissions varied more significantly across the farms in "Stacked" scenarios. There was between 9% and 34% lowering of GHG emissions where the composting barn inclusion appeared to have a "detrimental" effect. Confidence in these numbers is low as the science and knowledge around composting barns influence on GHG emissions requires further study.
    - At a high-level view, He Waka Eke Noa-announced pricing levels where mitigation through protein harvest would generate savings in GHG levies in the order of $10 to $20 per hectare. Over time, if GHG levies increase this benefit will accordingly increase.
- Farm profitability ($EBIT/ha) reduced as the protein harvest area increased, but that was prior to payment for the harvested protein.
- For our case study farms, a protein price in the order of $3 to $6 per kg of protein harvested would generate an EBIT position equivalent to Baseline (i.e., current farm operating status).
- Only where mitigations are stacked can we consistently see our case study farms in a position to meet regional council expectations for nutrient loss to water.

The impact of a change to 'Baseline'

This report has been prepared from the perspective that the current farming system represents the baseline for environmental emissions. Any change is then relative to current performance. But if the farm was required for compliance or farmer objective reasons to have a different level of emissions then change might be measured against a different standard.

To advance this discussion by way of an example would be if our case study farms had a compliance requirement to deliver a lower than current N loss to water. To deliver on this expectation, the farm might choose to simply reduce the stocking rate as per the modelled "SR Mitigation" and thereby lower profit and emissions. In which case, the breakeven protein price would drop because the baseline had changed.

In theory, the modelling work in this report suggests a farmer would be financially better if they adopted a land-use change such as protein harvesting to offset the EBIT reduction to meet emissions targets, as compared to just lowering stocking rate. Extending the example, further analysis suggests that regional council compliance requirements could drive an interest in changing the mix of land use.

Interestingly, when this information was presented to the Vested Interest Group their tendency was towards a lowering of stocking rate without land-use change because of the complications associated with the stacked mitigation farm system.

Sensitivity Analysis

During meetings with the Vested Interest Group's a common conversation was the risk associated with adopting protein harvesting as a land-use change. Who would be taking the risk and what might the relationships look like? Other questions included whether the farmer would be selling a commodity or if the processor would be leasing the land (and therefore minimising farmer risk).

Where farmers are using known technology and their skills to produce milk, meat and fibre, they are prepared to accept the risk of price and yield variability. For a harvest technology and market yet to be proven, our case study farmers were circumspect about taking all the risk on yield and price.

Our sensitivity analysis was based on pasture protein as a farmer-sold commodity, but future processors might need to consider the impact this might have on adoption.

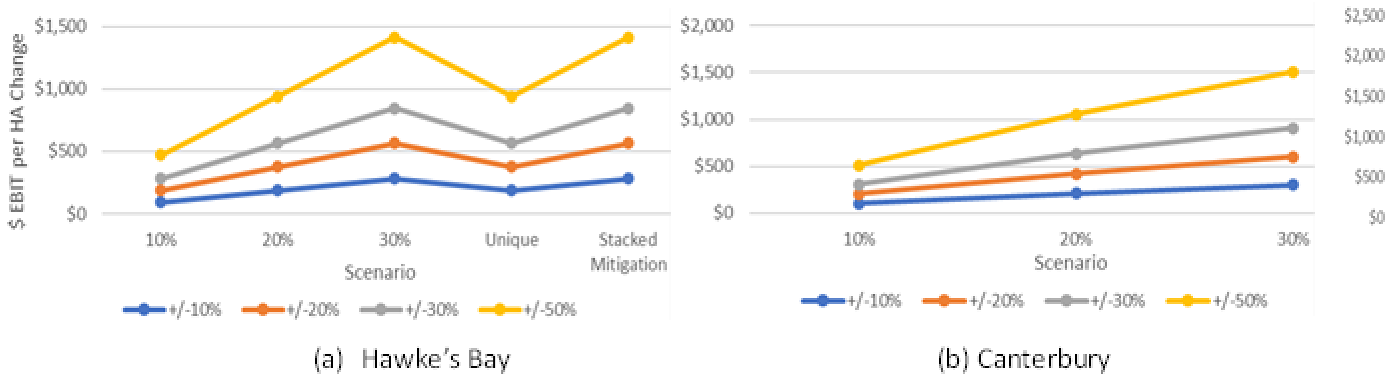
BakerAg generated sensitivity tables and graphs on the following three variables.

1. **Milk price (*Figure 5*);** where milk price changed the breakeven price for protein would change. What is the relationship in trend and quantum?

Protein yield (

2. ***Figure 6*);** where we know the quantity of crude protein in pasture changes through the season. If protein yield changes, at a given price for protein, then the farmers profitability measured as EBIT could be at risk. What is the relationship with changing protein yield?

Protein price (*This analysis has been done on case study farms located in (a) Hawke's Bay, (b) Canterbury and (c) Southland.*



3. ***Figure 7*); what would happen to the farm businesses EBIT if farmers accepted a breakeven price, but this price was prone to change?

How does the milk price influence the breakeven price for harvested protein?

- Our data (***Figure 5***) suggested that as the milk price increased the breakeven protein price would need to be higher to match the change in EBIT.
- At a $9/kg MS price, a breakeven protein price at the lower end would need to be at least $2 - $3/kg, whereas at the higher end of farm performance and milk price, the breakeven protein price would need to be in the range of $5 to $7 per kg.
- In a free market, higher profit farmers might be less inclined to adopt protein harvesting compared to a neighbouring lower-profit farms.
- Where the area in protein harvest was optimal, the breakeven protein price would be less. This relationship did not alter with a change in milk price.
- If the milk price and breakeven protein price were not connected, then those years with a higher milk price, farmers would be expected to reduce the area on offer for protein harvesting. Conversely, this might apply where the milk price is low. This being in the absence of drivers such as nutrient loss compliance.
- Where mitigations are stacked, farmers might still look to have the versatility to alter the land area in protein harvest according to milk and protein price.
- Where stacked mitigations enabled farmers to sustain a higher level of profitability, the breakeven milk price would need to be higher to match this "optimal" scenario.

How does the protein harvest yield affect EBIT?

To generate this sensitivity analysis, it was assumed the farmer would receive the highest breakeven protein price determined in the farm system analysis. The EBIT change was then a function of yield (

- ***Figure 6***).
- A 10% change in yield could alter farmer EBIT by $100 - $400 per ha. The higher the farm EBIT from milk the higher the risk of protein yield change.
- A 30% change in harvested protein could impact EBIT by $600 to $1,300 per ha.

- If the protein yield was at the farmer risk (i.e., given a fixed protein price) then the sensitivity analysis indicates a clear relationship with EBIT. More protein results in a higher EBIT, whereas less protein results in a lower EBIT.
- This might suggest farmers with a reliable protein yield, typically linked to soil moisture, might be more inclined to accept the risks associated with protein harvest.
- Conversely, a processor might be reluctant to locate a processing plant in a region/district with variable crude protein yields.

Sensitivity to protein price

What would happen to farm business EBIT ($/ha) if the price of protein was to vary? This sensitivity test used the breakeven protein price for each scenario, then altered this by 10%, 20%, 30% and 50% to determine the impact (plus or minus) on EBIT (*This analysis has been done on case study farms located in (a) Hawke's Bay, (b) Canterbury and (c) Southland.*

Figure 7).

- As the protein price changed, EBIT followed.
- A 10% change in protein price might change farmer EBIT by $100 - $150 per ha.
- A 50% change in protein price might change farmer EBIT by $1,400 to $2,000 per ha.

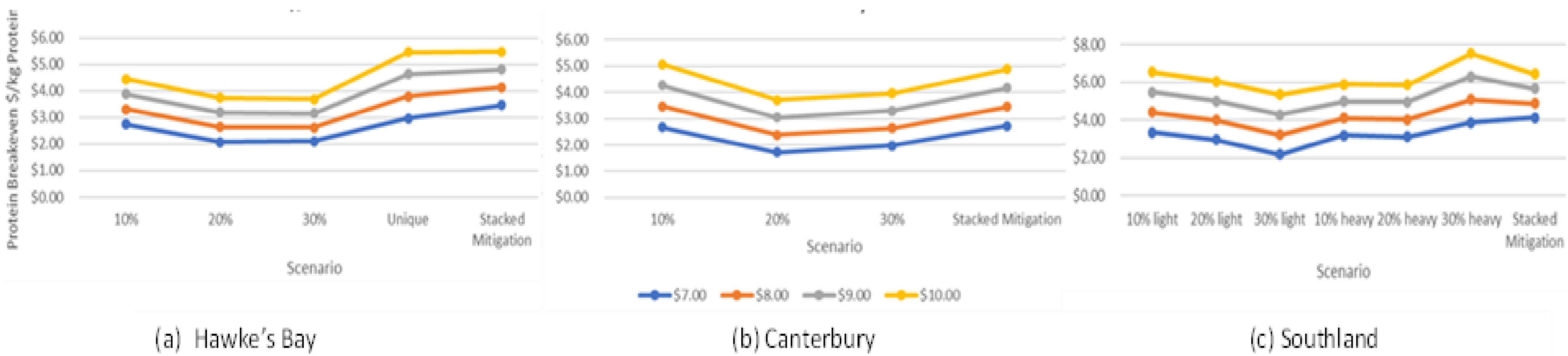


Figure 5. Sensitivity to milk price: *Modelling of different protein harvesting scenarios and the influence that milk price ($7, $8, $9, and $10/kg MS), can have on the breakeven price for harvested protein ($/kg protein) for the case study farms located in (a) Hawke's Bay, (b) Canterbury and (c) Southland.*

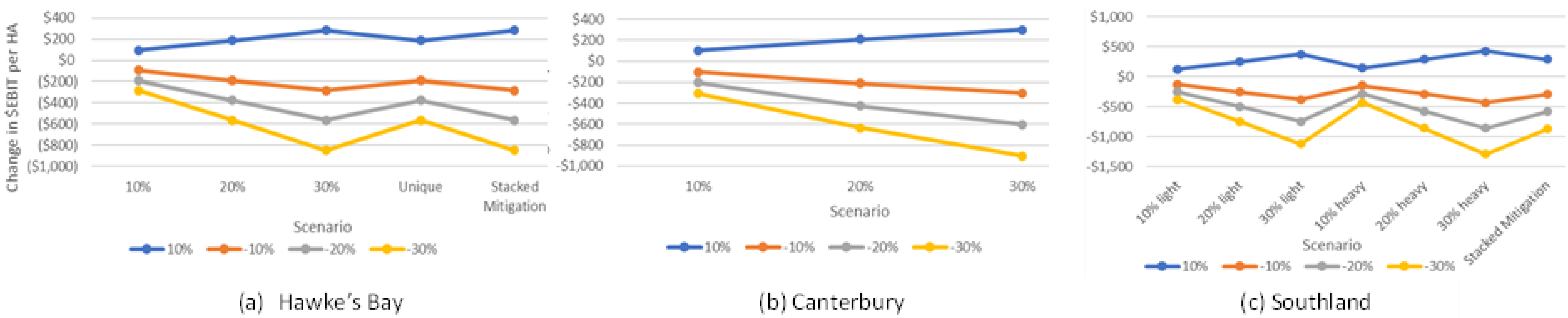
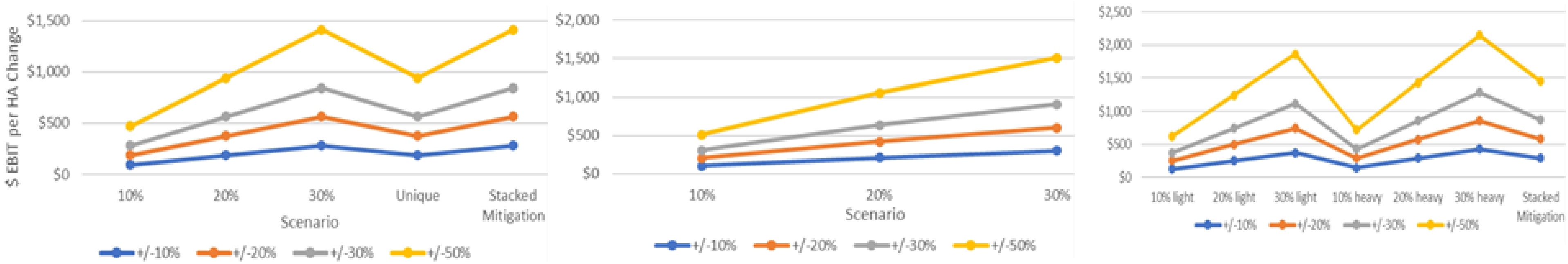


Figure 6. Sensitivity to protein yield: *Modelling of different protein harvesting scenarios (10, -10, -20, -30%) to determine the impact that a change protein yield would have on farm business EBIT (Earnings Before Interest and Tax, $/ha) Note: if the farmer was taking all the risk associated with yield variability. This assumed the farmer would receive the highest breakeven protein price determined in the farm system analysis. This analysis has been done on case study farms located in (a) Hawke's Bay, (b) Canterbury and (c) Southland.*



(a) Hawke's Bay (b) Canterbury (c) Southland

Figure 7. Sensitivity to protein price: *Modelling of different protein harvesting scenarios on the influence on farm business EBIT (Earnings Before Interest and Tax, $/ha) if the price of protein was to vary (+/- 10, 20, 30, 50%). This sensitivity test uses the breakeven milk price for each scenario, then alters this by 10%, 20%, 30% and 50% to determine the trend in changing (plus or minus) on EBIT. This analysis has been done on case study farms located in (a) Hawke's Bay, (b) Canterbury and (c) Southland.*

Stakeholder Consultation

A key part of this Think Piece was the consultation process of understanding how this technology would sit with end users and custodians of the land. It became very clear that the drivers for land-use change were varied and quite individual.

The concept of Kaitiakitanga with our stakeholder/consultation group is embedded in a healthy fashion but there remained a concern for the unknown that is a common theme for farmer hesitancy around land-use change. It came through that adoption will be a function of confidence in the business of protein harvesting, clear understanding of the environmental advantages, and faith that de-intensifying the farm will mean the farm, farming family and community will be no worse for the change.

We did see in two of the three stakeholder groups active discussion around the option to simply reduce stocking rates to reduce the environmental footprint, rather than adopt a more complicated or capital-intensive farm system with protein harvesting. This flags a potential outcome from farmers in response to the “hesitancy” described above.

In one of the stakeholder groups, the case study farmer was seeking alternative, innovative changes to the farm system which would provide greater future resilience. This was about keeping up profitability while reducing the environmental footprint. This farmer was strongly interested in the stacked mitigations approach taken as part of this study. This scenario provided a pathway to change the farm system, retain the core dairy farm but pick up on a land-use change that gave a viable return with a substantive reduction in gross emissions.

The Canterbury case study group encouraged a scenario for modelling that looked at the wider level of emissions, i.e., inclusion of the farm livestock grazed away from the milking area. When presented with the results, where even higher emissions were reported, they were not surprised. This wider footprint is arguably already considered where the support or dry stock farmland submits their emissions statement for compliance. However, the stakeholder could see that reduction of emissions on the milking area will have implications for farm policy and systems engaged on the supporting land.

We identified that mana whenua will need to have awareness that changing land-use and de-intensifying farms would reduce gross emissions to land, water and air by up to 60%, but this is also likely to reduce the number of people engaged in day-to-day business of farming. This could be as high as a 20% reduction, or 1 person in 5 no longer required for the day-to-day running of the business.

For mana whenua, this report flags the double-edged sword nature of de-stocking and diversifying land use through protein harvesting. Improvement to the environment with reduced emissions and de-intensifying farms will be a strong positive. However, such changes come with the risk of reducing the number of people living off the land and contributing to the community.

A processor perspective could not be captured in our stakeholder consultation. For this reason, BakerAg refers this to the section on “What are the next steps” where the relationship between farmer and processor will require more work.

WHAT ARE THE NEXT STEPS? | He aha ngā hikoi ko atu?

This project has demonstrated how a farmer could integrate pasture as crop for protein harvest into existing pastoral grazing systems. By engaging with farmers, stakeholders, iwi, and the wider farming community, we have provided an awareness of the opportunities presented through three case study farms, as summarised in this report.

For farmers considering land-use change, and more specifically protein harvesting, this report should provide insights into the implications of change. There are insights for the strategies and policies that need to be formed around protein harvesting.

The results presented here will also inform further investment in developing the processes, products, applications, and markets enabled by this technological revolution. More specifically, processors of harvested protein might use this report to better appreciate the implications for farmers around pricing and drivers for adoption.

From the farmer perspective, it was evident of the view that this technology could be seen as 'invasive' i.e., requiring significant system change. While being an innovative opportunity, farmers see the risk/uncertainty of the technology as a red flag for their business as protein harvest and processing through to sale as a food ingredient is yet to be proven. For protein harvesting to become an accepted practise worthy of adoption, farmers will need to see a successful commercial scale farmer-to-processor-to-market-to-consumer story that celebrates the physical, financial, and environmental outcomes. Along with support from all sectors of the community.

BakerAg is aware that full vertical integration is being researched for this initiative. Plant & Food along with other research groups are researching the requirements to scale-up and commercialise the process. With this commercialisation potential, processors are looking to find and build markets for this food ingredient which will take time but would appear to have global appeal. An end-to-end view of how protein harvesting will operate is needed to realise this opportunity. It will be an innovative food grown by innovative farmers utilising the initiative developed by pioneering researchers.

This project focussed its analysis on the area farmed for milk production. There was a part investigation into the off-farm emissions associated with dairy livestock grazing in Canterbury, but the wider implication of protein harvesting on the catchment, the community, other related farming systems and regional economic consequences of a partial conversion from ruminant grazing to harvesting pasture for food protein should be part of the next steps.

Table 5 below summarises our findings where the milksolids produced for the baseline (current situation) was contrasted with the outcome if stocking rate was reduced to lower gross emissions and then contrasted to total "food" produced in the stacked mitigation where land use change includes protein harvesting.

Our study identified that reducing the stocking rate without alternate land use as a mitigant reduced milk/food production. Reducing farm emissions through a strategic land-use change as exampled by protein harvesting has the potential to increase the food ingredients produced while reducing the environmental footprint to an equivalent standard (Table 5). This was an incidental finding and not core to our study but could signal a useful insight for future work.

Table 5. *A Comparison of Total "food" Production from the Case Study Farms for Baseline, SR Mitigation and Stacked Mitigations Scenarios (Hawke's Bay, Canterbury and Southland)*

Data (annual basis)	Hawke's Bay	Canterbury	Southland
Baseline			
kgMS Produced / HA	1060	1507	1655
Kg Protein Harvested / HA			
Total kg "food"	1060	1507	1655
SR Mitigation			
KgMS Produced / HA	852	1355	1153
Kg Protein Harvested / HA			
Total kg "food"	852	1355	1153
Stacked Mitigation			
kgMS Produced / HA	712	1080	1364
Kg Protein Harvested / HA	515	595	385
Total kg "food"	1226	1675	1749

- Tararua: baseline 1060 kg/HA Mitigated via SR reduction 852 kg/HA Stacked Mitigations 1,226 kg/HA
- Canterbury: baseline 1507 kg/HA Mitigated via SR reduction 1,355 kg/HA Stacked Mitigations 1,675 kg/HA
- Southland: baseline 1,655 kg/HA Mitigated via SR reduction 1,153 kg/HA Stacked Mitigations 1,749 kg/HA

APPENDIX 1 MODELLING ASSUMPTIONS

Modelling Assumptions for Farmax

Farmax software has been used to model the physical and financial implications of protein extraction from the case study farm.

The model is well validated with historical information which has been adapted to generate a long-term baseline, based on the last four-years average profile. This long-term baseline has been used in this report to form the basis of alternative scenarios for comparison (Baseline scenario).

The Farmax model for the case study farm evaluated and compared the following scenarios with the current status quo baseline.

- High Protein Extraction (see protein extraction and cake assumptions below) – 10%, 20% and 30% of the farm area dedicated for a twelve-month period to protein extraction.
- After consultation with the farmer and vested interest group further Farmax (& Overseer) modelling was done to determine a mitigation through lower stocking rate (SR) with protein harvesting.
- Further scenarios were modelled to determine the outcome for a unique circumstance for each case study farm (Unique scenario), and a Stacked Mitigations system with stacked mitigations (Stacked Mitigations scenario).
- The residue of the protein harvest process is termed "cake", which is digestible by ruminants and so provides an opportunity for it to be returned to the farm and fed back into the farm system.

In effect, there are at least six data points to compare against the Baseline.

To model these scenarios in Farmax with each of the protein extraction areas, the following critical assumptions or methodologies have been used:

- Stocking rates were adjusted downward to compensate for having less pasture available to graze.
- The default assumptions were that milk production per cow would be at Baseline levels. However, there was a slight decline in scenarios with a higher proportion of cake which has a metabolisable energy (ME) value below pasture and grain (***Table 6***).
- The cake could be stored as a silage-type product which could be fed when required rather than when it was processed as a direct cut feed.
- Cake was mainly fed to dry cows in the winter and at the shoulders of the season to milking cows.
- When adjusting the farm system, care was taken to match seasonal pasture covers to the baseline and ensure the scenario was both feasible (Farmax definition) and sustainable, which meant pasture covers and livestock numbers were constant at opening and closing of the season.

Modelling Assumptions for Overseer

Overseer FM software has been used to model the environmental implications of the protein extraction. Overseer was not testing to see if the scenario was feasible, rather, it evaluated the environmental implications of the scenario. Farmax determined if the scenario was feasible.

The Baseline models were developed as an "average" farm system from the previous year's results. Both the Canterbury and Hawke's Bay farms were developed as an average of the past four years, with adjustments made for on-going planned management (i.e., 190 kg N limits), and also adjusting for any outlying practises. The Southland farm was modelled on the 21/22 season, as that was the first season the farmers were running the farm. Based on discussions with the farmer, that was a sustainable long-term system which was planned to continue to be replicated. All baseline models have been adjusted to reflect the long-term average farm system, as modelled in Farmax software, and includes soils, climate, stock numbers, milk production, fertiliser use and supplements (both harvested and imported).

The long-term Baseline model was then adjusted to reflect the Farmax files to evaluate several different scenarios, based on a percentage of the farm being used for protein extraction. Note - the area modelled for protein harvest and grazing was as based on the Farmax model. The Overseer Baseline files used the same total farm area for each scenario by Farmax and Overseer and, as we are comparing results, the results are considered valid. The exception was the Canterbury 'Unique scenario' where the area of land required to winter dairy cows and graze replacement livestock was treated like a land extension. In this scenario the land area required to support the young stock and wintering dairy cows was calculated for each pasture protein scenario- 10%, 20% and 30%. The same base system was replicated, but scaled down to meet stock requirements. This resulted in the same emissions/ha, but a decreasing total emissions as pasture protein increased. This total was then "added" back onto the milking platforms emissions, to get an understanding of the whole farm business.

The protein extraction area was modelled as cut and carry, permanent ryegrass and white clover pasture. Only the Canterbury dairy farm had the protein pasture under irrigation. A harvest yield was consistent with the pasture production of the baseline model for each farm.

The area harvested was adjusted in accordance with the scenario modelled; 10%, 20%, 30%, SR mitigation, Unique and Stacked Mitigations. The nutrients required to sustain the level of yield on the protein harvested area was assumed to be the same as the baseline fertiliser nutrients applied. Animal numbers, milk production, supplement feeding (both imported and harvested) have been adjusted with each model to align with the Farmax Modelling.

Protein Extraction and Cake Assumptions

The protein extraction process involves recovering proteins (and other compounds) from the pasture into a juice fraction, which is taken off farm, and a residual cake, which is retained as a feed. See ***Table 6*** which describes the assumptions made of the protein cake and juice.

The degree to which protein is extracted from pasture can vary. It was elected to use the higher end of protein extraction which assumed maximum use of the technology to remove plant-based proteins.

Table 6. *Modelling assumptions made for perennial ryegrass pasture, protein cake, and protein juice data with high versus low protein extraction scenarios for farm case studies (Hawke's Bay, Canterbury and Southland).*

Data (annual basis)	Hawke's Bay	Canterbury	Southland
Perennial ryegrass pasture			
Pasture dry matter (DM) yield (T DM/ha)	13	15	13.5
Protein of pasture DM pre-extraction (%)	22%	22%	22%
Protein extraction (%)	60%	60%	60%
Protein yield (kg/ha)	1,716	1,980	1,782
Protein cake			
Cake DM retained from Pasture (kg DM/ha)	5,200	6,000	5,400
Cake DM yield (t DM) as a % of farm area			
10% of farm	84	162	137
15% of farm	165	319	278
20% of farm	251	483	377
Cake Residue Metabolizable energy (MJ ME/kg DM)	10.2	10.2	10.2
Cake Residue Protein (%)	10.7	10.7	10.7
Protein juice			
Juice protein yields (t raw protein) as a % of farm area			
10% of farm	27	53	40
15% of farm	55	111	81
20% of farm	82	158	121

Further assumptions used were:

- The perennial ryegrass cake and juice yield data was provided by Plant & Food Research and are based on processing trial work which used lucerne as a model pasture. It was assumed that the yields for lucerne would also be applicable to ryegrass.
- Ryegrass crude protein levels were standardised and used for this project although data from Hills Laboratories for the three seasons (19/20-21/22) supported the assumption of 22% protein.
- Cake and juice ME values were determined by Plant & Food Research using predicted cake compositions and the calculations detailed in National Research Council (NRC, 2001).
- The protein extraction crop (using 10% 20% and 30% of farm area) was established perennial ryegrass and white clover. The land used for the protein extraction crop came out of the cow grazing area and was 100% dedicated to the extraction process for twelve months, after which it was returned to milking cows.
- There was no cultivation or re-seeding of pastures prior to, or after extraction.
- The protein harvesting / extraction process was rotated around all suitable land on the farm over the course of several years.
- Stock reductions were less than grazing area reductions due to cake being fed back to stock.
- The financial assumptions used to calculate EBIT were based on the following:
    - A milk price of $9.00/kg MS was used.
    - Farm operating costs were based on actual costs from each case study farm through financial analysis of a previous financial year. Per unit costings at current market rates

were used for variable costs and included in Farmax for reporting the financial effect of changing farm systems.
    - Labour costs did vary where the change in cow numbers warranted a drop in staffing. The exception to this was the Hawke's Bay farm which by farmer stipulation was not negotiable. The Māori farm trust has an intent to train people and reducing staff numbers was not for consideration.
    - The only cost provision associated with protein harvesting was a $50/t cost applied to the protein cake to provide for storage and feeding out costs.
- All costs associated with the protein extraction (such as fertiliser additional to standard maintenance requirements, labour, harvesting and transport, overheads) were a cost to the processor and have not been included in the Farm EBIT.
- Nitrogen costs varied with the rate of application and maintenance fertiliser applications were assumed to remain static.

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