Ministry for Primary Industries
Manatū Ahu Matua

Evaluation of profitability and future potential for low emission productive uses of land that is currently used for livestock
SLMACC Project 405422

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Prepared for MPI
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Contents

Page

1 Executive summary

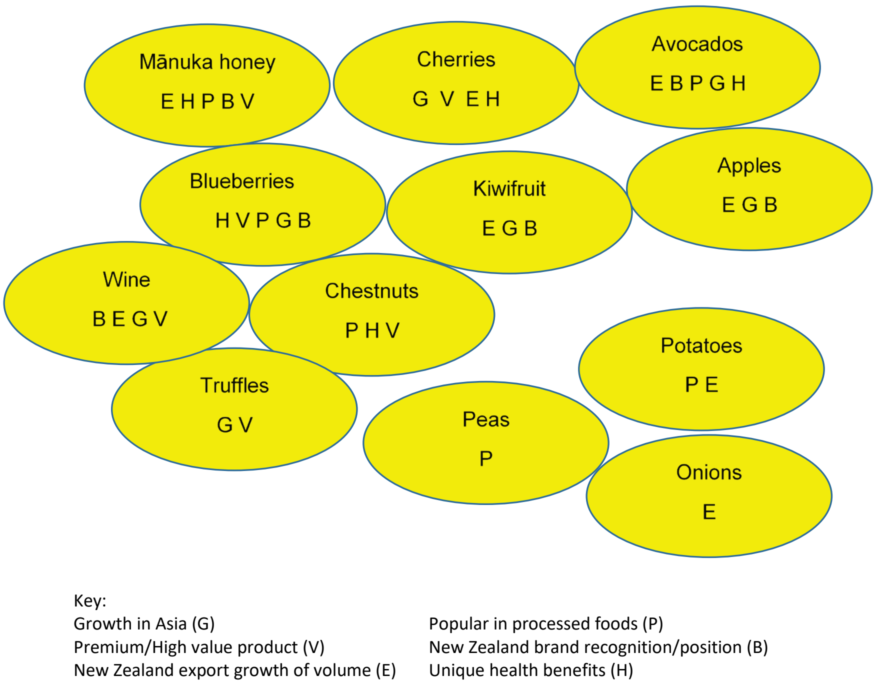
Agriculture accounts for 48% of New Zealand's gross greenhouse gas (GHG) emissions with nearly 75% of the emissions coming from methane (CH_4) production from ruminant animals (enteric-CH4) (Ministry for the Environment 2020). Changes to alternative low biogenic greenhouse gas emission (BGE) land uses is an option for reducing national GHG and meeting national reduction targets for overall GHG and CH_4. However, large land use change will have implications for New Zealand's economy. To address this, replacing profitable livestock with alternative profitable land uses would potentially overcome this concern.

This report describes work conducted in the Ministry for Primary Industries (MPI) Sustainable Land Management and Climate Change (SLMACC) Project 405422 - *Evaluation of profitability and future potential for low emission productive uses of land that is currently used for livestock*. The aim of the project was to evaluate potential agricultural land uses (including crop and forest options) that could provide an alternative to livestock production based on market growth opportunities, GHG footprints and suitability for current climate and soil conditions.

Our approach was to produce a framework whereby we could consider the trade-offs between BGE and profitability. Firstly, we identified potential high value crops that could increase their production areas based on an assessment of market opportunities. Secondly, we assessed their growing requirements and identified where they might grow throughout New Zealand. Then, for each crop we estimated potential BGE and ranges in profitability; we also considered the role of forestry in emission reductions and as a profitable land use. Finally, we considered CH_4 emissions reduction scenarios where these alternative land uses might replace livestock. Through the various stages of the work we ground-truthed our findings with stakeholders and industry experts.

1.1 ALTERNATIVE HIGH VALUE CROPS

We identified 12 crops to evaluate what we considered are either high value (profitability per hectare) or have potential for export growth. Many of these are already key export crops or products such as wine and kiwifruit with large export value, but others such as truffles, cherries and chestnuts currently have little or limited export value but have the potential for growth.



The 12 crops or products selected for evaluation.

1.2 GROWING SUITABLITY ASSESSMENT

We developed and tested sets of growing suitability rules and produced suitability maps for each land use (including plantation forestry) based on climate and land attributes, building on literature and advice from researchers and industry experts.

1.3 ESTIMATING BIOGENIC GREENHOUSE GAS EMISSIONS

We followed the Intergovernmental Panel on Climate Change (IPCC) approach (IPCC 2006) for estimating land use BGE. For most of these crops we had to gather new information about their fertiliser, lime and residue management to estimate their emissions. This was collected by a combination of literature and industry expert sources. All the crops we assessed had much lower BGE than livestock because of the dominance of enteric-CH_4 produced by ruminant animals in New Zealand agricultural BGE. We did not consider the non-BGE associated with production, such as fossil fuel emissions. We also did not estimate carbon sequestration by crops.

1.4 ECONOMIC ANALYSIS OF GROWING SELECTED CROPS

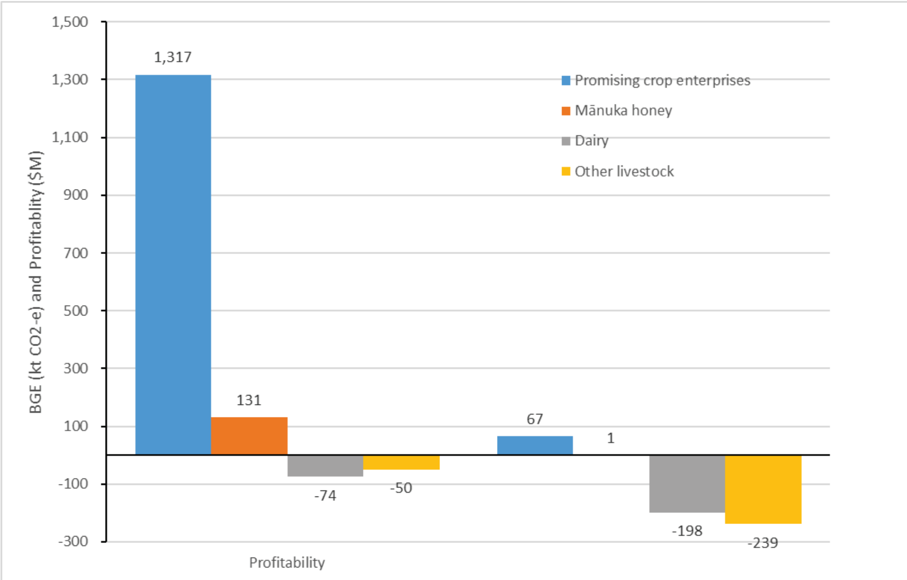
For each land use, we used literature and industry experts to estimate both the cost of establishing the new crop and the profitability. Financial data were sparse and often with large uncertainty. Per hectare, the selected crops were more likely to be more profitable than livestock.

1.5 ASSESSMENT OF OPPORTUNITIES FOR REPLACING LIVESTOCK WITH ALTERNATIVE PROFITABLE LAND USE

We used a spatial modelling and optimisation framework tool (LUMASS) to explore how replacing land area with high value crops would affect BGEs and profitability with scenarios based on optimistic growth projections for the selected crops for 2030 and 2050. These dates were selected as they are tied to New Zealand-specific emission reduction targets for 2030 and 2050 for enteric CH_4 and carbon zero. Time frames of 10 and 30 years are also realistic for significant land use changes to occur, especially considering the time between establishment and time for some crops to become profitable. Even with an optimistic growth scenario land use change was relatively small (about 200,000 ha).

Land use change of this size had a relatively small impact on reducing total CH_4 emissions to meet future CH_4 reduction targets.

In a scenario based on allocating the crops and mānuka trees onto the best-suited land, the net reduction in BGE was 370 kt carbon dioxide equivalent (CO_2-e), of which 323 kt CO_2-e was from enteric CH_4. This is the equivalent of a 1.0% reduction in total BGE emissions from agriculture, or 1.2% of the enteric CH_4 emissions.



Estimates of net changes in biogenic greenhouse gas emissions (BGE) and profitability from an optimistic scenario **of doubling the area of selected crop and mānuka plantings replacing existing livestock (dairy and other) land** across New Zealand. The land use allocation was based on maximising the most suitable land for the selected crops.

Alternatively, land change that maximised the emission reduction can have larger effects on BGE and profitability as most of the change would occur on intensive dairy land. Doubling the area of our selected crops in Canterbury reduced our estimates of total BGE by 460 kt CO_2-e or 7.1% of the region's emissions. The effects across regions varied. In Waikato, the doubling of the selected crops only reduced emissions by 1.6%. Whereas replacing the full range of livestock with the selected crops will lead to an even smaller reduction in BGE.

In all of the scenarios, changing the land use to the selected crops increased the overall profitability of that land several fold.

In the maximum suitability scenario, the predicted profitability of the land increased by NZ$1.32 billion. Maximising the reduction of BGE had a larger impact on profitability as it targeted the most profitable and intensive livestock land use.

1.6 OPTIONS TO MEET FUTURE CH_4 REDUCTION TARGETS

Converting nearly 200,000 ha of pastoral land to crops and mānuka plantations will have a relatively small effect on CH_4 emissions. Adoption and development of mitigation technologies is more likely to have a large effect towards meeting future CH_4 emission reduction targets. We considered how the uptake of two CH_4 reduction technologies (breeding of low emitting animals and inhibitors), land use change to crops, afforestation and retirement of livestock land might meet future reduction targets.

In simple scenarios to meet the 2030 and 2050 targets, we estimate that more than 200,000 ha of additional land would need to be retired by 2030, and at least another 1 million ha by 2050 (to meet the 47% CH_4 emission reduction target).

This estimation provides a hypothetical indication that to meet the most ambitious CH_4 emission reduction targets, even more effective CH_4 mitigations than currently predicted will be required and/or animal numbers will need to reduce. Potentially this could be through even greater conversion to cropping than in our optimistic growth scenario or afforestation. Converting land to plantation or natural forest will contribute towards net carbon emission targets for non-CH_4 emissions, but not directly to the CH_4 emission reduction targets.

1.7 CONCLUSIONS

We identified large areas where high value, low-emitting crops can be grown across New Zealand. Much of it is on land where its current use results in large BGE.

Our analysis of export markets indicates that there are growth opportunities for horticultural and arable crops. We selected 12 crops that were most promising, but also recognised there are others that deserve investigation in the future.

Replacing ruminant livestock with high value crops greatly increases the profitability of the land area, and modest changes should increase the economic well-being of New Zealand.

Although changing to these crops or land use will reduce agricultural emissions, the scale of land use change to high value crops and mānuka (200,000 ha) is unlikely to have a large impact on reducing CH_4 or total BGE emissions. The greatest effect on reducing BGE will occur when the alternative land use replaces the most intensive livestock farming (e.g. irrigated dairy farms) because of the high emissions per hectare.

From our assessment, there appears to be plenty of opportunity for increasing the areas of the highly profitable crops we selected; however, there are many driving or constraining factors that affect land use change decisions that need to be addressed, but their examination were largely beyond the scope of this project. These factors include access and competitiveness in international markets, investment in infrastructure, availability of skilled managers, labour availability more generally, cash-flow and biophysical factors such as climatic risk and water availability. Similarly, there will be similar or other factors driving or constraining large-scale afforestation that would be required to make up the difference in reaching net zero carbon emission targets.

2 Introduction

Agriculture accounts for 48% of New Zealand's gross greenhouse gas (GHG) emissions. Since 1990, agricultural emissions have increased by 13.5%. Nearly 75% of the emissions come from methane production from ruminant animals (enteric-CH_4) (Ministry for the Environment 2020).

New Zealand has set a domestic target to reduce all GHG emissions to net zero by 2050, with the exception of biogenic CH_4. It has set specific biogenic CH_4 emission reduction targets of 10% by 2030 and between 24% and 47% by 2050, referenced to 2017 emissions.

Even with all potential mitigation measures for livestock considered for New Zealand, only around 40% of CH_4 can be mitigated while sustaining production (Reisinger et al. 2016; Reisinger et al. 2018).

The challenge for New Zealand is to reduce emissions from intensive livestock. Compared to other New Zealand production systems, dairying has the greatest BGE per unit area. However, dairying is also by far the largest New Zealand export earner. In 2017–18 dairy exports were NZ$17.2B, and about 40,700 people were employed in the industry (DairyNZ).

An option to reduce agricultural GHG emissions is to replace intensive livestock with alternative low emission land uses. It is preferable that these land uses not only reduce agricultural GHG emissions and meet emission reduction targets, but also maintain economic value, avoiding any impact on the national economy. A recent report (Clothier et al. 2017) suggests that about 2.1 M ha of land suitable for low emitting, high value horticulture and that about 1.6 M ha of this was currently in livestock farming.

2.1 THE PROJECT

This report describes work conducted in the Ministry for Primary Industries (MPI) Sustainable Land Management and Climate Change (SLMACC) Project 405422 - *Evaluation of profitability and future potential for low emission productive uses of land that is currently used for livestock*.

2.1.1 Aim

To evaluate potential agricultural land uses (including crop and forest options) that could provide an alternative to livestock production based on market growth opportunities, GHG footprints and suitability for current climate and soil conditions.

2.1.2 Approach

In brief, our approach is described in Figure 1. The first step was to identify promising crops and products. This was followed by assessing the growing suitability conditions required for each crop and producing growing suitability maps. At the same time, we estimated the likely biogenic greenhouse gas emissions (BGE) associated with growing the crops and trees. More detailed economic analysis of the likely profitability from growing the crops or trees was undertaken. Finally, this allowed us to consider scenarios where these alternative land uses might replace livestock. Through the various stages of the work we ground-truthed our findings with stakeholders and industry experts.

2.1.3 Scope

Information relevant at regional and national scales.

2.1.4 Beyond the scope of the project

Understanding of the drivers and barriers for land use change.
The influence of climate change on crop suitability location and areas.
Non-BGE emissions and sequestration by perennial crops and shelter trees.

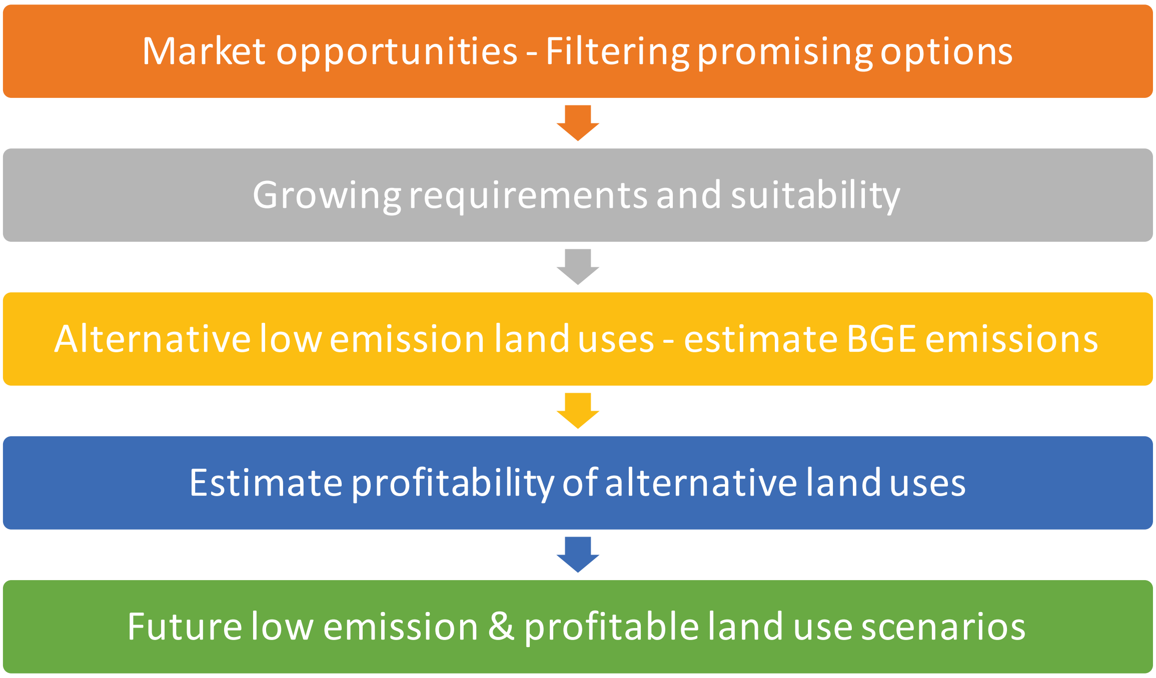


Figure 1. Schematic of the steps followed to estimate how replacing livestock with alternative low biogenic greenhouse gas emission (BGE) and forestry land uses could affect overall profitability and BGE.

3 Crop selection from market analysis

Aim – to identify fruit and vegetable products most likely to be successfully sold on the international market as exports from New Zealand. This focused our data collection on understanding which products may be successfully exported from New Zealand based on current patterns, demand trends and international trade. The analysis involved five steps as highlighted in Figure 2. These were:

Step 1: Available literature was used to identify all possible products and markets of interest
Step 2: Filters based on demand trends and New Zealand trade relationships were used to narrow down the products and countries of interest
Step 3: Trade data were used to cross-check that important products or markets had not been missed
Step 4: Trade data were used to quantify market size and growth opportunities to validate selection of the key crops
Step 5: A final list of products for stakeholder evaluation was identified.

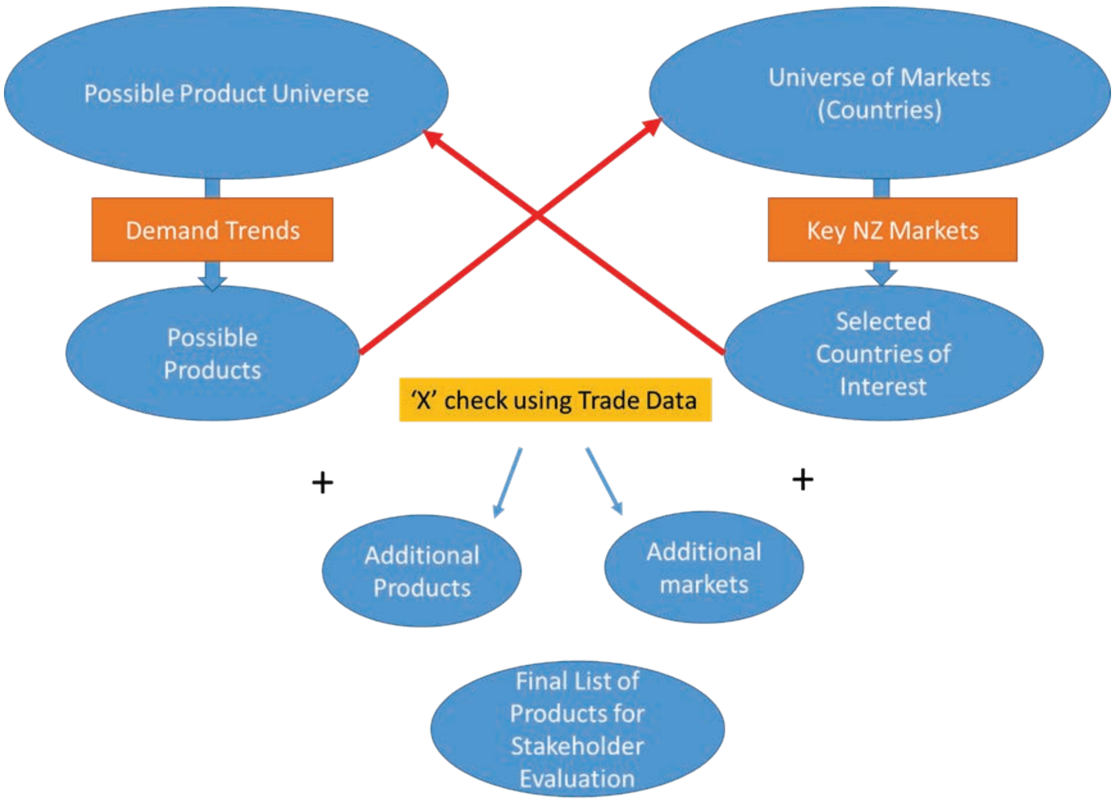


Figure 2. Schematic highlighting the approach adopted to identify possible crops and products.

3.1 THE 'BASKET' OF KEY CROPS

3.1.1 Methodology

Literature Review

As outlined above, a review of the literature was undertaken to identify a 'possible product universe'. The literature included:

- Trade publications in the New Zealand Horticulture and Fruit and Vegetable production industry
- Industry reports and strategic documents
- Reports and strategies from government departments and government-initiated working groups, and independent research organisations (both New Zealand and internationally).

Publicly available reports and documents covering the period 2010 to 2017 formed the basis of the review (although preference was given to more recent publications). In addition, some documents were obtained directly from industry or research groups on a by-request-only basis. The review

considered both quantitative assessment of volumes and values of production and consumption (export and domestic) and also qualitative aspects such as discussion around the key trends, degree of coverage and attention given to products.

The review not only provided data on products within our identified 'possible product universe', but also sought evidence to validate and augment the products that were included.[1]

Filters and Rationale

Key drivers of demand in the global fruit and vegetable market were identified through the literature review. These drivers were used as filters to select products that met the characteristics of these trends. In addition, the literature provided evidence concerning the extent that New Zealand's current market and production trends matched the emerging international consumer trends.

A key driver of demand identified consistently within the literature was a growing desire for premium products. Premium covered a range of characteristics including novelty, health benefits and convenience through processing and packaging (United Nations 2011; Coriolis 2014a; Coriolis and DAFWA 2016; Coriolis 2017; GroIntelligence 2017).

Within the literature it is argued that New Zealand has a strong brand competitiveness (Coriolis 2015; The New Zealand Consulate General - Los Angeles 2015). In the future, it is argued that New Zealand's greatest strength will come from focusing on distinctive, provenance-based and counter-seasonal products that take advantage of New Zealand's current reputation for quality and trustworthiness (Coriolis 2015). This speaks to consumers' growing demand for products that meet their needs for health, quality and attention to the origin of their food (Coriolis 2014a; Coriolis and DAFWA 2016; Fumasi 2016). In addition, New Zealand's move towards premium, from volume to high value, is supported by global trends, particularly in key markets such as the United States of America (USA) and China, for more premium products and high-priced luxury goods (United Nations 2011; Ministry for Primary Industries 2016; GroIntelligence 2017; RaboResearch 2017).

A key component of New Zealand's brand competitiveness is an ability to supply products counter-seasonally to Northern Hemisphere consumers and producers (The Agribusiness Group 2015; Horticulture New Zealand 2016a; Coriolis 2017).

A 'portfolio approach' was taken to encapsulate multiple criteria when selecting products, which should be seen as a complementary suite in aggregate. The value of a product extends beyond the selection criteria and has properties not well met by other products. This list of six criteria therefore helps achieve a 'portfolio approach' to the final selection and better addressing product investment risk.

The selection criteria are summarised below:

1. Growth in Asia (G)
2. Premium/High value product (V)
3. NZ export growth or volume (E)
4. Popular in processed foods (P)
5. NZ Brand recognition/position (B)
6. Unique perceived health benefits (H)

The identification of selection criteria was validated against research conducted by Coriolis, who have undertaken a series of studies for the New Zealand Government in this general area. The following paragraphs briefly summarise their findings.

In their 2012 report, Coriolis looked for mid-size export products (valued between USD$2m and $99m), and further screened based on absolute volume growth, compound annual growth rates, value per kg and compound annual growth rate per kg to indicate consumers willing to pay more per unit over time (Coriolis 2012). Their first screen identified honey, onions, capsicum, peas, avocados, cherries, berries and frozen potato chips[2].

Their secondary screening (which was based on an analysis of the successful growth of the New Zealand wine industry) identified selection criteria, similar to those employed in this study. Table 1

[1] The exact degree and nature of the literature review varied from product to product because few literature resources covered all products and no two products had the same type and volume of literature available concerning them.

[2] They also identified animal-based and processed products but as noted earlier these were considered outside the scope of this project.

provides a comparison between the criteria. The main difference is that at this stage of the analysis we are not considering the nature and extent of competition in the market place for possible products.

Table 1. Comparison of criteria used to select possible products of interest.

Our Criteria		Coriolis (2012) criteria
3.	NZ export growth or volume (E)	A large global market with strong growing demand
4.	Popular in processed foods (P)	
6.	Unique perceived health benefits (H)	
1.	Growth in Asia (G)	Asian opportunity
2.	Premium/High value product (V)	Premium for quality
5.	NZ Brand recognition/position (B)	Ability for leverage, differentiation, brand recognition and high capital barriers to entry
-	*Target market country analysis*	Presence or absence of tariffs in key markets
-	*Not considered in this study*	Number of NZ companies competing
-	*Not considered in this study*	Presence of other wealthy nations as exporters

In the Coriolis study, this secondary screening elevated honey and cherries to prime products (referred to as “Best”), with frozen potato chips, avocados and berries in the following tier (“Better”). Onions, capsicums, peas and beans were grouped below this (“Good”).

In 2014, Coriolis described New Zealand as consistently demonstrating high value through a strong ‘Brand New Zealand’, with a high degree of trust and positive image in Asian markets for products (Coriolis 2014b). In 2016, Coriolis reported that "This and all of our past research strongly suggests firms should focus here for defensible, profitable, long-term business" (Coriolis and DAFWA 2016). Their report emphasised the advantage possible from products that are distinctive, counter-seasonal, and status or provenance-based and that in this regard there are clear opportunities in honey, apples, avocados, wine, oranges/mandarins and carrots. They recommended future investigation into cherries, blueberries, figs and dried apples. Finally, their 2016 report also noted the demand for walnuts, hazelnuts and other nuts, categorising these as ‘blue sky’ opportunities in the future.

3.1.2 Selected ‘basket’ of key crops

Literature Review Results

Our review of literature identified a selection of 12 products, as illustrated in Figure 3.

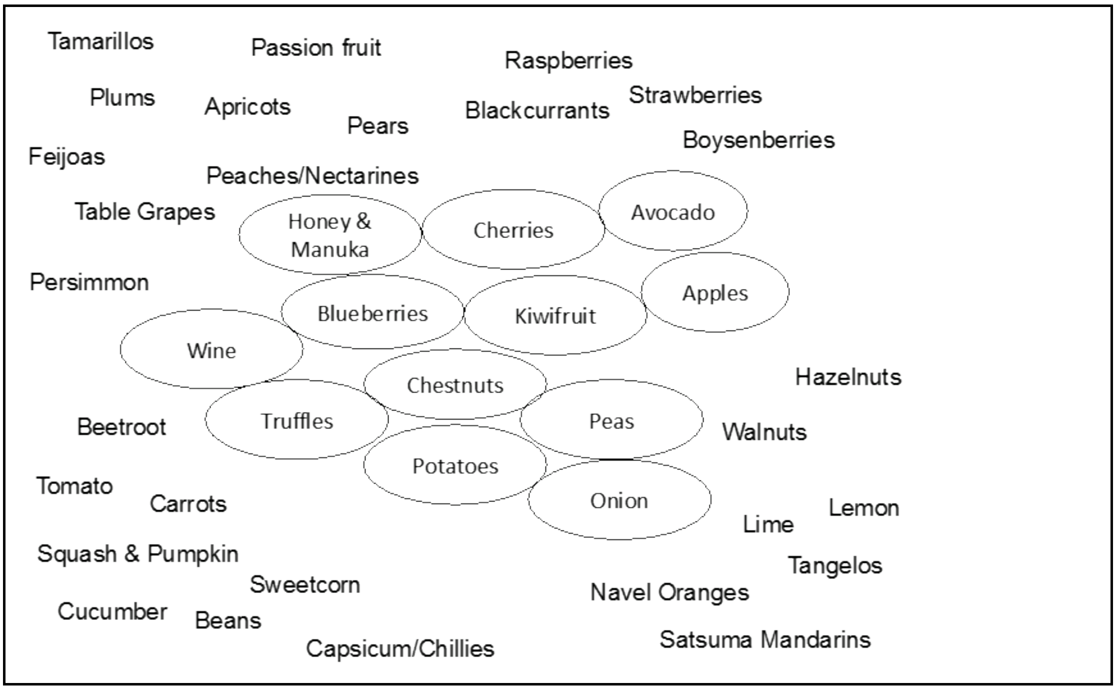


Figure 3. A selection of key products from potential product universe, based on a literature review.

Coriolis (2014b) identified New Zealand as a world leader in honey, apples, kiwifruit and wine. This report also identified cherries, frozen potato chips, avocados, berries, capsicum, peas and onions as emerging opportunities for New Zealand. In their 2017 report (Coriolis 2017), Coriolis produced three horizons for key products for growth:

Growth Stars	Cherries, avocados
Horizon One	Apples, kiwifruit, onions
Horizon Two	Avocados, cherries, berries and blueberries
Horizon Three	Feijoas, kiwiberries

We have mapped these findings with our product selection, and these are illustrated in Figure 4.

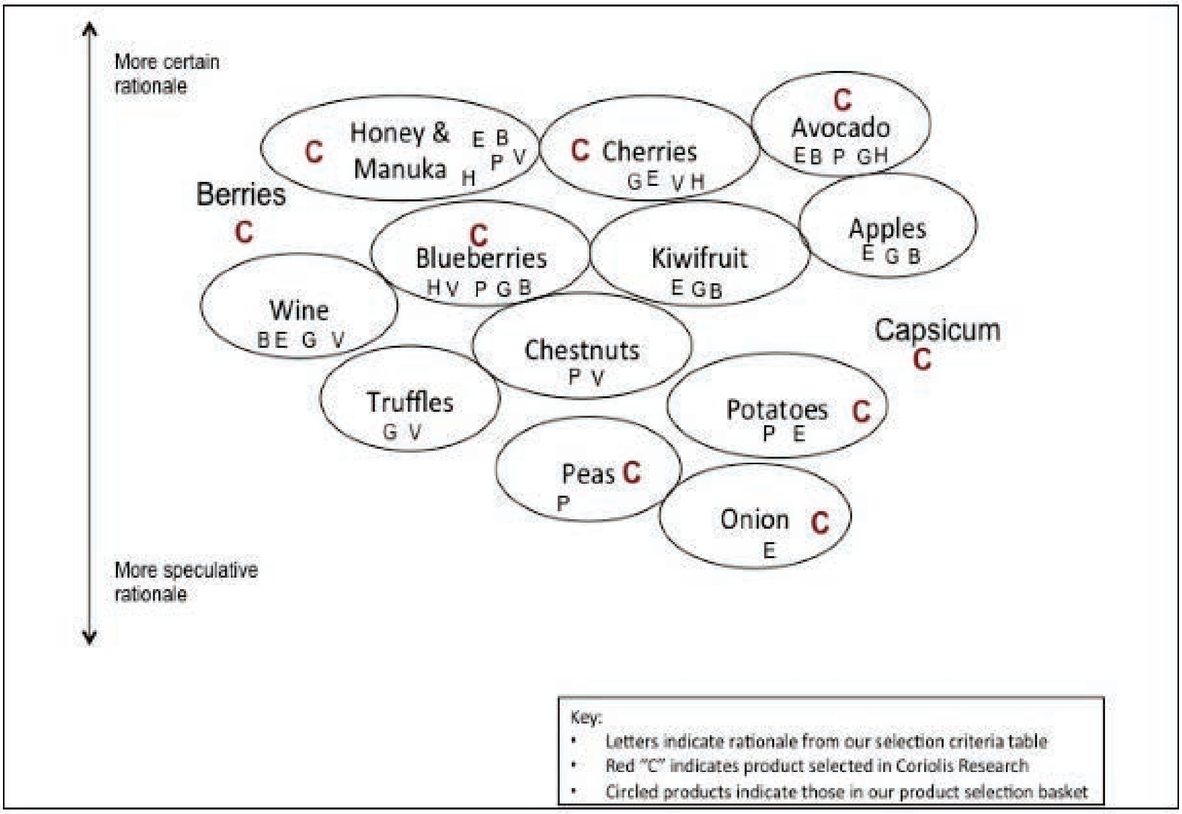


Figure 4. Selected products with criteria and Coriolis overlay. Note: Selection of key products from potential product universe, based on rationale presented in the selection criteria in Table 1 (Coriolis 2012, 2014b, a, 2015; The New Zealand Consulate General - Los Angeles 2015; Coriolis and DAFWA 2016; Fumasi 2016; Westpac 2016; Coriolis 2017).

3.2 THE GROUP OF TARGET COUNTRIES

3.2.1 Selection methodology

In order to set the boundaries for more detailed analysis, a process of identifying key countries of interest was undertaken. The starting point was the preliminary findings from the literature review regarding global trends and geo-political commentary. Additional data were obtained from The New Zealand Ministry of Foreign Affairs and Trade research, New Zealand trade agreements (current and pending), current New Zealand Government trade statistics (Coriolis 2014b) and Agribusiness and Economic Research Unit (AERU) research.

Previous work by Coriolis (Coriolis 2015) used the presence of current Free Trade Agreements (FTAs) to identify target markets for potential New Zealand export growth, and this approach was also considered by Horticulture New Zealand (Horticulture New Zealand 2016a). It was possible to use commonalities between the countries identified by the various sources to identify 17 export markets best placed to represent demand for New Zealand products. The results of this are presented in Figure 5.

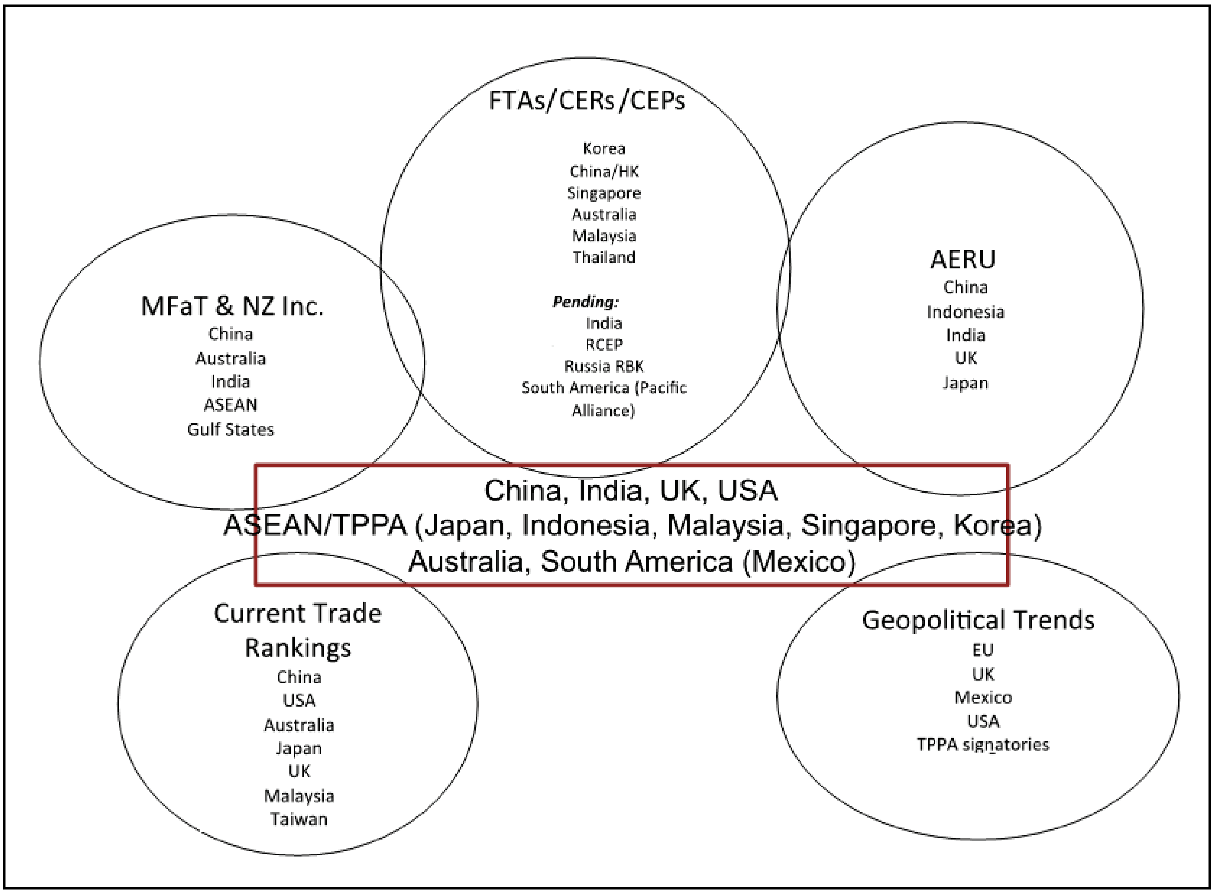


Figure 5. Sources for country identification. Note: Sources for country identification with common countries highlighted in the red central box. FTA – Free Trade Agreement. CER – Closer Economic Relations agreement. CEP – Closer Economic Partnership agreement. AERU – Agriculture and Economic Research Unit. ASEAN – Association of South East Asian Nations. TPPA – Trans Pacific Partnership Agreement. MFaT – New Zealand Ministry of Foreign Affairs and Tourism.

3.2.2 Literature review results

Target Market Countries

New Zealand has had trade agreements including FTAs, Closer Economic Partnership agreements (CEPs) and Closer Economic Relations agreements (CERs) with several Southeast Asian and other countries, and concerted efforts are being made for additional agreements in Asia and Europe (Horticulture New Zealand 2016b; New Zealand Ministry for Foreign Affairs and Trade N.D.). The New Zealand Ministry of Foreign Affairs and Trade, New Zealand Inc. and the AERU research group have used this grouping of countries to conduct research and analysis of New Zealand export products market demand (Guenther et al. 2015; Saunders and Driver 2016; Saunders et al. 2016).

The following briefly summarises some of the key features of potential countries of interest emerging from the literature. Indonesia and Mexico are identified by Euromonitor International (Euromonitor International 2016) and are part of the "NIMPTS (Nigeria, Indonesia, Mexico, The Philippines and Turkey)" group of newly emerging markets showing rapid growth in contrast to declining demand elsewhere.

India is an interesting target market because it has a high population of vegetarian consumers and as food consumption grows, fruit and vegetable consumption is growing more rapidly there than elsewhere (Euromonitor International 2015, 2017). India is not currently a strong trade partner with New Zealand, although trade agreement negotiations are underway (Saunders and Driver 2016). With India's increasing food needs, and looking towards their processing industry, there may be new opportunities to supply their processing industries with raw materials rather than consumer products (Thakur 2015).

Asia, and particularly China, remains a key focus of demand (Coriolis 2014a, 2015; Fumasi 2016; Westpac 2016; Coriolis 2017; Euromonitor International 2017; GroIntelligence 2017). Rising incomes and urbanisation are increasing consumer preference for perceived health-benefits and nutrition-based products. Aging populations, particularly in Japan, are further driving this trend (Ritin 2017).

According to Fumasi (2016), China's demand is growing, and the USA market is experiencing 'higher evolution'. Both markets are showing increasing diversity and quality expectations as to their fresh fruit and vegetable imports.

Euromonitor International (Euromonitor International 2015) also highlights New Zealand's advantage as the first developed nation to sign a FTA with China between 2004 and 2007, and cites the Association of South East Asian Nations (ASEAN) agreement as an important element of regional trade and economic integration affecting New Zealand over the last decade.

Our research drew on the commonalities between these sources and concluded the following countries to represent New Zealand's target markets (alphabetically): Australia, China, European Union, Fiji, Gulf States, India, Indonesia, Japan, Korea, Malaysia, Mexico, Russia, Singapore, Thailand, Taiwan, United Kingdom (UK), USA. These are represented in Figure 6 while Figure 7 presents details of these countries' features.

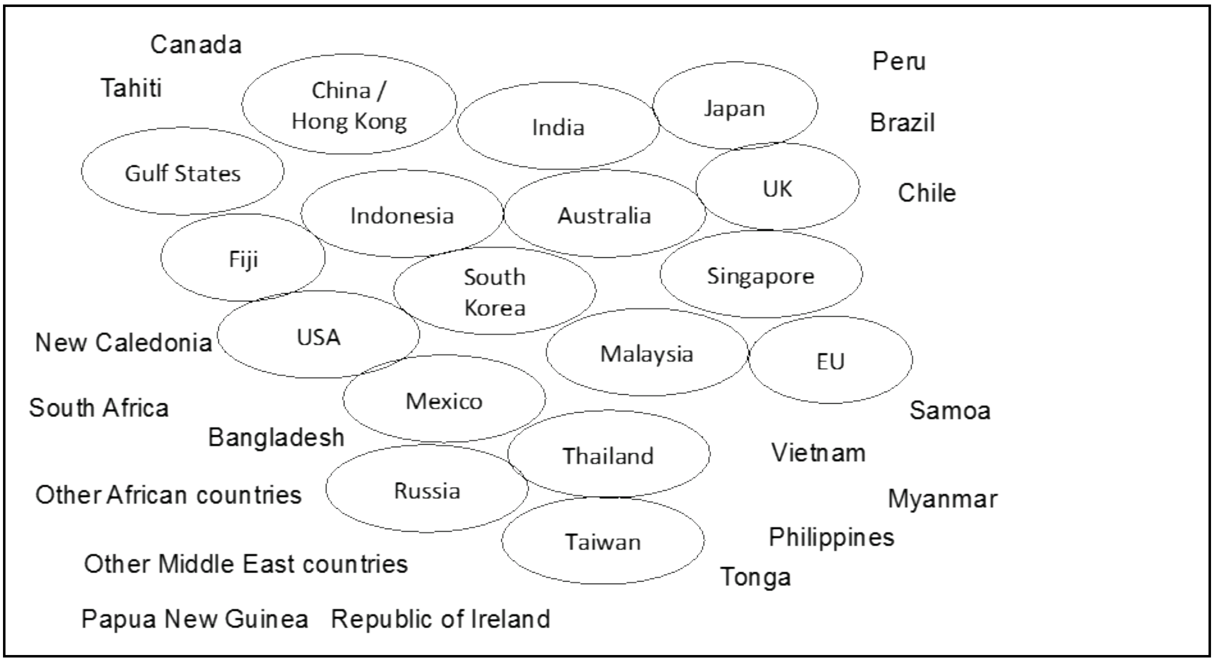


Figure 6. Target market countries identified. Selected markets for New Zealand exports (countries) from possible trade partners. Countries inside the circles indicate countries selected by this research, and those outside the circles represent possible countries that were excluded.

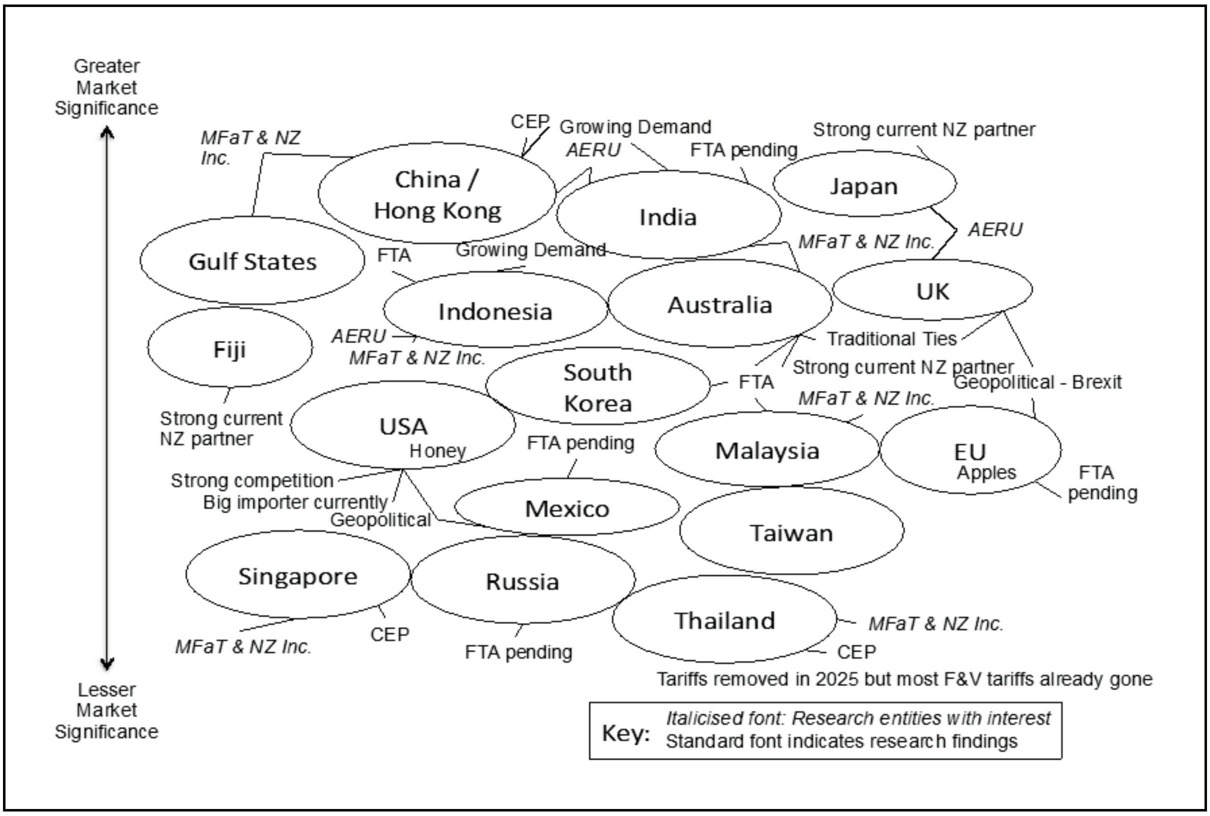


Figure 7. Target markets countries as analysed. Note: Selected markets for New Zealand exports (countries) and points of strength (Coriolis 2014a; The Agribusiness Group 2015; The New Zealand Consulate General - Los Angeles 2015; Coriolis and DAFWA 2016; Fumasi 2016; Euromonitor International 2017; RaboResearch 2017).Abbreviations: CEP - Closer Economic Partnership agreements; FTA – Free Trade Agreement; AERU – Agriculture and Economic Research Unit; MFaT – New Zealand Ministry of Foreign Affairs and Tourism.

3.3 COMTRADE DATA ANALYSIS

3.3.1 Methodology

In order to verify results from the literature review, ComTrade data was queried.[3] By reviewing import and export volumes and values from 2012 to 2016 (the latest data), we can identify which countries and which products are in demand internationally and which products and purchases are demonstrating the greatest growth over this time.

A series of questions were developed to guide the analysis. The questions that informed our ComTrade data queries were designed to provide a cross check for our findings, as described in the matrix below (Table 2). This approach assisted us in verifying whether the product basket and the target market countries selected through the literature review process are supported in terms of the quantity and value of trade. We used this approach to reduce the risk that key countries, products or markets had been omitted or overlooked as sources of demand for New Zealand products. In this manner, our ComTrade data queries have been constructed to identify outliers in country or product data.

[3] It should be noted that limitations exist when using UN Trade Data to draw conclusions regarding the demand for a product by a country. In particular, the use of UN trade codes constrains the level of detail available about a given product. For example, both mānuka honey and blueberries are not given their own code, but allocated with larger codes – 'honey' and 'genus Vaccinium', which also includes cranberries. This means we are extrapolating demand for these codes grouping several products as a proxy for our product of interest. Codes are also divided between different forms of processing of a product, for example peas and potatoes. This means that several codes may be aggregated to produce an accurate picture of the demand for a product in a country. Although complex processing is outside the scope of this research, simple processing such as freezing or drying has been included in the pea and potato products analysed, and aggregated for data analysis.

If, when querying who is buying which product, there are clear indications that other countries not in our country selection are major market participants, additional investigation can be made into the potential for this country to be added to our literature review-based selection.

If, when querying which products are being purchased by our group of key countries, products are shown to be significantly traded that are not within our literature review-based selection, then these additional products can be investigated through additional queries.

Through this data analysis design, it was intended to 'catch' any key countries or products that were excluded from our literature review-based selection but should be included as potential areas of demand for New Zealand produce.

Table 2. Matrix design of ComTrade data analysis.

		Products	
		All products on our 'potential product universe' list	*Selected product basket from literature review*
Countries	*All countries in ComTrade database*		Which country is buying the most of each item? Which country is buying increasing amounts of each produce item?
	Selected target market countries from literature review	Of our selected countries, how much of each product is each of them buying? Of our selected countries, what are they buying more of in 2016, compared with 2012? Which countries actually buy all of our products (or a greater selection of the investigated products)?	

Question set one:

- Which countries actually buy all of our products (or a greater selection of the investigated products)?
- Which country is buying the most of each item?
- Which country is buying increasing amounts of each produce item?

The data for these questions were extracted based on Harmonized System (HS) codes from the UN ComTrade Database[4]. Where appropriate, several HS codes were aggregated (peas, potatoes, tomatoes, truffles, nuts) where New Zealand's export products were distributed over several codes such as the HS code for fresh and frozen peas, and shelled and in-shell walnuts. Growth rates were calculated based on the difference between 2012 values and 2016 values in both volume and trade value.

Each country's most dominant import products in terms of volume and value were identified by filtering to identify the products that represented the top 20% of values. In some countries, the top 20% of values were covered by only three products, whilst in other countries it comprised multiple products. Judgment as to the products with the greatest growth in each country was undertaken on a more country-by-country basis, as in many cases growth rates extended into the many hundred percentages so an arbitrary cut-off to apply to all countries was difficult to obtain without more sophisticated analysis. In these cases, the products showing the highest growth rates were identified, with cut-off at 100% or 50% or 10% chosen based on the growth rate spread of each country. Summary data are presented in Appendix 10.2 Table A1.

[4] https://comtrade.un.org/data/

Question set two:

- Of our selected countries, how much of each product are they buying?
- Of our selected countries, what are they buying more of in 2016, compared with 2012?

Again, the data for these questions were extracted based on HS codes from the UN ComTrade Database[5]. Where appropriate, several HS codes were aggregated where New Zealand's export products were distributed over several codes. Countries were then ranked on a product by product basis, and those of countries purchasing high values of each product were identified. We could then identify those countries who were not purchasing high volumes, but where the amount purchased was rapidly growing. Again we analysed the trends that emerged from this process for the possible presence of countries not in our target market country set.

3.3.2 Analysis results

The Target Market Countries

While our preliminary data analysis of UN ComTrade data does not refute our conclusions regarding the key countries of New Zealand's export growth focus, it does emphasise the complexity of factors in the landscape of identifying New Zealand's target markets.

For example, as illustrated in Figure 8, the countries showing the greatest rate of growth in the most product categories are China, Thailand and Fiji. Highest growth in both volume and value is predominantly seen in China, Fiji, Indonesia and South Korea. In value, Thailand, India and The United Arab Emirates (UAE) rank highly for one or two products also.

However, the largest markets by volume are the USA, European Union (EU) and Russia (these are defined as countries that purchase greater than 1 billion kg of any product annually). Alternatively, when considering those countries purchasing more than USD$1 billion of a product annually, China is added to this list. Regarding areas where demand for some products is declining during the period (2012-2016), the picture is less clear with India, Mexico, Indonesia, China, Malaysia, Japan and Russia having the greatest decline for individual products.

The ComTrade Data analysis also identified distinct differences in trends between Hong Kong and China, indicating these may be best addressed as separate markets. In addition, both the Japanese and Russian markets are (in terms of average growth rates not adjusted for volume) in decline (–22% for both) during the period under consideration. Given the discussions around Brexit and opportunities for New Zealand, it is worth noting that during this period the UK had, overall, the smallest positive growth across the board, at 7%.

Thailand is a strongly diversified economy, with good levels of growth, indicating this may be a good market. The data provide further insights when considering growth of value in relation to growth in volume. For example, there are countries with value growth of imports of a given product that is greater than the corresponding growth in volume — a potential indicator of unmet demand in that market (e.g. wine is imported into UAE and Thailand in smaller volumes than other countries, but it is a high value import).

Further data from ComTrade Analysis are presented in Appendix 10.2 and the outcome represented in Figure 8. Appendix 10.2 Table A1 shows China, Indonesia, Fiji, India and South Korea as the target market countries showing the largest absolute aggregated growth. Appendix 10.2 Table A2 identify both Canada and Brazil as potential outliers to our target market country set, but not to a degree that warrants addition into our final set. These data also support the conclusion of China, the USA and Japan as large markets, with the United Kingdom and European Union countries as areas where growth is not so strong.

[5] https://comtrade.un.org/data/

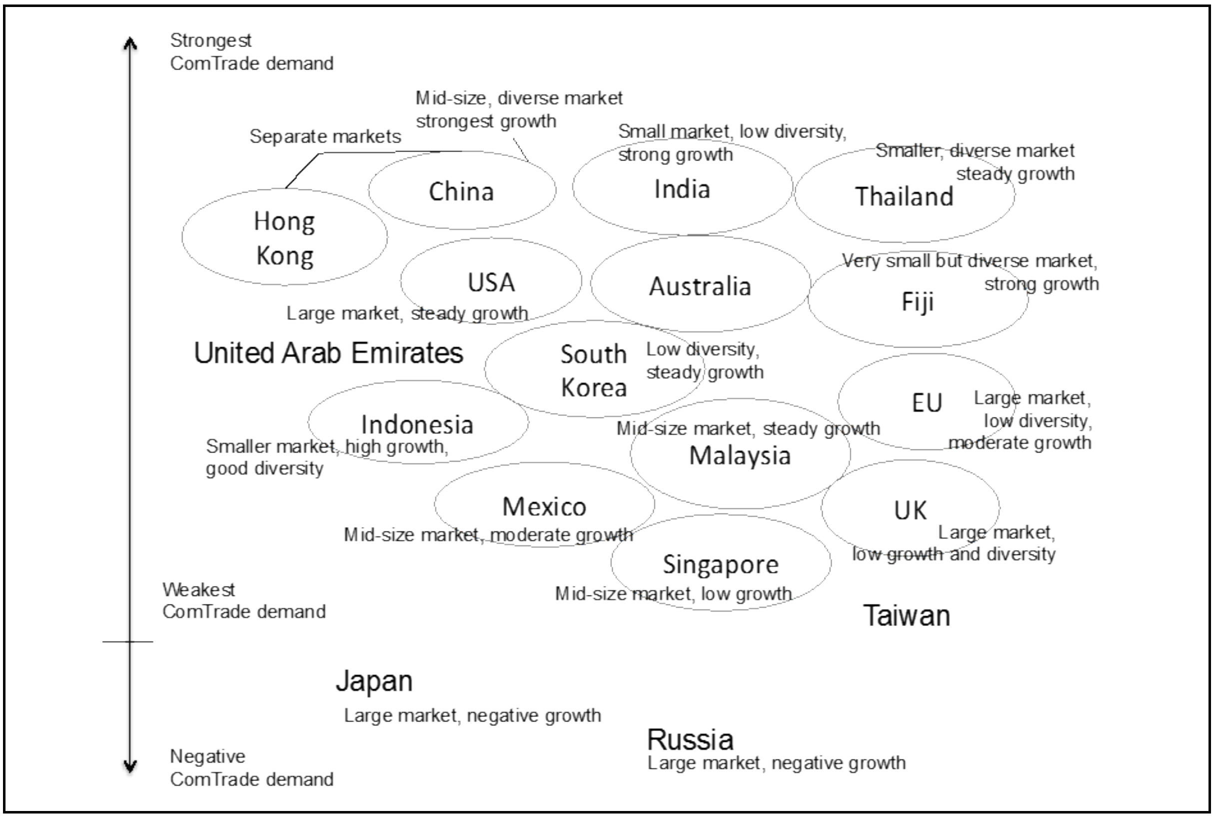


Figure 8. Target markets (countries) — adjusted. Note: Selected trade partners and marginal trade partners, based on the UN ComTrade data analysis on research 'product universe', not the entire ComTrade dataset. "ComTrade demand" on the left axis represents a combination of both volume and growth trends, with growth trends qualitatively weighted more heavily.

The 'Basket' of Key Crops

From the UN ComTrade data we conclude that apples, potatoes and onions are still strong staple crops in international trade. We also see that peaches, nectarines, asparagus and carrots feature more heavily in trade and demand than was addressed in the literature. Citrus, particularly orange, are also key products in many markets. As expected, avocados and cherries showed strong growth across several markets. Berryfruits are also growing in value as imports to the USA.

Overall, the UN ComTrade data supports our selected product basket, but identifies several additional products that could be investigated for inclusion: carrots, pears, squash and pumpkins, berryfruits, apricots, hazelnuts, walnuts and persimmons. This is represented in Figure 9. Further data are available in Appendix 10.2 Table A1.

In some markets, the increase in volume of products imported is exceeded by an increase in the value of these products, suggesting that a degree of unmet demand exists. This may warrant deeper analysis. This trend is observed in such cases as hazelnuts in Australia, apples and asparagus in China, apricots in India, and plums in Indonesia. Also, some countries are importing products in small comparative volumes yet ranking as high value importers, indicating potential room for higher returns in these markets. An example of this is the wine imports to UAE and Thailand.

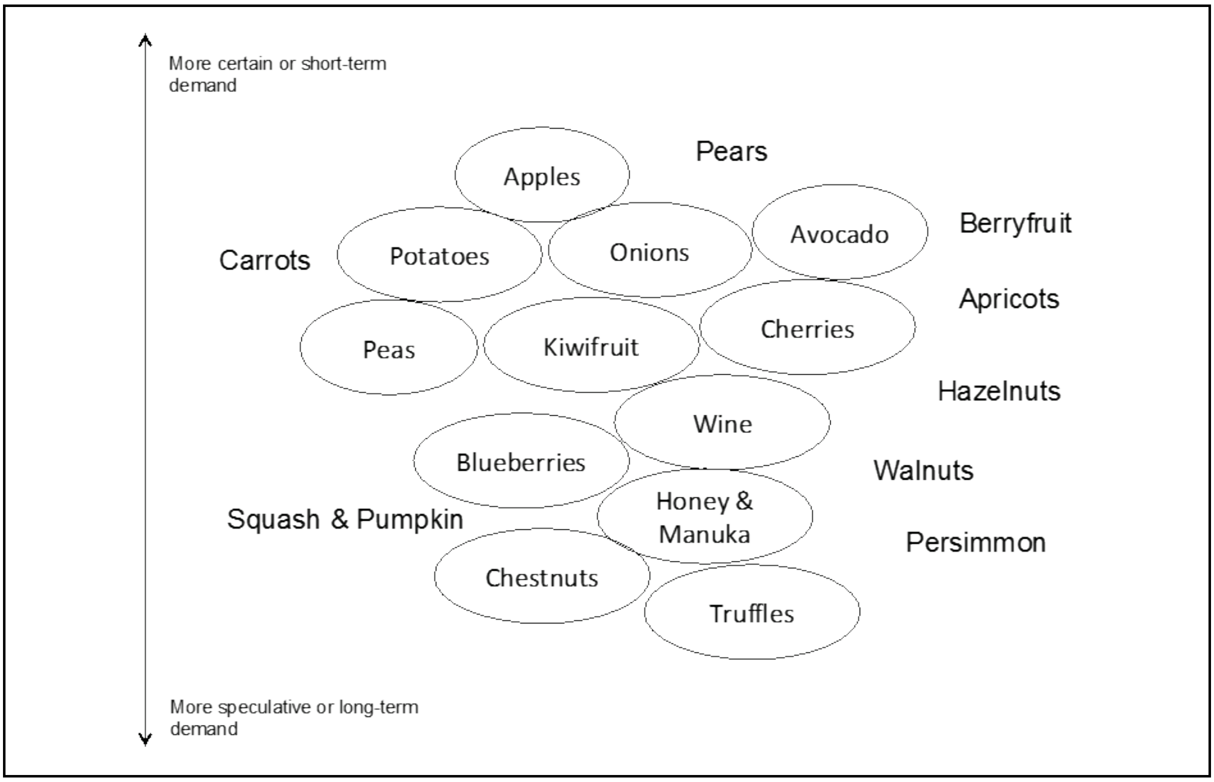


Figure 9. Selected products— adjusted. Note: Selection of key products with additional products of interest, based on the UN ComTrade data analysis.

In summary, our analysis indicates that there is significant market potential for a range of current or more novel arable and horticultural crops. Other promising crops and products worth further investigation are identified and discussed in Appendix 10.1.

4 Crop and forest suitability assessment

4.1 SUITABILITY ASSESSMENT METHODOLOGY

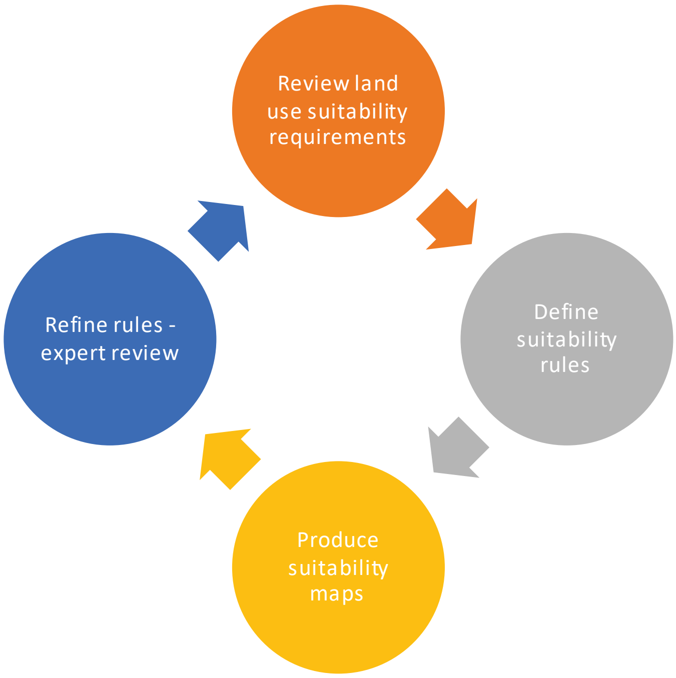


Figure 10. Iterative process for developing and evaluating crop suitability rules.

The land suitability concept described in this report is used to characterise the degree of fitness of a given environment for specific agricultural activities. The principles used for suitability assessments have been used widely at a range of scales from regional (Reid et al. 2006) to global (Fischer et al. 2010). In this project, suitability assessments are performed at the national level.

The key principle in the method is that land suitability for the growth of different plant species can be estimated from geo-referenced information on climate (e.g. temperature and rainfall regimes), soil (e.g. soil depth and pH) and terrain conditions (e.g. slope and aspect). The spatial datasets used to derive biophysical attributes for suitability assessment in this study are described in Table 3.

Table 3. Data sources and selected variables used to derive biophysical attributes to assess land suitability.

Type	Name	Format	Spatial/Temporal Resolution	Source
Soil	New Zealand Fundamental Soil Layer (NZFSL)	ESRI Shapefile	1:50,000 / na	MW-LR
Terrain attributes	Slope, Aspect	GeoTiff	500 m * 500 m / na	MW-LR
Climate	Maximum and minimum temperature, precipitation, solar radiation, wind speed and vapour pressure deficit (1971 to 2000)	NetCDF	0.05° * 0.05° / Daily	NIWA

MW-LR: Manaaki Whenua - Landcare Research https://soils.landcareresearch.co.nz/soil-data/fundamental-soil-layers/ from https://lris.scinfo.org.nz/; NIWA: the National Institute of Water and Atmospheric Research https://www.niwa.co.nz/climate/our-services/virtual-climate-stations; na: non-applicable.

To quantify land suitability for a given environment, the “biophysical attributes” are translated into “suitability indexes” through crop-specific “suitability rules” (Figure 10). For example, suitable growing conditions might occur between temperature ranges of 5 to 25°C for a given crop, with an optimum within a narrower range (e.g. 15 and 20°C). Suitability classes (e.g. from unsuited to well suited) for different attribute-crop combinations can be estimated based on such suitability rules (Figure 11). The suitability rules are simplifications of biophysically sound principles that operate at a much lower scale

of organisation (e.g. crop and plant physiological responses to the environment). Such simplification is necessary, given that suitability assessments are performed at the landscape level.

The analytical method and dataflow were developed to process geo-referenced input data into suitability maps as shown in Figure 11. Specifically, the suitability modelling framework utilises a wider range of GIS-rules adapting the method from Kidd et al. (2015) and simplified "categorical" parameter ranges. For method transparency and reproducibility, all crop suitability parameters are stored in a single database. In the database, the biophysical-attributes for a given crop and their relationship to the four possible suitability classes are specified, this information is then called the Python model.

In brief, a suitability modelling framework was developed by Manaaki Whenua – Landcare Research using the open source software Python (Python 3.6.5 version, https://www.python.org/) in conjunction with the external package Geospatial Data Abstraction Library (GDAL). For method transparency and reproducibility, all crop-suitability rules are represented as a set of parameters stored in a single configuration file (i.e. config.csv in Figure 11). The parameter file informs the suitability model, which biophysical-attributes to use for a given crop, and how these relate to four possible suitability classes (Figure 11).

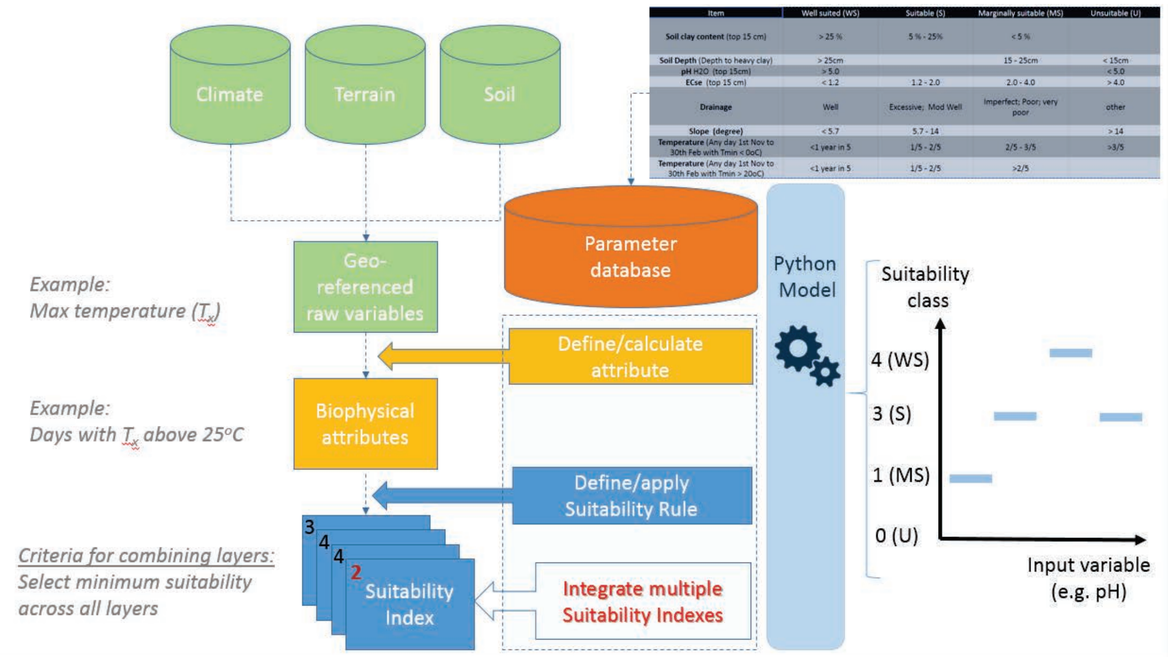


Figure 11. Graphical representation of information flow for the assessment of land suitability in this study. Raw data (climate, terrain and soil) are used to calculate suitability classes (unsuited to well suited) using rules and parameters in the config.csv file processed by the spatial Python model.

Initially the intention was to develop the suitability rules for all the crops identified. However, we focused on providing suitability rules for chestnuts, mānuka honey, onions, peas, potatoes, truffles and plantation forests (Appendix 10.3). This is because a second aligned MPI project running concurrently was developing maps for cherries, avocados, blueberries, apples, kiwifruit and grapes (Hall et al. 2018). The suitability data were provided to us for the other crops and have been used in our land use suitability assessment.

4.1.1 Refining crop suitability rules and parameters.

A key part of our crop suitability assessment was an iterative process of refinement and improvement using research and industry crop-specific experts. Maps were reviewed through each iteration and, where experts identified a need for improvement, the underlying data and rules were assessed and refined. To enable this process, a new visual interface (Shiny app – funded by The New Zealand Institute for Plant and Food Research Limited (Plant & Food Research)) was developed for fast and efficient communication with crop experts. The new system also facilitates storing, tracking and revising GIS-rules for different crops that can be applied to the data created by the SLMACC project (Figure 12).

Figure 12. Illustration of visualisation app developed by Plant & Food Research's Discovery Science Programme, which enables suitability maps to be shared with crop-specific experts. This allows a systematic scrutiny and improvement of GIS-rules of suitability.

This app now enables the sharing of suitability maps (and underlying suitability map layers, e.g. "growing-degree days" suitability; Figure 13) with crop-specific experts for scrutiny and improvement of the suitability rules. A benefit is that it has enabled much faster revision of crop suitability rules.

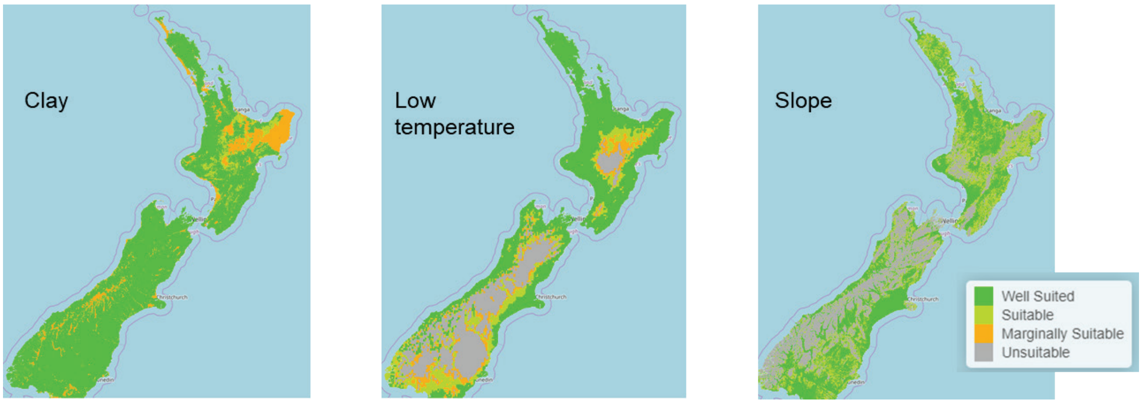


Figure 13. Examples of the underlying suitability maps used for refining potato growing suitability rules.

4.1.2 Managed and "non-managed" suitability maps

Finally, another new feature is now included to create separate suitability maps for intensive and extensive management conditions. The approach is, for intensively managed crops, to remove underlying layers in which limitations can be overcome with management interventions (e.g. pH with lime application or rainfall with irrigation).

4.1.3 Forestry suitability

A slightly different approach is used for the forest suitability. Briefly, the map data were developed using fuzzy membership principles, that is values that are optimal for a species to be planted, and grown are given a value of one (optimal Degree of Membership [DOM]), conversely zero where the species are unsuitable (unsuitable DOM) (Figure 14). These data (raster stack) are then interrogated to find the most limiting cell. This is the lowest value in the raster stack, suggesting that this number is the most limiting. Maps have been produced for three key forestry options: *Pinus radiata* (radiata pine), *Pseudotsuga menziesii* (Douglas fir) and *Eucalyptus fastigata* (brown barrel).

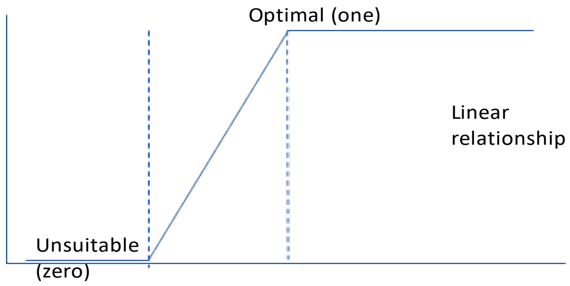


Figure 14. Schematic of the Degree of Membership (DOM) approach for forestry.

4.2 LAND USE SUITABILITY MAPS AND DATA

We have generated suitability maps for each of the selected crops and forestry (Appendix 10.5 Figures A3 to A23) and the areas estimated for a range of four suitability classes from non-suited to well-suited by region (Appendix 10.6, Tables A3 to A23). Maps are based on crop responses to environment (land and soil properties) and climate-based information. These figures and tables provide the maximum extent to which these land uses might expand based on land suitability criteria. In some cases, limiting suitability constraints such as insufficient rainfall, poor drainage or unfavourable pH conditions could be modified through management. Hence, for a number of crops (chestnuts, onions, peas, potatoes and truffles) we have also included maps and tables where constraints have been removed or “managed”. This can have some large effects on the suitability of crops in a region. For example, potatoes in Canterbury would seldom be grown without irrigation, when rainfall in particular is removed as a constraint (other factors have minimal effect), the well-suited area increases from 6,775 to 555,325 ha. About 4,350 ha is currently grown in Canterbury, typically on 10-year rotations.

Note that some land uses are likely to be similarly suited to the same land areas. Furthermore, some of the suitable land is likely to be already occupied by the crop or crops of interest.

While this provides us with information about what might grow in each region, it does not address the questions about contributions to GHG emissions or economic viability. These factors are addressed in the next sections.

5 Biogenic greenhouse gas emissions and removals for alternative land use options

5.1 APPROACH

We have followed New Zealand's Intergovernmental Panel on Climate Change (IPCC) methodology for estimating BGE from each land use, primarily because of the lack of data or models to apply at smaller scales. Following this methodology provides a consistent means to allow comparisons of BGE between crop types and land uses. Simply, the methodology requires applying a range of factors to land use activity data, such as the amount of fertiliser nitrogen (N) applied or the amount of N excreted by an animal (Figure 15). The total BGE for a particular land use is the sum of emissions from the various contributing activities.

Details of the collection of the activity data and the various factors used to estimate BGE for the selected crops and livestock are described below. Methane (CH_4) and nitrous oxide (N_2O) emissions are reported as carbon dioxide equivalents (CO_2-e). N_2O and CH_4 emissions are converted to CO_2-e on a molecular basis by multiplying with the 100-year Global Warming Potentials of 25 and 298, respectively (Ministry for the Environment 2020).

To estimate the emissions from a land use area the emissions are reported on a CO_2-e per ha basis. For livestock this requires a two-step process whereby emissions are calculated on a per animal basis then converted to a per ha basis using Statistics New Zealand livestock data.

Carbon (C) sequestration (net CO_2 uptake) by growing trees and understorey is estimated using yield tables (Ministry for the Environment 2020). We can account for the effects of land use change in C stored in soils and biomass following the Land Use, Land Use Change, and Forestry (LULUCF) methodology (Appendix 10.8; IPCC 2006; Ministry for the Environment 2020). This estimates the net emissions (CO_2-e) due to the change in C stocks in the biomass and soil from the land use change (i.e. dairy to crop or forestry). However, because of large uncertainty in these values (changes from long term pasture to crops) we have excluded the effect of land use change on C in our assessment.

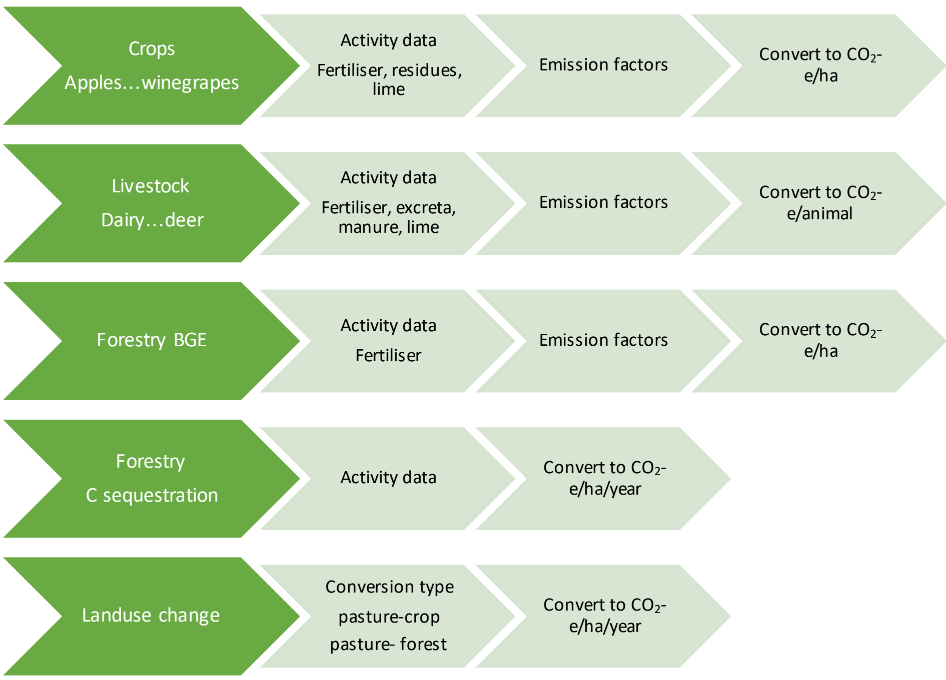


Figure 15. Schematic of the process for converting land use activity into biogenic greenhouse gas emissions (BGE).

5.2 ESTIMATING BGE FROM CROPS

5.2.1 Activity data

Direct and indirect nitrous oxide (leached and volatilised) from:

1. Synthetic fertilisers (urea, urea with urease inhibitors and other)
2. Crop residues
3. Lime and dolomite.

5.2.2 Method

As livestock are not typically part of the crop systems, we restricted the emissions to those producing N_2O. There may be cases when livestock (e.g. sheep) will graze in orchards but this is either exceptional or of short duration.

Unlike estimating rates of fertiliser N applications to pastoral farms, the amount applied to many crops cannot be simply estimated from data collected by Statistics New Zealand. This is mainly because a wider range of other fertilisers containing N (both synthetic and organic) is used for crops. With limited data sources available we have been unable to separate out the proportions of organic and synthetic fertiliser applied to each crop. Statistics New Zealand collects data for urea, urease inhibitor-coated urea, di-ammonium phosphate (DAP), ammonium sulphate and "other". We are unable to estimate how much N is contained in the "other" category, as this depends on the concentration of N (if any) in the product; i.e. these products will be targeting other macro or micro nutrients and may not include N. Unfortunately, this "other" category can be large. For example, 5,046 tonnes of "other fertiliser" was applied to kiwifruit grown in New Zealand compared with the 2,763 tonnes of the N-containing fertilisers reported by Statistics New Zealand in 2017.

Table 4. Summary of sources of activity information for selected crops used to estimate CO_2-e emissions. Values in parentheses provide a range of inputs reported.

Crop	Fertiliser kg N/ha	Yield t/ha[a]	Residues kg N/ha	Lime, dolomite & urea kg C/ha
Apples	40[b] (0–120)[d]	-	105[b]	21[c] (22)[d]
Avocados	95[e]	-	3[f]	-
Blueberries	50[e] (50–72)[d,f]	-	6[g]	0[c]
Cherries	35[e]	-	80[q]	19[c]
Chestnuts	0[h]	-	-	0h
Honey & mānuka	0	-	-	0
Kiwifruit	130[b] (50–220)[d,I,j]	-	70[b]	55[c] (70)[d]
Onions	150[k] (135–170)[l]	50[b]	7[m]	105[c] (161)[c,l]
Peas	0	7[b]	14[m]	64[c]
Potatoes	250[n] (200–360)[j]	50[b]	35[m]	105[c] (127)[c,i]
Truffles	0[o]	-	-	60[o] 4800[p]
Wine grapes	18[d] (5–68)[b,d,e]	-	30[b]	18[c] (100)[d]

[a]Yield is used to calculate residue inputs for annual crops following Thomas et al. (2011); [b]Clothier et al. (2017); [c]Statistics NZ (2017); [d]Tang et al. (2010); [e]Yara – Fertiliser recommendations. https://www.yara.co.nz/crop-nutrition/; [f]Lovatt (1996); [g]Estimated from Bryla et al. (2012); [h]pers. comm. D Klinac (New Zealand Chestnut Council); [i]Carey et al. (2009); [j]Ferguson and Eiseman (1983); [k]pers. comm. B Searle (Plant & Food Research); [l]Barber et al. (2011); [m]Thomas et al. (2011); [n]pers. comm. S Sinton (Plant & Food Research); [o]Maintenance application rate to maintain pH. pers. comm. A Guerin (Plant & Food Research); [p]Capital application rate to bring up pH to optimal pH for a non-calcareous soil. pers. comm. A Guerin (Plant & Food Research). [q]Based on estimated returns for Hawke's Bay peach crops and Central Otago apricot crops reported by Mills (2009).

As we cannot extract all the relevant N-containing fertiliser data reported by Statistics NZ, we have: (i) reviewed available literature where typical applications are reported, (ii) reviewed fertiliser recommendations for specific crops, and/or (iii) captured expert opinion (Table 4). To check whether our estimates are reasonable we made comparisons with the Statistics NZ "Other" fertiliser. We estimated typical annual kiwifruit applications were 130 kg N/ha. Based on the Statistics NZ data

reported for kiwifruit, approximately, 72 kg N/ha would come from the four N fertiliser forms reported, i.e. 57 kg N/ha less than our estimate for the total N input. However, this difference would be accounted for if the "other" fertiliser reported by Statistics NZ, on average, contained 13.3% of N. This value seems reasonable, fitting with the range of N containing fertilisers applied to horticultural and arable crops, e.g. commonly applied calcium ammonium nitrate is at the high end of the range and contains 27% N.

Data on the application of lime and dolomite are reported by Statistics NZ. Where crops are reported by Statistics NZ we have used the lime and dolomite data and attributed those to the number of hectares of crops grown, to provide a per ha application rate.

5.3 ESTIMATING BGE FROM LIVESTOCK

5.3.1 Activity data

1. Enteric methane emissions and any other methane emissions relevant to livestock farming (as per expert judgement)
2. Direct and indirect nitrous oxide (leached and volatilised) from:
    a) Synthetic fertilisers (urea, urea with urease inhibitors and other)
    b) Manure management
    c) Urine and dung deposition during grazing
    d) Lime and dolomite.

5.3.2 Method

Activity data, derived from Agricultural Production Survey (APS) data collected by Statistics NZ and supplied by Joel Gibbs (MPI); provided in Appendix 10.7 Table A24.

N excretion, fertiliser, lime and dolomite use was disaggregated by livestock type on a pro-rata basis. The relevant farm types in the APS data include 'sheep and beef farming', 'dairy cattle farming' and 'deer farming'. It was necessary to separate fertiliser, lime and dolomite use by 'sheep and beef farming' into sheep and non-dairy cattle production. This was done by using the livestock activity data and average live weight from the 2018 national GHG inventory report (Ministry for the Environment 2018). Total livestock populations of 'sheep and beef farming' were represented by 88.6% sheep and 11.4% non-dairy cattle, while the average live weight was 53 and 564 kg, respectively (Appendix 10.7 Table A24). The correction for live weights accounts for differences in pasture consumption, and therefore, stocking rate, by each livestock class. Emission factors were sourced from the national inventory (Ministry for the Environment 2018) report.

For each livestock type, total emissions were divided by the number of livestock to derive a GHG emission per animal (kg CO_2-e/head) (Appendix 10.7 Table A24).

5.4 N_2O AND CH_4 EMISSION FACTORS FOR LIVESTOCK, CROP AND FORESTRY EMISSIONS

Factors to estimate BGE for livestock, crops and forestry were taken from the 2018 national greenhouse gas inventory report (Ministry for the Environment 2018), Thomas et al. (2011) and (Thomas et al. 2014) (Appendix 10.7 Tables A27 to A29).

5.5 BGE FROM CROPS AND LIVESTOCK

Using the activity data and factors provided in the tables above we have estimated the BGE (as CO_2-e/ha or /animal) from the selected crops (Table 5) and livestock (Table 6). This information can then be applied to spatial data to estimate the change in emissions due to a land use change.

Table 5. Nitrous oxide and total greenhouse gas emissions from selected crops (kg CO_2-e/ha).

	Fertiliser	Residues	Total from N inputs	Lime, dolomite & urea	Total
	kg N_2O/ha	kg N_2O/ha	kg CO_2-e/ha	CO_2-e	CO_2-e
Apples	0.7	1.7	733	76	809
Avocados	1.7	0.0	526	0	526
Blueberries	0.9	0.1	300	0	300
Cherries	0.9	1.3	664	70	734
Chestnuts	0	0	5	0	<8
Honey & mānuka	0	0	0	0	<8
Kiwifruit	2.4	1.2	1047	203	1250
Onions	2.7	0.1	843	386	1229
Peas	0.0	0.2	68	234	302
Potatoes	4.5	0.6	1523	386	1909
Truffles	0.0	0.0	0	220	220
Wine grapes	0.3	0.5	245	66	311

Table 6. Total greenhouse gas emissions per head (kg CO_2-e/head).

Greenhouse gas	Dairy cattle	Non-dairy cattle	Sheep	Deer
Methane	2199	1500	308	564
Nitrous oxide	660	293	35	85
Carbon dioxide	90	61	6	15
TOTAL	2949	1853	349	665
Percentage of total				
Methane	75%	81%	88%	85%
Nitrous oxide	22%	16%	10%	13%
Carbon dioxide	3%	3%	2%	2%
TOTAL	100%	100%	100%	100%

5.6 BGE EMISSIONS FROM FORESTRY AND PASTURE RENEWAL

5.6.1 Forestry and pasture renewal

Current emissions from applying fertiliser and lime were estimated using data collected by Statistics NZ data (pers. comm. Joel Gibbs). However, if forestry is converted from high-producing pasture it would be normally assumed that no application is required.

Direct emissions based on Statistics NZ (2017) data for N fertiliser and lime applied to forest are extremely small (<8 kg CO_2-e/ha). This does not include the returns from pruning and residues, which are expected to be small.

Emissions from dairy pasture renewal are similarly small (29 kg CO_2-e/ha, assuming annual renewal of 7.5%; Thomas et al. (2014)). Additional emissions would occur if organic soils were cultivated producing more BGE.

BGE emissions from forestry are small and dominated by C uptake while the trees are growing. Net sequestration by forests has been used to offset CO_2-e GHG emissions under Kyoto accounting, but will not be used to offset CH_4 emissions in 2030 and 2050 targets. Typical C sequestration for radiata pine is about 25 t CO_2-e/ha/year, whereas native forestry sequesters about 6.5 t CO_2-e/ha/year.

Perennial woody crops sequester CO_2, but trees grown primarily for fruit or nuts are currently excluded from the New Zealand Emissions Trading Scheme (ETS) and international accounting. Carbon stocks in perennial cropland are concentrated in trees established for shelter, but these do not qualify for accounting. However mānuka grown for honey is eligible for earning carbon credits under the ETS.

6 Economic analysis of growing selected crops

Our analysis was designed to produce the best information to compare profitability of the different land uses (Figure 16).

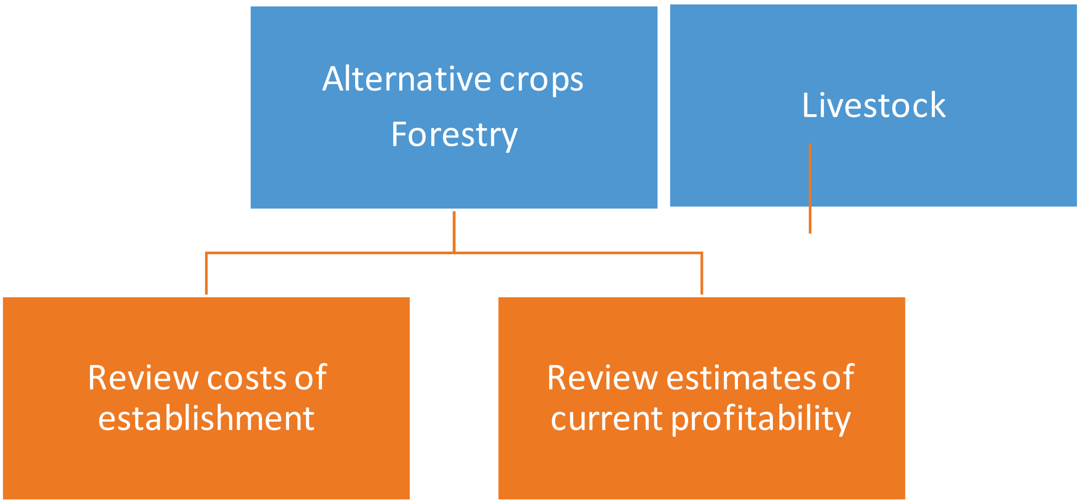


Figure 16. Components of the economic analysis of the alternative crops, forestry and livestock

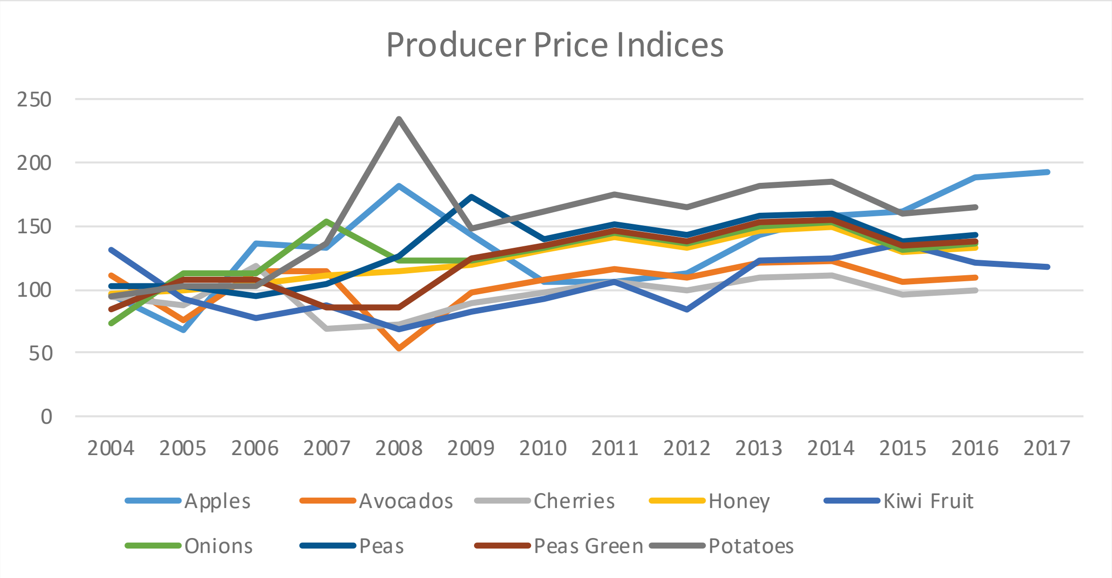
Table 7 provides estimates of the establishment costs of the various enterprises as well as time taken to reach production. Whilst recognising the importance of these factors in determining the overall returns on investment, for the purposes of comparison with existing livestock enterprises, the decision has been made to use the annual costs and returns when mature production levels are reached.

Table 7. Estimates of establishment costs of selected crops and years to production

Crop Enterprise	Estimated Establishment costs $ per hectare	Estimated Years to Production	Maturity
Apples	85,000	3–5	
Avocados	50,000 (range 45–61,000)	4–5	8–10
Blueberries	50,000	5	
Cherries	200,000	4–5	
Chestnuts	20,000–30,000	4–6	10
Mānuka hHoney	2500*	8	
Kiwifruit	400,000–600,000+	3–4	5
Onions	n/a	<1	
Peas	690	<1	
Potatoes	n/a	<1	
Truffles	40,000	6–8^	
Wine Grapes	150,000	4	
Radiata pine	1,200–1,500+†	25–28	

*Currently there is a $1,300 per hectare grant that would reduce establishment to $1,200; + For greenfield Sungold orchard on owned land including licence fees of $400,000 per hectare; ^ Estimate for black truffles, which are the most common in NZ. White truffles can be produced significantly quicker. † lower value is for flatland while the upper value is for steeper land.

Data from the Food and Agriculture Organization (FAO) provides some indication of the trends in price movements for the commodities emerging from these land uses and this is highlighted in Figure 17 where producer price indices are presented from 2004 to either 2016 or 2017 depending on the commodity.



Source: Food and Agriculture Organization (FAO) Statistics
Note: Not available for chestnuts, truffles, wine grapes and blueberries

Figure 17. Producer price indices for selected crops in New Zealand (2014:2016 = 100)

Table 8 provides estimates of the returns from the various enterprises, whilst the following discussion highlights the process by which these estimates were arrived at. As mentioned above, confidence in these figures will vary by enterprise.

6.1 AVOCADOS

Recent official statistics for avocados are not available; however, according to the ANZ Bank (ANZ) (2018) the average return across the avocado industry in the previous four years was $27,300/ha. However, they note that the top growers achieving higher yields were returning $78,000/ha. These figures were achieved with an average 5-year price of $18.9/tray, although in recent years prices had reached the low $20/tray range (ANZ 2018). Although ANZ estimate that returns could be higher in future (in their budgeting exercise they estimate returns of $43,000/ha from a fully mature orchard), it would seem reasonable to take the $27,300/ha figure as an indication of current returns.

6.2 KIWIFRUIT

ANZ (2019) produced an analysis of kiwifruit returns from 2013 to 2017 and estimated that the median returns /ha were $17,657 (ranging from $10,685 for the lower quartile to $26,418 for the upper quartile). They noted that the analysis covered a period where the kiwifruit industry recovered from *Pseudomonas syringae* pv. *actinidiae* (Psa) disease, which negatively affected profits. In addition, the increasing proportion of overall production that is accounted for by Gold3 (*Actinidia chinensis* var. *chinensis* ‘Zesy002’), marketed as Zespri® SunGold Kiwifruit has increased over the period and therefore the average kiwifruit EBIT (earnings before interest and tax) in 2017 was likely to be higher than this average figure. Their indicative EBIT for *Actinidia chinensis* var. *deliciosa* ‘Hayward’ and ‘Zesy002’ orchards are $22,500 and $79,000, respectively, assuming an orchard gate return (OGR) /ha of $60,500 and $119,000 and growing costs of $38,000 and $40,000 for ‘Hayward’ and ‘Zesy002’, respectively (and assuming no amortisation or depreciation). Zespri Group Limited orchard gate return OGR estimates for 2018/19 were even higher for ‘Zesy002’ at $146,000, whilst green (Hayward) were slightly higher at $64,000. However, to be prudent, the 2013–2017 average figure forms the basis for our analysis. Table 9, derived from the Zespri Annual Report highlights the variability in returns between the top and bottom quartile of producers.

The kiwifruit orchard values have been increasing over the last few years. Licences for ‘Zesy002’ were an average of $400,000/ha in 2020, an increase of 37% on the previous year with demand far outstripping availability (Farmers Weekly, 11 June 2020).

In terms of future scale, Zespri have announced that they are planning to issue licences for a further 750 ha of ‘Zesy002’ per year up to 2022, and between 350 and 750 ha per year from 2023 to 2026

(Zespri Outlook Report). Given the intellectual property requirements, this effectively places an upper limit on the increase in 'Zesy002' area up to this time.

Table 8. Cost and return estimates for selected land-uses ($ per hectare).

	Gross Revenue	Costs	Profit	Low Profit	High Profit	Comment
Apples	71,653	50,481	21,172			Recent estimates
Apples			14,976	6751	35,489	ANZ 2013–2017
Apples Hawke's Bay Model			16,704			MPI 2013–2017
Apples Nelson			12,776			MPI 2013–2017
Avocados	63,000	20,000	43,000			ANZ Budgeted future returns
Avocados			27,200		78,000	ANZ 2013–2017
Blueberries	115,000	49,000	66,000	n/a	n/a	
Blueberries*	67,170	45,000	22,170			2009 Gross Margin
Cherries	100,000	60,000	40,000	25,000	n/a	Website information
Chestnuts	10,000	4,200	5,800			Website information
Mānuka+ honey	1750	450	1300	–200	1950	2016 estimates
Kiwifruit	56,597	38,900	17,697	10,685	26,418	2013–2017 average
Onions*	16,000	10,615	5385			2018 estimates
Onions*	14,000	9,060	4940			2008/9 estimates (Cantab)
Peas*	3,230	1693	1537			2018 Lincoln Budget
Potatoes* (processed)	14,134	10,761	3373			2018 estimates
Potatoes*			6331		9063	ANZ 2013 figures
Potatoes* (processed)			2835			2005–2009 average
Truffles	40–140,000	10–20,000	30,000–110,000			Pers. Com and websites
Wine grapes	26,055	10,770	15,285			Recent estimates
Wine grapes			13,468			2014–2017
Contract growing wine	22,000	12,000	10,000			
Dairy			1300	684	2,074	ANZ 2013–2017
Dairy	7041	5241	1800			DairyNZ 2013–2017
Sheep and beef	773	522	250			Beef and Lamb Class 9: All classes 2013–2017
Sheep and beef			337	145	732	ANZ 2013–2017
Radiata pine^			1,000	67	3,267	Survey of 215 woodlots

Notes: *Gross Margins
^Annualised over 30 year rotation.

Table 9. Variation in yield and Orchard Gate Return.

Product	Top 25%	Average	Lower 25%
Zespri Gold			
Yield (trays)	17,600	13,400	8,400
Orchard Gate Return $/ha	170,300	140,900	114,900
Zespri Green			
Yield (trays)	14,500	11,700	7,800
Orchard Gate Return $/ha	74,800	61,500	47,900

Source: Zespri Annual Report 2018-2019 (2019)
Zespri Gold: *Actinidia chinensis* var. *chinensis* 'Zesy002'. Zespri Green: *Actinidia chinensis* var. *deliciosa* 'Hayward'.

6.3 APPLES

The Ministry for Primary Industries (MPI) publish annual pipfruit orchard reports based on model orchards in Hawke's Bay and Nelson. For the 2013 to 2017 period, the estimated average EBIT for the Hawke's Bay model was $16,704/ha and for the Nelson model it was $12,776/ha. ANZ also produced EBIT figures for apples, comparable with those that they calculated for kiwifruit (as reported above) and the median figure for this period was $14,976/ha. This ranged from $6,751/ha to $35,489 for the lower and upper quartiles, respectively. It would seem reasonable to take a figure of between $12,000 and $16,000 /ha to represent recent returns from apples.

In terms of future scale, new techniques and varieties mean there is the potential for apples to expand into other areas of New Zealand. The Australian market does offer significant opportunities for increased exports, despite the stringent biosecurity requirements. There is therefore potential for significant growth in this sector.

6.4 WINE GRAPES

Using MPI published information from their wine models, we calculated an average EBIT over the period 2013 to 2017 of $13,468/ha for the Marlborough model (Viticulture Monitoring Report various years). The model for Hawke's Bay highlights significantly lower returns. It is clear that region and grape type are very important in determining profitability. For example, Table 10 highlights that for 2017 the gross margin ranged from $15,225 /ha for Sauvignon blanc in Marlborough, down to $2,650 for Merlot in Hawke's Bay (New Zealand Wine and Ministry for Primary Industries 2017). In terms of different models for growing grapes, estimates of contract growing in Otago for example highlight 'a return of $10,000/ha' (Otago Daily Times 2014). Note that it was unclear from this article what was included in the 'return'. Assuming there is the ability to contract produce and taking Marlborough as the benchmark, it would seem reasonable to take a figure of between $10,000 and $13,468 /ha.

Table 10. Variety Gross Margins across regions (2017, $ per hectare).

	Variety			
Region	Pinot noir	Sauvignon blanc	Merlot	Chardonnay
Hawke's Bay		$7,240	$2,650	$6,820
Gisborne			$11,625	
Wairarapa	$3,605			
Otago	$2,335			
Marlborough	$11,615	$15,215		

Source: New Zealand Wine and Ministry for Primary Industries (MPI) Gross Margin Benchmarking Report (2017)

6.5 CHERRIES AND BLUEBERRIES

Moving from the main established fruit crops, the costings become more speculative in nature and figures have to be gleaned from various sources. For cherries, an analysis comparing their performance in the Otago region with other land uses estimated a potential revenue of $100,000 /ha. With estimated costs of around $60,000 /ha, this leaves a possible return of $40,000 /ha (Otago Daily Times 2014). However, the analysis notes risks with flowering and frosts, for example, may reduce yield and therefore reduce the return to $25,000 /ha. Clearly this was the case in 2018/19 where late frosts and significant spring rain were blamed for a significant fall in production. Elsewhere, it is also noted that there is a risk of a complete crop failure one year in five. Based on these figures, an average return over a 5-year period of between $25,000 and $30,000 /ha would seem reasonable.

For blueberries, official figures for 2009 indicated a gross margin of around $22,000 /ha (based on 7 t/ha and $9.6 per kg). However, prices have risen considerably since this time and average yields have also improved. Assuming a yield of up to 10 t/ha for a mature blueberry orchard and a price of up to $15 per kg, it is estimated that returns /ha can be between $100,000 and $150,000 (Young and Kiwi-Knight 2017). Conservatively, taking a lower figure in this range of around $115,000, and with estimated costs of $49,000 /ha, the annual return from blueberries can be estimated at $66,000 /ha (excluding start-up costs).

Examining more detailed costs that are available from Australia (source NSW Government), it may be reasoned that this figure is more of a gross margin from blueberry production. In order to be consistent with our other enterprise estimates, and in the absence of further information, we take an average figure for the other fruit crops of the difference between the gross margin and EBIT and apply this to blueberries. This reduces the figure by 17% to around $55,000 /ha.

6.6 PEAS, POTATOES AND ONIONS

Up-to-date official published statistics on the field crops considered in this study (peas, potatoes and onions) are not available. For peas, one source of information is the Budget Manual produced annually by Lincoln University (Lincoln University 2018). The most recent manual estimates the costs of field operations and variable costs of production for vining and field peas. For field peas, based on a yield of 3 t/ha and a price of $960 per tonne, they estimate gross returns from the crop as $2,880 /ha. In addition, it is estimated that a tonne of forage can be harvested from a field with a value of $349 per tonne. This generates an overall revenue /ha of $3,230. The estimated costs of production were $1,692, giving a margin of $1,537 /ha. While the cost estimate includes machinery costs associated with production (e.g. cultivation, sowing, spraying), it does not include a share of the farm overhead costs and these need to be considered in the overall return. Vining peas are budgeted to achieve a very similar gross margin of $1,521 /ha.

Interestingly, in 2013, ANZ (2013) highlighted gross margins for a range of types of peas and these are highlighted in Table 11.

Table 11. ANZ estimates of Gross Margins from peas (2013).

Type	Base Price	Medium Yield	High Yield
Peas blue	$600	$908	$1,713
Peas garden	$950	$1,096	$2,182
Peas maple sprouting	$1,000	$2,000	$3,543
Peas marrowfat	$750	$1,042	$2,086
Peas white	$500	$840	$1,628
Peas vining	$415	$1,386	$2,614

Source: ANZ (2013) Returns from irrigation

There is interest in developing proteins from peas and this may lead to a new market opportunity. Given that they fit well into current farming systems, it would seem that there is the potential for increased areas of peas in New Zealand.

Unfortunately, recent costs and returns for potatoes and onions are not reported in MPI statistics, nor are they covered in the Lincoln budget manual. For potatoes, ANZ in 2013 estimated the gross margin for medium yield producers to be $6,331 /ha and this rose to $9,033 /ha for high yield producers (ANZ 2013). Older estimates are available from MPI dating back to 2009/10. For processed potatoes, we took the estimates of cost from this time period and inflated these to attain an estimated cost for 2018 of $10,761 /ha. Assuming a yield of 60 t/ha and a 2018 price of $234, then the revenue can be estimated as being $14,132 /ha, with the costs estimated at $10,761, giving a return of $3,373 /ha for processed potatoes. Again, these costs relate to the specifics of potato growing and more general farm overhead costs need to be taken into account in identifying a comparable return to the other enterprises considered in this study. While fresh potato prices are obviously higher, so are the associated costs; between 2004 and 2009 (when MPI reports no longer became available), fresh potatoes only once generated a positive gross margin.

For onions, it is estimated that average yields for brown onions vary between 33 and 50 t/ha depending on the season. Like potatoes, official cost and return estimates were discontinued in 2009. Following a similar approach to potatoes, published costs from this period were inflated to 2018 values and are estimated at $10,615 /ha (ANZ 2013). Taking a figure of around 40 t/ha and an estimated price per tonne of $400/t gives us a total revenue of $16,000 and a gross margin of $5385 /ha. A lower price of $350/t would reduce this to $3,385 /ha. Again, a share of fixed and overhead costs needs to be apportioned to the enterprise.

For control of pests and diseases, rotational constraints are important for potatoes and onions. Although export market demand appears relatively strong for the two enterprises, suitable land availability and the need for specialist skills and machinery may constrain their development.

6.7 TRUFFLES AND CHESTNUTS

It is fair to say that the commercial truffle industry in New Zealand is in its infancy, although interest and the planted area are rising. There are three types of truffles grown in New Zealand (black, burgundy and white), and currently the price ranges from around $1,000 to $3,500 per kg. The black truffle is currently the most widely grown of the three. Establishment costs for a greenfield truffiere are around $32,000 to $35,000 /ha (for plants and materials but excluding labour). Yields of between 100 and 200 kg/ha have been touted for a mature truffiere, but discussion with an expert in the area suggests a more reasonable estimate of a good yield is 50 kg/ha (Alexis Guerin, personal communication). Yields of 20 to 40 kg/ha have been suggested elsewhere (Southern Woods Plant Nursery 2014). Taking a yield of 40 kg/ha, with prices of between $1,000 and $3,500 per kg, in theory gross revenue could be between $40,000 and $140,000 /ha. Annual costs of production are hard to find. One website suggests an estimate of $1200 /ha for general truffiere management (e.g. mowing). Harvesting costs will include either hiring or owning, and training, a specialist truffle dog to find the truffles. Furthermore, there are sorting and packing costs, as well as general overhead costs. Even if these costs were in the region of $10,000–20,000 /ha, the potential returns from the crop are very high. However, there are still many uncertainties associated with the crop. On the positive side, understanding of the production process is increasing all the time and this should lead to more certain crops in the future and possibly with higher yields. On the other hand, it should also be noted that scarcity is one of the reasons for high truffle prices, as commercial production increases, it is likely to negatively impact on prices (this has been witnessed in Australia already).

According to the New Zealand Chestnut Council's website, growers' gross returns (at gate) can range from $1.50–3.00/kg depending on size or grade of the nuts, with the larger or earlier-season nuts usually fetching a premium (New Zealand Chestnut Council Inc. 2000). The Council estimate that harvesting costs can range from 50c to $1.00/kg, depending on tree age. They assume that under reasonable conditions most orchards are capable of achieving around 4 t/ha once the trees reach maturity by year 10. Average gross returns (calculated at $2.50/kg average) at maturity would then be in the vicinity of $7,500/ha. Allowing for overhead and other costs may reduce this figure to around $5,600 /ha. They note some advantages of chestnuts, for example, in comparison with many horticultural crops a chestnut orchard is cheap to establish and maintain and has a low time input requirement (except at harvest). They do note that estimating grower returns and production levels /ha is difficult because of variations in the market from year to year and the fact that there is wide variation in tree performance from one site to another.

Both truffles and chestnuts have the potential to grow significantly in New Zealand (David Klinac, personal communication). However, chestnuts have been around for a number of years and the industry has failed to take-off. Opportunities exist because of increasing overseas demand and decreasing overseas production (largely because of climate change, population change, pests and diseases). There is especially good demand from Asia where chestnuts are very popular. New Zealand is fortunate in that the climate and general growing conditions are suited to chestnut production and it is free from serious chestnut pests and diseases, so there is the possibility to grow chestnuts spray-free and organically. Chestnuts have the potential to fit with increasingly health conscious consumers and, unlike other nuts, are not associated with nut allergy problems. There are also significant opportunities in a variety of high-priced, value-adding processing applications. However, despite these opportunities, the New Zealand chestnut industry is still small and struggling. In part this is because New Zealand lacks a domestic market and the export markets for fresh or frozen are a long distance away; unlike some other products, being out of season in the Northern hemisphere is not an advantage. There are challenges with maintaining quality and New Zealand lacks a chestnut processing industry. Overall, New Zealand chestnuts are not well known, there is a limited number of species, and those that are produced are different from those grown in many northern hemisphere countries, which offers further challenges.

6.8 **MĀNUKA** TREES AND HONEY

Whilst mānuka honey is a well-established product, mānuka plantations are less so. Mānuka Farming New Zealand, an organisation encouraging mānuka [what?], undertook analysis that suggests the returns to a landowner of planting mānuka trees (with a 30% share of the honey revenue) could be $1,020/ha when they reach maturity (Mānuka Farming New Zealand 2020). Other estimates suggest a lower return to the landowner, with an average estimate of $525 (ranging from a $75 for a low price/yield to $720 with higher prices and a higher yield; McPherson (2016). If the landowner also operates the hives, then McPherson (2016) estimated the annual return could be $1,300 (ranging from a possible loss under a low yield and low price scenario to $1,950 under a higher yield and higher price scenario). These returns are highlighted in Table 12 and illustrate that working the hives can increase the return /ha, but clearly it involves more work and potentially more risk. In general, it is argued that the level of returns suggest that mānuka plantations may be a viable alternative for hard hill sheep and beef and currently non-productive land. In addition, mānuka trees grown for honey can be eligible for earning carbon credits under the ETS, whereas perennial tree crops are excluded from the New Zealand ETS scheme.

Table 12. Estimated returns from **mānuka** honey production on plantation **mānuka**.

	Average expectation	**Higher yield higher price**	**Lower yield lower price**	**Low yield low price**
Hives (/ha)	1	1	1	1
Honey yield (kg/ha)	35	40	20	10
Price $/kg	50	60	35	25
Mānuka establishment cost $/ha	2,205	2,205	2,205	2,205
Hive purchase ($)	700	700	700	700
Total set-up costs ($/ha)	2,905	2,905	2,905	2,905
Income ($/ha)	1,750	2,400	700	250
Operational costs/hive ($/ha)	450	450	450	450
Annual Return ($)	1,300	1,950	250	–200
Return to Landowner if not producing honey themselves ($/ha) (assuming 30% share of honey revenue)	525	720	210	75

Source: Adapted from McPherson (2016).

6.9 DAIRY, AND SHEEP & BEEF

Given their importance and prevalence in New Zealand, it is not surprising that extensive information on the economics of these enterprises is available. The producer funded bodies report annually on the profitability in great detail across a range of systems. In Table 8, we have highlighted average profitability for two enterprises (dairy and sheep/beef). For dairy, over the 2013–2017 period gross revenue was estimated at $7,041 /ha on average, and costs at $5,241 leaving a dairy operating profit of $1,800 /ha. This is slightly higher than the ANZ EBIT estimate over the same period of $1,300 /ha. For sheep and beef, the average return across all classes was $773 /ha; with costs of $522 /ha, this left a figure of $250 before interest and tax. This is slightly lower than the ANZ EBIT estimate for the same period ($337). For both dairy, and beef and sheep, more detailed regional and system costings are available, which can be used to assess more precisely the economic impact of changing land-use in specific locations of New Zealand.

6.10 FORESTRY

There are surprisingly little published data on the economics of forestry, which is strongly site-specific. For Table 8 we have presented net harvesting returns derived from a survey of woodlot harvesting outcomes with a sample size of 215 (West 2019). Note that these do not represent likely returns under 'best practice' management, but give an indication of what has been achieved in practice in recent years, adjusted to 2017 dollar values.

Nominal annual returns were also estimated from the survey results where stand age was known. The mean was $1,156 per hectare per year (range $56 to $2,941 per hectare per year). This is not a discounted annuity, but rather the return at harvest divided by the length of the rotation. An alternative approach would be to average over space rather than time. The assumption here would be that a forest has been established over time with an equal area in each age class. In this case, the return from a nominal hectare would be (1/*r* * *net harvest return) – ((r-1)/r * mean annual growing costs)*, where *r* is the rotation length. The mean rotation length in the survey dataset was 27, so the harvest return would be $1,113 per hectare, leaving about $1,000 per hectare after growing costs on the unharvested stands are deducted. On better sites (e.g. flat productive land close to ports), the return could be 3–4 times greater. There is also potential to earn revenue from selling carbon credits over the first rotation which has not been accounted for here. The inclusion of carbon credits greatly increases the profitability of afforestation, but under “averaging accounting” the carbon cashflow only arises in the first rotation.

7 Assessment of replacing livestock farming with crops and forestry

The work described in the previous sections provides the information required to assess the impact that expanding some key existing high value crops and more novel crops could have on overall BGE and profitability (Figure 1).

To understand the consequences of changes we need to be able to compare the current land uses against future projections. Fortunately, in New Zealand we have very good agricultural production information collected by Statistics New Zealand. Our primary source of land use is the Statistics New Zealand 2017 agricultural production census, which provides data at district and regional levels. This is also highly relevant as the national Climate Change emission targets use a baseline of 2017.

Ten of the 12 selected crops have information collected in the 2017 census (Appendix 10.9 Table A33). Unfortunately, there are no land coverage data for mānuka that produces mānuka honey or the areas or type of trees grown for truffle production. Based on the reported data, the other 10 selected crops account for 89,363 ha and 1,703,830 ha of exotic forestry (Appendix 10.9 Table A34). Livestock (dairy, beef, sheep and deer) numbers are also provided for each region in the 2017 census (Appendix 10.9 Table A35).

We have used the national targets for enteric CH_4 emission reduction targets for 2030 and 2050 (Table 16) set out in the New Zealand Climate Change Response (Zero Carbon) Amendment Act 2019 (https://www.mfe.govt.nz/climate-change/zero-carbon-amendment-act) to investigate how land use change based on growth of our selected high value crops and forestry might meet these targets. We have not specifically targeted land use change to meet national zero carbon targets.

7.1 GROWTH PROJECTIONS FOR ALTERNATIVE LAND USES

The analysis of market demand, potential per hectare profitability and land suitability all highlight that, in theory at least, there is the potential for significant growth in production of the enterprises under consideration in this study. This section considers the assumptions that are made about growth and briefly discusses some of the factors that in reality may determine the extent that expansion in these crops occurs.

Attempting to predict or forecast growth in area of the enterprises considered in this study up to 2050 is challenging, especially for those that have not yet been established in New Zealand. In addition, even for those sectors where information is available, growth in output is occurring at the intensive margin (i.e. higher yield per hectare) as well as the extensive margin and it is hard to separate out the likely impacts of the two. Therefore, rather than try and predict area growth, we undertook a scenario or 'what-if' approach that enables consideration of the possible impact of growth in these enterprises on emissions and profitability. To achieve this, we followed a number of steps:

First, available statistics were used to estimate current areas (if known) of the 12 enterprises considered in the study.

Second, current areas of similar crops were added to these areas, so for example, for apples we also incorporated the area down to pears.[6]

Third, for established enterprises the approach adopted was to assume that the area grown would double by 2050. Growth for 2030 was assumed to be in proportion to this doubling by 2050. Effectively, this assumes a growth rate of about 2.4% per year. To put this in context, this is higher than the rate of growth that occurred in the last two decades which has been around 1.35% per year. Although specific enterprises have grown much faster (for example, the wine grape area grew at 6.2% a year between 2002 and 2016).

Fourth, for crops that are not really established yet, or no official statistics are available (e.g. chestnuts and truffles) the assumption was made that they would become established by 2050, with 4,000 and 2,000 ha of nuts and truffles grown, respectively.

[6] Therefore the assumption is that emissions and profitability is similar across these types of crops. Whilst of course this is a simplification, it does allow us to capture growth in the sector more generally than just our specific enterprises.

Finally, for mānuka plantations, estimates of growth up to 2035 were available from the recent PGP final report.[7] Therefore, for 2030, the area was taken directly from the estimates for this year from the report. Rather than extrapolate beyond 2035, the decision was made to take the 2035 figures from the report for our 2050 estimates. This implies that growth would plateau beyond 2035.
Table 13 presents the current and future estimated areas for the different land uses based on these approaches. In the next section, possible factors that can influence growth in these sectors are discussed in more detail.

Table 13. Future land area growth scenarios for the different land uses for 2030 and 2050.

Crop	Area (ha)	Total of similar crops (ha)	Area after Optimistic Growth for Sector 2030 (ha)	Area after Optimistic Growth for Sector 2050 (ha)
Apples	8,615	9,030	12,040	18,060
Avocados	3,979	3,979	5,305	7,958
Blueberries	624	1,163	1,551	2,326
Cherries	726	2,140	2,853	4,280
Chestnuts	86	958	1,972	4,000
Kiwifruit	11,705	11,705	15,607	23,410
Onions	6,009	6,009	8,012	12,018
Peas	14,188	14,188	18,917	28,376
Potatoes	9,450	9,450	12,600	18,900
Wine grapes	33,981	34,021	45,361	68,042
Forestry	1,703,830	1,703,830		
Truffles	n/a	n/a	1,000	2,000
Plantation Manuka and Honey	16,800	16,800	88,800	118,800

n/a data not available

7.1.1 Possible Factors Influencing Growth

At first glance the potential international market demand for the products and the profit differential between many of the enterprises discussed in this report and livestock supports the contention that an increase in the growth rate to levels that can lead to a doubling of area by 2050 can be achieved. However, a wide range of factors, including those that may influence the ability to reach markets and the profitability of the enterprises will determine whether growth will occur. These include competitiveness in international markets, investment in infrastructure, availability of skilled managers, labour availability more generally, cash-flow and biophysical factors such as climatic risk and water availability.

7.1.2 Competitiveness and supply chain infrastructure

It is clear that for established enterprises (e.g. kiwifruit, wine etc.), New Zealand products are competitive on the world market and sophisticated supply chains have been established that help maintain this competitiveness. For these enterprises, growth can build on what exists currently, although investments will need to be made as scale increases or if production moves to new areas. However, for the less established enterprises, being competitive on international markets will require getting the product to its final market at a price consumers are willing to pay. For these enterprises this will depend upon whether markets and effective supply chains to supply these markets can be developed. Major investments in order to develop the necessary supply chain infrastructure will be required, for example, in packing or processing facilities and broader infrastructure.

7.1.3 Skills and Labour

Due to the specialised nature of the enterprises, growth will require a substantial increase in the number of those with the skills to grow and manage these enterprises. Without significant investment in training and education throughout the sector growth is likely to be constrained. This said, new horticultural programmes are coming on stream in the higher education sector at both the degree and diploma level which will increase the supply of skilled managers.

[7] The figures taken reflect the conservative scenario of growth (Scenario 1). Details can be found at https://www.mpi.govt.nz/dmsdocument/37392-high-performance-manuka-pgp-programme

More generally, labour availability will be an important determinant of the extent that the enterprises can expand. This is due to the high labour requirements of many of the enterprises, particularly for harvesting and processing. Whilst automated harvesting and processing technology is developing, there is likely to continue to be a high labour requirement for the near future at least. The recent COVID-19 outbreak has highlighted the reliance of the horticultural sector on migrant labour and how labour shortages may put a brake on expansion. This said, labour could become more available in the short term at least due to the greater impact of COVID-19 on other domestic sectors (particularly tourism)

7.1.4 Cashflow

The per hectare costs and returns and profitability of the alternative enterprises were based on the enterprise being fully productive which has the potential to overstate their attractiveness when compared to pastoral systems. Potentially large start-up costs, associated with orchard establishment in particular, have not been factored in. As Table 7 highlights, these can be significant, particularly where viable production may not occur for a number of years. Inclusion of these costs would alter the relative economic return of the different crops, potentially reducing their attractiveness to landowners. For example, many of the enterprises may have pay-back periods of anything from 8 to 12 years which will influence the willingness of individuals to invest (and financial institutions to support the investment).

7.1.5 Biophysical Risks

It is clear that climatic risks (hail, frosts, drought etc.) are much higher for horticultural crops than for pastoral based systems which also means that variability in profit is likely to be greater. This is because in some years yields may be very low or even non-existent. These risks may make it unattractive for firms to invest in horticulture. In addition as the climate changes issues around water availability will raise potential challenges particularly as many of the enterprises require irrigation and the most suitable areas for production are those that are, or are likely to become, water stressed.

Of course these challenges are not insurmountable and kiwifruit and wine grapes have already shown that it is possible for products to break-out and move from niche to the mainstream. However, some of the other enterprises have been around in New Zealand for a number of years without reaching critical mass and scale. There will need to be a step change in these enterprises for them to grow significantly. If this were to occur it is likely to require large scale investment from the private sector as well as support from the public sector.

7.2 ESTIMATING BGE AND PROFITABILITY FROM GROWTH SCENARIOS BY REGION

We used the spatial modelling and optimisation framework LUMASS (Herzig et al. 2013; Herzig et al. 2018) to explore how replacing livestock farming with our selected crops in Table 13 might affect greenhouse gas emissions and profitability.

We modelled three different scenarios using the land use defined though our suitability maps (Appendix 10.5 Figures A3 to A23) and tables (Appendix 10.6 Tables A3 to A23), BGE (Table 5 and Table 6) and profitability data (Table 14).

In all scenarios, we assumed an optimistic growth of low emission land-uses, resulting in doubling individual crop areas in New Zealand by 2050 (Table 13). New low-emission land uses were allocated to current livestock farming areas according to crop suitability and emission reduction objectives (Table 15). Thereby, low-emission land-use expansion was modelled to occur proportionally to current crop areas per region. Since current areas for honey (mānuka) and truffles were not available, we spread the estimated areal growth (by 2050) evenly across all regions with sufficient suitable or well-suitable pastoral farming land available for the given crops. In these scenarios we did not attempt to allocate forestry to livestock areas.

Table 14. Ranges of profitability for each land use ($/ha).

Land use	Well Suited	Average	Low
Apples Hawke's Bay Model	$27,264	$17,147	$8,745
Apples Nelson	$23,484	$14,770	$7,533

Avocados	$78,000	$27,000	$13,960
Blueberries	$104,940	$66,000	$33,660
Cherries	$65,000	$40,000	$25,000
Chestnuts	$12,966	$8,155	$4,159
Mānuka trees + honey	$1,950	$1,300	–$200
Kiwifruit	$26,418	$17,697	$10,685
Onions	$8,591	$5,385	$2,784
Peas	$2,452	$1,537	$795
Potatoes (processed)	$4,829	$3,373	$1,744
Potatoes	$9,063	$6,331	$3,273
Truffles	$63,600	$40,000	$20,400
Wine grapes	$24,303	$15,285	$7,795
Dairy	$2,872	$1,800	$931
Sheep and beef	$732	$337	$145

Table 15. Scenario objectives and specific allocation constraints.

	Scenario 1	Scenario 2	Scenario 3
Objective(s)	Maximum Suitability	Maximum Suitability Minimum BGE	Maximum suitability Minimum BGE
Constraints			50% of crop expansion on dairy land 50% of crop expansion on other pastoral farming land
Regions	All NZ regions	Waikato, Canterbury	Waikato, Canterbury

BGE – biogenic greenhouse gas emissions

7.2.1 Effects of land use change scenarios on emissions and profitability

Doubling the area of our crops (Table 13, Table 15, Scenario 1) based on utilising the most suitable land first resulted in a net reduction in BGE of 370 kt CO_2-e of which 323 kt CO_2-e was from enteric CH_4 (Figure 18). This is the equivalent of a 1.0% reduction in total BGE emissions from agriculture, or 1.2% of the enteric CH_4 emissions. However, it predicted a large increase in profitability of $1.32 billion (Figure 18).

In the other land use allocation scenarios for the Waikato and Canterbury, where the focus was on maximising reduction in BGE, the reduction in BGE could be increased where the highest emitting land uses were removed first. In Scenario 3, focused on minimising BGE, almost all the land use change (11,278 ha) predicted for the Waikato was on dairy land, resulting in a reduction in BGE of 1.6% (116.9 kt CO_2-e). The reduction in area of dairy was 1.5% of current dairy farmland. In the constrained case (Scenario 3, Figure 19), where no more than 50% of the change was allowed on to current dairy land, the reduction was 1.4%.

In Canterbury, the reduction in BGE was much larger in absolute emissions and proportion of change. Doubling the area of alternative crops by about 30,000 ha and allocating them on to highest emitting land use (29,240 ha of dairy) in Scenario 2 could reduce Canterbury BGE by 460 kt CO_2-e, or 7.1%. The dairy area constrained scenario (Scenario 3, Figure 20) still would have resulted in a large reduction of Canterbury BGE by 6.25%.

The scenarios targeted at minimising BGE would have had a larger impact on profitability as they affected the most intensive and profitable livestock land use; however, our estimates of profitability would still make the land between 2.9 and 3.7 times more profitable in a crop in Scenario 2, or 5.7 to 7.3 times for Scenario 3 for Canterbury and the Waikato, respectively.

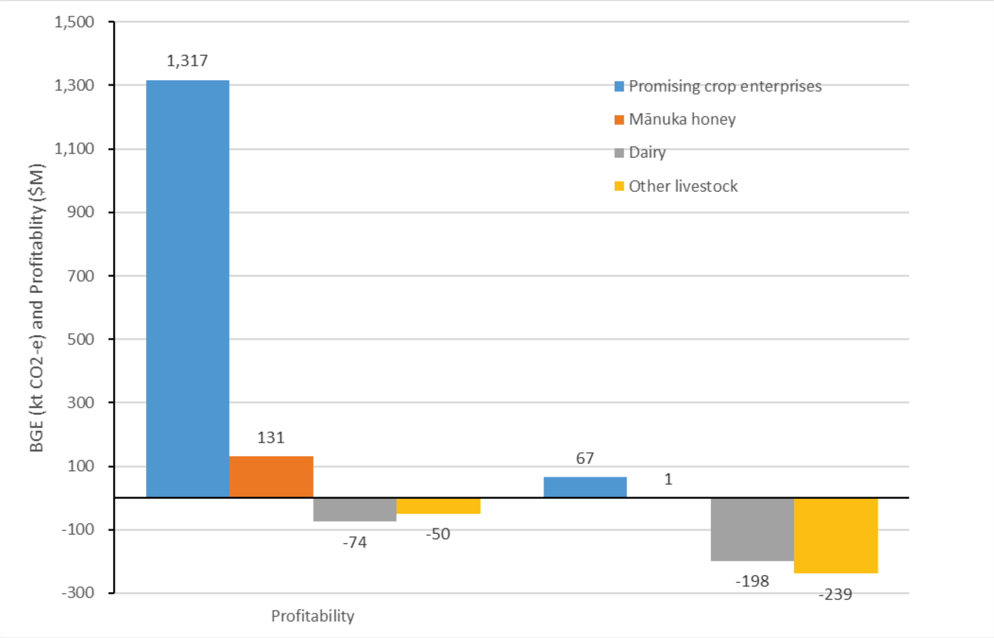


Figure 18. Estimates of net changes in biogenic greenhouse gas emissions (BGE) and profitability from an optimistic scenario of doubling the area of alternative crops replacing existing livestock land across New Zealand (Scenario 1). The land use allocation was based on maximising the most suitable land for the selected crops.

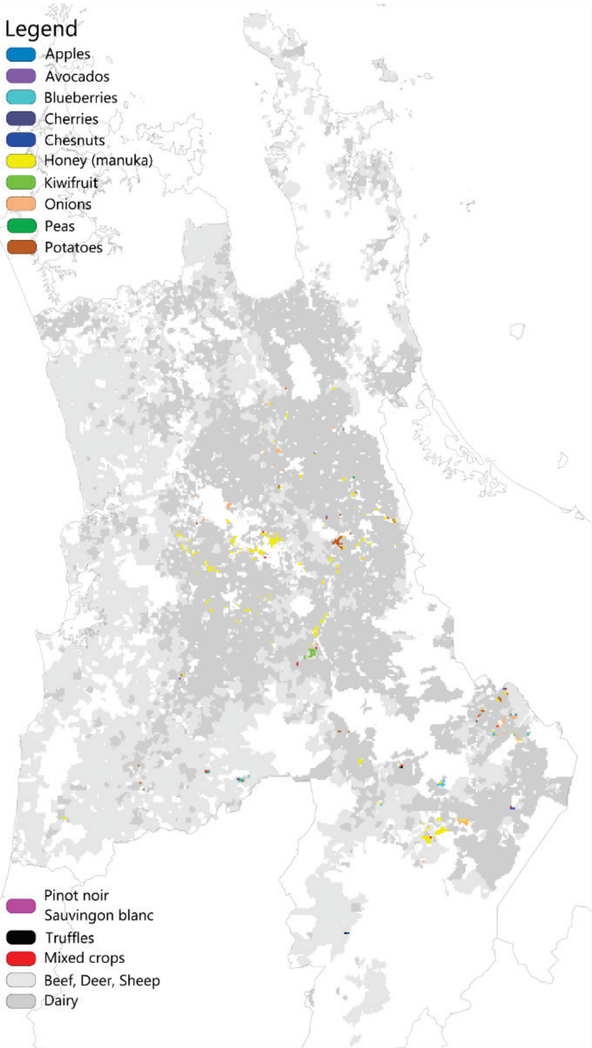


Figure 19. New land use allocation of alternative low greenhouse gas emitting crops simulated for Waikato region.

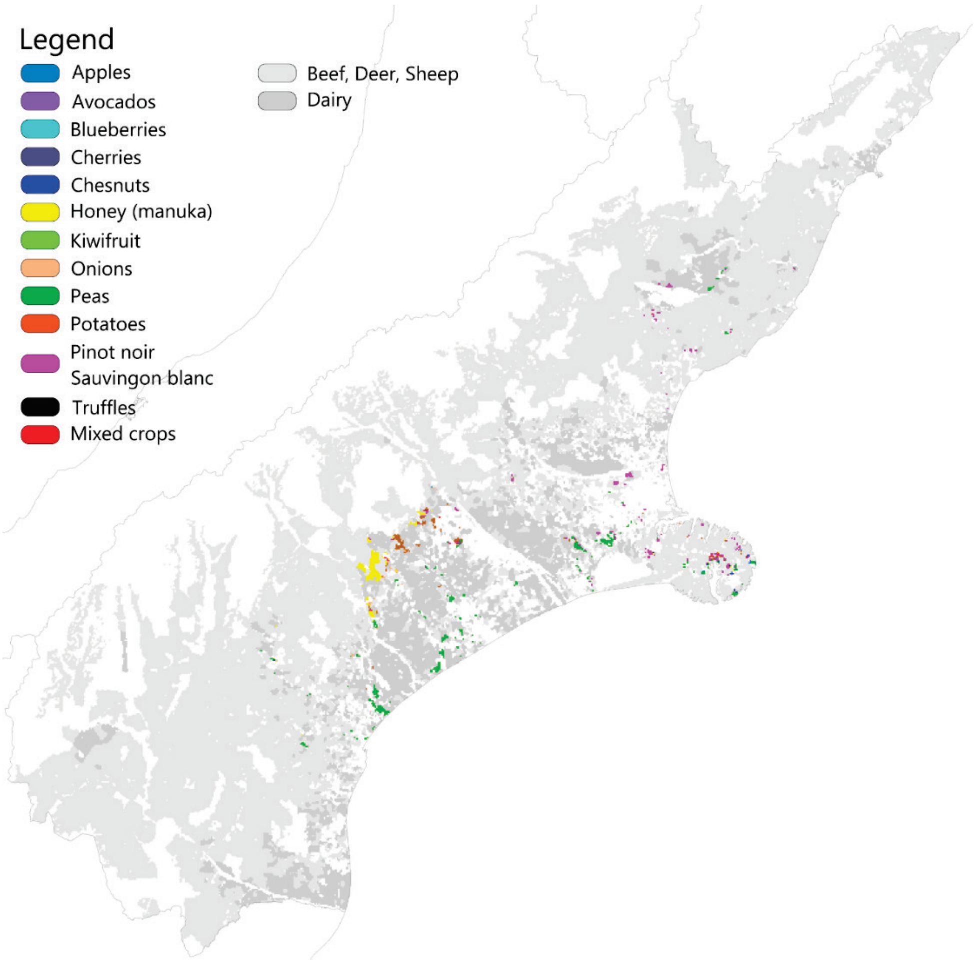


Figure 20. New land use allocation of alternative low greenhouse gas emitting crops simulated for Canterbury region.

In these scenarios we have not attempted to estimate changes to sequestered carbon in soil or biomass changing from pastures to crops. Such estimates are highly uncertain with limited New Zealand-based information. Perennial woody crops sequester CO_2, but trees grown primarily for fruit or nuts are currently excluded from the New Zealand Emissions Trading Scheme (ETS) and international accounting. Carbon stocks in perennial cropland are concentrated in trees established for shelter, but these do not qualify for accounting. However, mānuka grown for honey is eligible for earning carbon credits under the ETS. Factors based on IPCC default values used for estimating changes in C stocks in the National GHG inventory are provided in Appendix 10.8.

7.3 WHAT SIZE OF LAND USE CHANGE COULD ADDRESS METHANE REDUCTION TARGETS?

One of our objectives was to make a simple assessment on how potential land use change, including the use of crops and forestry, might meet future emission targets. To keep this simple we focused on the New Zealand CH_4 emissions reduction targets for 2030 and 2050 (Table 16).

From our modelling in Section 7.2, our optimistic land use change scenarios based on doubling the areas of the high value crops unsurprisingly have low impact on the national inventory because of the dominant contribution from livestock. For example, our increase of nearly 200,000 ha is small relative to 1.74 million ha used for dairying (Dairy NZ 2019). This makes it unlikely that land use change with high value crops will not a big impact on current CH_4 reduction targets without other significant land use changes or land retirement, such as forestry (plantation or natural).

Fortunately, it is likely that there will be mitigation options to help meet these CH_4 reduction targets (Reisinger et al. 2016; Reisinger et al. 2018). We selected two promising CH_4 reduction mitigations – inhibitors and breeding of low emitting animals and estimated new reduction targets based on their efficacy and uptake by 2030 and 2050 (Table 16 and Table 17).

Table 16. Methane (CH_4) emissions (2017) and future reduction targets for 2030 and 2050 in kt CO_2-e.

Targets	Business as usual 2017 (baseline)	Scenario 1 2030	Scenario 2 2050	Scenario 3 2050
% CH_4 reduction	0	10	24	47
	kt CO_2-e			
National enteric CH_4 target	27,647	24,882	21,011	14,653
CH_4 reduction required from baseline.	0	2,765	6,635	12,994
With mitigations	0	1,819	-563	6,034

Table 17. Assumed methane (CH4) emission reductions for dairy, sheep and beef by 2030 and 2050 through advances in mitigations. Values are calculated based on assumptions of efficacy and uptake. Based on (Reisinger et al. 2018).

Target date	Mitigation	Type	Efficacy (%)	Uptake (%)	Overall (%)
By 2030	Inhibitor	Dairy	20	30	6
		Beef	20	5	1
		Sheep	0	0	0
	Low emission animals	Dairy	5	5	0
		Beef	5	2	0
		Sheep	5	10	1
By 2050	Inhibitor	Dairy	40	60	24
		Beef	40	30	12
		Sheep	40	30	12
	Low emission animals	Dairy	15	70	11
		Beef	15	40	6
		Sheep	15	40	6

Using these lower CH_4 mitigation adjusted targets and our optimistic projections for increasing the area of alternative crops, we estimated the additional land use change required to meet these targets. In this scenario we assume that the change (reduction of land) will occur across livestock types. The contribution to the reduction in CH_4 emissions was divided across dairy (50% reduction), sheep and beef (25% reductions for each), using stocking rates of 2.9 cows, 10 sheep and 2 cattle per hectare (Figure 21). Because of the relatively lower /ha emissions for non-dairy livestock, the area required for retiring or converting would be much larger than dairying.

Based on this scenario, assuming native or plantation forestry would be the main option for land use conversion or retirement, to meet the 2030 and 2050 targets, 270,097 ha forestry could be planted by 2030 and 1,000,453 ha by 2050 (47% target).

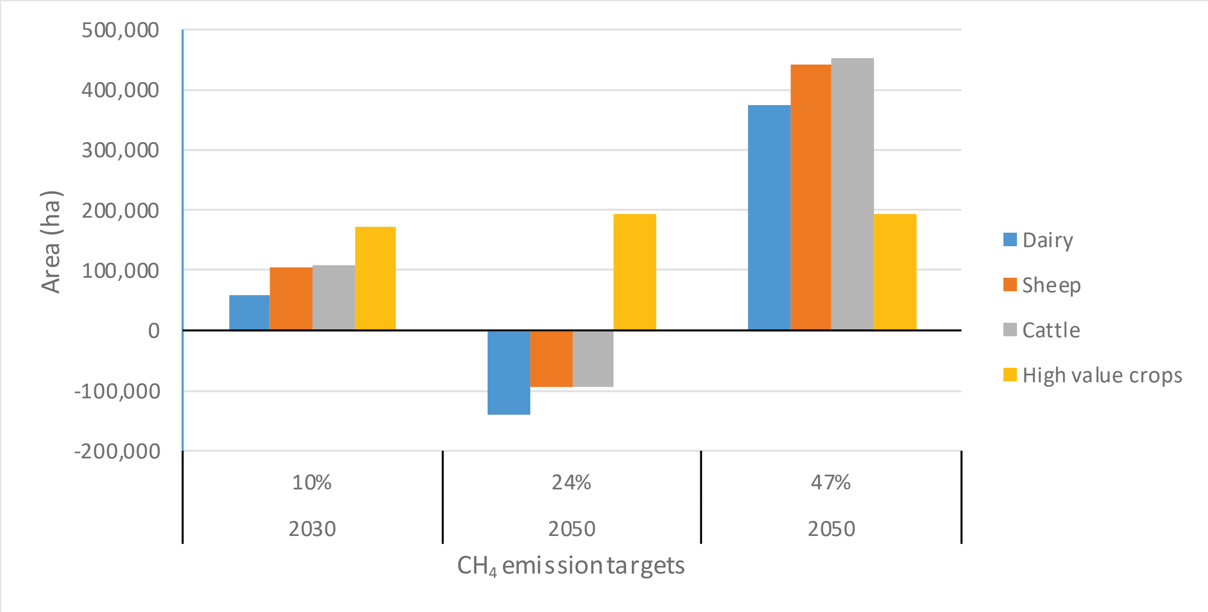


Figure 21. Predicted net reduction in livestock area from conversion to crops and other land use required to meet 2030 and 2050 methane emission reduction targets assuming effective mitigation reduction (Table 17). Assumption: 50% of the difference in methane emissions is achieved by retiring dairy land stocked at 2.9 cows /ha and the remaining 50% by sheep and cattle stocked at 10 and 2 head per hectare, respectively, and optimistic increases in high value crops (Table 13). Note that the lower 2050 target (24%) is already met through assumed mitigations.

This is very simplistic and illustrative only. Conversion to high value crops is more likely to occur on land suited to dairying, while conversion to forestry is unlikely to occur on land suited to dairying due to the much lower economic returns. Whereas forestry is much more likely to occur on more economically marginal sheep and beef land that has lower stock carrying capacity.

The important point to make is that to meet the most ambitious CH_4 emission reduction targets even more effective CH_4 mitigations will be required and/or animal numbers will need to reduce. Potentially this could be achieved by even greater conversion to cropping than in our optimistic growth scenario or through afforestation of pastoral land.

While planting trees does not reduce CH_4 emissions, it will have the benefit of reducing agricultural BGE towards net zero targets for non-CH_4 emissions.

8 Conclusions

We identified large areas where high value, low-emitting crops can be grown across New Zealand. Much of it is on land where its current use results in large BGE.

Our analysis of export markets indicates that there are growth opportunities for horticultural and arable crops. We selected 12 crops that were most promising, but also recognised there are others that deserve investigation in the future.

Replacing ruminant livestock with high value crops greatly increases the profitability of the land area, and modest changes should increase the economic well-being of New Zealand.

Although changing to these crops or land use will reduce agricultural emissions, the scale of land use change to high value crops and mānuka (200,000 ha) is unlikely to have a large impact on reducing CH_4 or total BGE emissions. The greatest effect on reducing BGE will occur when the alternative land use replaces the most intensive livestock farming (e.g. irrigated dairy farms) because of the high emissions per hectare.

From our assessment, there appears to be plenty of opportunity for increasing the areas of the highly profitable crops we selected; however, there are many driving or constraining factors that affect land use change decisions that need to be addressed, but their examination were largely beyond the scope of this project. These factors include access and competitiveness in international markets, investment in infrastructure, availability of skilled managers, labour availability more generally, cash-flow and biophysical factors such as climatic risk and water availability. Similarly, there will be similar or other factors driving or constraining large-scale afforestation that would be required to make up the difference in reaching net zero carbon emission targets.

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10 Appendices

10.1 APPENDIX – ALTERNATIVE CROP OPTIONS – FURTHER OPTIONS

Additional products

Our selected product basket excluded a number of products and some of the excluded products may warrant further research to more accurately include or exclude. These products include:

Product	Comments
Persimmons	Growth trends of interest in UN data, discussed in Horticultural Industry literature
Asparagus	Growth trends of interest in UN data
Pears	Showing strong growth, industry development closely linked with the apple industry and discussed in current Horticulture Industry literature
Apricots and Berryfruits	Growth trends of interest in UN data, aligned with health and nutrient trends
Carrots	Growth trends of interest in UN data
Squash/Pumpkin	Growth trends of interest in UN data, discussed in Horticultural Industry literature
Walnuts/Hazelnuts	Growth trends of interest in UN data, discussed in Horticultural Industry literature, aligned with health and nutrient trends

Alternative or emerging products

In addition, anecdotal evidence and mention in literature and industry publications has brought attention to two areas of alternative or emerging products that would warrant further consideration:

- Powdered products, such as avocado and beetroot, discussed in New Zealand Innovation Network's "Non-dairy powders in New Zealand" report in 2016[8]
- Gold kiwifruit as a distinct product from green kiwifruit, currently undergoing distinct divergence in both marketing, and research and development, whereby separate analysis is increasingly warranted.

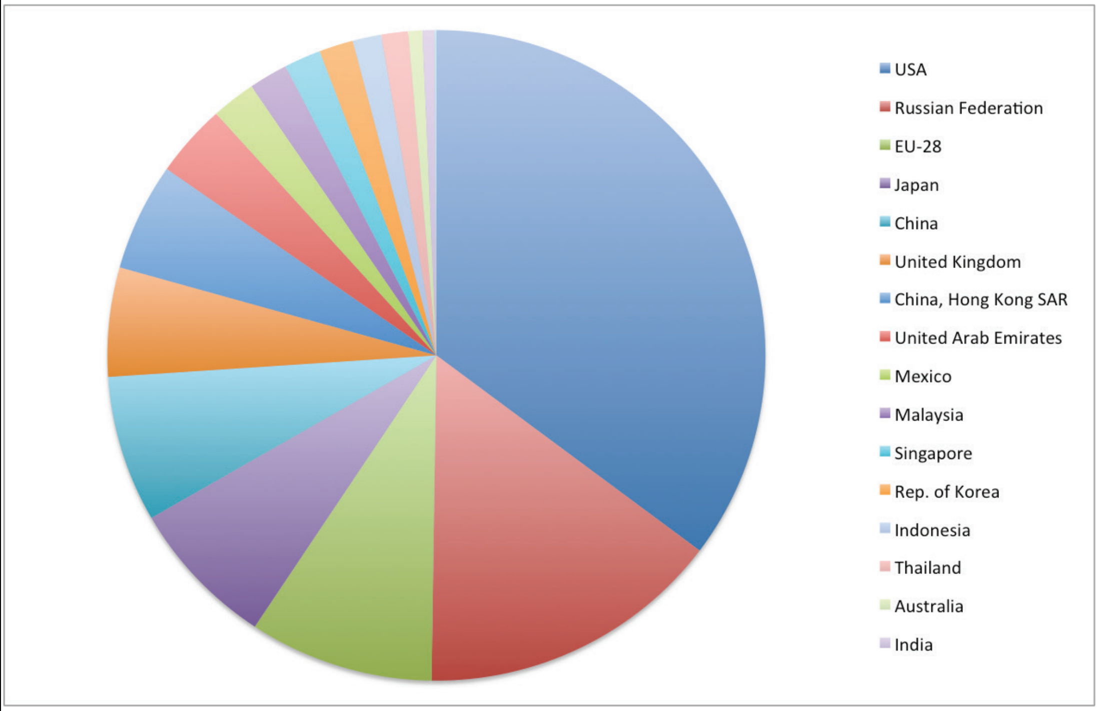
Emerging trends

Two emerging trends deserve mention when considering future markets to drive land-use decisions in New Zealand. The recent New Zealand Horticulture Report "New Zealand domestic vegetable production: the growing story (2017)" (Horticulture New Zealand 2017) highlighted New Zealand's reliance on overseas produce, potential food insecurity and the potential to develop the horticulture industry in New Zealand to meet domestic needs and demands. This may be a relevant element of identifying market-based perspectives on land-use in New Zealand: the markets that drive our future land use may not need to be exclusively export, as is assumed in the research presented here.

Finally, the emergence of organic produce is closely aligned with many of the selection criteria identified above. Greater availability of literature and data regarding the markets and demand for organic produce as distinct economic drivers suggests future research would do well to consider organic produce as a factor.

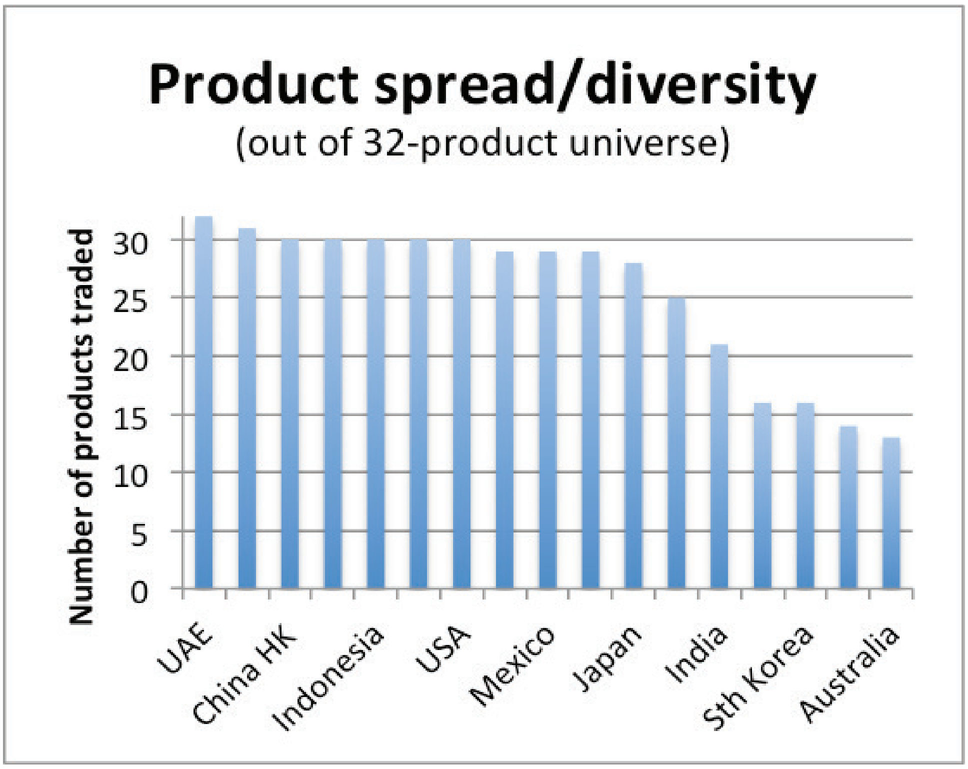
[8] https://bioresourceprocessing.files.wordpress.com/2018/03/non-dairydryingproject_22-11-2016.pdf

10.2 APPENDIX – MARKET ANALYSIS



Country	Total USD Value 2012–2016		Country	Total USD Value 2012–2016
USA	$80,438,561,911.00		Malaysia	$4,374,205,540.00
Russian Federation	$34,225,307,586.00		Singapore	$4,134,287,741.00
EU-28	$20,692,862,510.00		Rep. of Korea	$3,827,897,609.00
Japan	$16,824,610,972.00		Indonesia	$3,206,384,168.00
China	$16,584,719,671.00		Thailand	$3,010,874,137.00
United Kingdom	$12,375,577,432.00		Australia	$1,569,221,631.00
China, Hong Kong SAR	$12,197,535,315.00		India	$1,397,851,489.00
United Arab Emirates	$8,256,399,319.00		Fiji	$168,179,973.00
Mexico	$4,951,059,243.00			
TOTAL				$228,235,536,247.00

Figure A1: Market size of HS codes available to represent the product universe, of target market countries. Values in United States dollars (USD) represent the total spend by each country on all products between 2012 and 2016. Note not all countries purchase all products (see Figure A2).



Country	Products out of 32 possible	Country	Products out of 32 possible
UAE	32	Russia	29
Thailand	31	Japan	28
China HK	30	China	25
Fiji	30	India	21
Indonesia	30	EU-28	16
Singapore	30	Sth Korea	16
USA	30	UK	14
Malaysia	29	Australia	13
Mexico	29		

Figure A2: Product spread and diversification. Not all target market products produced ComTrade data on all products queried, indicating no market exists for that product in that country. A country purchasing a greater range of our products of interest can be assumed to represent a greater demand for New Zealand products, and countries are ranked according to number of products they purchase.

Table A1: Size of market and market growth in products, by target market countries.

	Apples	Avocados	Blueberries	Cherries	Chestnuts	Honey	Kiwi	Onion	Peas	Potato	Potato Starch	Truffles	Wine	Carrots	Squash/Pumpkin	Pears	Berries	Persimon	Walnuts	Hazelnuts	Apricots	Currants	Peaches/Nectarines	Oranges/Citrus	Asparagus	Tomatoes	Cumumber	Capsicum	Growth Catergories	Value Change
China		g	g	s			s	g		s			s	g			g						g	s					76.00%	10823%
Indonesia	s			g				s		s			g	s	g	s							g	s					43.33%	3897%
Fiji	s		g	g	g			s		s			s							g		g		s			g	g	90.00%	1977%
India	s	g					sg									sg							g	s					61.90%	1923%
Sth Korea				s	g				g	sg	g								s	g				s	g				50.00%	1705%
UAE	s	g		g				s		s			s		g	g	g	g				g		s		s			84.38%	294%
China HK	s	g	g	sg									g					g			g	g		s					73.33%	170%
Thailand	s						g	s		s				s	g	s	g	g	g				g	s	g			g	58.06%	160%
Australia									s	s				g	g				s	g				s					38.46%	91%
Malaysia	s	g	g		g		g	s		s			g	s	g		g						g	s	g				68.97%	90%
USA		sg		g			g			s			s				sg	g	g	g		g	g	sg		s	s	s	90.00%	61%
Mexico	s		g					s		s			s		g	sg	g	g	s	g			s		g	s			55.17%	49%
EU-28				g	g			s	s	s			g						s	sg				s					50.00%	48%
Singapore	s	g					g	s		s			s				g							s		s			46.67%	20%
UK								s		s	g			g					g	g				s	g				50.00%	7%
Japan		sg					sg	s		s			s	g					sg					s		g		sg	3.57%	-22%
Russia																													3.45%	-36%

‘s' represents a product of the largest annual import size into a given country. 'g' represents a product showing the largest growth in market volume or value annually 2012–2016. Column 'Value Change’ represents: Average absolute change in value aggregated across all products 2012–16 (not weighted by volume). Column 'Growth Categories' represents: of categories showing >10% growth

Table A2: Growth and country market strength across the selected product basket.

	China	Indonesia	Fiji	India	Sth Korea	UAE	China HK	Thailand	Australia	Malaysia	USA	Mexico	EU-28	Singapore	UK	Japan	Russia	*Germany*	*Netherlands*	*France*	*Canada*	*Italy*	*Belgium*	*Belarous*	*Brazil*
Apples	G	G				d						d			R		R	R	d					RG	
Avocados	G										R				RG	G				R					
Blueberries	G										RG				RG				R						
Cherries	RG				Rd													RG			d				
Chestnuts	Rd															RGd		d		G		RG			
Honey (inc. Manuka)	G										Rd				d	RG		Rd		d					
Kiwi	RG										d		d			RG							R		
Onions		R								Rd	RG				d	G		d			G				G
Peas	G										Rd				Rd								Rd		
Potato Starch	R				RG						RG														
Potatoes											RG				Rd			RG	RG	Rd			G		
Truffles																R		RG		R					
Wine	RG										R				R						d				

‘R' represents top-ranked country in product value. ‘[G' represents growth leaders. d' represents decline in value.

10.3 APPENDIX – MAPPING SUITABILITY RULES - CROPS

10.3.1 Chestnuts

Rule	Well Suited (WS)	Suited (S)	Marginal (MS)	Unsuited (U)	Managed
Rainfall annual (mm)	>800	650-800	500-650	<500	Yes
Winter chill hours (0-7°C) (April to August)	>800	500-800	150-500	<150	No
Drainage Class	Well drained, Moderately well drained			V poorly drained	Yes
Frost (Tmin <-4 deg C, 15 Sep-31 Jan)	<1 year/5	1/5 to 2/5	2/5 to 3/5	>3/5	No
Heat Stress (Tmax >40 deg C, Sep-Nov)	<1 year/5	1/5 to 2/5	2/5 to 3/5	>3/5	No
pH H_2O (top 15cm)	5.5-6.5	5.0-5.5/6.5-7.0	4.5-5.0/7.0-8.0	4.5</>8.0	Yes
Soil/rooting depth	>50 cm			<50 cm	No
Slope (º)	<7.5	7.5-10	10--15	>15	No

10.3.2 Honey and mānuka

Rule	Well Suited (WS)	Suited (S)	Marginal (MS)	Unsuited (U)	Managed
Winter (22 June-22 Sep) Mean Minimum Temperature	>-1°C	-2' to-1°C	-3' to-2°C	<-3	No
Summer Mean Tmax Temperature during flowering & foraging (15 Oct-31 Jan)	>14	12 to 14	10 to 12	<10	No
PAW Class (mm to 90 cm)	Class 3 (90 to 149 mm)	Class 2 (150 to 249 mm)	Class 4 (60 to 89 mm)	Other	No
Rain days (01 Dec-31 Jan) days receiving >1mm over the foraging period	<8	8 to 9	9 to 10	>10	No

10.3.3 Onions

Rule	Well Suited (WS)	Suited (S)	Marginal (MS)	Unsuited (U)	Managed
Drainage Class	Well/ Mod Well	Imperfect	Poor	very poor	Yes
Salinity (ECse in top 15 cm)	<2.0	2.0-4.0	2.0-4.0	>4.0	Yes
Spring frost (=<1 day where Tmin <0 deg C in Nov)	2 in 5 years	2/5 years	>2/5	>2/5	No
Heat at harvest (>3 days in 7 days where Tmax >31deg C Jan-Feb)	<1/10 years	1/10-2/10	2/10-3/10	>3/10	No
pH H_2O (top 15cm)	>6.0	>6.0	5.8-6.0	<5.8	Yes
Soil Depth (Depth to heavy clay)	>25cm	>25cm	20-25cm	<20cm	No
Rainfall at harvest (>3 days in any 7 day period with >10 mm rain/day during Jan-Mar)	<1/5 years	1/5-3/10	3/10-2/5	>2/5	No
Slope (º)	<5	5 to 10	10 to 20	>20	No

10.3.4 Peas

Rule	Well Suited (WS)	Suited (S)	Marginal (MS)	Unsuited (U)	Managed
Rainfall annual (mm)	1000-2000	700-1000	500-700	<500/>2000 mm	Yes
Annual Rainfall Two (mm)	<2000			>2000 mm	No
Drainage Class	Well; Mod Well	Imperfect		Poor; Very poor	Yes
Spring Frost (Tmin <0 deg C, Sep-Nov)	<2years/5	2/5-3/5	3/5-4/5	>4/5	No
GDD (Tb=3 deg C) flowering (Sep-Apr)	>1500	1000-1500	800-1000	<800	No
Heat Stress Flowering (Tmax >30oC from Nov to Feb)-3 sequential days over 1 week	"<3 in 10 years"	"3 in 10 years"	"5 in 10 years"	"9 in 10 years"	No
pH H_2O (top 15cm)	5.5-6.5	5.0-5.5/ 6.5-7.0	4.5-5.0/ 7.0-8.0	<4.5/ >8.0	Yes
Slope (º)	<5.7	5.7 to 14		>14	No

10.3.5 Potatoes

Rule	Well Suited (WS)	Suited (S)	Marginal (MS)	Unsuited (U)	Managed
Annual Rainfall (mm)	1000-2000	700-1000	500-700	<500 & >2000	Yes
Annual Rainfall Two (mm)	<2000			>2000	No
Soil clay content (top 15 cm)	>20	5-20	<5		No
Salinity (ECse in top 15 cm)	<1.2	1.2-2.0	2.0-4.0	>4.0	Yes
pH H_2O (top 15cm)	>5.0			<5.0	Yes
Low temperature (Tmin <0°C any day 1 Nov-30 Feb)	<1 year in 5	1/5-2/5	2/5-3/5	>3/5	No
High temperature (Any day 1st Nov to 30th Feb with Tmin >20°C)	<1 year in 5	1/5-2/5	>2/5		No
Soil Depth (Depth to heavy clay)	>25cm		15-25cm	<15cm	No
Drainage Class	Well/ Excessive; Mod Well	Imperfect	Poor; very poor	other	Yes

10.3.6 Truffles

Rule	Well Suited (WS)	Suited (S)	Marginal (MS)	Unsuited (U)	Managed
Annual Rainfall (mm)	600-750	750-900	900-1800	>1800 what if <600	Yes
Annual Rainfall Two (mm)	<1800			>1800 mm	No
Drainage Class	Well/ Moderately well	Imperfect	Poor	Very Poor	Yes
Average temperature (Jan-Mar)	≥16°C	15-16°C	14-15°C	<14°C	No
Sunshine hours per year	>2200	2000-2200	1900-2000	<1900	No
pH H_2O (top 15cm)	6.5 to 8.3	5.8 to 6.4	5.5 to 5.8	<5.5 OR >8.3	Yes
Slope (°)	<7	7 to 15	15 to 20	>20	No

10.4 APPENDIX – MAPPING SUITABILITY RULES - FORESTRY

Biophysical suitability rules for *Pinus radiata*, *Pseudotsuga menziesii* and *Eucalyptus fastigata* used to generate maps. Suitability in terms of potential profitability (e.g. distance from markets), regional council restrictions (e.g. high erosion susceptibility or water-sensitive catchments), wilding spread risk and other social and cultural factors are not included.

10.4.1 *Pinus radiata*.

Rule	Zero	One
Temperature	< 7.9°C	
Growth rate	< 15 m^3/yr	> 40 m^3/yr

10.4.2 *Pseudotsuga menziesii*.

Rule	Zero	One
Mean annual temperature	< 6.0 °C	
Production (40 year)	< 1850 m^3	> 2300 m^3
Temperature in October to avoid Swiss needle-cast	< 3.2°C	> 5.0°C

10.4.3 *Eucalyptus fastigata*.

Rule	Zero	One
Mean annual temperature	< 7.9 or >15°C	
Direct saw log volume (35 year)	< 250 m^3	> 1000 m^3
Degree Ground Frosts in October	0 days	> 5 days
Topographic exposure (exposed or sheltered from wind)	< - 600	> 400
Potential Rooting Depth	< 30 cm	> 100 cm
February rainfall - potential evapotranspiration	< 80 mm	0 mm

10.5 APPENDIX – SUITABILITY MAPS

10.5.1 Apples

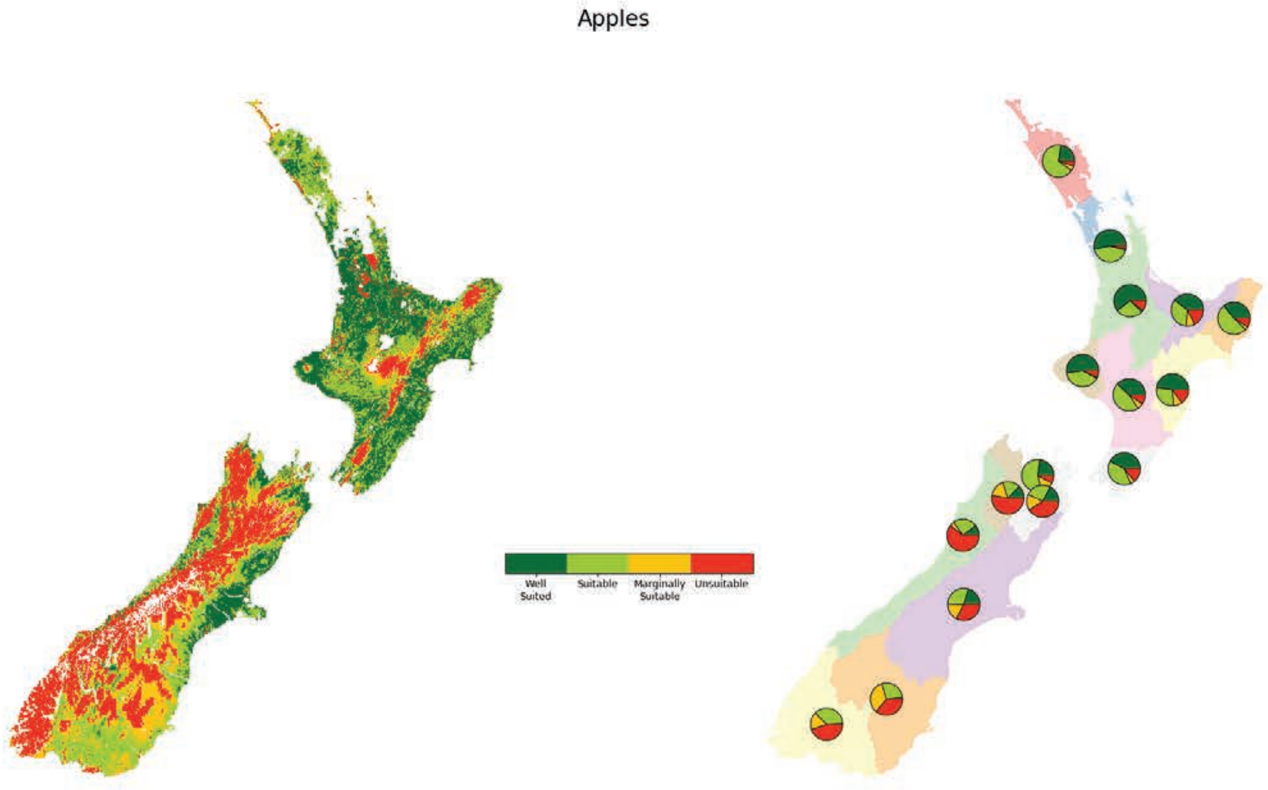


Figure A3. Suitability maps for growing apples according to region in New Zealand.

10.5.2 Avocados

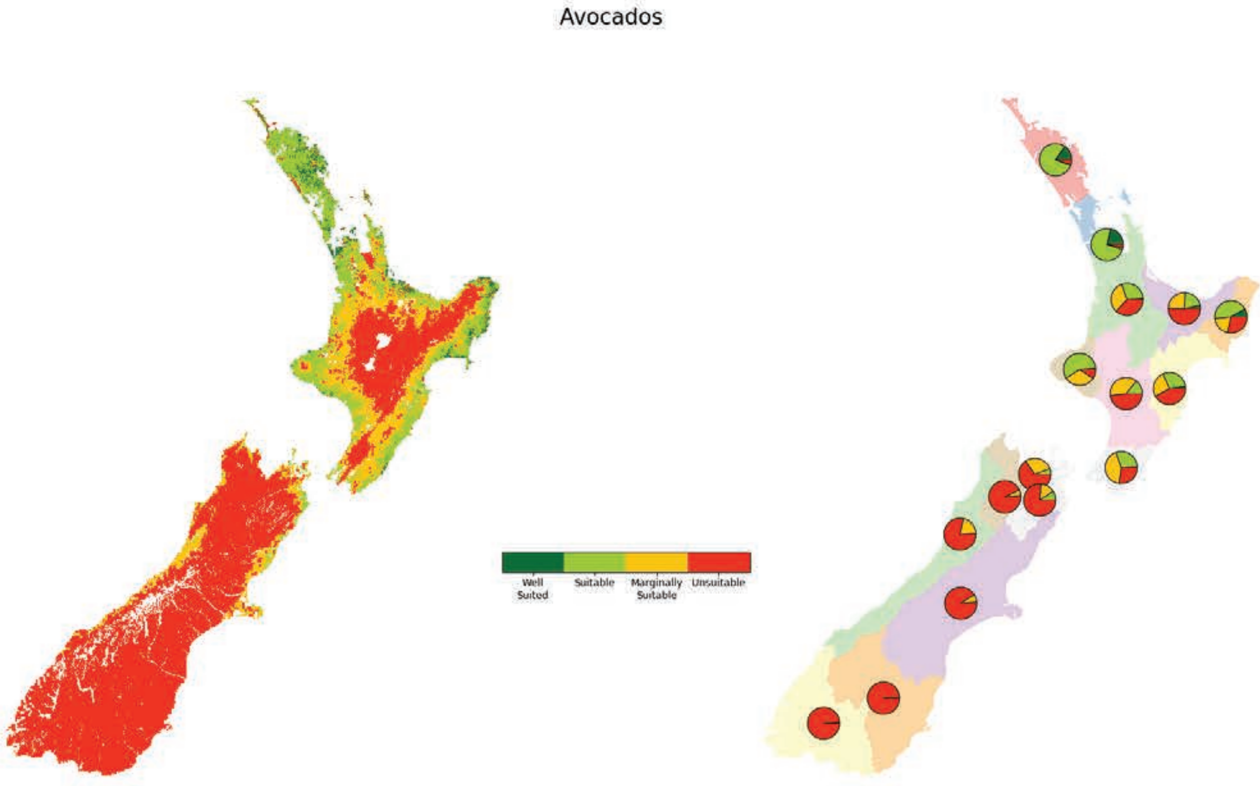


Figure A4. Suitability maps for growing avocados according to region in New Zealand.

10.5.3 Blueberries

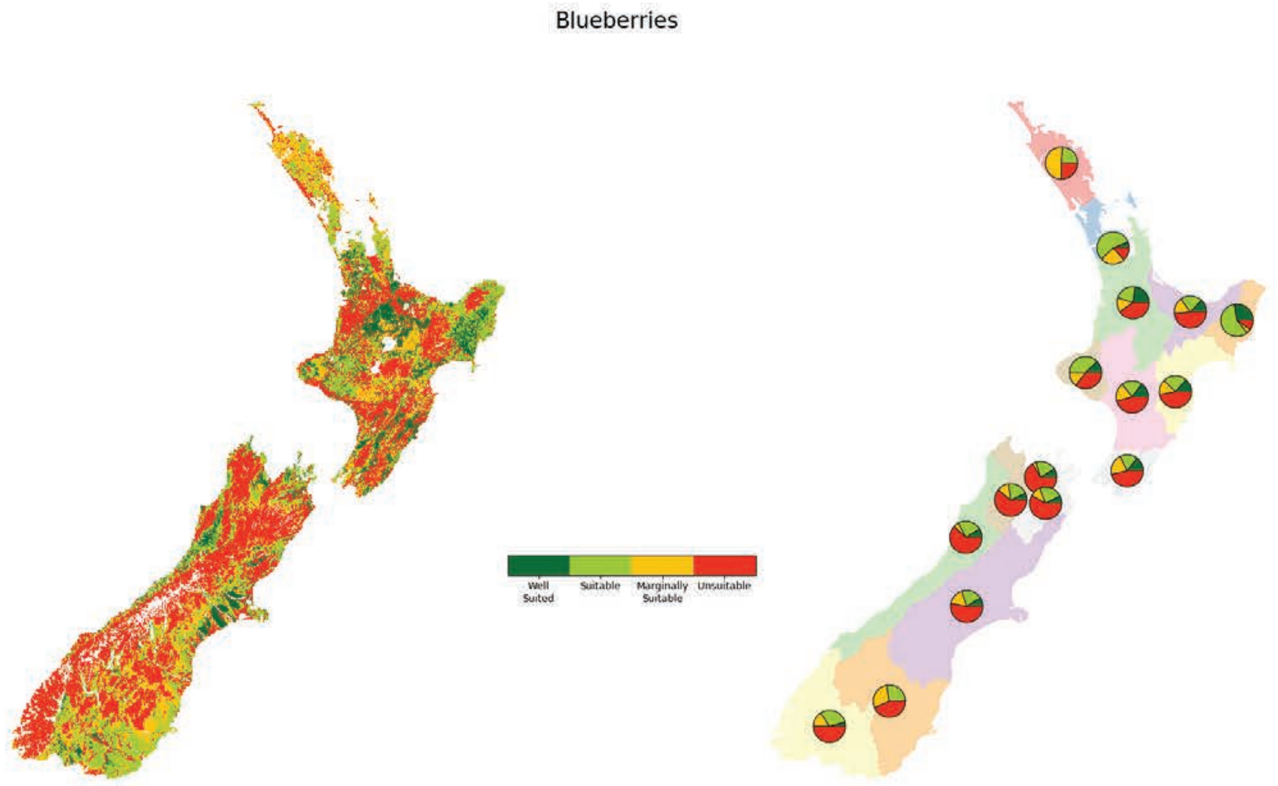


Figure A5. Suitability maps for growing blueberries according to region in New Zealand.

10.5.4 Cherries

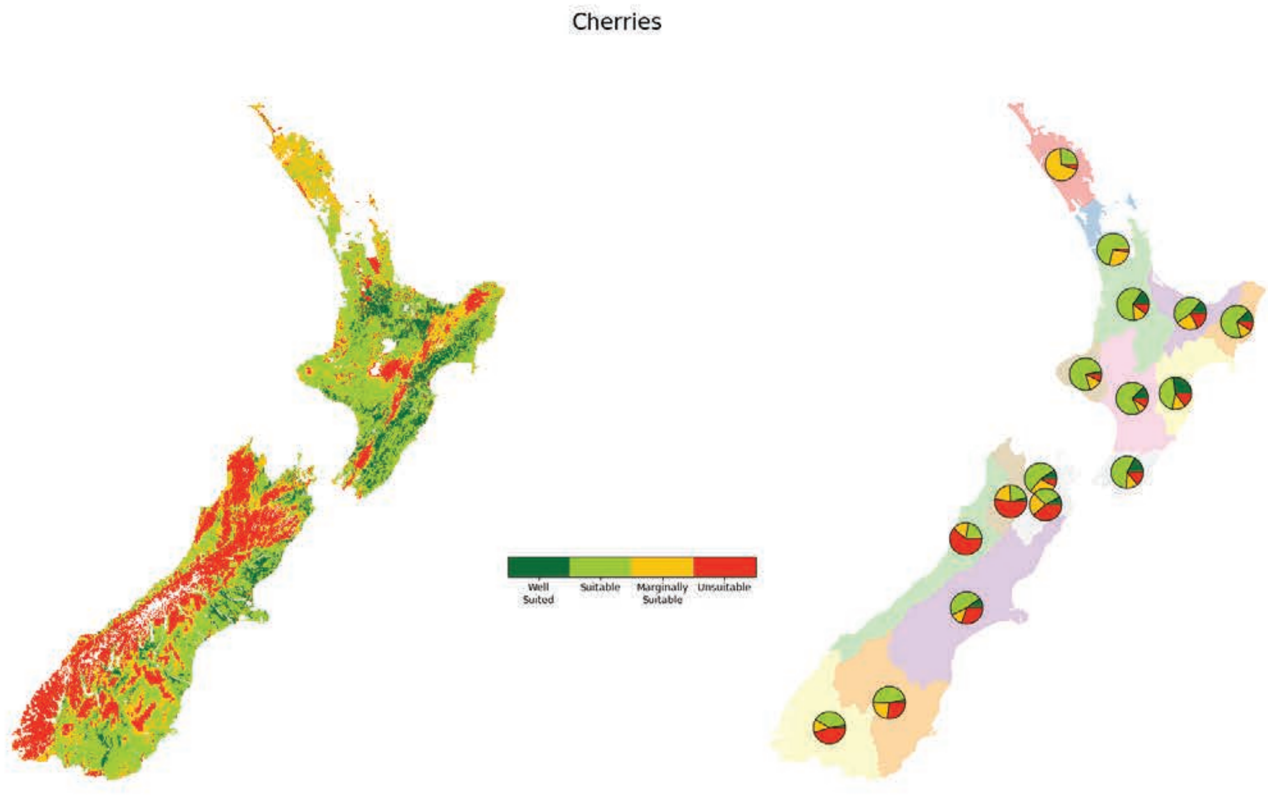


Figure A6. Suitability maps for growing cherries according to region in New Zealand.

10.5.5 Chestnuts

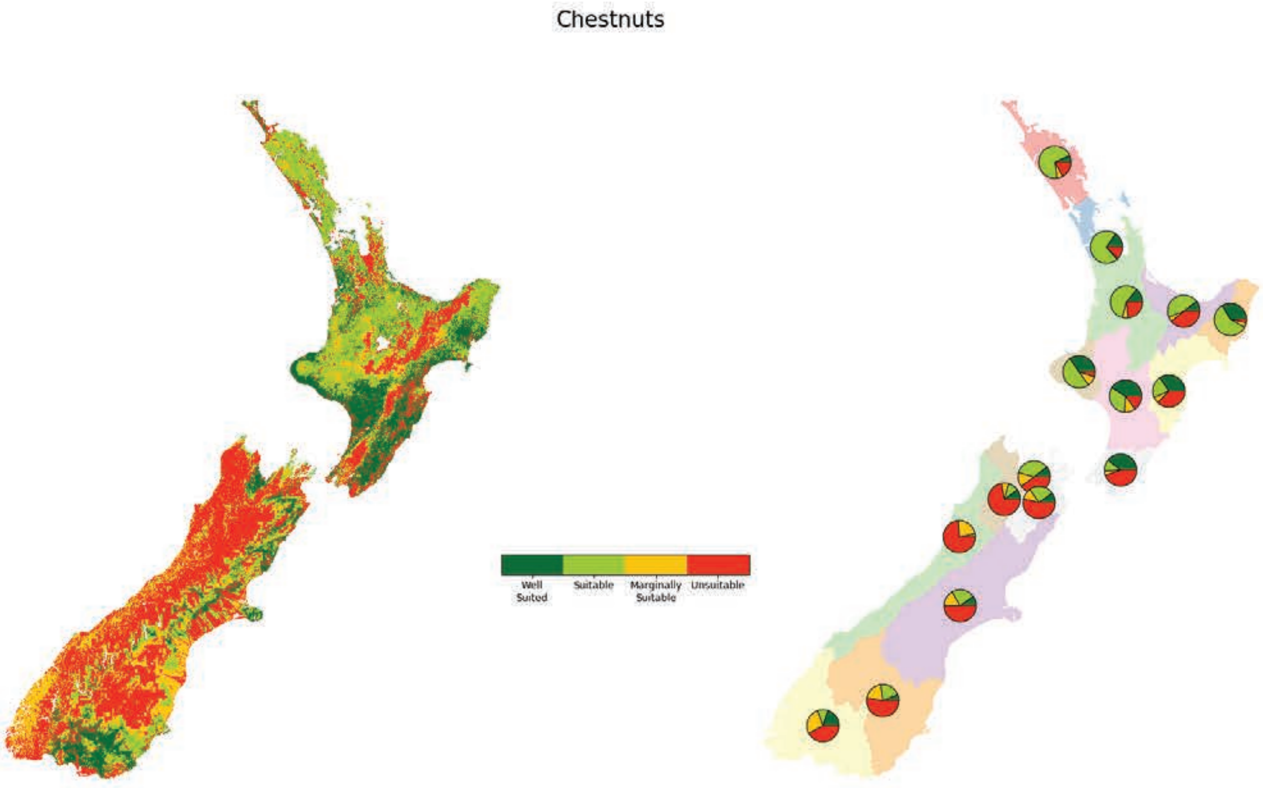


Figure A7. Suitability maps for growing chestnuts according to region in New Zealand with pH, drainage and rainfall rules included.

Chestnuts

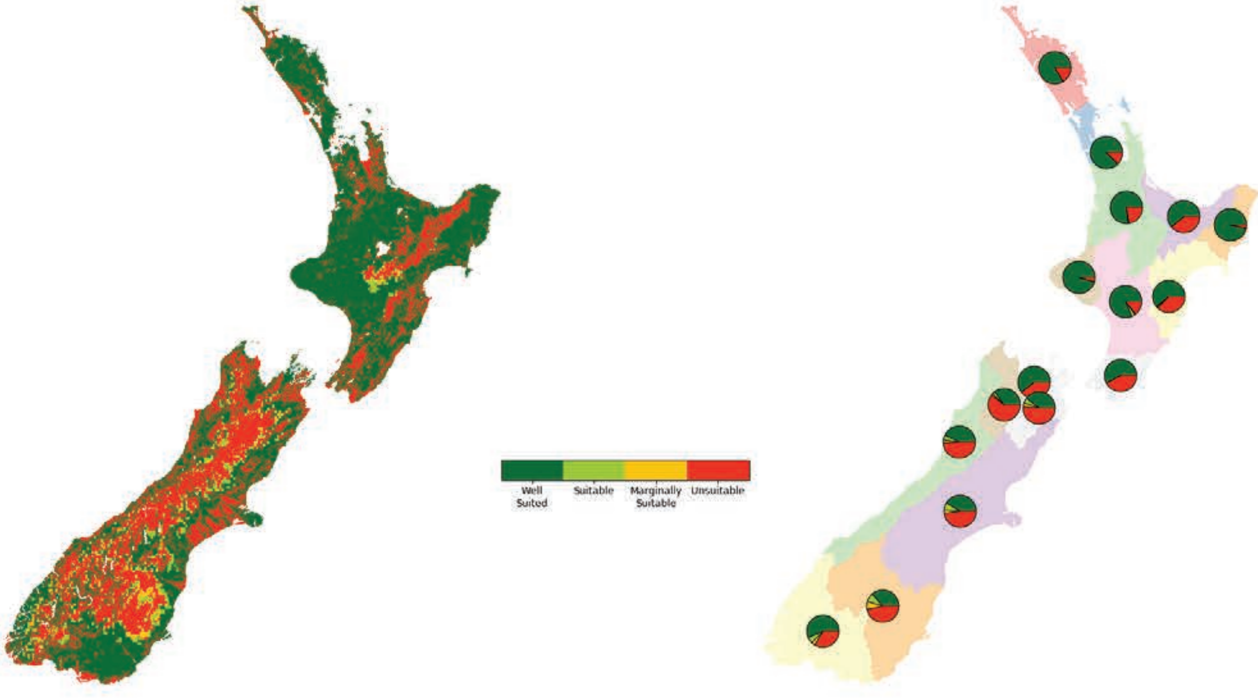


Figure A8. Suitability maps for growing chestnuts according to region in New Zealand with pH, drainage and rainfall rules excluded.

10.5.6 Honey and mānuka

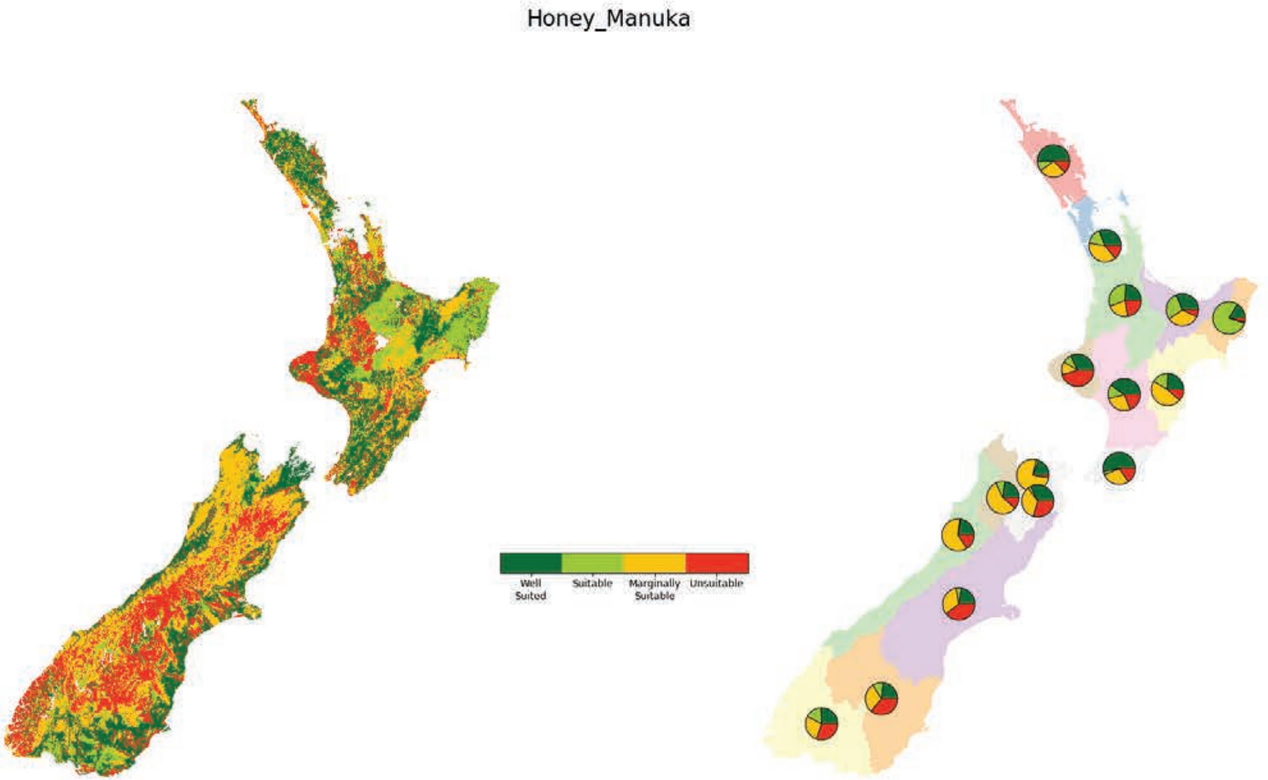


Figure A9. Suitability maps for honey and mānuka according to region in New Zealand.

10.5.7 Kiwifruit

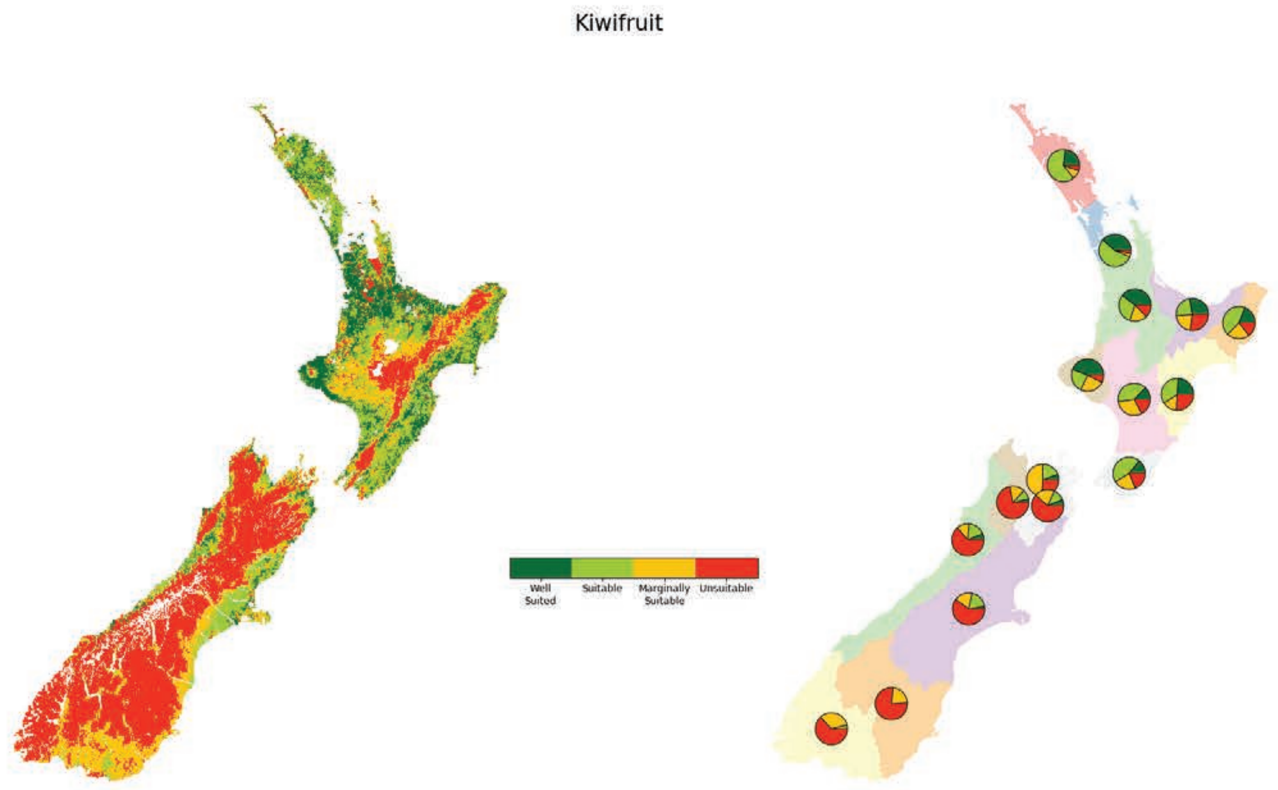


Figure A10. Suitability maps for growing kiwifruit according to region in New Zealand.

10.5.8 Onions

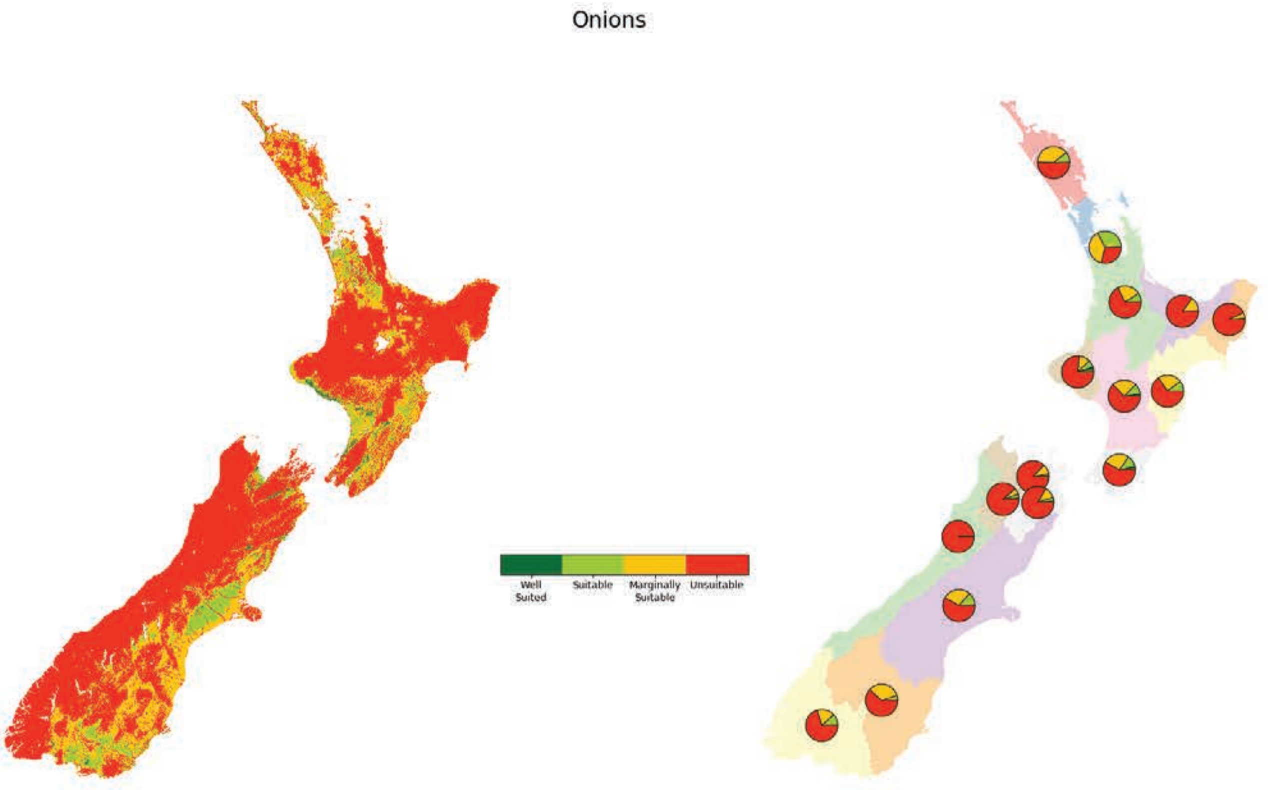


Figure A11. Suitability maps for growing onions according to region in New Zealand with pH, drainage and salinity rules included.

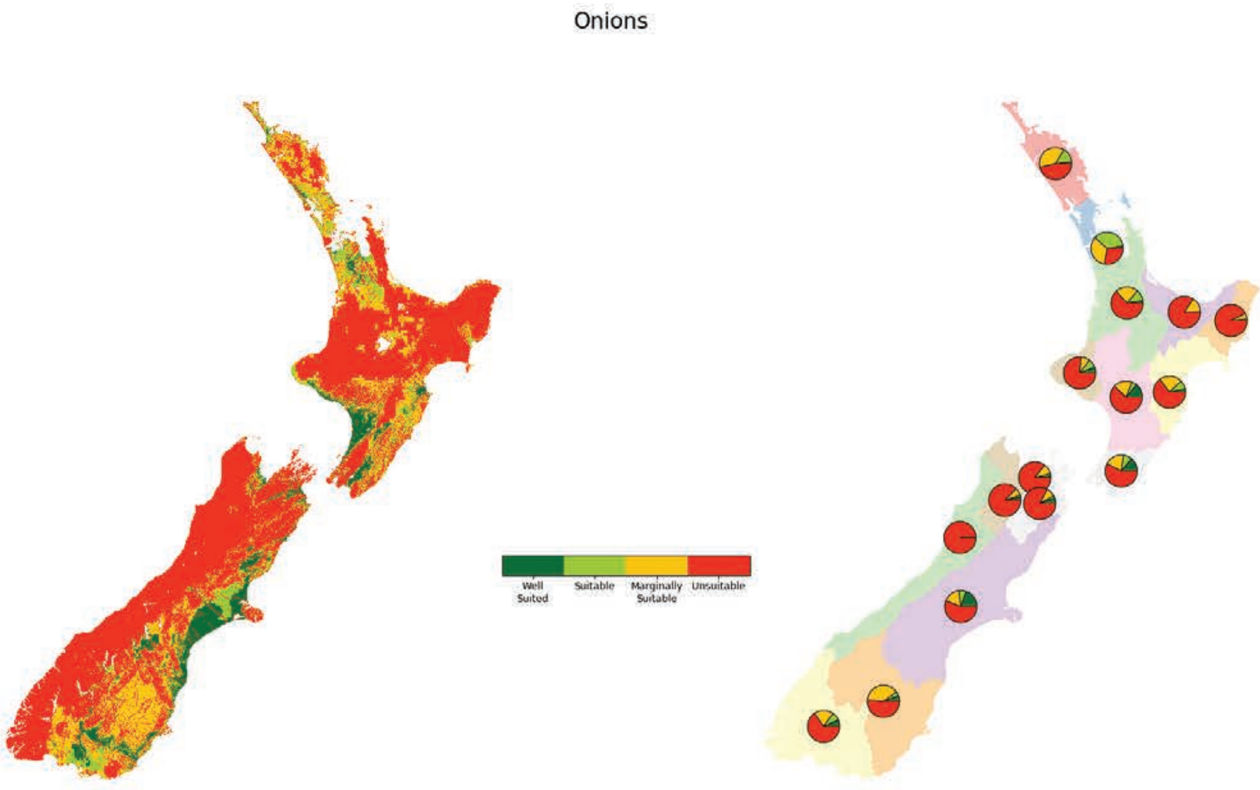


Figure A12. Suitability maps for growing onions according to region in New Zealand with pH, drainage and salinity rules excluded.

10.5.9 Peas

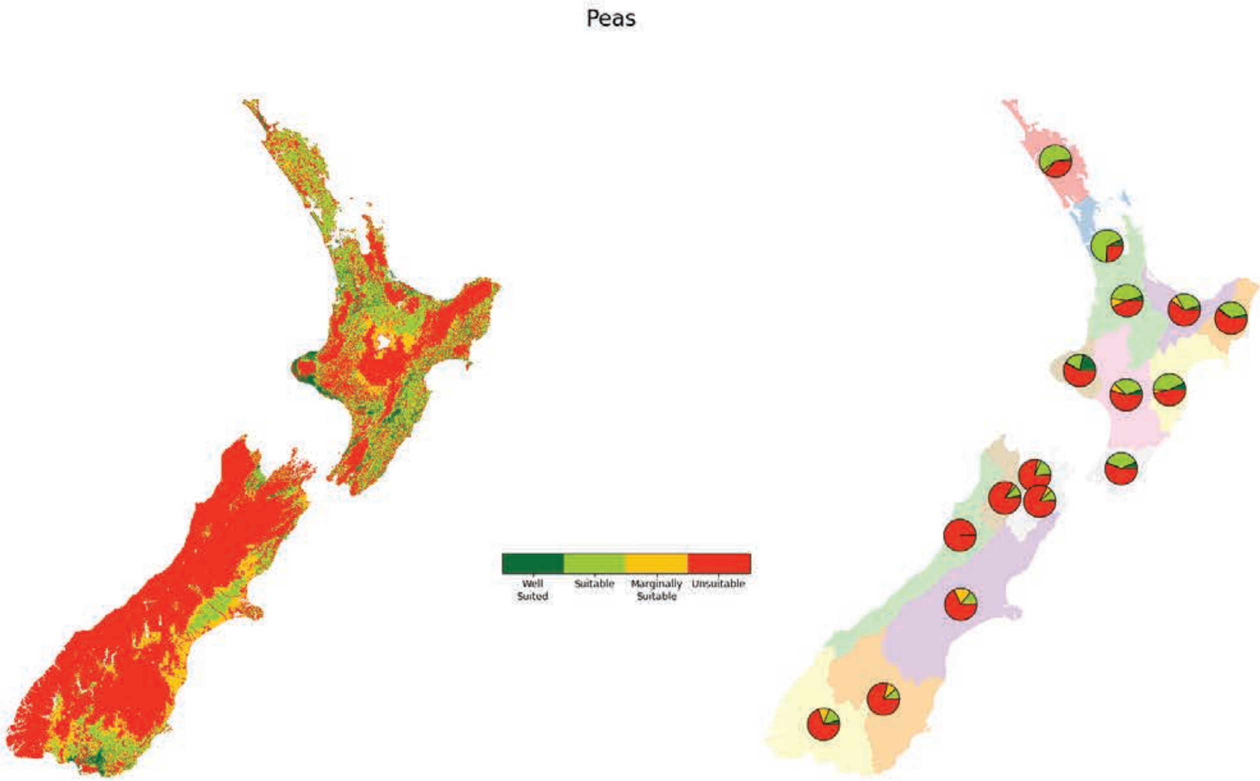


Figure A13. Suitability maps for growing peas according to region in New Zealand with pH, drainage and rainfall rules included.

Peas

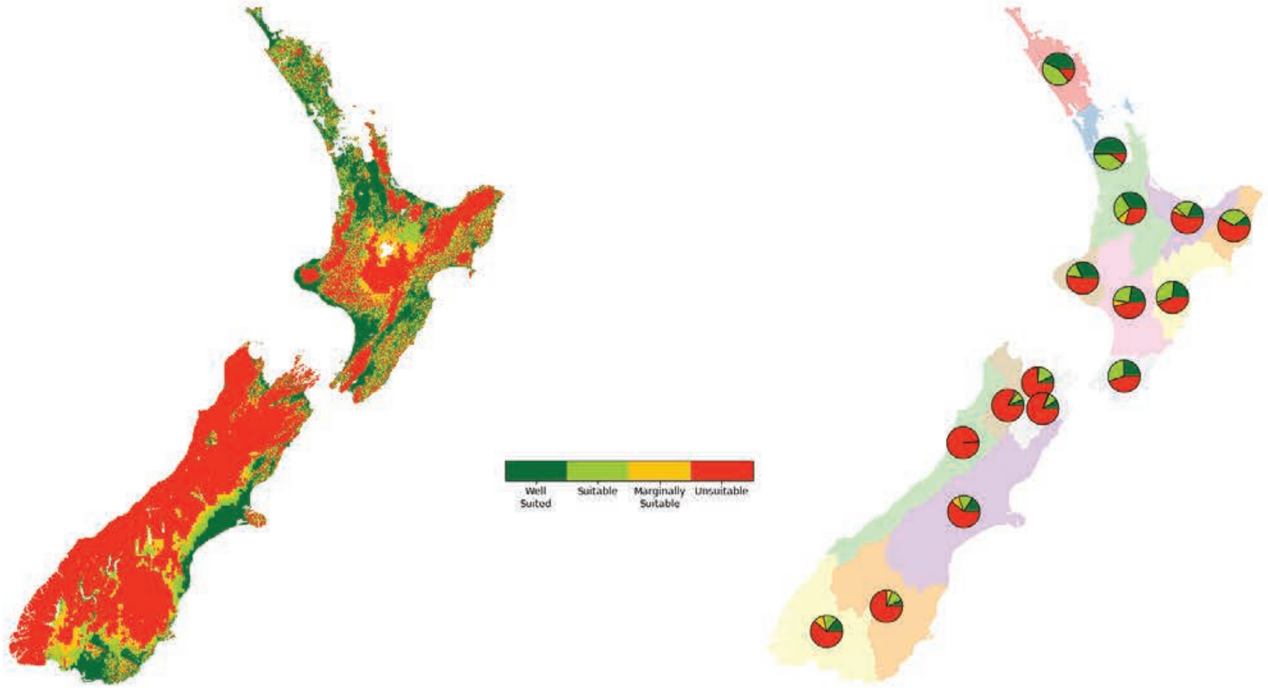


Figure A14. Suitability maps for growing peas according to region in New Zealand with pH, drainage and rainfall rules excluded.

10.5.10 Potatoes

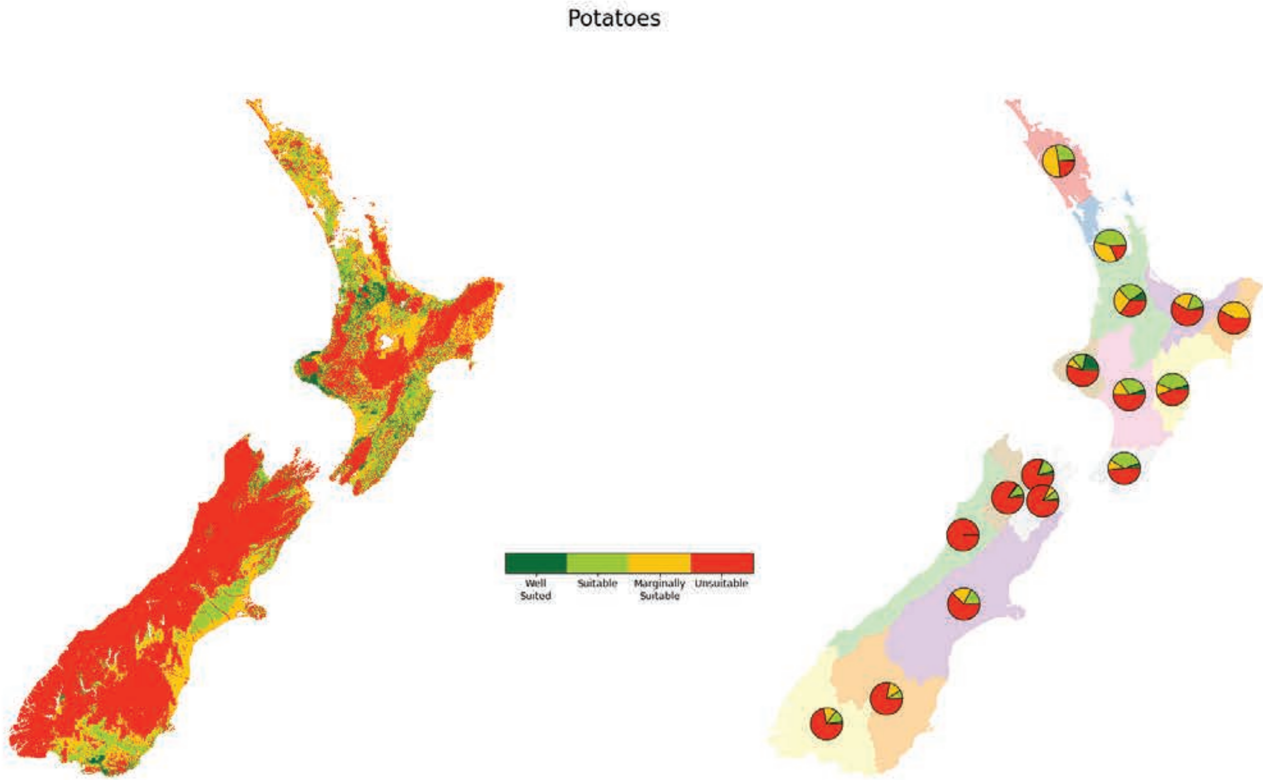


Figure A15. Suitability maps for growing potatoes according to region in New Zealand with pH, drainage, salinity and rainfall rules included.

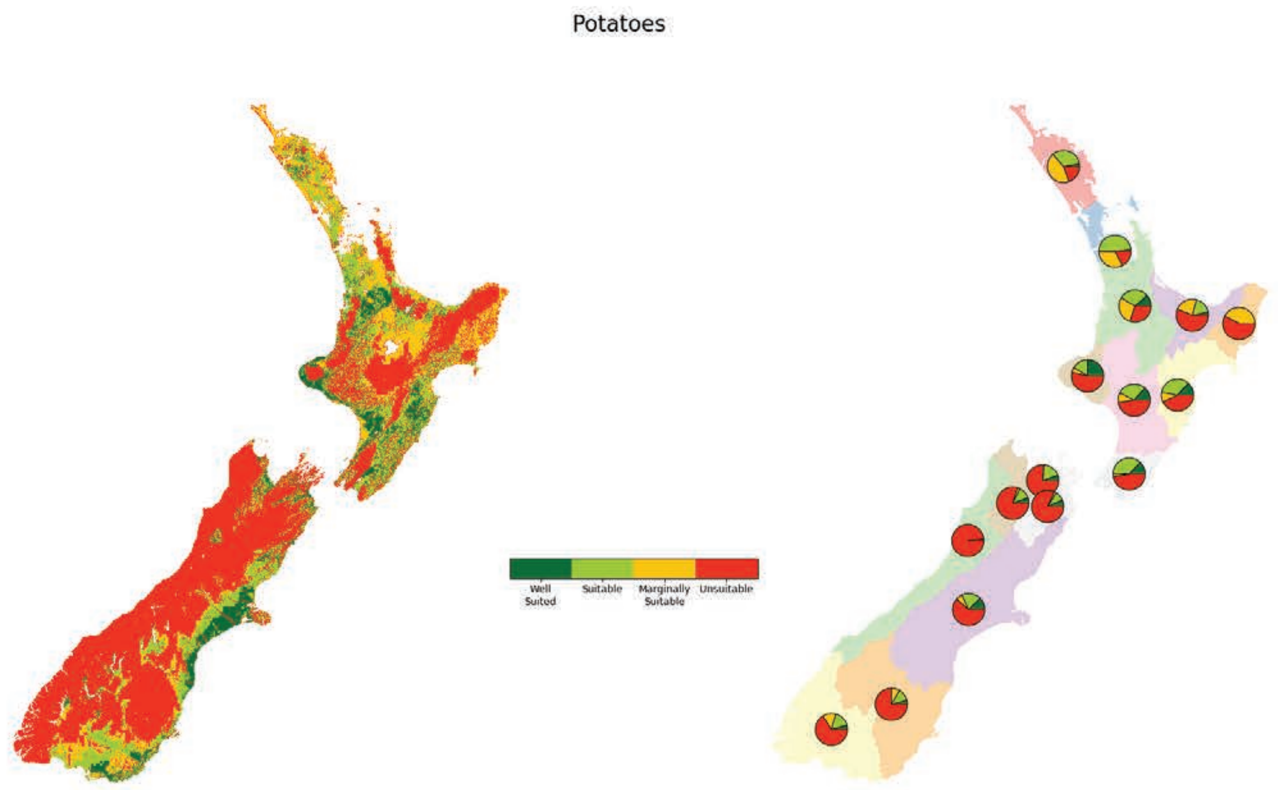


Figure A16. Suitability maps for growing potatoes according to region in New Zealand with pH, drainage, salinity and rainfall rules excluded.

10.5.11 Truffles

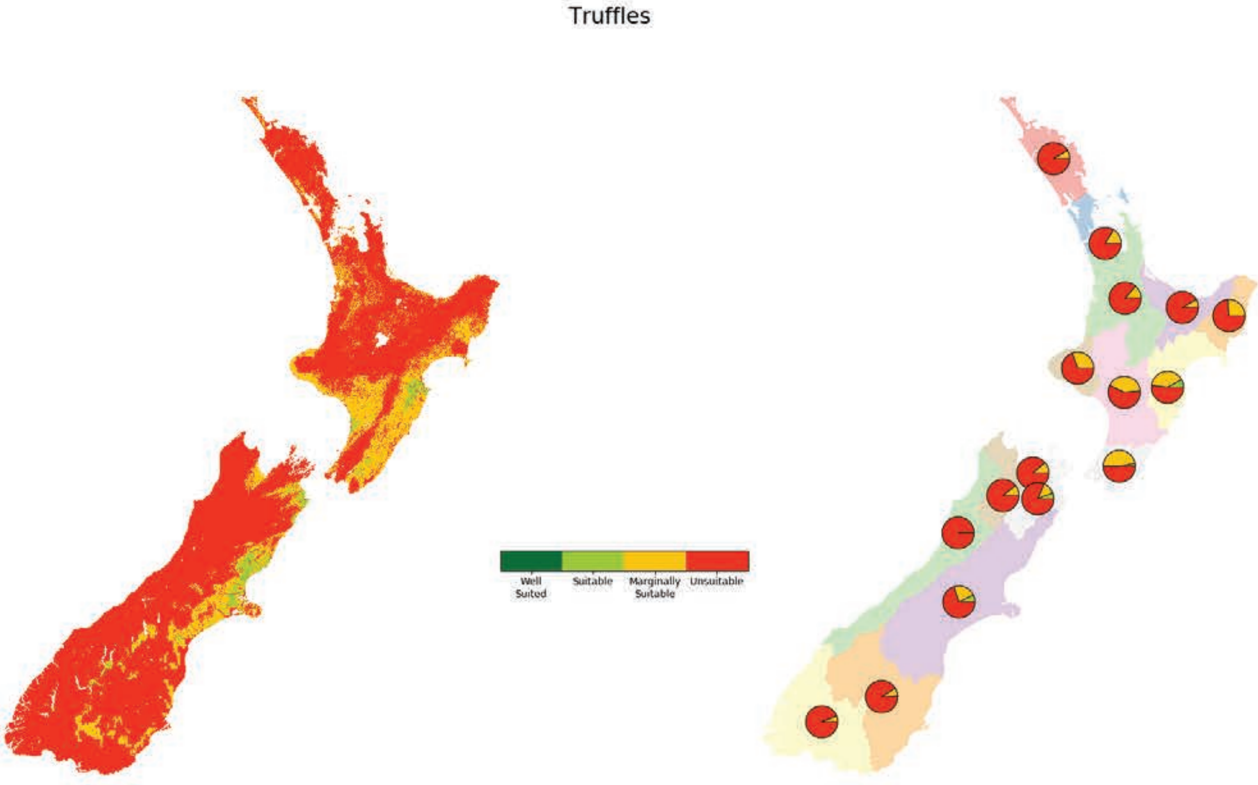


Figure A17. Suitability maps for growing truffles according to region in New Zealand with pH, drainage and rainfall rules included.

Truffles

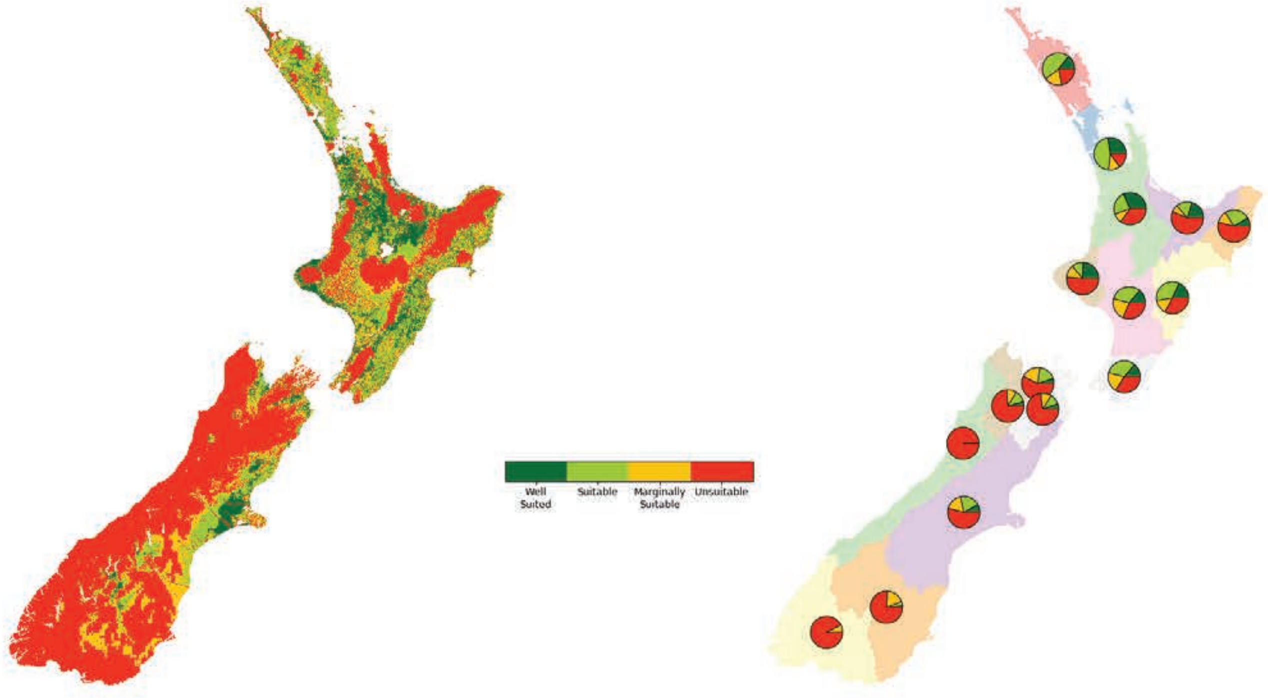


Figure A18. Suitability maps for growing truffles according to region in New Zealand with pH, drainage and rainfall rules excluded.

10.5.12 Wine grapes – Sauvignon blanc

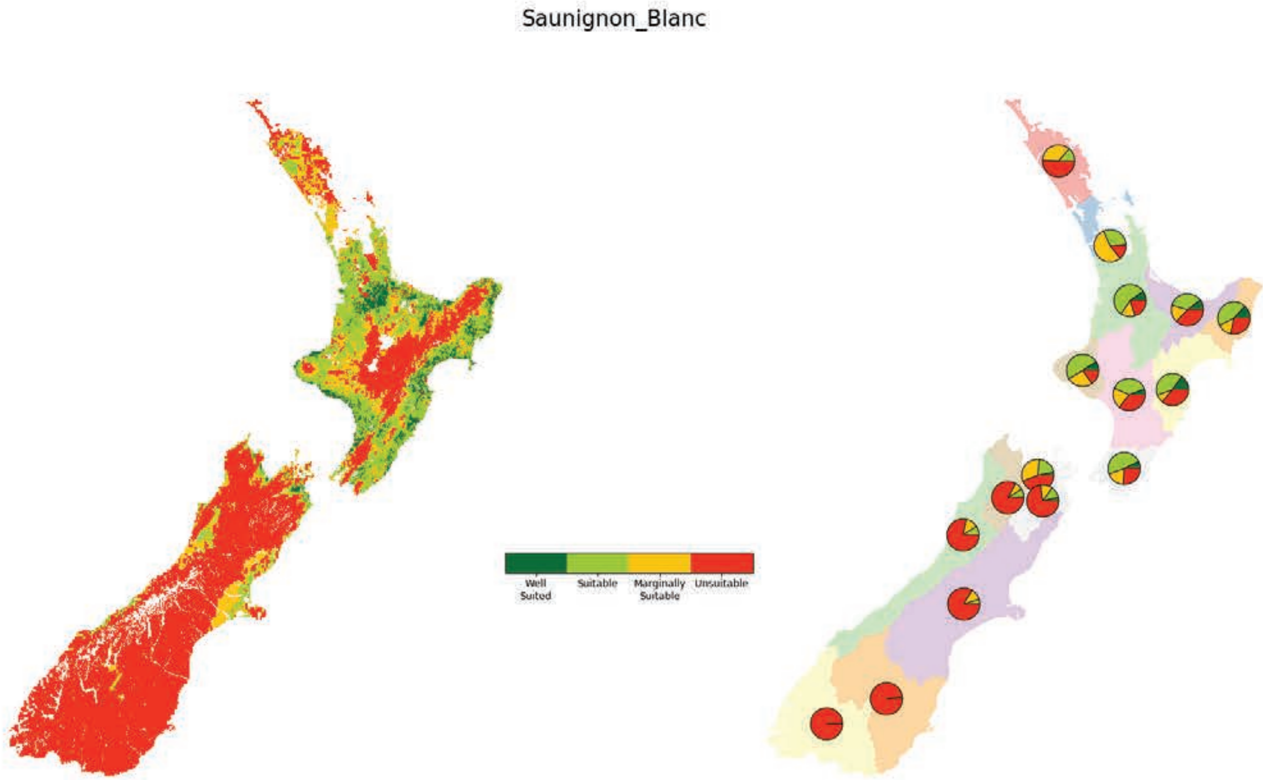


Figure A19. Suitability maps for growing Sauvignon blanc grapes according to region in New Zealand.

10.5.13 Wine grapes – Pinot noir

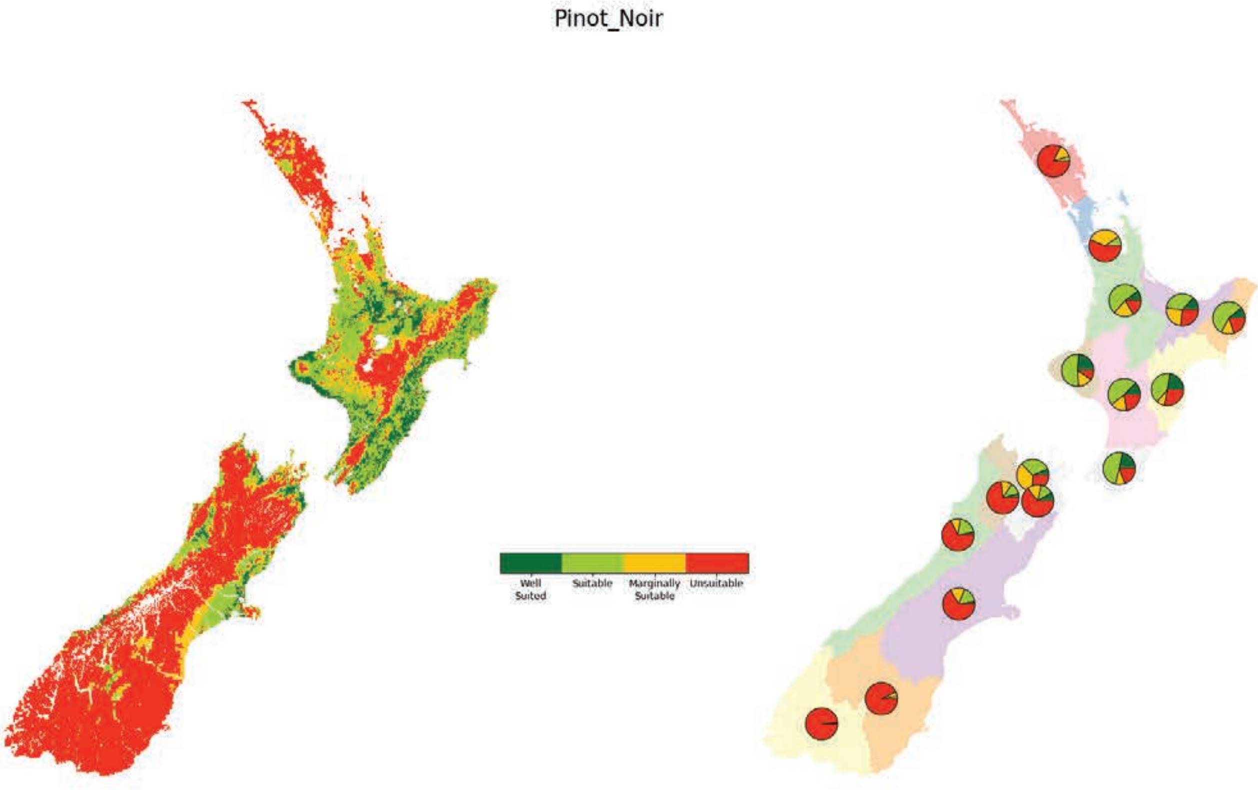


Figure A20. Suitability maps for growing Pinot noir grapes according to region in New Zealand.

10.5.14 Radiata pine

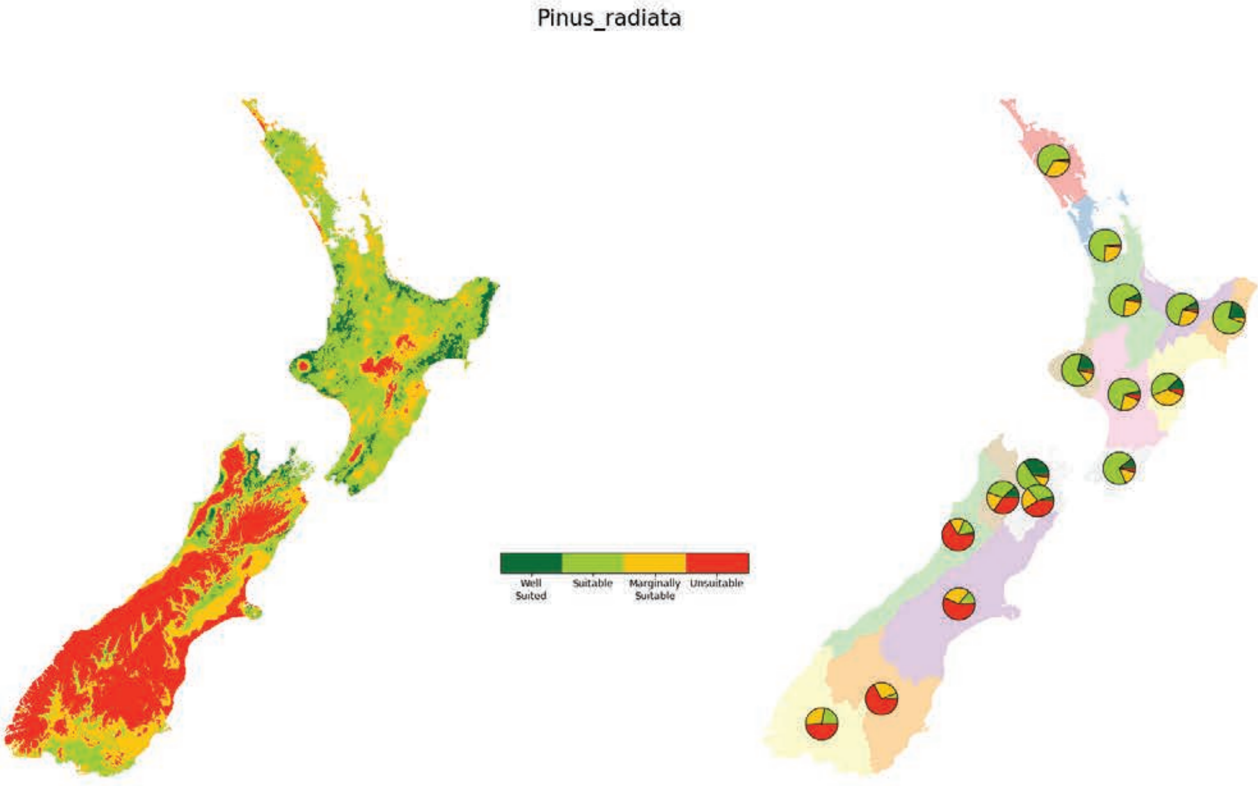


Figure A21. Suitability maps for growing *Pinus radiata* according to region in New Zealand.

10.5.15 Douglas fir

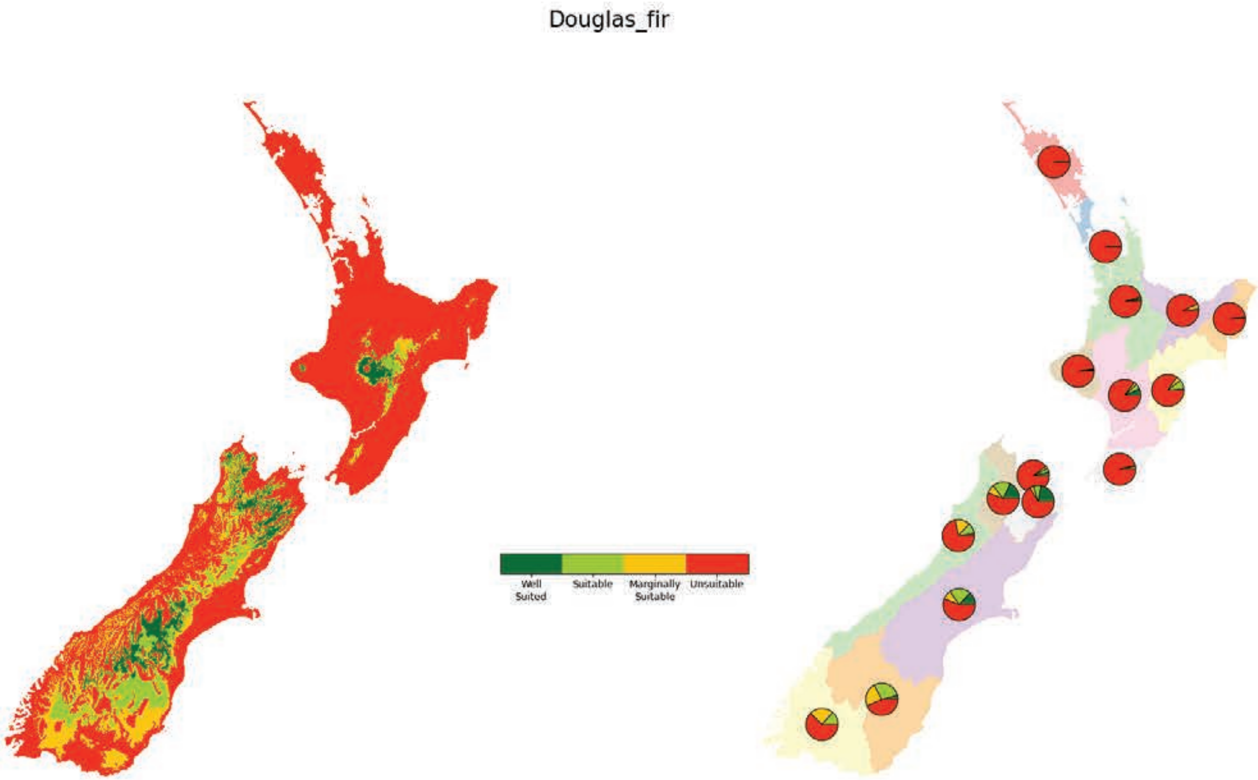


Figure A22. Suitability maps for growing Douglas fir according to region in New Zealand.

10.5.16 Eucalyptus fastigata

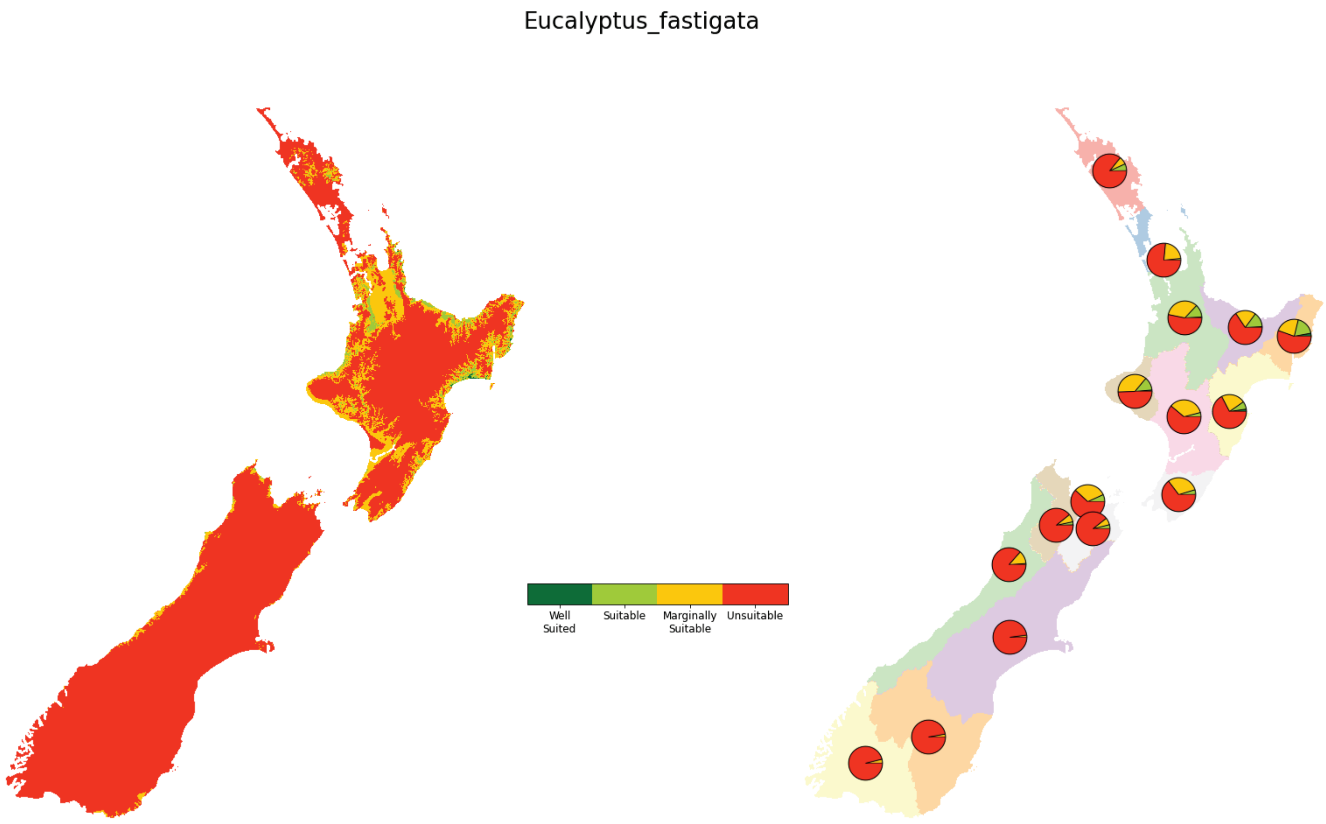


Figure A23. Suitability maps for growing *Eucalyptus fastigata* according to region in New Zealand.

10.6 APPENDIX – AREAS OF CROP SUITABLITY

Table A3. The areas (ha) estimated for a range of four suitability classes for growing apples by region in New Zealand.

Region	Well Suited	Suitable	Marginally Suited	Unsuitable	Total area
Northland	247,775	736,275	56,300	221,000	1,261,350
Auckland	197,400	156,450	5,025	80,775	439,650
Waikato	1,380,125	629,650	37,175	349,200	2,396,150
Bay of Plenty	459,825	398,725	99,250	255,925	1,213,725
Gisborne	292,950	425,150	28,200	91,050	837,350
Hawke's Bay	653,025	385,225	120,700	255,775	1,414,725
Taranaki	360,225	276,125	5,400	81,925	723,675
Manawatu-Wanganui	828,900	985,950	132,725	269,400	2,216,975
Wellington	315,300	298,300	33,875	152,800	800,275
West Coast	214,350	492,050	98,000	1,523,550	2,327,950
Canterbury	818,300	1,183,000	707,975	1,755,425	4,464,700
Otago	71,250	814,425	1,014,475	1,247,250	3,147,400
Southland	15,650	1,015,250	471,850	1,474,025	2,976,775
Tasman	115,375	163,875	161,450	523,175	963,875
Nelson	8,400	20,525	4,875	7,325	41,125
Marlborough	161,000	236,900	150,500	494,450	1,042,850

Table A4. The areas (ha) estimated for a range of four suitability classes for growing avocados by region in New Zealand.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	165,400	867,625	7,325	221,000	1,261,350
Auckland	79,075	272,225	7,575	80,775	439,650
Waikato	17,125	680,825	744,800	953,400	2,396,150
Bay of Plenty	40,050	243,200	293,925	636,550	1,213,725
Gisborne	68,325	355,425	162,275	251,325	837,350
Hawke's Bay	26,750	402,775	360,875	624,325	1,414,725
Taranaki	7,225	400,625	218,525	97,300	723,675
Manawatu-Wanganui	350	305,525	813,375	1,097,725	2,216,975
Wellington	8,350	218,950	321,500	251,475	800,275
West Coast	0	21,950	415,675	1,890,325	2,327,950
Canterbury	0	70,025	297,200	4,097,475	4,464,700
Otago	0	0	700	3,146,700	3,147,400
Southland	0	0	13,050	2,963,725	2,976,775
Tasman	0	13,650	52,775	897,450	963,875
Nelson	0	2,075	10,600	28,450	41,125
Marlborough	1,225	85,850	132,575	823,200	1,042,850

Table A5. The areas (ha) estimated for a range of four suitability classes for growing blueberries by region in New Zealand.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	0	263,850	557,125	440,375	1,261,350
Auckland	22,375	208,275	91,600	117,400	439,650
Waikato	520,025	501,375	334,775	1,039,975	2,396,150
Bay of Plenty	148,825	259,700	188,625	616,575	1,213,725
Gisborne	224,925	477,325	37,925	97,175	837,350
Hawke's Bay	183,325	327,700	210,600	693,100	1,414,725
Taranaki	85,300	258,675	100,000	279,700	723,675
Manawatu-Wanganui	316,750	451,775	400,300	1,048,150	2,216,975
Wellington	108,825	132,650	161,050	397,750	800,275
West Coast	184,050	481,900	107,525	1,554,475	2,327,950
Canterbury	359,450	848,575	694,775	2,561,900	4,464,700
Otago	17,950	808,725	856,925	1,463,800	3,147,400
Southland	114,650	816,675	423,375	1,622,075	2,976,775
Tasman	65,900	186,475	111,450	600,050	963,875
Nelson	3,300	7,650	1,325	28,850	41,125
Marlborough	71,325	216,750	98,375	656,400	1,042,850

Table A6. The areas (ha) estimated for a range of four suitability classes for growing cherries by region in New Zealand.

Region	Well sited	Suitable	Marginally suited	Unsuitable	Total area
Northland	0	287,925	752,425	221,000	1,261,350
Auckland	0	263,050	95,825	80,775	439,650
Waikato	348,475	1,386,600	312,600	348,475	2,396,150
Bay of Plenty	158,625	537,650	261,525	255,925	1,213,725
Gisborne	99,900	546,275	98,825	92,350	837,350
Hawke's Bay	372,675	606,775	183,400	251,875	1,414,725
Taranaki	18,375	530,550	90,150	84,600	723,675
Manawatu-Wanganui	262,625	1,525,600	162,375	266,375	2,216,975
Wellington	129,000	425,775	92,700	152,800	800,275
West Coast	7,775	447,300	331,850	1,541,025	2,327,950
Canterbury	407,225	1,887,500	525,125	1,644,850	4,464,700
Otago	102,875	1,378,900	696,475	969,150	3,147,400
Southland	70,525	1,063,075	356,000	1,487,175	2,976,775
Tasman	35,300	207,775	198,475	522,325	963,875
Nelson	3,325	20,100	10,375	7,325	41,125
Marlborough	79,175	270,300	216,650	476,725	1,042,850

Table A7. The areas (ha) estimated for a range of four suitability classes for growing chestnuts by region in New Zealand with pH, drainage and rainfall rules included.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	84,825	886,450	74,175	215,900	1,261,350
Auckland	67,225	311,925	5,150	55,350	439,650
Waikato	335,975	1,361,400	141,775	557,000	2,396,150
Bay of Plenty	125,550	555,850	61,875	470,450	1,213,725
Gisborne	278,575	493,550	38,400	26,825	837,350
Hawke’s Bay	484,675	309,225	94,450	526,375	1,414,725
Taranaki	249,225	366,525	73,375	34,550	723,675
Manawatu-Wanganui	917,750	717,400	246,750	335,075	2,216,975
Wellington	312,075	94,875	34,175	359,150	800,275
West Coast	650	64,125	543,975	1,719,200	2,327,950
Canterbury	444,625	1,042,175	734,675	2,243,225	4,464,700
Otago	202,150	646,575	635,850	1,662,825	3,147,400
Southland	593,450	312,875	813,400	1,257,050	2,976,775
Tasman	96,775	101,650	69,875	695,575	963,875
Nelson	4,275	14,575	5,900	16,375	41,125
Marlborough	107,300	253,075	122,425	560,050	1,042,850

Table A8. The areas (ha) estimated for a range of four suitability classes for growing chestnuts by region in New Zealand with pH, drainage and rainfall rules excluded.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	1,053,625	0	0	207,725	1,261,350
Auckland	384,650	0	0	55,000	439,650
Waikato	1,837,375	11,500	12,375	534,900	2,396,150
Bay of Plenty	742,375	1,775	0	469,575	1,213,725
Gisborne	810,425	100	0	26,825	837,350
Hawke's Bay	857,575	11,900	18,875	526,375	1,414,725
Taranaki	691,150	0	0	32,525	723,675
Manawatu-Wanganui	1,800,700	79,000	23,050	314,225	2,216,975
Wellington	461,850	25	100	338,300	800,275
West Coast	988,250	123,275	68,875	1,147,550	2,327,950
Canterbury	1,844,350	340,250	137,825	2,142,275	4,464,700
Otago	1,138,400	275,250	261,300	1,472,450	3,147,400
Southland	1,675,775	192,150	112,625	996,225	2,976,775
Tasman	337,600	28,200	15,625	582,450	963,875
Nelson	24,950	0	0	16,175	41,125
Marlborough	409,350	55,375	42,275	535,850	1,042,850

Table A9. The areas (ha) estimated for a range of four suitability classes for honey and **mānuka** by region in New Zealand.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	637,775	126,175	337,000	160,400	1,261,350
Auckland	137,025	70,525	169,275	62,825	439,650
Waikato	580,250	752,800	532,775	530,325	2,396,150
Bay of Plenty	380,900	342,250	401,950	88,625	1,213,725
Gisborne	136,075	656,525	11,375	33,375	837,350
Hawke's Bay	346,575	238,550	668,325	161,275	1,414,725
Taranaki	231,775	66,375	94,225	331,300	723,675
Manawatu-Wanganui	890,675	303,175	602,900	420,225	2,216,975
Wellington	424,325	26,900	226,250	122,800	800,275
West Coast	516,625	21,000	1,430,075	360,250	2,327,950
Canterbury	1,001,375	236,325	1,449,425	1,777,575	4,464,700
Otago	734,375	336,775	936,075	1,140,175	3,147,400
Southland	763,400	501,575	815,425	896,375	2,976,775
Tasman	222,050	87,875	544,300	109,650	963,875
Nelson	7,700	1,075	31,350	1,000	41,125
Marlborough	336,375	31,500	368,000	306,975	1,042,850

Table A10. The areas (ha) estimated for a range of four suitability classes for growing kiwifruit by region in New Zealand.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	253,675	688,325	98,350	221,000	1,261,350
Auckland	143,725	201,250	13,900	80,775	439,650
Waikato	896,425	697,650	409,050	393,025	2,396,150
Bay of Plenty	323,875	271,800	249,575	368,475	1,213,725
Gisborne	154,750	358,700	187,825	136,075	837,350
Hawke's Bay	330,625	477,425	202,800	403,875	1,414,725
Taranaki	306,075	163,550	170,250	83,800	723,675
Manawatu-Wanganui	274,275	852,000	659,425	431,275	2,216,975
Wellington	107,750	334,475	168,925	189,125	800,275
West Coast	128,125	355,400	255,750	1,588,675	2,327,950
Canterbury	106,050	760,700	742,825	2,855,125	4,464,700
Otago	0	46,100	644,875	2,456,425	3,147,400
Southland	0	102,900	907,875	1,966,000	2,976,775
Tasman	32,625	86,525	139,525	705,200	963,875
Nelson	2,075	7,075	18,100	13,875	41,125
Marlborough	59,850	109,525	187,800	685,675	1,042,850

Table A11. The areas (ha) estimated for a range of four suitability classes for growing onions by region in New Zealand with pH, drainage and salinity rules included.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	3,650	129,250	493,025	635,425	1,261,350
Auckland	3,900	140,225	168,850	126,675	439,650
Waikato	2,200	219,450	553,275	1,621,225	2,396,150
Bay of Plenty	-	5,975	171,000	1,036,750	1,213,725
Gisborne	-	7,825	53,550	775,975	837,350
Hawke's Bay	350	143,700	343,150	927,525	1,414,725
Taranaki	34,600	54,250	79,450	555,375	723,675
Manawatu-Wanganui	51,600	226,100	552,700	1,386,575	2,216,975
Wellington	26,100	96,225	209,550	468,400	800,275
West Coast	-	-	-	2,327,950	2,327,950
Canterbury	16,125	589,950	1,264,425	2,594,200	4,464,700
Otago	1,700	153,200	1,043,775	1,948,725	3,147,400
Southland	8,750	329,700	545,675	2,092,650	2,976,775
Tasman	15,025	33,375	58,650	856,825	963,875
Nelson	325	850	4,050	35,900	41,125
Marlborough	12,700	43,825	118,500	867,825	1,042,850

Table A12. The areas (ha) estimated for a range of four suitability classes for growing onions by region in New Zealand with pH, drainage and salinity rules excluded.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	24,225	177,350	476,100	583,675	1,261,350
Auckland	10,275	159,525	149,175	120,675	439,650
Waikato	57,050	275,875	546,275	1,516,950	2,396,150
Bay of Plenty	-	7,300	182,650	1,023,775	1,213,725
Gisborne	-	11,175	51,800	774,375	837,350
Hawke's Bay	43,300	124,125	329,925	917,375	1,414,725
Taranaki	41,950	62,975	66,875	551,875	723,675
Manawatu-Wanganui	309,875	113,900	424,050	1,369,150	2,216,975
Wellington	112,525	68,275	157,600	461,875	800,275
West Coast	-	-	-	2,327,950	2,327,950
Canterbury	874,400	330,125	761,125	2,499,050	4,464,700
Otago	189,875	129,650	1,213,450	1,614,425	3,147,400
Southland	192,725	248,725	590,225	1,945,100	2,976,775
Tasman	29,575	21,475	68,200	844,625	963,875
Nelson	600	1,075	4,175	35,275	41,125
Marlborough	60,750	25,175	94,350	862,575	1,042,850

Table A13. The areas (ha) estimated for a range of four suitability classes for growing peas by region in New Zealand with pH, drainage and rainfall rules included.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	30,600	724,850	45,025	460,250	1,260,725
Auckland	29,175	296,450	3,075	110,200	438,900
Waikato	118,825	1,024,300	214,100	1,038,900	2,396,125
Bay of Plenty	51,550	354,550	81,825	725,800	1,213,725
Gisborne	30,950	294,825	10,775	500,775	837,325
Hawke's Bay	94,700	611,200	46,475	662,325	1,414,700
Taranaki	154,200	141,900	8,575	419,000	723,675
Manawatu-Wanganui	117,375	724,550	167,625	1,207,425	2,216,975
Wellington	55,925	290,850	6,975	446,525	800,275
West Coast	50	6,300	9,825	2,311,725	2,327,900
Canterbury	6,525	639,475	776,650	3,042,000	4,464,650
Otago	11,400	335,375	307,350	2,493,275	3,147,400
Southland	119,700	454,175	325,700	2,077,100	2,976,675
Tasman	24,200	102,100	29,125	808,350	963,775
Nelson	500	7,150	1,525	31,950	41,125
Marlborough	10,450	114,975	54,375	862,900	1,042,700

Table A14. The areas (ha) estimated for a range of four suitability classes for growing peas by region in New Zealand with pH, drainage and rainfall rules excluded.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	539,425	542,250	-	179,675	1,261,350
Auckland	221,775	171,425	-	46,450	439,650
Waikato	814,275	650,350	204,125	727,400	2,396,150
Bay of Plenty	216,800	250,350	65,800	680,775	1,213,725
Gisborne	87,750	255,025	9,375	485,200	837,350
Hawke's Bay	332,275	443,200	37,550	601,700	1,414,725
Taranaki	231,675	111,325	-	380,675	723,675
Manawatu-Wanganui	496,625	555,425	144,500	1,020,425	2,216,975
Wellington	202,675	237,700	-	359,900	800,275
West Coast	13,950	18,200	3,100	2,292,700	2,327,950
Canterbury	723,525	620,700	390,200	2,730,275	4,464,700
Otago	202,575	403,100	190,225	2,351,500	3,147,400
Southland	419,450	424,375	314,050	1,818,900	2,976,775
Tasman	58,100	83,600	22,975	799,200	963,875
Nelson	2,825	7,050	600	30,650	41,125
Marlborough	93,500	96,625	10,175	842,550	1,042,850

Table A15. The areas (ha) estimated for a range of four suitability classes for growing potatoes by region in New Zealand with pH, drainage, salinity and rainfall rules included.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	12,175	337,725	612,750	298,075	1,260,725
Auckland	4,675	196,600	157,900	79,725	438,900
Waikato	229,575	658,250	661,200	847,100	2,396,125
Bay of Plenty	34,125	201,650	270,875	707,075	1,213,725
Gisborne	0	150	348,450	488,725	837,325
Hawke's Bay	59,300	561,825	166,925	626,650	1,414,700
Taranaki	156,000	105,625	63,925	398,125	723,675
Manawatu-Wanganui	110,275	659,125	331,250	1,116,325	2,216,975
Wellington	43,300	282,050	87,625	387,300	800,275
West Coast	4,225	775	2,225	2,320,675	2,327,900
Canterbury	6,775	765,200	905,825	2,786,850	4,464,650
Otago	17,875	256,950	407,850	2,464,725	3,147,400
Southland	68,800	374,225	394,750	2,138,900	2,976,675
Tasman	34,350	100,950	12,775	815,700	963,775
Nelson	1,625	6,075	575	32,850	41,125
Marlborough	20,550	94,650	68,400	859,100	1,042,700

Table A16. The areas (ha) estimated for a range of four suitability classes for growing potatoes by region in New Zealand with pH, drainage, salinity and rainfall rules excluded.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	35,425	423,475	558,525	243,925	1,261,350
Auckland	8,800	210,325	144,275	76,250	439,650
Waikato	275,600	713,900	683,775	722,875	2,396,150
Bay of Plenty	37,400	215,300	278,850	682,175	1,213,725
Gisborne	-	150	350,575	486,625	837,350
Hawke's Bay	184,925	478,850	144,175	606,775	1,414,725
Taranaki	179,775	118,450	38,675	386,775	723,675
Manawatu-Wanganui	297,125	644,550	216,575	1,058,725	2,216,975
Wellington	104,575	292,400	24,100	379,200	800,275
West Coast	11,600	16,225	8,525	2,291,600	2,327,950
Canterbury	555,325	871,525	294,275	2,743,575	4,464,700
Otago	134,850	385,175	264,700	2,362,675	3,147,400
Southland	121,550	490,975	400,225	1,964,025	2,976,775
Tasman	54,600	113,500	25,600	770,175	963,875
Nelson	2,275	7,525	-	31,325	41,125
Marlborough	69,525	98,150	22,275	852,900	1,042,850

Table A17. The areas (ha) estimated for a range of four suitability classes for growing truffles by region in New Zealand with pH, drainage and rainfall rules included.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	0	0	105,825	1,154,900	1,260,725
Auckland	0	0	70,800	368,100	438,900
Waikato	0	0	327,200	2,068,925	2,396,125
Bay of Plenty	0	0	98,600	1,115,125	1,213,725
Gisborne	0	0	219,675	617,650	837,325
Hawke's Bay	400	112,325	569,700	732,275	1,414,700
Taranaki	0	0	220,575	503,100	723,675
Manawatu-Wanganui	0	31,550	920,525	1,264,900	2,216,975
Wellington	0	22,350	375,625	402,300	800,275
West Coast	0	0	50	2,327,850	2,327,900
Canterbury	200	311,725	1,024,175	3,128,550	4,464,650
Otago	0	23,825	257,475	2,866,100	3,147,400
Southland	0	275	174,575	2,801,825	2,976,675
Tasman	0	0	103,575	860,200	963,775
Nelson	0	0	4,525	36,600	41,125
Marlborough	0	63,450	130,525	848,725	1,042,700

Table A18. The areas (ha) estimated for a range of four suitability classes for growing truffles by region in New Zealand with pH, drainage and rainfall rules excluded.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	179,175	584,200	223,775	274,200	1,261,350
Auckland	118,675	204,325	50,450	66,200	439,650
Waikato	759,450	566,300	233,125	837,275	2,396,150
Bay of Plenty	247,350	194,275	88,000	684,100	1,213,725
Gisborne	73,725	208,325	103,075	452,225	837,350
Hawke's Bay	257,875	490,600	204,175	462,075	1,414,725
Taranaki	177,775	82,000	92,775	371,125	723,675
Manawatu-Wanganui	302,175	715,025	505,375	694,400	2,216,975
Wellington	111,650	255,225	158,975	274,425	800,275
West Coast	2,775	8,900	2,150	2,314,125	2,327,950
Canterbury	368,175	888,200	792,375	2,415,950	4,464,700
Otago	48,775	141,375	562,900	2,394,350	3,147,400
Southland	-	5,900	219,400	2,751,475	2,976,775
Tasman	43,800	111,450	96,350	712,275	963,875
Nelson	2,050	7,275	8,225	23,575	41,125
Marlborough	60,525	109,300	113,000	760,025	1,042,850

Table A19. The areas (ha) estimated for a range of four suitability classes for growing sauvignon blanc grapes by region in New Zealand.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	0	146,900	395,550	718,900	1,261,350
Auckland	5,675	111,975	199,800	122,200	439,650
Waikato	225,450	1,272,450	328,350	569,900	2,396,150
Bay of Plenty	119,175	407,150	205,800	481,600	1,213,725
Gisborne	107,975	363,000	116,000	250,375	837,350
Hawke's Bay	206,400	552,275	114,200	541,850	1,414,725
Taranaki	63,250	340,850	180,375	139,200	723,675
Manawatu-Wanganui	122,425	818,575	450,625	825,350	2,216,975
Wellington	55,175	361,700	138,350	245,050	800,275
West Coast	0	190,975	254,075	1,882,900	2,327,950
Canterbury	550	188,525	470,150	3,805,475	4,464,700
Otago	0	7,450	56,750	3,083,200	3,147,400
Southland	0	0	5,200	2,971,575	2,976,775
Tasman	10,700	72,100	74,975	806,100	963,875
Nelson	1,150	7,450	11,925	20,600	41,125
Marlborough	34,800	106,825	112,750	788,475	1,042,850

Table A20. The areas (ha) estimated for a range of four suitability classes for growing pinot noir grapes by region in New Zealand.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	0	53,150	142,125	1,066,075	1,261,350
Auckland	125	34,400	128,150	276,975	439,650
Waikato	233,375	1,215,550	467,050	480,175	2,396,150
Bay of Plenty	149,625	410,250	291,300	362,550	1,213,725
Gisborne	90,300	457,400	108,575	181,075	837,350
Hawke's Bay	306,300	564,350	112,925	431,150	1,414,725
Taranaki	165,125	357,925	102,425	98,200	723,675
Manawatu-Wanganui	269,750	1,041,200	354,625	551,400	2,216,975
Wellington	162,125	371,375	73,325	193,450	800,275
West Coast	57,350	404,500	196,150	1,669,950	2,327,950
Canterbury	95,675	670,000	586,750	3,112,275	4,464,700
Otago	4,775	86,075	130,950	2,925,600	3,147,400
Southland	0	3,850	14,150	2,958,775	2,976,775
Tasman	38,025	107,050	103,550	715,250	963,875
Nelson	2,225	11,475	13,650	13,775	41,125
Marlborough	80,500	119,650	131,050	711,650	1,042,850

Table A21. The areas (ha) estimated for a range of four suitability classes for growing *Pinus radiata* by region in New Zealand.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	18,175	809,550	389,775	20,400	1,237,900
Auckland	5,250	350,975	114,000	9,825	480,050
Waikato	175,950	1,620,775	596,250	54,625	2,447,600
Bay of Plenty	96,775	774,775	313,325	39,425	1,224,300
Gisborne	181,150	609,700	45,925	1,125	837,900
Hawke's Bay	176,350	620,375	530,750	89,925	1,417,400
Taranaki	151,700	469,500	76,050	25,200	722,450
Manawatu-Wanganui	74,600	1,508,225	488,175	147,175	2,218,175
Wellington	86,850	571,625	116,450	32,375	807,300
West Coast	53,225	382,850	345,050	1,552,150	2,333,275
Canterbury	24,375	618,000	1,331,300	2,545,075	4,518,750
Otago	1,200	189,775	863,475	2,134,125	3,188,575
Southland	25	662,350	858,750	1,473,700	2,994,825
Tasman	114,250	315,625	198,350	334,200	962,425
Nelson	14,250	21,350	4,925	1,025	41,550
Marlborough	50,750	321,525	237,150	426,300	1,035,725

Table A22. The areas (ha) estimated for a range of four suitability classes for growing Douglas fir by region in New Zealand.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	-	-	-	1,263,925	1,263,925
Auckland	-	-	-	497,675	497,675
Waikato	46,400	36,125	39,350	2,334,725	2,456,600
Bay of Plenty	725	20,175	59,900	1,146,800	1,227,600
Gisborne	750	3,475	6,850	827,150	838,225
Hawke's Bay	17,450	133,550	68,825	1,198,475	1,418,300
Taranaki	6,825	3,525	4,125	710,100	724,575
Manawatu-Wanganui	142,125	117,325	67,150	1,893,675	2,220,275
Wellington	-	21,050	11,450	777,575	810,075
West Coast	52,875	256,525	345,725	1,683,250	2,338,375
Canterbury	598,800	958,000	433,450	2,530,925	4,521,175
Otago	136,125	901,900	764,075	1,387,750	3,189,850
Southland	-	396,025	740,475	1,869,800	3,006,300
Tasman	171,500	173,675	83,000	536,575	964,750
Nelson	1,600	1,650	1,200	37,725	42,175
Marlborough	231,100	78,275	39,600	695,400	1,044,375

Table A23. The areas (ha) estimated for a range of four suitability classes for growing *Eucalyptus fastigata* by region in New Zealand.

Region	Well suited	Suitable	Marginally suited	Unsuitable	Total area
Northland	3,100	83,725	93,325	1,083,775	1,263,925
Auckland	-	7,875	109,150	380,650	497,675
Waikato	21,750	297,625	830,850	1,306,375	2,456,600
Bay of Plenty	9,775	172,650	239,450	805,725	1,227,600
Gisborne	24,700	153,100	195,325	465,100	838,225
Hawke's Bay	33,325	105,300	324,600	955,075	1,418,300
Taranaki	9,700	92,325	264,250	358,300	724,575
Manawatu-Wanganui	500	90,350	773,550	1,355,875	2,220,275
Wellington	1,675	36,650	247,700	524,050	810,075
West Coast	-	25,350	289,100	2,023,925	2,338,375
Canterbury	-	2,275	85,350	4,433,550	4,521,175
Otago	-	25	86,350	3,103,475	3,189,850
Southland	150	3,325	112,375	2,890,450	3,006,300
Tasman	3,850	28,225	72,100	860,575	964,750
Nelson	-	2,850	13,200	26,125	42,175
Marlborough	775	39,225	70,200	934,175	1,044,375

10.7 APPENDIX – BIOGENIC GREENHOUSE GAS EMISSIONS

Table A24. Activity data used for estimating BGE per livestock type.

Input data ('Activity data')	Dairy cattle	Non-dairy cattle	Sheep	Deer
Number of animals	6,618,799	3,533,054	27,583,673	834,608
Average live weight (kg)	450	564	53	129
Total urine N excreted (t)	550,576	177,814	309,525	16,910
Total dung N excreted (t)	201,064	92,010	160,164	8,467
Stored effluent N (t)	39,560			
Effluent N applied to land (t)	25,714			
Urea N applied to land (pro rata based on livestock type) (t)	185,634	29,911	21,757	1,386
Urease inhibitor treated urea N applied to land (pro rata based on livestock type) (t)	66,854	10,772	7,835	499
Non-urea N applied to land (pro rata based on livestock type) (t)	50,385	8,119	5,905	376
Urea application (pro rata based on livestock type) (t)	548,886	88,441	64,331	4,099
Lime application (pro rata based on livestock type) (t)	430,354	336,189	244,540	21,672
Dolomite application (pro rata based on livestock type) (t)	10,775	4,124	3,000	670

Table A25. Implied methane (CH_4) emission factors for enteric fermentation and manure management per livestock type.

Methane source	Implied emission factors (kg CH_4/head/year)
Enteric fermentation	
Dairy cattle	82.3
Non-dairy cattle	59.2
Sheep	12.2
Deer	22.3
Manure management	
Stored effluent	4.83
Dung on soil - Dairy cattle	0.79
Dung on soil - Non-dairy cattle	0.79
Dung on soil - Sheep	0.13
Dung on soil - Deer	0.27

Table A26. Nitrous oxide (N_2O) emission factors (EF) to estimate direct N_2O emissions from managed soils.

N source	EF symbol	Emission Factor (kg N_2O-N/kg N)
Direct N_2O emissions		
Urine	$EF_{3(PRP-URINE)}$	0.01
Dung	$EF_{3(PRP-DUNG)}$	0.0025
Synthetic N fertiliser (urea)	EF_{1-UREA}	0.0059
Organic fertiliser (dairy cattle manure)	$EF_{1-DAIRY}$	0.0025
Synthetic N fertiliser (other), organic fertiliser (non-dairy cattle), crop residues	EF_1	0.01
Indirect N_2O emissions		
Indirect emissions from ammonia volatilisation	EF_4	0.01
Indirect emissions from N leaching	EF_5	0.0075

Table A27. Parameters for indirect nitrous oxide (N_2O) emissions from agricultural soils.

N source	Frac symbol	Parameter	Unit
Fraction of volatilisation from synthetic fertiliser	$Frac_{GASF}$	0.1	kg NH_3-N + NO_x-N/kg N
Fraction of volatilisation from organic N additions	$Frac_{GASM}$	0.1	kg NH_3-N + NO_x-N/kg N
Fraction of leaching and runoff from all nitrogen applied to soil	$Frac_{LEACH - (H)}$	0.07	kg N/kg N

Table A28. Factors to calculate emissions from above- and below-ground crop residues, including pasture renewal (F_{CR}).

N Source	Frac symbol	Parameter	Unit
Crops			
Fraction of N in above-ground residues	NAG	Crop dependent1	kg N/kg DM
Fraction of N in below-ground residues	NBG	Crop dependent	kg N/kg DM
Pasture renewal			
Fraction of pasture renewed each year	FracRenew	0.0752 Year dependent	ha/ha
Fraction of N in above-ground residues	NAG	0.022	kg N/kg DM
Fraction of N in below-ground residues	NBG	0.0162	kg N/kg DM

[1]Factors for individual crops see (Ministry for the Environment 2018), Thomas et al. (2011).
[2]Factors for individual crops see Thomas et al. (2014).

Table A29. Carbon dioxide (CO_2) emission factors to CO_2 emissions from urea, lime and dolomite.

CO_2 source	EF symbol[A]	Emission Factor (kg CO_2-C/kg product)
Urea	EF	0.20
Lime	$EF_{Limestone}$	0.12
Dolomite	$EF_{Dolomite}$	0.13

[A] Symbol taken from IPCC guidelines (IPCC 2006), as no symbols are provided in New Zealand national inventory (Ministry for the Environment 2018)

10.8 APPENDIX – FACTORS FOR LAND USE CHANGE

10.8.1 Activity data

Factors used for biomass (Table A30) and annual growth in biomass (Table A31) are taken from the 2018 national greenhouse gas inventory report (Ministry for the Environment 2018).

Table A30. Biomass carbon and soil carbon stocks in land use before conversion (Tables 6.1.3. and 6.3.1. in Ministry for the Environment 2018).

Land use	Biomass t C/ha	Soil C t C/ha
High producing grassland	6.345	105.34
Low producing grassland	2.867	105.98
Grassland with woody biomass – transitional	13.05	98.23
Post-1989 planted forest	(C yield table)[1]	91.92
Annual crop land	5	89.77
Perennial crop land	18.76	88.44

[1]Age-based carbon yield table by biomass pool derived from the LUCAS plot network and the Forest Carbon Predictor model (Ministry for the Environment 2018).

Table A31. Annual growth in biomass carbon stock in land after conversion (Table 6.1.4. in Ministry for the Environment 2018).

Land use	Biomass t C/ha	C stock maturity cycle
High producing grassland	6.345	1
Low producing grassland	2.867	1
Grassland with woody biomass – transitional	0.47	28
Post-1989 planted forest	(C yield table)[1]	NA
Annual crop land	5	1
Perennial crop land	0.67	28

[1]Age-based carbon yield table by biomass pool derived from the LUCAS plot network and the Forest Carbon Predictor model (Ministry for the Environment 2018). Average annual C sequestration for *Pinus radiata* over 28 years = 9 t/ha.

10.8.2 Method

Biomass changes in C from change in land use (Ministry for the Environment 2018) are:

$$\left(\begin{matrix}\text{Loss of biomass} \\ \text{C in previous} \\ \text{crop}\end{matrix} + \begin{matrix}\text{Annual biomass C} \\ \text{accumulation in} \\ \text{new land use}\end{matrix}\right) \times \text{Area} \qquad \text{(Equation 1)}$$

Changes in soil C are calculated by:

$$\frac{\begin{matrix}\text{Mineral soil C} \\ \text{at steady state in} \\ \text{new land use}\end{matrix} - \begin{matrix}\text{Mineral soil} \\ \text{at steady state in} \\ \text{previous land use}\end{matrix}}{\text{20 years (transition period)}} \times \text{Area} \qquad \text{(Equation 2)}$$

The change in total emissions is the sum of the changes in biomass C and soil C, presented here as CO_2-e/ha. Note this is for the year of conversion.

10.8.3 Land use change – emissions and removals

The effects of key land use changes on crop or forest biomass and soil carbon (Table A32) was estimated using the Land Use, Land Use Change, and Forestry (LULUCF) methodology (IPCC 2006), and factors described in Section 10.8.3.

Table A32. Land use change examples estimated using Equations 1 and 2, and factors from Tables 8 and 9. Positive values are a net removal of CO_2.

Land use change From	To	Biomass C Mg C/ha	Soil C Mg C/ha	Total Mg CO2/ha
High producing grassland	Perennial crop	-5.68	-0.85	-23.91
High producing grassland	Annual crop	-1.35	-0.78	-7.79
High producing grassland	Planted forest	2.66[1]	-0.67	7.27
Low producing grassland	Planted forest	6.13[1]	-0.70	19.91

[1]Based on average annual C sequestration of 9 Mg C/ha.

10.9 APPENDIX – LAND USE INFORMATION

Table A33. Land use information collected from Statistics New Zealand Agricultural 2017 Census.

Crop enterprise	Area collected	Statistics New Zealand codes	Comments
Apples	Yes	lc8500	
Avocados	Yes	lc8500	
Blueberries	Yes	lc8570	
Cherries	Yes	lc8625	
Chestnuts	Yes	lc8540	
Honey and mānuka	No	-	
Kiwifruit	Yes	lc8555	Made up of lc8551 – green, lc8552 – gold, lc8553 – other
Onions	Yes	lc9120	
Peas	Yes	lc6351 + lc9130	lc6351 – fresh and process peas, lc9130 – field/seed peas
Potatoes	Yes	lc9135	
Truffles	No	-	
Wine Grapes	Yes	lc8600	
Forestry	Yes	Sum (lc6009, lc6019, lc6050, lc6051	lc6009 – plantations of exotic trees intended for harvest, lc6019 – harvested exotic forest area awaiting restocking, lc6050 – new area planted, lc6051 area replanted

[1]S Suppressed

Table A34. Land use areas for crops and exotic forestry from Statistics New Zealand Agricultural 2017 Census.

Statistics New Zealand codes:	lc8500	lc8570	lc8625	lc8540	lc8720	lc8555	lc9120	lc6351+lc9130	lc9135	lc8600	lc6009, lc6019, lc6050, lc6051
Region	Apples	Avocados	Blueberries	Cherries	Chestnuts	Kiwifruit	Onions	Peas	Potatoes	Wine grapes	Forestry
Northland	20	1,647	29	0	5	551	2	0	8	0	153,860
Auckland	84	281	27	0	18	494	1,919	15	2,242	836	39,837
Waikato	144	101	316	9	13	412	1,733	26	1,280	15	246,299
Bay of Plenty	67	1,834	24	0	6	9,227	0	0	0	75	314,967
Gisborne	186	48	1	0	0	282	0	166	0	1,245	140,809
Hawke's Bay	4,746	20	99	25	0	121	963	1,222	236	3,616	124,867
Taranaki	3	23	1	0	0	0	0	0	10	0	24,515
Manawatu-Wanganui	0	3	12	0	4	116	281	579	984	88	132,547
Wellington	102	8	8	0	4	10	1	9	2	832	59,875
West Coast	0	0	6	0	0	0	0	0	0	0	19,185
Canterbury	312	0	11	26	35	0	1,001	11,157	4,332	1,769	87,750
Otago	427	0	0	579	0	0	0	305	196	1,173	120,019
Southland	0	0	63	31	0	0	0	461	140	0	82,679
Tasman	2,400	8	27	6	2	440	46	0	9	980	79,120
Nelson	0	0	0	0	0	0	0	0	0	24	9,120
Marlborough	21	0	2	36	0	0	33	218	1	23,051	67,733
Total	8,615	3,979	624	726	86	11,705	6,009	14,188	9,450	33,981	1,703,830

Table A35. Livestock information for total dairy, beef, sheep and deer from Statistics New Zealand 2017 Agricultural Production Census.

Statistics New Zealand codes:	lc7193	lc7077	lc6731	lc7699
Region	Dairy	Beef	Sheep	Deer
Northland	379,401	382,957	328,033	4,913
Auckland	132,323	111,948	253,074	11,284
Waikato	1,871,594	488,033	1,478,921	62,714
Bay of Plenty	325,175	104,751	281,535	32,645
Gisborne	9,407	247,238	1,412,045	11,859
Hawke's Bay	87,675	421,163	2,794,237	51,713
Taranaki	590,846	117,954	497,505	3,999
Manawatu-Wanganui	463,057	567,856	5,061,676	54,965
Wellington	96,804	134,924	1,512,079	10,637
West Coast	156,204	27,422	40,384	28,340
Canterbury	1,308,058	467,550	4,473,916	238,633
Otago	333,850	262,823	4,586,781	115,730
Southland	681,011	175,201	3,987,294	192,480
Tasman	66,114	39,805	261,878	10,348
Nelson	2,925	[1]S	[1]S	0
Marlborough	25,315	52,448	468,697	6,077

10.10 APPENDIX – ESTIMATES OF GREENHOUSE GAS EMISSIONS AND PROFITABILITY BASED ON CURRENT LAND USE

Using the land use information and BGE for each land use we have provided some regional estimates of BGE by selected crops and forestry by region (Table A36), and livestock type by region (Table A37) that is further disaggregated into methane emissions only (Table A38).

Table A36. Estimated biogenic greenhouse gas emissions (as CO_2 equivalents; Mg CO_2-e) for each land use by region based on Statistics New Zealand land use data (Table A34) and estimated emissions for each land use (Table 5). Note there are no area data for honey and **mānuka**, or truffles collected by Statistics New Zealand.

	Apples	Avocados	Blueberries	Cherries	Chestnuts	Kiwifruit	Onions	Peas	Potatoes	Wine grapes	Forestry	Total
Northland	16	866	9	0	0.0	688	3	0	15	0	1,161	2,758
Auckland	68	148	8	0	0.1	618	2,358	4	4,280	260	301	8,045
Waikato	116	53	95	7	0.1	515	2,129	8	2,442	5	1,859	7,229
Bay of Plenty	54	964	7	0	0.0	11,531	0	0	0	23	2,378	14,957
Gisborne	150	25	0	0	0.0	353	0	50	0	388	1,063	2,029
Hawke's Bay	3,840	10	30	18	0.0	151	1,183	369	451	1,126	943	8,121
Taranaki	2	12	0	0	0.0	0	0	0	19	0	185	218
Manawatu-Wanganui	0	2	4	0	0.0	145	345	175	1,877	27	1,001	3,576
Wellington	83	4	2	0	0.0	12	1	3	4	259	452	821
West Coast	0	0	2	0	0.0	0	0	0	1	0	145	147
Canterbury	252	0	3	19	0.2	0	1,230	3,367	8,269	551	662	14,354
Otago	345	0	0	425	0.0	0	0	92	375	365	906	2,508
Southland	0	0	19	23	0.0	0	0	139	267	0	624	1,072
Tasman	1,942	4	8	5	0.0	550	57	0	17	305	597	3,484
Nelson	0	0	0	0	0.0	0	0	0	0	8	69	76
Marlborough	17	0	0	27	0.0	0	41	66	1	7,179	511	7,842
Total	6,885	2,088	187	523	0.4	14,563	7,346	4,273	18,017	10,497	12,857	77,237

Table A37. Estimated biogenic greenhouse gas emissions (as CO_2 equivalents; Mg CO2-e) for dairy, sheep, beef and deer livestock by region based on Statistics New Zealand land use data (Table A35) and estimated emissions for each land use (Table 6).

	Dairy	Beef	Sheep	Deer	Total
Northland	1,132,133	740,256	127,933	3,528	2,003,849
Auckland	394,852	216,395	98,699	8,102	718,048
Waikato	5,584,836	943,368	576,779	45,029	7,150,012
Bay of Plenty	970,322	202,484	109,799	23,439	1,306,044
Gisborne	28,070	477,911	550,698	8,515	1,065,194
Hawke's Bay	261,622	814,108	1,089,752	37,130	2,202,613
Taranaki	1,763,084	228,005	194,027	2,871	2,187,988
Manawatu-Wanganui	1,381,762	1,097,666	1,974,054	39,465	4,492,946
Wellington	288,863	260,808	589,711	7,637	1,147,019
West Coast	466,113	53,007	15,750	20,348	555,217
Canterbury	3,903,245	903,774	1,744,827	171,338	6,723,185
Otago	996,208	508,037	1,788,845	83,094	3,376,184
Southland	2,032,137	338,664	1,555,045	138,201	4,064,046
Tasman	197,284	76,943	102,132	7,430	383,790
Nelson	8,728	1S	1S	0	8,728
Marlborough	75,540	101,382	182,792	4,363	364,077
Grand Total	19,484,801	6,962,807	10,700,841	600,490	37,748,939

[1]S suppressed.

Table A38. Estimated methane emissions (Mg CO_2-e) for livestock land uses by region based on Statistics New Zealand land use data (Table A35) and estimated emissions for each land use (Table 6).

	Dairy	Beef	Sheep	Deer	Total
Northland	837,778	577,400	101,067	2,787	1,519,031
Auckland	292,190	168,788	77,972	6,401	545,351
Waikato	4,132,779	735,827	455,656	35,573	5,359,834
Bay of Plenty	718,038	157,937	86,741	18,517	981,234
Gisborne	20,772	372,771	435,051	6,727	835,321
Hawke's Bay	193,600	635,004	860,904	29,333	1,718,842
Taranaki	1,304,683	177,844	153,281	2,268	1,638,076
Manawatu-Wanganui	1,022,504	856,179	1,559,502	31,177	3,469,363
Wellington	213,759	203,430	465,872	6,034	889,094
West Coast	344,923	41,345	12,442	16,075	414,786
Canterbury	2,888,401	704,944	1,378,414	135,357	5,107,116
Otago	737,194	396,269	1,413,187	65,644	2,612,295
Southland	1,503,781	264,158	1,228,485	109,179	3,105,603
Tasman	145,990	60,016	80,685	5,870	292,560
Nelson	6,459	[1]S	[1]S	0	6,459
Marlborough	55,900	79,078	144,406	3,447	282,830
Grand Total	14,418,753	5,430,990	8,453,665	474,387	28,777,794

[1]S suppressed.

10.11 APPENDIX – PROFITABILITY OF CURRENT SELECTED LAND USES

Similarly, we have estimated the overall profitability of livestock (Table A39) and the selected crops and forestry (Table A40).

Table A39. Estimated profitability ($Million, $M) for livestock land uses by region based on Statistics New Zealand land use data (Table A35) and estimated profitability for each land use (Table 6).

	Dairy	Beef	Sheep	Total
Northland	588	112	96	797
Auckland	205	33	74	312
Waikato	2,901	143	434	3,478
Bay of Plenty	504	31	83	617
Gisborne	15	73	414	502
Hawke's Bay	136	124	820	1,080
Taranaki	916	35	146	1,096
Manawatu-Wanganui	718	167	1,486	2,370
Wellington	150	40	444	633
West Coast	242	8	12	262
Canterbury	2,027	137	1,313	3,478
Otago	517	77	1,346	1,941
Southland	1,056	51	1,170	2,277
Tasman	102	12	77	191
Nelson	5	0	0	5
Marlborough	39	15	138	192
Grand Total	10,121	1,057	8,053	19,231

Table A40. Estimated profitability ($Million, $M) for selected land-uses by region based on Statistics New Zealand 2017 census data (Table A34) and estimates of current profitability (Table 5).

	Apples	Avocados	Blueberries	Cherries	Chestnuts	Kiwifruit	Onions	Peas	Potatoes	Wine grapes	Forestry	Total
Northland	0.3	57.8	1.3	0.0	0.0	9.7	0.0	0.0	0.0	0.0	153.9	223.1
Auckland	1.4	9.8	1.2	0.0	0.1	8.7	9.9	0.0	7.0	10.8	39.8	88.8
Waikato	2.4	3.5	13.9	0.4	0.1	7.3	8.9	0.0	4.0	0.2	246.3	287.0
Bay of Plenty	1.1	64.4	1.1	0.0	0.0	163.3	0.0	0.0	0.0	1.0	315.0	545.8
Gisborne	3.0	1.7	0.0	0.0	0.0	5.0	0.0	0.3	0.0	16.1	140.8	166.9
Hawke's Bay	77.9	0.7	4.4	1.0	0.0	2.1	5.0	1.9	0.7	46.7	124.9	265.2
Taranaki	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.5	25.4
Manawatu-Wanganui	0.0	0.1	0.5	0.0	0.0	2.1	1.5	0.9	3.1	1.1	132.5	141.8
Wellington	1.7	0.3	0.3	0.0	0.0	0.2	0.0	0.0	0.0	10.7	59.9	73.2
West Coast	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.2	19.4
Canterbury	5.1	0.0	0.5	1.0	0.2	0.0	5.2	17.1	13.4	22.8	87.7	153.2
Otago	7.0	0.0	0.0	23.2	0.0	0.0	0.0	0.5	0.6	15.1	120.0	166.4
Southland	0.0	0.0	2.8	1.3	0.0	0.0	0.0	0.7	0.4	0.0	82.7	87.8
Tasman	39.4	0.3	1.2	0.2	0.0	7.8	0.2	0.0	0.0	12.7	79.1	140.9
Nelson	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	9.1	9.4
Marlborough	0.3	0.0	0.1	1.4	0.0	0.0	0.2	0.3	0.0	297.7	67.7	367.8
Total	139.6	139.4	27.5	28.5	0.5	206.2	30.9	21.8	29.3	435.4	1703.2	2762.2

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