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Forage crop opportunities as a result of climate change

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Climate change – 'Plan of action' research programme
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Contents

1 Executive summary

This report identifies the major opportunities that climate change brings to extend the growing season and increase forage crop yields through radical changes in forage germplasm and management.

The authors used existing crop models and simulated weather data to predict the likely changes in forage crop production in 2040 and 2090. The models grew maize silage over the summer, followed by winter wheat; the biomass was then summed to give total annual biomass production. Three different management practices (sowing dates for maize) were investigated. These studies were carried out for six regions of New Zealand, represented by weather data from Kaikohe (Northland), Hamilton (Waikato), Palmerston North (Manawatu), Masterton (Wairarapa), Lincoln (Canterbury) and Gore (Southland). More detailed modelling was done for Northland: a range of maize hybrids, from short-maturing to novel tropical maize, were tested across three sowing dates, followed by either winter wheat (to simulate a grass or cereal crop) or kale (to simulate a productive forage brassica).

The results suggest that climate change causes maize yields to decline slightly in the northern regions of New Zealand (from Hamilton north), change little in the central regions, and increase as it is grown further south, particularly in Gore. The warmer winters resulting from climate change increased the biomass of winter wheat by 13–19% by 2040, and 17–38% by 2090.

As a result climate change is predicted to have little effect on total annual biomass yields in Kaikohe (a 2% increase by 2090), but should increase yields further south (a 12% increase by 2090 in Lincoln). (Note that the Gore results are not quoted since late-maturing maize is not currently grown in Gore.) In general, there was little difference in total annual biomass yields between sowing maize in September or in November (Table 4).

The more detailed modelling in Northland showed that the tropical hybrid was the most productive maize, with the short-maturing hybrid the least productive. Again September sowings produced more maize biomass. A grass (wheat) winter crop was generally more productive than kale, except when medium- or late-maturing maize was sown in September.

The modelling simulations suggested that climate change may lead to increases in biomass production if maize can be sown in early September. However, in practice this may not be feasible due to the high August rainfall in Kaikohe and the heavy soils.

Gross margins on the crops indicated that there is potential to make more money from tropical and late-maturing maize hybrids sown early in the spring, in combination with a winter forage. Assuming that maize silage remains the most profitable forage, then higher income per hectare can be expected in 2040 due to greater production, but this declines in 2090 to similar returns to those in 1990. The greater returns from maize silage will tempt farmers to plant as early as possible, but this must be balanced by the risk of frost and how quickly the soil dries out over winter. Climate change reduces the frost risk, as expected, and reduces winter rainfall in northern and eastern regions, but increases rainfall in western and southern regions.

This analysis suggests that there are opportunities for maize followed by kale in Northland. However, this would require new methods for making silage out of kale to fully take advantage of this option, and adequate pest and disease control methods. The report also suggested that more research should be done to match the timing of sowing, the maize hybrid, and the choice of winter forage to ensure that the feed quality of both the winter and the summer crop is maximised. The high value of maize silage also indicated that there may be economic benefits from using long-maturing or tropical maize hybrids. Tropical hybrids would require testing under New Zealand growing conditions. There is also the potential to increase biomass by sowing maize in Gore if it can be provided with adequate frost protection.

Further modelling studies are needed to understand the impacts on forage production of more extreme or more conservative emissions scenarios. These will help the government make the policy decisions now that are necessary for a sustainable future.

2 Scope

This research programme addresses MAF's Plan of Action Research Programme 2007. In particular it addresses the needs of the Cluster 3 – Adaptation topic "Identification of opportunities as a result of climate change for New Zealand's pastoral and planted forest systems including at a regional level".

3 Research goal

Identify the major opportunities that climate change brings to extend the growing season and achieve a step change in cumulative forage crop yields via radical changes in forage germplasm and management.

4 Rationale

Climate change will bring warmer temperatures to many regions of New Zealand, but day lengths will remain the same. That combination opens the door to reliably achieve much higher production levels of quality dry matter in forage crops. The opportunity arises through longer growing seasons achieved through wider potential ranges of forage species and cultivars in combination with new management techniques. For example, existing New Zealand cultivars will develop more quickly and could be planted earlier, and grazed or cut early enough for a subsequent crop (or intercrop) of a different species to achieve significant growth. Warmer temperatures could enable some tropical maize hybrids to be grown in New Zealand. Flowering in these hybrids is usually triggered by short days. At New Zealand latitudes flowering could be greatly delayed – and vegetative growth greatly extended – increasing dry matter production. The research programme described in this report identified the scope for such opportunities and recommends research priorities so New Zealand can rapidly exploit such positive potential from climate change.

The programme designed enables two talented young scientists (Brown and Trolove) to develop and prepare themselves and the wider research community for the new challenges that climate change brings. Senior staff (notably Dr Jeff Reid) mentored these scientists, while ensuring that all contracted outputs were achieved on time and to the highest standard.

5 Collaboration

The main collaboration underpinning this programme is between the Crop & Food Research team and Andrea Pearson of the Foundation for Arable Research (FAR). Andrea is a Research Co-ordinator for FAR, managing research and extension for the national grain and silage maize industry. She is also involved in FAR's soil research and extension activities throughout New Zealand. In this programme Andrea used her FAR and pre-FAR experience with forages and contacts within the dairy industry to act as facilitator for the industry discussions. Also, her experience was invaluable for assessing the practical achievability of potential productivity gains.

We also collaborated with Dr Andrew Tait of NIWA via a subcontract. He provided the weather data for us to calculate forage yields under different climate and location scenarios. Andrew also contributed to the interpretation of our scenarios and calculations.

6 Background

Much of New Zealand's economy is based on agriculture and forestry. Nearly half New Zealand's area is used for primary production: 39% of our total land area is in pasture, 1.6% in horticulture and cropping, and 6.6% in planted production forest. These sectors are vulnerable to changes in the world's climate environmentally and economically (Jim Anderton in: New Zealand's climate change solutions: sustainable land management and climate change, 2007). Primary production is the engine room of New Zealand's economy and it will be affected by climate change driven by global warming.

Production from agriculture and forestry is projected to decline by 2030 over parts of eastern New Zealand due to increased drought. In New Zealand, initial benefits to agriculture and forestry are projected (in western and southern areas and close to major rivers due to a longer growing season, less frost and increased rainfall) (Hennessy et al. 2007). In eastern New Zealand and Northland, pasture production is likely to decline by 2030 due to increased drought frequency. Sub-tropical pastoral species with lower feed quality such as paspalum are like to spread southwards, reducing productivity (Clark et al. 2001). The range and incidence of pest and diseases are likely to increase. Drought and water security problems are likely to make irrigated agriculture vulnerable (Hennessy et al. 2007).

Climate change is likely to be positive for arable crops (Kenny 2001). Higher temperature will allow earlier sowing of crops, and they will generally mature faster. Simulation studies by Jamieson & Cloughley (2001) indicated a 10–15% increase in wheat productivity by 2050. A greater range of hybrids of maize is expected in the southern regions of New Zealand due to the reduced risks of frost and higher summer temperatures (Kenny 2001).

As well as a general increase in temperature means, there is likely to be an increase in both the mean and variance of those temperatures (IPCC 2001; Salinger 2005). Simulation modelling of the effects of climatic variability concluded that increased annual variability in weather causes increased variation in yields (Porter & Gawith 1999). In an analysis of a 55-year panel of crop yield in the United States, Schlenker & Roberts (2008) found yield increases for corn and soybean up to a temperature of 29°C, with temperatures above these thresholds quickly becoming harmful for growth.

Forage crops are an important part of agriculture, providing high quality feed that enables high output from sheep and beef, and dairy farms in particular. Climate change will offer significant increases in the productivity of forage crops, with flow on effects to other production systems. With warming, growing seasons will be longer, opening opportunities for the use of potential new forage species and cultivars with new management techniques. Management techniques include the growing of two consecutive forage crops to take advantage of the extended growing season as well as the use of very long duration forage crops that can grow for the whole season and produce high yields of quality forage.

One such forage crop is tropical maize. Tropical maize or any other long-maturity maize hybrid can produce high yields due to the lack of photoresponse seen in short season hybrids currently grown in New Zealand. The warmer temperatures allow for earlier sowing and therefore greatly extend the growing season for maize, so it is possible that tropical maize hybrids may give farmers the opportunity to greatly enhance their annual biomass production.

Interest in tropically adapted maize hybrids has increased in the south-eastern US during the past few years. It has been estimated that over 20 000 ha were grown in 1991, primarily for silage. The estimated potential for tropical maize in the Southern US is about 75 000–100 000 ha. Due to its late planting date, tropical maize can serve as an alternative crop in double-cropping systems using soybean (*Glycine max* (L.) Merr.), grain sorghum (*Sorghum bicolor* (L.) Moench) and temperate maize (*Zea mays* L.) The potential to produce a late season grain crop, in addition to high silage yields, makes tropical maize an attractive alternative crop for warm temperate/subtropical regions (Mullins et al. 1998)

There are instances where crops are already growing close to their limits of heat tolerance and moisture availability (Parry et al. 1999). For wheat, Ortiz et al. (2008) argues that future climate scenarios suggest that global warming may be harmful in some regions, and could reduce productivity in zones where optimal temperatures already exist. This also applies to maize forage crops grown in some areas of New Zealand. At present farmers require information on short-term seasonal and inter-annual variability on very specific locations to make informed decisions (Burton & Limm 2005).

This report is a first attempt. It uses six regions and two future scenarios for each region (2040 and 2090) to assess opportunities for forage cropping in New Zealand. In this report we assess the opportunity that climate change brings to extend the growing season in cumulative forage crop yields under New Zealand conditions. A range of scenarios was used based on the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) (EcoClimate Report 2008) using three Special Report on Emissions Scenarios (SRES) for six locations for the periods 2040 and 2090. The scenarios used 32 years (11 or 12 years for two sites) of current climate data (1972–2003) adjusted with the predicted monthly changes in temperature and rainfall for 2040 and 2090. The choice of six locations gave us a good spread over both islands of New Zealand. A modelling approach allowing two crops to be grown in sequence over a number of years was used.

7 Programme objectives

The programme is a desk top study with three objectives.

7.1 Objective 1

Objective Title: National opportunities for step change

Objective Leader: Dr Huub Kerckhoffs

Description:

This is a broad scoping study to identify opportunities across New Zealand for markedly improved forage production arising from increased temperatures.

Methodology:

Information will be reviewed from a wide variety of published sources. We will compare known crop requirements with anticipated weather scenarios for the 2030s. The weather data will be taken from medium-low and medium-high temperature scenarios (identified from the IPCC Third Assessment Report) generated by the HadCM2 model. Consultation with other climate and agricultural experts will ensure that in the limited time available we cover the most important opportunities. Where possible, we will use existing forage crop models to pose and answer “what if” questions for realistic scenarios.

7.2 Objective 2

Objective Title: Regional case study – Northland maize

Objective Leader: Dr Stephen Trolove

Description:

We will explore in some detail the potential for tropical and existing New Zealand hybrids of maize to be grown alone, in sequence or intercropped with other species in Northland. This will illustrate some of the opportunities dealt with in Objective 1, providing a specific “concrete” example to help prompt industry action. Northland was chosen as it is already one of the more consistently warm regions of New Zealand. So, if the results are favourable, Northland offers an early chance for subsequent practical demonstration of the opportunities to be brought by climate change elsewhere. Maize was chosen because it is already an important forage and we have an excellent quantitative model of crop development and growth. We also have a valuable start in a review of intercropping options for maize in New Zealand (Carey et al. 2006).

Methodology:

Information will be gathered from a wide variety of published sources and, where possible, we will pose and answer “what if” questions for realistic climate and management scenarios. We will do this by simulation analysis using an adapted version of the AmaizeN model (SFF Project 05/096) and a variety of other existing models of forage crops. The methodology developed and results obtained will greatly help interpretation of findings in Objective 1, as well as having substantial value in their own right for MAF Policy.

7.3 Objective 3

Objective Title: Recommendations for research

Objective Leader: Dr Huub Kerckhoffs

Description:

Results from Objectives 1 and 2 will be collated, summarised and prioritised, to assist development of policy for climate change adaptation.

Methodology:

We will collate the results from Objectives 1 and 2, discussing them with representatives of industry, community and science providers. For each major opportunity we will identify the likely requirements for new physical, biological and social science, and conduct a cost-benefit-risk analysis. Our final report will contain a summary of that analysis and recommendations arising from it.

8 National opportunities for step change (Objective 1)

Huub Kerckhoffs and Stephen Trolove

8.1 Description

This is a broad scoping study to identify opportunities across New Zealand for markedly improved forage production arising from increased temperatures.

8.2 Changes

1. To align this project to others within the MAF-POL/CPO3 Research-01 portfolio we are using the AR4 scenarios and not the HadCM2 framework as outlined in our proposal. This work is now based on the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4).
2. This report outlines climate change scenarios projected for the period 2040 and 2090, based on the average of output from 12 global climate models (GCMs) statistically downscaled for New Zealand.
3. Of the various options in the Special Report on Emissions Scenarios (SRES), the A1B (Balanced Energy, ‘middle-of-the-road’ emissions) scenario was chosen.

8.3 Methodology

The amount of biomass produced under climate change was predicted using crop models. The Land Use Change and Intensification (LUCI) framework model (developed by Crop & Food Research) was used because this combines several crop models, allowing different crops to be grown in sequence. For this project maize was grown over the summer, since this crop has been shown to be one of the most productive summer crops, and winter wheat was grown over the winter (to simulate a grass crop). A late-maturing maize hybrid (33J24) was chosen for this objective. The model was run over a number of years (32 years for most sites, 11 for Palmerston North and 12 for Gore) of current climate data and then averaged to find the mean yearly yield.

8.4 Experimental design

To identify the effects of climate change on the biomass production of both winter and summer forage crops a matrix of sowing dates by maize hybrid maturity lengths was established. Planting dates were set to the 1st of the month and ranged from September through to November, and four maize hybrids of different maturation lengths were used, as described above. The model was programmed to plant the winter forage crop (either winter wheat or kale) after the maize was harvested for silage (at $^2/_3$ milk line). To determine the effects of climate change throughout New Zealand, a number of sites where forage crops are grown were selected, from Northland to Southland. For the regional effects of climate change, the “intermediate” climate change emissions scenario (A1B) was used, and the projected temperature and rainfall for New Zealand (based on this scenario) was averaged from the output of 12 GCMs. The predicted monthly increase in temperature was added equally to both the maximum and minimum temperature for each day of the month (although some models predict that the increase in the minimum temperature may be greater than the increase in maximum temperature). The predicted change in monthly rainfall was distributed proportionally across the various rainfall events for that month. Thirty-two years (1972–2003) of daily current climate data (11 years for Palmerston North and 12 for Gore) were adjusted with the predicted monthly changes in temperature and rainfall for 2040 and 2090. Monthly averages for the climate data used in the model, and the adjustments for climate change, are given in Appendix I (Tables 19–24).

8.5 Model settings

The maize model used by the LUCI framework was Amaize-N (Li et al. 2006), the wheat model was Sirius (Jamieson et al. 1998), and the kale model is a potential yield model developed by Rob Zyskowski et al. The soils used for growing the forages were some of the better soils in the region, with a high water-holding capacity, so that the potential for maximum forage production in the region could be seen. A summary of the important soil parameters are given in Table 1. The crops were provided with ample fertiliser to ensure that nutrition was not limiting maximum forage production. The amount of fertiliser N applied to maize was 100 kg N/ha at planting, and an additional 200 kg N/ha as a side-dressing, while wheat received 60 kg N/ha at establishment and a side-dressing of 60 kg N/ha. The kale model is simply a potential yield model so assumes no nutritional limitations. No irrigation was used in the model because forage crops are not usually irrigated and this also allows for the effects of changes in rainfall to be seen in crop production.

Two weeks of fallow period per year were allowed in the model for cultivation and sowing of the two crops. The way the model was programmed meant these 2 weeks occurred in spring, whereas in reality 1 week would occur in autumn and 1 week in spring, but it is assumed that there would be little difference in annual biomass production between these two scenarios. This is a relatively short allowance of time for cultivation and sowing, but this project assumes a rapid cultivation period (which is certainly possible) so that maximum biomass can be determined.

Table 1: Soil names for the regions used in the model.

Location and region	Soil
Kaikohe, Northland	Kerikeri silt loam
Hamilton, Waikato	Horotui silt loam
Palmerston North, Manawatu	Kairanga silt loam
Masterton, Wairarapa	Takapau sandy loam
Lincoln, Canterbury	Templeton silt loam
Gore, Southland	Silt loam

8.6 Results and discussion

8.6.1 Maize

Yields of late-maturing maize are greatest with a September sowing (Table 2). Maize yields generally decrease the further south the crop is grown in New Zealand. There is the occasional exception due to local climatic effects, e.g. maize yields are greater in Lincoln than in Masterton due to higher solar radiation (Appendix I, Tables 22 and 23). In general, climate change causes maize yields to decline slightly in the northern regions of New Zealand (from Hamilton north), change little in the central regions, and increase as maize is grown further south, particularly in Gore, where yields will increase by 46% in 2090 compared to possible yields in 1990. There is a surprising exception to the trend with increased yields at more southern plantings, e.g. the 13% increase in maize production in Kaikohe in the 2040 scenario compared with sowing in 1990. This may be because an increase in temperature enables maize to reach maximum leaf area around the longest day (21 December) when planted in September, enabling maximum production, whereas in the current climate scenario maximum leaf area is reached 8 days later. In the 2090 season September-sown maize also reaches maximum leaf area around the longest day, but the warmer temperatures shorten the growing season by approximately 9 days compared with the 2040 season, reducing yield.

8.6.2 Wheat

Wheat yields are greater as the maize crop is sown later in the spring (Table 3). The shorter autumn growing season for the wheat crop is more than compensated for by the longer spring because wheat grows much more rapidly during the spring as it approaches flowering. Yields of wheat grown after long season maize increase throughout New Zealand because the increase in winter temperatures gives more growing degree days for wheat development. Hence wheat will grow leaves faster and catch more light with which to grow biomass. In general, the increase in biomass of winter wheat is 13–19% by 2040, and 17–38% by 2090. This agrees with the 10–15% increase predicted by Jamieson & Cloughley (2001). Disproportionally large percentage increases are observed in Gore. This is because under current climate conditions there were not enough growing degree days for the late maturing maize hybrid to reach maturity over the summer until July, leaving a very short window for growing the wheat. The increase in temperature with climate change considerably shortened the maturity time for maize in Gore, providing a much longer growing window for wheat.

8.6.3 Total annual biomass yields (maize plus wheat)

In general, there is little difference in total annual biomass yields between sowing maize in September or in November (Table 4). Therefore, growers are likely to delay sowing until later in the season to lessen the risk of frost (see Table 18). There are two regions where September sowings were calculated to be superior to other dates: Gore, and Kaikohe in 2040 (Table 5). The increase in production by sowing long season maize hybrids in Gore in September does not occur in practice due to the frost risk (as discussed previously). The 5% increase in total annual biomass production by sowing maize in Kaikohe in September 2040 is an interesting find, and has been discussed previously (maize).

One factor that is not accounted for by examining total annual biomass yields is forage quality. Winter wheat produces stalk in October, which considerably lowers silage quality. Therefore, if the option of September-sown maize produces only marginally less total annual biomass than November-sown maize, then growers may opt for the

September-sown maize, which will give them better quality wheat silage. The flip-side of that option is that it is much harder to harvest silage in September because it requires a period of fine weather to ensure the soil is dry enough to get the machinery over the ground, and the silage requires a short period of wilting before ensiling.

Climate change is predicted to have little effect on total annual biomass yields in Kaikohe, but should increase yields more further south. The disproportionately large increase in yield in Gore as a result of climate change is an artefact of the modelling process because the maize yields remained almost stagnant for 2–3 months while waiting for the final few growing degree days to accumulate before the wheat was sown. In reality a grower would have harvested in May (rather than July) and sown wheat, which would have greatly lifted total biomass yields for Gore under the 1990 climate.

The poor performance of the long season maize hybrid in Gore prompted the question as to whether the very short season maize hybrid plus wheat would produce more annual biomass, so that scenario was modelled and the results are given in Table 5. Use of the short season maize gives much lower maize yields than the long season maize hybrid, but also gives much increased wheat yields due to the longer growing period for wheat. The total annual biomass produced using a short season maize hybrid is only greater than using a long season hybrid in the November sowing under the 1990 climatic conditions, but not with the September or October sowings or in other years. However, a short season hybrid and late sowing is what growers use in practice, since there is too great a risk of frost in Gore to sow a long season maize hybrid in the early spring (see Objective 3, Risk of Frost). Even using a short season hybrid with late sowing, crop failure occurs about every second year (John de Ruiter, pers. comm.). Currently the furthest south maize is regularly grown is Timaru.

Table 2: Maize silage yields (kg DM/ha) for five regions of New Zealand under 1990, 2040 and 2090 climate scenarios when a late maturing maize hybrid is grown followed by winter wheat. The percent change in yield relative to 1990 is also given.

	1990			2040				2090			
	Sep	Oct	Nov	Sep	Oct	Nov	change	Sep	Oct	Nov	change
Kaikohe, Northland	35.4	34.3	31.7	40.1	33.6	30.9	-4.6%*	35.4	31.8	29.6	-4.5%
Hamilton, Waikato	35.7	35.0	32.1	35.5	34.3	31.8	-1.2%	34.3	33.1	30.8	-4.5%
Palmerston North, Manawatu	33.9	33.2	29.8	34.0	33.3	30.7	1.1%	33.8	32.7	30.5	0.1%
Masterton, Wairarapa	33.4	32.7	29.1	33.9	33.2	30.3	2.3%	33.9	33.0	30.6	2.4%
Lincoln, Canterbury	34.1	33.1	28.9	35.0	34.4	31.0	4.5%	35.3	34.8	32.1	6.3%
Gore, Southland	22.0	19.1	14.1	26.1	23.5	18.3	23.0%	29.5	27.8	23.3	46.0%

*September 2040 has been excluded from this figure since it is an exception to the general pattern, see text.

Table 3: Wheat yields (kg DM/ha) for five regions of New Zealand under 1990, 2040 and 2090 climate scenarios when a late maturing maize hybrid is grown followed by winter wheat. The percent change in yield relative to 1990 is also given.

	1990			2040				2090			
	Sep	Oct	Nov	Sep	Oct	Nov	change	Sep	Oct	Nov	change
Kaikohe, Northland	12.2	13.8	16.4	11.1	13.8	18.2	13.2%*	12.2	17.4	20.1	17.2%
Hamilton, Waikato	11.8	13.0	15.4	13.8	15.1	17.3	14.9%	15.0	17.0	19.1	27.1%
Palmerston North, Manawatu	7.2	9.1	12.0	8.9	10.7	13.6	17.3%	10.2	11.8	14.8	30.0%
Masterton, Wairarapa	7.6	9.1	11.8	8.9	10.9	13.6	17.2%	10.5	11.9	15.4	32.6%
Lincoln, Canterbury	4.5	6.3	9.2	5.7	7.5	10.6	19.0%	6.9	8.7	12.0	38.0%
Gore, Southland	1.6	2.4	3.3	3.2	4.5	6.3	91.8%	5.1	6.4	9.0	180.8%

*September 2040 has been excluded from this figure since it is an exception to the general pattern, see text.

Table 4: Total (maize + wheat) annual yields (kg DM/ha) for five regions of New Zealand under 1990, 2040 and 2090 climate scenarios when a late maturing maize hybrid is grown followed by winter wheat. The percent change in yield relative to 1990 is also given.

	1990			2040				2090			
	Sep	Oct	Nov	Sep	Oct	Nov	change	Sep	Oct	Nov	change
Kaikohe, Northland	47.6	48.1	48.1	51.2	47.4	49.1	0.7%*	47.6	49.2	49.7	1.9%
Hamilton, Waikato	47.5	48.0	47.5	49.3	49.4	49.1	3.4%	49.3	50.1	49.1	3.8%
Palmerston North, Manawatu	41.1	42.3	41.8	42.9	44.0	44.3	4.8%	44.0	44.5	45.3	6.9%
Masterton, Wairarapa	41.0	41.8	40.9	42.8	44.1	43.9	5.7%	44.4	44.9	46.0	9.4%
Lincoln, Canterbury	38.6	39.4	38.1	40.7	41.9	41.6	7.0%	42.2	43.5	44.1	11.8%
Gore, Southland	23.6	21.5	17.4	29.3	28.0	24.6	31.0%	34.6	34.2	32.3	61.8%

*September 2040 has been excluded from this figure since it is an exception to the general pattern, see text.

Table 5: Dry matter yields (kg DM/ha) for Gore in the 1990, 2040 and 2090 climate scenarios when a short season maize hybrid is grown followed by winter wheat. Data are average of 10 years.

	1990			2040			2090		
	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov
Maize	12	12.8	11.3	13.7	14.6	13.5	15.5	16.5	15.7
Wheat	4.1	5.3	7.3	6.0	7.0	9.3	8.4	9.1	11.3
Total	16.1	18.1	18.6	19.7	21.6	22.8	23.9	25.6	27

9 Regional case study – Northland maize (Objective 2)

Stephen Trolove

9.1 Description

We explored in detail the potential for tropical and existing New Zealand maize hybrids to be grown alone, in sequence or intercropped with other species in Northland. This illustrates some of the opportunities dealt with in Objective 1, providing a specific “concrete” example to help prompt industry action. Northland was chosen as it is already one of the more consistently warm regions of New Zealand. So, if the results are favourable, Northland offers an early chance for subsequent practical demonstration of the opportunities created by climate change elsewhere. Maize was chosen because it is already an important forage and we have an excellent quantitative model of crop development and growth. We also have a valuable start in a review of intercropping options for maize in New Zealand (Carey et al. 2006).

9.2 Changes

To align this project to others within the MAF-POL/CPO3 Research-01 portfolio, we used the AR4 scenarios and not the HadCM2 framework as outlined in our proposal.

1. This work is now based on the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4)
2. This report outlines climate change scenarios projected for the period 2040 and 2090, based on the average of output from 12 global climate models (GCMs) statistically downscaled for New Zealand
3. Of the various options in the Special Report on Emissions Scenarios (SRES), the A1B (Balanced Energy, ‘middle-of-the-road emissions) scenario was chosen.

9.3 Methodology

The amount of biomass produced under climate change was predicted using crop models. The LUCI framework model (developed by Crop & Food Research) was used because this combines several crop models, allowing different crops to be grown in sequence. For this project, maize was grown over the summer, since this crop has been shown to be one of the most productive summer crops, and two different crops were grown over the winter: wheat (which was used to simulate a grass crop) and kale (as an example of a productive winter brassica). Four different maize hybrids were modelled: a short, medium and late season hybrid, as well as a tropical maize hybrid. Key information about the hybrids is given in Table 6. The short season hybrid produces only 12 leaves and can be considered quite an extreme example of a short season maize hybrid, and similarly the tropical maize hybrid produces 32 leaves and is therefore an example of an extremely long season hybrid. There is little difference in leaf number between the medium and late season hybrids.

There was no actual phenology data (data of thermal time required for different developmental stages of crop growth) for lowland tropical maize. However, the main factor influencing biomass production for maize is the leaf number, for which data was available (Aitken 1977). Therefore, a lowland tropical maize hybrids was created for the model by increasing the number of leaves in a long season maize hybrid from 20 (long season) to 32. Other developmental factors such as thermal time to emergence and phyllochron were assumed to stay the same. This would provide the best estimate for biomass production by tropical lowland maize in New Zealand under climate change.

Table 6: Name and leaf numbers for the maize hybrids used in the modelling.

Hybrid	Name	Number of leaves
Short season	Elita	12
Medium season	N5901	18
Long season	33J24	20.2
Tropical	Perableo	32

9.4 Experimental design

To provide more detail about the effects of climate change on the choice of hybrid and the effect of sowing date, a matrix of sowing dates by maize hybrid maturity lengths was established. Biomass production of two different winter forage crops was also modelled: winter wheat (as an example of a grass crop), and kale (as an example of a productive brassica). The model was programmed to plant the winter forage crop after the maize silage crop was harvested (at $^2/_3$ milkline). Planting were set to the 1st of the month and ranged from September to November, and four maize hybrids of different maturation lengths were used, as described above. The “intermediate” climate change emissions scenario (A1B) was used and the temperature and rainfall data was adjusted as described under Objective 1.

9.5 Model settings

The maize model used by the LUCI framework was Amaize-N (Li et al. 2006), the wheat model was Sirius (Jamieson et al. 1998), and the kale model is a potential yield model developed by Rob Zyskowski et al. The soils used for growing the forages were some of the better soils in the region, with a high water-holding capacity, so that the potential for maximum forage production in the region could be seen. The soil names are given in Table 1. The crops were provided with ample fertiliser to ensure that nutrition was not limiting maximum forage production. The amount of fertiliser N applied to maize was 100 kg N/ha at planting, and an additional 200 kg N/ha as a side dressing. Wheat received 60 kg N/ha at establishment and a side dressing of 60 kg N/ha. The kale model is simply a potential yield model so assumes no nutritional limitations. No irrigation was used in the model because forage crops are not usually irrigated and this also allows for the effects of changes in rainfall to be seen in crop production.

Two weeks of fallow period per year were allowed in the model for cultivation and sowing of the two crops. The way the model was programmed meant that these two weeks occurred in spring whereas in reality one week would occur in autumn and one week in spring. However, it is assumed that there would be little difference in annual biomass production between these two scenarios. This is a relatively short time for cultivation and sowing, but this project assumes a rapid cultivation period (which is certainly possible) so that maximum biomass can be determined.

9.6 Results

9.6.1 Maize

The short season maize produces much less biomass than the other hybrids (Tables 7–9). This is because it only has 12 leaves and a shorter growing period, whereas the other hybrids produce 18• 32 leaves and grow for a longer period. (The amount of thermal time the plant takes to grow a new leaf is constant, regardless of the hybrid, therefore a greater number of leaves increases the growing season of the plant.) The highest maize yields are achieved by the tropical maize, which produces the most leaves (Tables 7–9). However, this extra biomass comes at the expense of production from the winter crop. There is less time for the wheat crop to grow so the highest annual biomass is produced by planting the long season maize hybrid, which produces less biomass but allows more time for biomass production of the winter crop.

9.6.2 Wheat

Wheat is a slightly more productive winter forage crop than kale under the current climate in Kaikohe (Table 7), and also under the predicted climatic conditions in Kaikohe in 2090 (Table 9). Interestingly though, this trend is reversed under the 2040 scenario, where kale in combination with maize becomes the higher producing winter crop (Table 8).

The increased productivity of wheat over kale is greater with November-sown maize than with earlier sowings of maize. A further reason to sow a grass crop (wheat) rather than a forage brassica (kale) in combination with November-sown maize is that there is little demand for forage brassicas in October when the crop would be ready to graze because farmers have plenty of forage at this time of the year. It is extremely difficult to make good quality silage with kale, so this crop is almost always grazed. Therefore, a kale crop has little value in combination with November-sown maize (see gross margins in Objective 3).

9.6.3 Kale

Kale yields increase slightly as maize sowing date becomes later, as the climate warms, and obviously as the kale growing time gets longer when shorter season maize hybrids are sown (Tables 7–9).

9.7 Total annual biomass

Under current weather conditions in Kaikohe the most biomass is produced using a long season maize hybrid sown in either October or early November, and using a grass/cereal crop for winter forage. A greater amount of quality fodder would be produced by the October sowing of maize, which grows more maize and less wheat because the wheat begins to bolt in late October, greatly lowering quality.

Interestingly, as the climate warms in 2040, the model predicts that 13% more biomass can be grown by planting a long season maize hybrid in September in combination with kale (Table 8) compared with the highest producing strategy in 1990 (long season maize + wheat sown in October or November, Table 7). The quality of the wheat silage would also be high since the wheat would not yet have begun to bolt. Practically, however, sowing maize on 1 September in Kaikohe would be near impossible because the soils will be very wet (average rainfall predicted for 2040 in August is 137 mm, Table 19). Such crops would also be difficult to cultivate and sow in these conditions.

Further increases in the temperature by 2090 decrease maize biomass (Table 9). This is because the increase in temperature hastens the development of maize, shortening the time to harvest and therefore giving it less time to capture light. The reduction in maize biomass is not completely compensated for by the resulting longer growing season for wheat. Furthermore, the longer growing season for wheat also means that the quality of the wheat for silage declines because the wheat becomes stalky, and in some cases even begins to produce grain (Table 9). If the wheat develops through to the “cheesy” dough stage (around 90% of grain fill), then a second optimum time to harvest cereals for silage is reached as the starch content of the crop increases.

9.8 Effect of climate change in Northland

As the climate warms, maize yields are predicted to decline in Kaikohe (Northland) because the crop develops faster and so gets fewer days to intercept light. The one exception to this is medium and long season maize sown in September 2040, or short season maize sown in October 2040, because these maize crops will have their maximum leaf area over the period of the longest day so will intercept more light. Wheat yields generally increase in 2040 (Table 10), but show large increases (22–34%) in 2090 (Table 11) due to the warmer winter and also to the longer growing season as a result of the summer maize crop maturing faster. These two factors combine to give increases in total biomass production that are generally less than 10%, apart from the option of sowing long season hybrids in September 2040, when gains of 12–16% may be achieved (Tables 10 and 11). In 2090 the increases in total biomass production are predicted to be less than 6% apart from short season maize, which is not a very productive option.

Predicted changes in rainfall will have less impact on crop growth in Northland than changes in temperature because the changes are predicted to be small over the summer months (Table 19). The changes are larger over winter when rainfall is predicted to decrease. Considering that rainfall is far in excess of crop requirements during winter in Kaikohe, the decrease in rainfall will mean the soils are slightly drier, which will allow farmers to cultivate their soils slightly earlier, and will warm up slightly earlier in spring, which will promote crop growth.

Table 7: Total dry matter production (t DM/ha) for the **current climate** when either short, medium, long or tropical hybrids of maize are grown and harvested for silage (milk line). This is followed by either winter wheat or kale. Crops were sown on 1 September, October or November in Kaikohe. Data are averages of 32 years (10 years for Palmerston North and Gore) weather from 1972 to 2003.

	September				October				November			
	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical
Maize	21.4	33.2	35.4	37.9	20.0	32.5	34.3	35.7	19.4	30.4	31.7	31.6
Wheat	15.1	13.1	12.2	9.9	17.1	14.5	13.8	11.4	19.3	17.0	16.4	14.4
Kale	14.9	12.4	11.7	9.3	15.0	12.7	12.1	10.1	15.9	14.1	13.6	12.0
Maize + wheat	36.5	46.3	47.6	47.8	37.1	47.0	48.1	47.1	38.7	47.4	48.1	46.0
Maize + kale	36.3	45.6	47.1	47.2	35.0	45.2	46.4	45.8	35.3	44.5	45.3	43.6

Table 8: Total dry matter production (t DM/ha) in **2040** when either short, medium, long or tropical hybrids of maize are grown and harvested for silage ($^{2}/_{3}$ milkline). This is followed by either winter wheat or kale. Crops were sown on 1 September, October or November in Kaikohe. Data are averages of 32 years (10 years for Palmerston North and Gore) weather adjusted for the A1B scenario for 2040.

	September				October				November			
	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical
Maize	19.3	37.2	40.1	41.7	22.0	31.7	33.6	34.8	18.9	29.6	30.9	31.5
Wheat	18.0	11.9	11.1	10.5	17.7	16.2	13.8	13.3	19.3	18.8	18.2	16.1
Kale	16.7	14.2	13.6	11.2	16.9	14.6	14.0	11.9	17.8	16.0	15.4	13.7
Maize + wheat	37.3	47.8	51.2	52.2	39.7	47.9	47.4	48.1	40.4	49.2	49.1	47.6
Maize + kale	36.0	51.4	53.7	52.9	38.9	46.3	47.6	46.7	38.7	48.4	49.1	45.2

Table 9: Total dry matter production (t DM/ha) in **2090** when either short, medium, long or tropical hybrids of maize are grown and harvested for silage ($^{2}/_{3}$ milkline). This is followed by either winter wheat or kale. Crops were sown on 1 September, October or November in Kaikohe. Data are averages of 32 years (10 years for Palmerston North and Gore) weather adjusted for the A1B scenario for 2090.

	September				October				November			
	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical
Maize	18.9	31.6	33.3	35.4	19.0	30.4	31.8	33.2	17.9	28.1	29.6	30.5
Wheat	20.2*	16.7	15.7	13.3	21.2*	17.8	17.4	15.1	23.8*	20.7*	20.1*	18.1*
Kale	18.6	16.3	15.7	13.3	18.9	16.8	16.2	14.0	19.9	18.0	17.4	15.7
Maize + wheat	39.1	48.3	49.0	48.7	40.2	48.2	49.2	48.3	41.7	48.8	49.7	48.6
Maize + kale	37.5	47.9	49.0	48.7	37.9	47.2	48.0	47.2	37.8	46.1	47.0	46.2

*This includes some grain yield in the wheat in some years.

Table 10: Change (%) in yields of forage crops grown in Kaikohe in 2040 relative to 1990, as predicted by the A1B climate change scenario.

	September				October				November			
	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical
Maize	-10	12	13	10	10	-2	-2	-3	-3	-3	-3	0
Wheat	19	-9	-9	6	4	12	0	17	0	11	11	12
Kale	12	15	16	20	13	15	16	18	12	13	13	14
Maize + wheat	2	3	8	9	7	2	-1	2	4	4	2	3
Maize + kale	-1	13	14	12	11	2	3	2	10	9	8	4

Table 11: Change (%) in yields of forage crops grown in Kaikohe in 2090 relative to 1990, as predicted by the A1B climate change scenario.

	September				October				November			
	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical
Maize	-12	-5	-6	-7	-5	-6	-7	-7	-8	-8	-7	-3
Wheat	34	27	29	34	24	23	26	32	23	22	23	26
Kale	25	31	34	43	26	32	34	39	25	28	28	31
Maize + wheat	7	4	3	2	8	3	2	3	8	3	3	6
Maize + kale	3	5	4	3	8	4	3	3	7	4	4	6

9.9 Discussion

Little wheat is grown in Northland because it is susceptible to disease, so in reality the graminaceous winter forage crop is likely to be Italian ryegrass (*Lolium mutliflorum*), which is closely related to wheat and will produce a similar biomass yield. Similarly, little kale is grown in the north of New Zealand due to disease risk and insect attack, particularly diamondback moth and white butterfly. The risk of insect attack is greatly increased by water stress. Although the climate gets drier over winter, water stress is unlikely to be a problem in winter-grown kale (Table 19).

10 Recommendations for research (Objective 3)

10.1 Description

Objective 3 involves results from Objectives 1 and 2 being collated, summarised and prioritised to guide the development of policy for climate change adaptation.

10.2 Methodology

We collated the results from Objectives 1 and 2 and discussed them with representatives of industry, the community and science providers. For each major opportunity we identified the likely requirements for new physical, biological and social science, and conduct a cost-benefit-risk analysis. We present a summary of that analysis and recommendations arising from it below.

Gross margins were calculated based on production costs of $2061/ha for maize, $1111.50/ha for wheat and $957.56/ha for kale. Maize was sold standing for 22 c/kg DM. Wheat (grass) harvested in mid September and mid October (October and November scenarios) was assumed to be made into silage, and was sold for 18 c/kg DM. Wheat (grass) cannot be made into silage in Kaikohe in mid August because it is too wet (even in September this can be difficult). Therefore, wheat for the September scenario was assumed to be grazed at $12/cow/week. For the other regions, wheat was assumed to be grazed in both the September and October scenarios, but made into silage in the November scenario. Kale cannot be made into silage so was grazed at a rate of $12/cow/week, except when the maize was sown in November when the rate was reduced to $7/cow/week. This is because demand for feed is low in October when the kale would be ready for grazing, whereas there is more demand for feed in August and September. More details on the gross margins are given in Appendix II.

10.3 Results and discussion

Based on the data generated in Objectives 1 and 2 we have calculated the gross margins for each crop (Tables 12 and 13) and a combination of both maize and wheat (Table 14).

The gross margins are high as they are based on potential yields. In practice growers would attain a slightly lower yield, due to nutritional stress on the plant imposed by the application of economic rates of fertiliser (rather than maximum rates) or to pest and disease pressure. In the 1990 scenario, the returns from maize sown later in the season decrease, but this is compensated for by an increase in returns from wheat. The resulting effect is that the sowing date of maize has little impact on the total (maize + wheat) gross margins under the 1990 climate scenario, although there is a tendency for greater returns with earlier sowing dates, particularly as crops are grown further south (Table 12). At Gore and Lincoln, September sowing looks better on paper but in reality sowing in September is not practical due to the risk of frost (Table 18).

In the 2040 scenario there is a definite advantage in sowing maize in September in Kaikohe (due to the high yields of maize). There is also a slight economic benefit at Hamilton from sowing maize in September. As maize is grown further south the best sowing date for optimum returns moves back to October. Lincoln and Gore show optimum returns from a September sowing, but again the risk of frost is still too great, even with warmer temperatures (Table 18).

The 2090 scenario is similar to the 1990 scenario in that there is little difference in total gross margin between the three sowing dates, although there is a tendency for greater returns with later sowing dates. Again September sowing looks an attractive option for Gore, but the frost risk is still high (Table 18).

From the Kaikohe gross margins (Tables 15–17) it is clear that maize is the most profitable crop to grow due to the higher returns of maize silage rather than grass (wheat silage) per kilogram of DM and especially because of the high yields achieved by maize. Therefore, despite total biomass yields often being higher when maize is sown in November, the higher profitability of the maize crop relative to the winter crops make September sowing the most profitable option. September sowing poses no risk of crop failure due to frost in Kaikohe (see Section 10.4 on Risk of frost).

Wheat is the second most economic crop in the October and November scenarios because it can be made into silage rather than being grazed. In the September scenario, when both winter forage crops needed to be grazed, kale was a more valuable crop than wheat because of lower production costs.

A long season maize hybrid sown in November in combination with wheat was the most productive option for Kaikohe in both 1990 and 2090 (Table 15 and 17). The long season hybrid in combination with wheat was again the most productive combination in 2040. However, the September sowing date gave much greater returns than sowing in November (Table 16). A September sowing date may not be practical, as discussed previously. These returns are highly vulnerable to price changes so by 2090 a different combination may be more profitable. Technology is also likely to change in 80 years. If technology becomes available so that silage can be made from kale the economics will change in favour of kale over wheat. Similarly, if wheat silage can be made in August the gross margins will change in favour of the late maturing and tropical maize hybrids.

Table 12: 1990 regional gross margins for maize silage followed by winter wheat.

	Maize			Wheat			Maize + wheat		
	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov
Kaikohe	5691	5449	4877	562	781	1138	6253	6230	6015
Hamilton	5757	5603	4965	507	671	1001	6264	6274	5965
Palmerston North	5361	5207	4459	-124	137	534	5361*	5343	4993
Masterton	5251	5097	4305	-69	137	507	5251*	5233	4812
Lincoln	5405	5185	4261	-494	-248	150	5405*	5185*	4411
Gore	2743	2105	1005	-892	-782	-659	2743*	2105*	1005*

*Where the gross margin indicated a negative return for wheat, it is assumed that the farmer would leave the field fallow, so the gross margin for maize only is given as the total.

Table 13: 2040 regional gross margins for maize silage followed by winter wheat.

	Maize			Wheat			Maize + wheat		
	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov
Kaikohe	6725	5295	4701	815	1373	2165	7611	6667	6865
Hamilton	5713	5449	4899	781	959	1261	6494	6408	6160
Palmerston North	5383	5229	4657	109	356	754	5492	5585	5411
Masterton	5361	5207	4569	109	383	754	5470	5590	5323
Lincoln	5603	5471	4723	-330	-83	342	5603*	5471*	5065
Gore	3645	3073	1929	-673	-494	-248	3645*	3073*	1929*

*Where the gross margin indicated a negative return for wheat, it is assumed that the farmer would leave the field fallow, so the gross margin for maize only is given as the total.

Table 14: 2090 regional gross margins for maize silage followed by winter wheat.

	Maize			Wheat			Maize + wheat		
	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov
Kaikohe	5691	4899	4415	1085	2021	2507	6775	6919	6921
Hamilton	5449	5185	4679	1589	1949	2327	7037	7133	7005
Palmerston North	5339	5097	4613	725	1013	1553	6063	6109	6165
Masterton	5361	5163	4635	779	1031	1661	6139	6193	6295
Lincoln	5669	5559	4965	131	455	1049	5799	6013	6013
Gore	4393	4019	3029	-194	41	509	4393*	4059	3537

*Where the gross margin indicated a negative return for wheat, it is assumed that the farmer would leave the field fallow, so the gross margin for maize only is given as the total.

Table 15: 1990 gross margins for forage crops in Kaikohe.

	September				October				November			
	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical
Maize	2611	5207	5691	6241	2303	5053	5449	5757	2171	4591	4877	4855
Wheat	959	685	562	246	1967	1499	1373	941	2363	1949	1841	1481
Kale	1086	743	647	318	1100	784	702	428	314	170	130	2
Maize + wheat	3570	5892	6253	6487	4269	6551	6821	6697	4533	6539	6717	6335
Maize + kale	3697	5950	6338	6559	3402	5837	6151	6184	2485	4761	5007	4857

Table 16: 2040 gross margins for forage crops in Kaikohe.

	September				October				November			
	Early	Medium	Late	Tropical	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical
Maize	2149	6087	6901	7077	2743	4877	5295	5559	2061	4415	4701	4833
Wheat	1357	521	411	329	2075	1805	1373	1283	2363	2273	2165	1787
Kale	1333	990	908	578	1360	1045	962	674	466	322	274	138
Maize + wheat	3506	6607	7312	7405	4817	6681	6667	6841	4423	6687	6865	6619
Maize + kale	3482	7077	7808	7655	4103	5922	6257	6233	2527	4737	4975	4971

Table 17: 2090 gross margins for forage crops in Kaikohe.

	September				October				November			
	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical	Short	Medium	Long	Tropical
Maize	2061	4855	5229	5691	2083	4591	4899	5207	1841	4085	4415	4613
Wheat	1659	1179	1042	713	2705	2093	2021	1607	3173	2615	2507	2147
Kale	1593	1278	1196	866	1634	1346	1264	962	634	482	434	298
Maize + wheat	3720	6034	6271	6403	4787	6683	6919	6813	5013	6699	6921	6759
Maize + kale	3654	6133	6424	6557	3717	5937	6163	6169	2475	4567	4849	4911

10.4 Risk of frost

Frost will kill maize leaves and the entire plant if the growing point is above the ground (which occurs when the plant has 6 leaves), and a -2°C frost will kill maize when the growing point is below the ground. The climate change projections we used here (based on the average of output from 12 GCMs run under the A1B emission scenario) show a greatly reduced risk of frost. For this project, we have assumed that climate change increases the maximum and minimum temperature by the same amount. However, some climate models predict that the increase in temperature arises mostly as an increase in the minimum temperature, with little change in the maximum temperature. A proportionally larger increase in minimum temperature would mean that frosts are even less likely than has been assumed in this exercise (Table 18). Frost risk is not an issue for maize in Kaikohe since 32 years of data showed no incidence of frost in spring (Table 18). However, the reduced risk of frost will improve the reliability of maize establishment around Hamilton. Crop modelling (Table 4) showed that under the current climate and the 2090 scenario that the greatest annual biomass production is achieved by sowing in October when there is still a 19% risk of frost. However, by 2090 the A1B scenario suggests no likelihood of frost. Frost risk for Gore greatly reduces, and by 2090 the frost risk in October becomes similar to the current likelihood of frost in Hamilton in October, which will greatly enhance the reliability of maize establishment in Gore.

Table 18: Probability (%) that there will be at least one air frost (air temperature of 0°C or below) during the months of September, October or November in five different regions of New Zealand under current weather conditions and for 2040 and 2090 under the A1B climate change scenario. Data are for 32 years for all sites except Palmerston North (11 years) and Gore (12 years).

	1990			2040			2090		
	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov
Kaikohe	0	0	0	0	0	0	0	0	0
Hamilton	47	19	6	31	0	0	16	0	0
Palmerston North	91	36	0	54	9	0	27	0	0
Masterton	91	63	38	69	47	16	38	6	0
Lincoln	97	59	16	69	44	9	38	16	3
Gore	92	58	33	67	33	17	42	17	0

10.5 Opportunities

10.5.1 Opportunity 1. Maize followed by kale

The highest yielding scenario for 2040 was maize in combination with kale. The feasibility of growing kale in Northland over winter needs to be investigated. Currently, not much kale is grown in Northland due to disease and insect pressure, but during winter the crop should not be attacked by insects so kale may be a good option.

New physical science: methods of producing kale silage may need to be developed to fully take advantage of this option. Methods for producing silage in winter wet conditions would also give some advantage to this option.

New biological science: novel methods of pest and disease control for kale will need to be updated and implemented. Novel cultivars that are resistant to pest and disease would be beneficial.

New social science: Adoption of kale as a crop in Northland will require intensive technology transfer as it is not commonly grown. Technology transfer of management techniques for optimum production will be needed. Individual grower adoption of new methods of growing and managing their system will need to be encouraged.

10.5.2 Opportunity 2. Increased silage yield and quality

The feed value of wheat/grass silage is greatly influenced by the growth stage of the crop at harvest. There are two good times to harvest wheat silage: at boot stage, when protein levels are high, then again at the “cheesy” dough stage (around 90% grain fill) when the grain starch content is high but the crop has not begun to dry off. In between these two stages the metabolisable energy values of the crop decline. There is likely to be some benefit in matching up the right hybrids of maize and wheat (grass) with local climatic conditions to enhance the likelihood of both forage crops yielding good quality silage during the year.

New physical science: methods of producing kale silage may need to be developed to take full advantage of this option. Methods for producing silage in winter wet conditions would also give some advantage to this opportunity. Methods for measuring standing quality to make choices about timing would benefit this opportunity.

New biological science: Novel hybrids with high metabolisable energy values should be developed. Hybrids of maize and wheat that match in terms of timing requirements need to be identified or developed if necessary; management options to optimise the quality of this system need to be developed.

New social science: Technology transfer of management techniques for optimum production will be needed. Individual grower adoption of new methods of growing and managing their system will need to be encouraged.

10.5.3 Opportunity 3. Use of tropical maize hybrids

The high value of maize silage indicates that there may be economic benefits from using long season hybrids of maize that take advantage of the whole growing season. Long season maize hybrids will also have a place in situations with wet winters where it is difficult to get machinery over the ground to plant the winter crop. In these situations it is important to plant a crop that has as long a growing season as possible.

New physical science: Frost protection methods for growing of tropical maize in southern parts of New Zealand need to be developed.

New biological science: Novel hybrids should be developed. The management techniques for the production of tropical maize need to be determined in New Zealand conditions, particularly the effect of sowing rate on quality and lodging. However, a number of long season hybrids have already been developed that are being used in the south-eastern US. It may be worth investigating how these perform in New Zealand, as the climate warms, or getting hybrids from parts of the world that have a similar climate to that predicted in New Zealand in a few years.

New social science: Individual grower adoption of new methods of growing and managing their system will need to be encouraged. Identification of risks of production in southern parts of New Zealand and management of those risks will need to be determined

10.6 Recommendations

1. Investigate the use of plastic mulch for growing early-sown maize.
2. Model the best fit of maize hybrid and grass/cereal cultivar for the optimum amount and quality of forage. In co-ordination with the Foundation for Arable Research (FAR) we will formulate the priorities of this research and co-ordinate that with the New Zealand maize industries.
3. Investigate the use of tropical or late-maturing maize hybrids to take advantage of the predicted extension to the growing season.
4. Investigate the possibility of growing kale in combination with maize in the warmer parts of Northland.
5. This report only considers an average climate change scenario – the A1B model. Additional simulations need to be run that investigate the likely impacts of a more extreme (A1F1) or more conservative (B1) emissions model.
6. Investigations involving predicted changes in plant growth should be expanded to include the likely effects of elevated atmospheric CO_2 concentrations on plant growth.
7. Investigations need to be run to consider the effect of changes in the distribution of rainfall. “A rise up to 2°C; that by itself could be coped with, the much bigger problem is what happens to rainfall” (Howden 2008).
8. The likely effects on weeds, and pest and diseases need to be assessed in more detailed studies.

11 References

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Appendix I Current climate and climate change data

Table 19: Kaikohe. Current climate data are means from 1972 to 2003. Temperature and rainfall adjustments are from the A1B Special Report on Emission Scenario.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum (°C)	22.9	23.3	21.9	19.4	16.8	14.7	13.9	14.0	15.3	16.9	18.8	21.1
Minimum (°C)	14.2	14.6	13.9	12.1	10.4	8.7	7.7	7.8	8.7	9.8	11.3	12.9
Temp. adjustment for 2040 (°C)	1.1	1.1	0.9	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	1.0
Temp. adjustment for 2090 (°C)	2.2	2.4	2.0	2.1	2.0	2.0	2.0	2.0	1.7	1.8	1.9	2.2
Rainfall (mm)	112.9	90.3	110.6	121.1	123.1	163.3	173.2	154.4	147.2	114.3	101.5	103.4
Rainfall adjustment for 2040 (mm)	2.6	2.8	2.5	-0.1	0.1	-5.6	-13.7	-17.8	-12.9	-6.2	-8.9	-0.9
Rainfall adjustment for 2090 (mm)	-2.1	6.2	5.2	-2.2	-3.5	-7.5	-20.1	-25.2	-25.5	-14.0	-9.2	-3.0
Solar radiation (MJ/m^2)	20.9	18.7	15.1	11.3	8.4	6.9	7.6	9.7	13.1	16.5	19.1	20.9

Table 20: Hamilton. Current climate data are means from 1972 to 2003. Temperature and rainfall adjustments are from the A1B Special Report on Emission Scenario.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum (°C)	23.7	24.4	22.8	20.1	16.9	14.3	13.7	14.6	16.2	18.0	19.8	22.0
Minimum (°C)	12.7	13.0	11.6	9.2	6.9	4.8	4.0	4.9	6.7	8.3	10.0	11.8
Temp. adjustment for 2040 (°C)	-1.13	-1.21	-0.90	-1.01	-0.92	-0.91	-0.96	-0.92	-0.80	-0.76	-0.77	-0.91
Temp. adjustment for 2090 (°C)	2.32	2.57	2.07	2.18	2.03	2.12	2.11	2.09	1.71	1.78	1.87	2.12
Rainfall (mm)	87.1	63.8	87.7	88.9	103.4	112.5	127.9	110.9	94.8	90.1	89.8	96.7
Rainfall adjustment for 2040 (mm)	0.31	1.67	1.67	3.07	-0.08	1.14	2.54	2.41	-3.01	-0.91	-1.57	-0.93
Rainfall adjustment for 2090 (mm)	-4.75	0.92	0.28	-1.69	-2.33	1.63	3.92	8.73	-1.84	-5.25	-4.56	-0.10
Solar radiation (MJ/m^2)	21.9	19.4	15.2	11.2	7.5	5.9	6.6	9.1	12.5	16.2	19.8	21.8

Table 21: Palmerston North. Current climate data are means from 1992 to 2002. Temperature and rainfall adjustments are from the A1B Special Report on Emission Scenario.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum (°C)	22.8	23.5	21.3	18.6	15.9	13.4	12.7	13.1	14.9	16.9	17.9	20.8
Minimum (°C)	12.3	12.8	11.0	8.7	7.1	4.9	4.6	4.8	6.6	8.3	9.2	11.5
Temp. adjustment for 2040 (°C)	-1.10	-1.19	-0.88	-1.02	-0.91	-0.92	-1.00	-0.95	-0.81	-0.74	-0.72	-0.85
Temp. adjustment for 2090 (°C)	2.24	2.51	2.05	2.17	2.03	2.15	2.17	2.13	1.72	1.75	1.78	2.02
Rainfall (mm)	56.6	63.8	59.9	74.2	77.3	85.8	83.7	75.7	73.6	84.3	96.1	91.2
Rainfall adjustment for 2040 (mm)	-1.39	-0.11	2.22	3.03	1.17	1.52	5.86	6.63	1.18	2.15	0.62	-0.61
Rainfall adjustment for 2090 (mm)	-3.92	-2.72	0.72	0.06	-0.43	2.80	8.04	13.34	4.10	0.82	-2.08	0.19
Solar radiation (MJ/m^2)	22.0	19.1	14.9	10.2	6.8	5.2	5.9	8.3	11.9	15.3	18.9	20.8

Table 22: Masterton. Current climate data are means from 1972 to 2003. Temperature and rainfall adjustments are from the A1B Special Report on Emission Scenario.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum (°C)	23.6	24.0	21.9	18.8	15.7	13.0	12.1	13.0	15.2	17.3	19.0	21.5
Minimum (°C)	11.0	11.1	9.9	7.4	4.7	3.1	2.7	3.5	5.1	6.6	8.0	10.1
Temp. adjustment for 2040 (°C)	1.04	1.15	0.85	1.03	0.91	0.92	1.00	0.94	0.87	0.77	0.71	0.83
Temp. adjustment for 2090 (°C)	2.14	2.39	1.98	2.14	2.01	2.16	2.17	2.13	1.82	1.79	1.76	1.98
Rainfall (mm)	57.9	57.5	76.5	71.1	87.6	96.8	106.0	89.1	79.2	79.5	77.9	67.2
Rainfall adjustment for 2040 (mm)	1.11	2.04	5.73	1.18	2.22	-4.25	-7.81	-3.23	-4.56	-0.08	0.84	0.01
Rainfall adjustment for 2090 (mm)	0.70	4.30	6.27	1.31	-0.93	-4.36	-9.85	-3.51	-4.63	-3.28	-2.06	0.79
Solar radiation (MJ/m^2)	21.8	19.4	14.3	10.1	6.9	5.3	5.8	8.3	12.2	17.0	19.9	21.5

Table 23: Lincoln. Current climate data are means from 1972 to 2003. Temperature and rainfall adjustments are from the A1B Special Report on Emission Scenario.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum (°C)	22.2	22.0	20.3	17.5	14.3	11.5	10.8	12.1	14.4	16.8	18.5	20.8
Minimum (°C)	11.5	11.4	9.9	6.9	3.8	1.4	1.2	2.3	4.3	6.2	8.0	10.1
Temp. adjustment for 2040 (°C)	0.96	1.08	0.79	1.01	0.91	0.98	1.14	1.07	0.93	0.78	0.66	0.74
Temp. adjustment for 2090 (°C)	1.99	2.27	1.89	2.08	2.01	2.24	2.37	2.35	1.92	1.80	1.68	1.85
Rainfall (mm)	49.4	42.1	51.0	50.7	51.3	60.0	66.4	65.5	44.7	52.3	50.2	51.1
Rainfall adjustment for 2040 (mm)	1.00	2.52	5.83	-0.32	2.15	-2.61	-10.78	-6.05	-3.42	0.09	1.65	0.62
Rainfall adjustment for 2090 (mm)	2.33	4.25	7.44	1.69	-0.11	-4.80	-13.46	-9.59	-2.28	-0.61	0.06	0.91
Solar radiation (MJ/m^2)	22.6	19.6	14.5	9.9	6.2	4.7	5.2	7.8	12.3	17.1	21.1	22.8

Table 24: Gore. Current climate data are means from 1992 to 2003. Temperature and rainfall adjustments are from the A1B Special Report on Emission Scenario.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum (°C)	18.8	19.0	17.1	14.5	12.0	9.1	8.1	9.8	12.4	14.2	15.1	17.8
Minimum (°C)	9.3	9.3	7.6	5.6	4.1	2.2	0.6	2.1	3.8	5.5	6.2	8.3
Temp. adjustment for 2040 (°C)	0.93	1.04	0.75	0.94	0.85	0.93	1.03	0.97	0.77	0.68	0.55	0.66
Temp. adjustment for 2090 (°C)	1.94	2.30	1.82	1.97	1.93	2.12	2.19	2.15	1.64	1.63	1.55	1.71
Rainfall (mm)	95.8	73.6	77.4	69.3	89.0	77.7	60.9	69.1	55.5	80.1	91.4	94.0
Rainfall adjustment for 2040 (mm)	-5.98	2.88	-0.87	2.30	3.62	5.99	7.53	11.93	2.79	5.04	6.10	2.24
Rainfall adjustment for 2090 (mm)	-4.47	-5.55	-1.92	1.71	3.25	8.05	13.38	23.66	12.07	10.62	5.66	4.63
Solar radiation (MJ/m^2)	20.0	17.9	13.5	8.8	5.2	3.9	4.9	7.4	11.5	15.8	19.2	20.9

Appendix II Gross margins for maize, wheat and kale

1. Maize silage

Operation	Quantity		Unit rate		Cost/ha	
Liming	1.25	t/yr	78.00	/t	97.50	
Plough (1)	1.6	hr	65.00	/h	104.00	
Disc & harrow (1)	1	hr	65.00	/h	65.00	
Power harrow (2)	1.5	hr	107.00	/h	160.50	
Level (1)	0.4	hr	65.00	/h	26.00	
Rolling pre and post planting (2)	2	hr	60.00	/h	120.00	
Sowing	1	ha	120.00	/ha	120.00	
Seed	1.375	bags	400.00	/bag	550.00	
Seed treatment	1.375	bags	80.00	/bag	110.00	
FAR levy	11		0.90		9.90	
Fertiliser contract	1	ha	12.00	/ha	12.00	
Fertiliser at sowing (CropMaster 11)	0.2	t	1220.00	/t	244.00	
Fertiliser side-dress (Urea)	0.2	t	960.00	/t	192.00	
Fertiliser side-dressing	1.00	ha	43.00	/ha	43.00	
Cartage (25 km)	0.4	/t	30.00	/t	12.00	
Contract spray	2	ha	37.00	/ha	74.00	
Roustabout	3	l/ha	21.50	/l	64.50	
Dicamba	1.5	l/ha	19.00	/l	28.50	
Atrazine	3	l/ha	6.09	/l	18.27	
Application of Dicamba and Atrazine	1	ha	26.00	/ha	26.00	
Rat bait incl application	1	ha	4.00		4.00	
Slug Out applied at sowing	2	kg	5.63		11.26	
Roundup every 3 years (1/3 = 0.3 ha)	0.33	ha	14.00		4.67	
Total growing costs					2097.10	
Revenue						
Price received ($/t)	1				$220.00	/t

2. Wheat silage

Operation	Quantity		Unit rate		Cost $/ha	
Plough (1)	1.6	hr	65.00	/h	104.00	
Power harrow (2)	2	ha	107.00	/ha	214.00	
Seeding contract	1	ha	84.00	/ha	84.00	
Seed	130	kg	0.91	/kg	118.30	
Fertiliser contract	1	ha	12.00	/ha	12.00	
Fertiliser at sowing (CropMaster 11)	0.2	t	1220.00	/t	244.00	
Fertiliser side-dress (Urea)	0.12	t	960.00	/t	115.20	
Cartage (25 km)	0.4	/t	30.00	/t	12.00	
Fertiliser aplication	1	ha	43.00	/ha	43.00	
Contract spray	2	ha	37.00	/ha	74.00	
Herbicide post-plant (Glean)	20	g	1.15	/g	23.00	
Fungicide (Opus)	1	L	68.00	/L	68.00	
Total growing costs					1111.50	
Revenue						
Price received $/t DM					180.00	/t

3. Grazed wheat

Operation	Quantity		Unit rate		Cost/ha
Plough (1)	1.6	hr	65.00	/h	104.00
Power harrow (2)	2	ha	107.00	/ha	214.00
Seeding contract	1	ha	84.00	/ha	84.00
Seed	130	kg	0.91	/kg	118.30
Fertiliser contract	1	ha	12.00	/ha	12.00
Fertiliser at sowing (CropMaster 11)	0.2	t	1220.00	/t	244.00
Fertiliser side-dress (Urea)	0.12	t	960.00	/t	115.20
Cartage (25 km)	0.4	/t	30.00	/t	12.00
Fertiliser aplication	1	ha	43.00	/ha	43.00
Contract spray	2	ha	37.00	/ha	74.00
Herbicide post-plant (Glean)	20	g	1.15	/g	23.00
Fungicide (Opus)	1	L	68.00	/L	68.00
Total growing costs					1111.50
Revenue calculation					
MJ/cow/day (Nov)	150				
MJ/kg DM in the crop	12				
kg/ha (DM)	1000				
MJ/ha	12000				
cows/ha/day	80				
cows/ha/week	11.4				
grazing fee ($/cow/week) in Sep and Oct	12				
Income ($/ha)	137.14				
Income per tonne of DM in Sept	137.14				

4. Grazed kale

Operation	Quantity		Unit rate		Cost/ha
Plough (1)	1.6	hr	65.00	/h	104.00
Power harrow (2)	2	ha	107.00	/ha	214.00
Seeding contract	1	ha	84.00	/ha	84.00
Seed	4	kg	16.00	/kg	64.00
Fertiliser contract	1	ha	12.00	/ha	12.00
Fertiliser at-sow (CropMaster 11)	0.2	t	1220.00	/t	244.00
Fertiliser side-dress (Urea)	0.12	t	960.00	/t	115.20
Cartage (25 km)	0.4	/t	30.00	/t	12.00
Fertiliser aplication	1	ha	43.00	/ha	43.00
Contract spray	1	ha	31.00	/ha	31.00
Herbicide pre-sow (Trifluralin)	2	L	17.18	/L	34.36
Total growing costs					957.56
Revenue calculation					
MJ/cow/day (Nov)	150				
MJ/kg DM in the crop	12				
kg/ha (DM)	8740				
MJ/ha	104880				
cows/ha/day	699.2				
cows/ha/week	99.9				
grazing fee ($/cow/week) in Sep and Oct	12				
grazing fee ($/cow/week) in Nov	7				
Income ($/ha)	1198.63	699.2			
Income per tonne of DM in Sept and Oct	137.14				
Income per tonne of DM in Nov	80.00				