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Adaptation Strategies for New Zealand Dairy Farms under Climate Change Scenarios

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Abstract: Assessments of climate change for New Zealand indicate not only increasing average temperatures but also more climatic variability with moderate to high likelihood of increases in the frequency of extreme events such as droughts and floods. Detailed Whole Farm Model simulations of climate change impacts and potential adaptation options were undertaken for five representative, pasture based dairy farms located in the major dairying regions of New Zealand. First, tactical changes to current management practices were considered, followed by three strategic adaptations that introduced larger changes into the farming system: a reduction in intensity, the introduction of irrigation and an alternative pasture species. The analysis established that these adaptation options provide both benefits and management challenges across the different regions and climate years were identified. The insights and limitations of this modelling study are discussed in the context of climate change adaptation using New Zealand dairy farms as examples; further research directions are also identified.

***Keywords**: Adaptation; Climate change; Dairy; Impact assessment; Modelling.*

1 INTRODUCTION

The dairy industry is a cornerstone of the New Zealand economy, and has continued to expand in recent years (KPMG 2010). Because New Zealand dairy farms are pasture based, they are lower cost, but may be more vulnerable to climate fluctuations than more intensive systems like most Northern European dairy systems which are based on feeding larger amounts of concentrates (New Zealand Government, 2010). The most recent climate assessment (Renwick et al., 2010) observes that, aside from the large seasonal and interannual variations, there has been a long-term warming trend in New Zealand of 1.1ºC between 1990 and 2009. Climate change is likely to exacerbate existing pressures on both the productivity and environmental sustainability of New Zealand dairy farming systems. Because of its position in the mid-latitude Westerly wind belt, the main climatic influences for New Zealand come from changes in wind flow (Renwick et al., 2010) implying that effects may be quite different in different parts of the country. For example, on

average, it is projected that rainfall in the western parts of the country will increase up to 10% by 2090, and that in the eastern and northern regions rainfall may decrease by over 5% in the same timeframe (Ministry for the Environment 2009).
Previous climate change impact studies relevant to dairy farming have primarily focused on pasture productivity. In general, they have found that, while average changes in pasture productivity may be small, there is likely to be large variability and regional variation in these impacts (Zhang et al., 2007, Clark et al., 2001, Wratt et al., 2008). One modelling study recently applied a whole systems perspective to the potential follow-on effects of these changes in pasture growth in the context of New Zealand dairy farms (Dynes et al., 2010). They compared a specific set of adaptation management strategies (cow numbers, calving date, supplements fed and grazing strategies under a mid-range climate scenario, for a dairy farm in the lower central North Island (Manawatu) and demonstrated that those strategies had the potential to turn a negative climate change impact into a financially positive outcome for the case study farm.
This present study aims to further knowledge on the potential impacts of climate change on New Zealand dairy systems by extending the approach taken by Dynes et al., (2010) to more sites, higher quality climate change scenarios that account for shifts in variability and a farm systems model that allows a wider range of management options to be simulated.

2 METHODS

Five case study farms were selected from major dairying regions in New Zealand: Northland, Waikato, and Taranaki in the North Island, and Canterbury and Southland in the South Island, covering a range of climatic zones with different anticipated responses to climate change. All of the case study farms were commercial farms, and the farmers were identified as respected operators by regional consultants and/or researchers. They also exhibited a range of management approaches (Table 1).

Table 1: Current management practices on the five case study farms

	Northland	Waikato	Taranaki	Canterbury	Southland
General description	Only milking platform is modelled. Large support block is managed as a separate operation	Diverse 300ha operation. Only the dairy component modelled, including some maize.	Coastal Taranaki farm	Milking platform of the "No. 2" farm of a larger operation.	Southland demonstration farm
Area (ha)	Milking platform: 75	Milking platform: 175 Support block: 30	Milking platform: 104 Support block: 53	Milking platform: 141	Milking platform: 166 Support block: 88
Stocking rate	3.7 cows/ha	3.7 cows/ha	3.6 cows/ha	3.8 cows/ha	2.9 cows/ha
Milking	Once a day	Twice a day	Twice a day	Twice a day	Twice a day
Pasture	Ryegrass/ clover	Ryegrass/ clover	Ryegrass/ clover	Ryegrass/ clover	Ryegrass/ clover
Crops and silage	Turnip brassica	Maize, chicory for grazing	Silage made on support block	Not on milking platform	Turnips, swedes, silage made
Irrigation	None	Some effluent	Some effluent	Fully irrigated	Some effluent
N Fertiliser	200kg N/ha	180kg N/ha	200kg N/ha	200kg N/ha	140kg N/ha
Drying off	Based on milk yield, 10th May, earlier if covers low.	On milk yield in May	Based on pasture cover towards the end of May	25 May, earlier if cow condition is low.	based on milk yield, pugging danger during May
Planned start of calving	14 July	7 July	19 July	1 August	9 August
Supplements bought in	Palm kernel, silage as required.	Palm kernel, straw, maize silage.	Palm kernel, maize silage, molasses, hay, silage as required.	Palm kernel, silage as required.	Silage and maize as required

For each of the case study farms, a model farm was created using the DairyNZ Whole Farm Model (WFM) (Beukes et al., 2011) to mimic the management practices and outputs of the real farm as closely as possible. The WFM is an integrated model that includes pasture growth, animal metabolism and economic models. The fact that it is weather-driven and uses flexible decision rules makes it well suited to the analysis of the effects of different management strategies on interactions between climate, management, and cow and pasture production in a farming system (Beukes et al., 2011; Bryant and Snow, 2008). Outputs are provided for pasture growth and animal production on a daily basis, and economic results on an annual basis.

The case study farms were modelled at $1/10^{th}$ of the scale of the real farms, as the effects modelled can be linearly scaled up to a whole farm and all results are presented on a per cow or per hectare basis. Management practices such as drying off, culling, mating, silage making and supplement feeding, as described by the farmers, were calibrated with outputs from the model for the year 2010-2011. Economic input for the 2010-2011 year was used repeatedly for all scenarios and climate years. To ensure the management policies were flexible within the current range of weather, for each farm the culling rules, drying off rules and supplementary feeding rules were set up to be flexible enough to cope with the recent drought years 2007-2008, and 1995-1996, maintaining the farmer's overall strategy (e.g. emphasising supplementary feeding and maintaining stocking rate if the farmer indicated this was a priority). The "model" case study farms were also set up to ensure that there were minimal carryover effects to the next year. For example, culling rules were set to ensure the number of potential milkers remained the same from year to year with no major changes in starting and finishing liveweight.

These model farms were then run under the climate change projections developed for the analysis of New Zealand agricultural systems by the National Institute of Water and Atmospheric Research (NIWA) using the physical Regional Climate Model (PRECIS, RCM) nested in the HadAM3P Global Circulation Model (GCM). Meteorological fields were generated at a $30km^2$ resolution across New Zealand for the IPCC A2 (high carbon) and B1 (low carbon) emissions scenarios to generate the "high" and "low" carbon climate scenarios used in this study out to 2050. The simulations were bias corrected and downscaled, to provide site specific climate fields for WFM simulations (Clark et al., 2012). Although the RCM simulations are generated from a single GCM, they have been compared with the full range of change projected for New Zealand (Mullen et al., 2008) and shown to represent a mid to high end temperature change and cover the broad range of seasonal and locational changes in rainfall.

Each farm was run for two 10 year periods for each climate scenario to form a baseline for the years 1980-2000. This was followed by four 10 year runs for the high and low carbon climate scenarios for the years 2030-2050 to provide an impact assessment.

A two-tailed t-test with heterogeneity of variance was performed for this impact analysis comparing the future impact with the baseline for each climate scenario. Four management adaptations were then tested in turn for the years 2030-2050, and these were compared with the future "no adaptation" impact for each scenario using a paired t-test. The first was a set of tactical adaptations, including making silage on the main milking platform and feeding silage to all cows all year round, in order to effectively smooth any variability in pasture growth. Conservation paddocks were set aside during October-April, and when the farm has a conservation paddock with cover over 4500kgDM, all paddocks over 400kgDM are cut for silage to residual 1500 kgDM. These rules were based on current management practices of the Southland farm. The next three adaptations were more strategic, involving changes to the farming system: 1) The addition of irrigation, based on the current management practices of the Canterbury farm. In addition to limited effluent irrigation already carried out, an irrigation rule was added to irrigate 6mm when soil moisture goes below 75% saturation, between October and April; 2) A change in pasture species to tall fescue. Pasture species was changed to tall fescue for all farms except the Southland farm, as the climate is known to be unsuitable for tall fescue in the lower South Island. In the Canterbury farm, irrigation was also removed for this treatment; and 3) an approximate 15% reduction in stocking rate.

3 RESULTS AND DISCUSSION

The downscaled weather effects of the two climate scenarios (high and low carbon) are highly variable depending on the location of the farms. According to the projections, the climate is expected to warm on average up to one degree in all areas under the low carbon scenario. Average temperature is also projected to increase up to one degree for the Southland, Canterbury and Waikato sites under the high carbon scenario, while the Northland and Taranaki sites are projected to warm between 1-2^{o}C on average. Under the high carbon scenario, precipitation is expected to remain the same for the Southland and Canterbury sites, decrease in the Waikato and increase for Taranaki and Northland. Under the low carbon scenario, it is expected to increase slightly for the South Island sites, decrease slightly for Northland and Taranaki and remain unchanged in the Waikato.

Projected changes in pasture growth from each of the farms are presented in Figure 1. Figure 2 shows the impact of the low and high carbon climate scenarios, followed by the modelled effects of the four management strategies tested on three key indicators for each farm (milksolids production, operating profit and pasture growth).

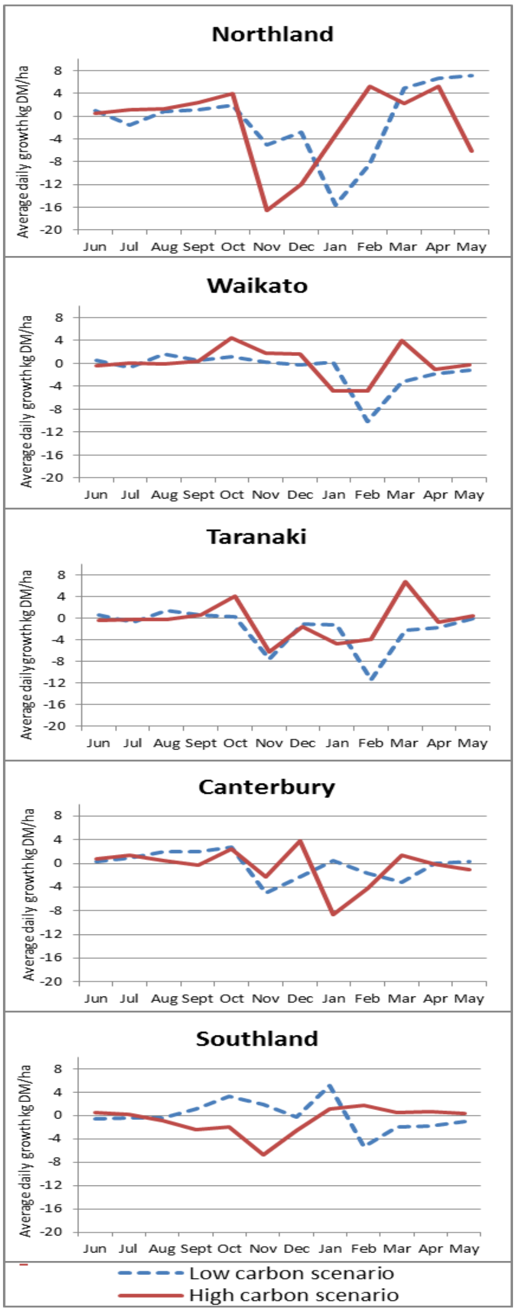


Figure 1: Projected changes in pasture growth rates compared with the 1980-2000 baseline for each climate scenario.

3.1 Impact analysis

While climate change generally had some negative impact on average for all of the five farms, there were clear differences both between farms and between the two scenarios. Under the low carbon scenario, there was a more negative impact for the North Island farms than under the high carbon scenario; additionally, local geography and weather patterns are important in determining these effects. Changes in seasonal variations in pasture growth rates were also more evident for the North Island farms (Figure 1) and these variations appeared to of key influences on changes in operating profit. For example, on the Northland farm in the low carbon scenario, despite lower annual pasture production, pasture growth increases towards the end of the milking season (May) meant that the milking period was effectively extended.

Under current management in the low carbon climate scenario, the feed gap caused by reduced pasture growth in the middle of the season was compensated for by supplement feeding and there was no change in operating profit. In the high carbon scenario, pasture productivity dropped towards the end of the season, so that cows were dried off earlier, less milk was produced and operating profit dropped (Figure 2).

On the Waikato farm, maize silage forms a large component of the existing system. The farm on which the model was based is a much larger operation which includes maize production. This creates a discrepancy with the modelled farm which must "buy in" extra maize silage, increasing costs. Under the low carbon climate scenario, less maize is grown (approximately 1380 kg DM/ha less on average) due to seasonal effects, and this is strongly reflected in the operating profit. In the high carbon scenario, maize production increases by approximately 1310 kg DM/ha, although less pasture is produced. As total supplement feeding is limited on this farm, increased variability in pasture production may have a greater impact. The cows may be more dependent on maize silage fed during January and February when pasture growth drops, and generally cows produce less milk on maize silage compared to pasture.

The Waikato example highlights the importance of maize and other crops in some farming systems and potential changes to growing conditions, which are not linear and might vary considerably depending on the climate change scenario. It suggests the need to ensure appropriate varieties for different sets of conditions are available, a "basket of options" e.g. with different harvesting and sowing dates.

3.2 Tactical adaptations

The tactical adaptations tested consisted of increasing the silage making on the main milking platform and feeding silage to all cows to demand all year. This adaptation strategy had a positive impact on the four farms tested under most scenarios (Figure 2). The tactical adaptations compensated for changes in the seasonal variation and variability in pasture growth and showed clear evidence of net benefits to all the farms, particularly compared with the impact under current management (Figure 2). In most cases, operating profit was equal to or higher than the baseline scenarios. This implies that simple tactical adaptations may effectively mitigate the impacts of climate variability.

A number of issues should be considered in the context of silage making as a tactical adaptation. Silage making involves considerable labour and energy inputs, which need to be taken into account in the context of farm management. Also the use of different silage making technologies and their relative benefits (including how long it lasts), costs (including energy) and workload need to be considered.

3.3 Strategic adaptations

The three strategic adaptations selected reflect different approaches to increasing the capacity of the farming system to cope with climatic changes: 1) Increasing the resources (water) available to the farm system, through irrigation; 2) More efficient use of the resources available through a change in pasture species; and 3) Reducing the pressure on resources available by reducing stocking rates.

3.3.1 Irrigation

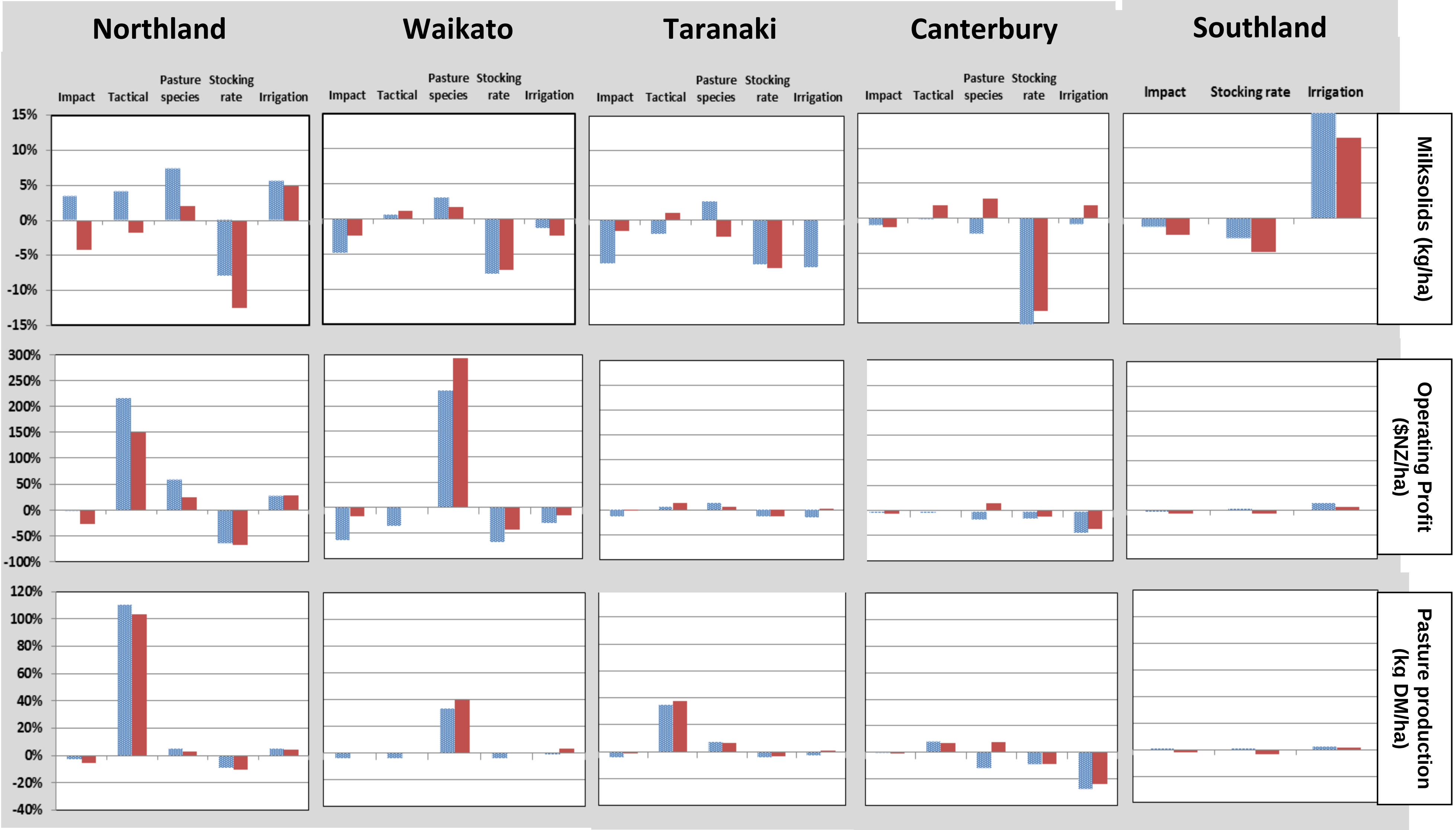
Irrigation showed benefits for all farms tested except the Taranaki farm, and the Waikato farm under the high carbon climate scenario. Removing irrigation on the Canterbury farm had a strongly negative effect. However, it is likely that the model underestimates the effects of irrigation: In setting up the model for the irrigated Canterbury farm, it was possible to irrigate less than half of the amount indicated by the farmer for the 2010-11 calibration year before the model soil became pugged and started producing less pasture. It should also be noted that while operational costs for irrigation are accounted for in this model, capital (setup) costs for irrigation are not included. Consideration of irrigation as an adaptation option clearly also needs to include water availability, which may decrease under climate change scenarios (Clark and Tait, 2008).

3.3.2 Pasture species

A likely southwards spread of subtropical pasture species has been suggested (Clark et al., 2001) and the need to consider more drought tolerant species in the climate change context has been identified (Zhang et al., 2007).

Changing the pasture species to tall fescue resulted in clear benefits for all three North Island farms and in the absence of irrigation, also showed benefits for the Canterbury farm, particularly under the high carbon climate scenario. However, the modelled version of "tall fescue" is based on limited growth data and information on rooting depth and photosynthetic efficiency. The model does not take into account differences in the nutritional quality of ryegrass and tall fescue and requires further

Figure 2: Percentage change in averages for three indicators at the five case study farms between the baseline (1980-2000) and future (2030-2050) for the two climate scenarios: High carbon (red) and low carbon (blue)



development. However, the results are supported by other studies indicating tall fescue's superior tolerance to heat and moisture stress (Minnee 2011).

3.3.3 Reduced stocking rate

The relative profitability and environmental impacts of dairying systems under different system intensities are heavily debated issues, both of which are highly relevant in the climate change context. While Dynes et al., (2010) include increased stocking rates as part of their adaptation package to mitigate the economic effects of climate change, Zhang (2007) suggested adjusting stocking rate to match changes in annual feed supply as a good management practice.

In the present modelling scenarios, stocking rates were reduced by approximately 15% for each farm. This had a negative effect for all three indicators for the North Island farms and Canterbury. In Southland, although milk production dropped, there was little impact on operating profit (Figure 2). Compared with the no adaptation future scenario (paired t-test), profit reductions were not significant for the low carbon scenario on the Taranaki farm, and for neither scenario in the Waikato or Southland. This implies that where there are other incentives to lower stocking rates, such as environmental concerns, this may be possible without significant loss of profit in some cases.

3.4 Limitations of the study

As with all modelling studies, this research was limited by the capacity of the model. Many elements of the farm system may be beyond the scope of the model and yet contribute significantly to improving the system's resilience to climate change, for example changes in soil quality or vegetation on the farm such as trees. Biophysical models do not integrate the inherent complexities of farming systems, such as pests, diseases, animal health effects, or the capacity of the farmer to cope with adversity (Newton et al., 2008). The outputs of this study should, therefore, be seen as a starting point for further research and consultation with farmers rather than as a prediction of the future.

Modelling studies generally tend to underestimate variability (Fowler et al., 2007) and this is an area which requires further attention, as climatic variability may be more important to farmers than changes in average temperature and precipitation.

As noted in the methods section, the two climate scenarios used in this study are driven by a single Global Circulation Model. In addition, the potentially positive effects of changes in atmospheric carbon dioxide on pasture growth rates were not included in this study; and no consideration was given to trade-offs with and implications for environmental concerns such as nitrogen use efficiency, the risk of nitrogen leaching or greenhouse gas mitigation.

Finally, climate change is only one of a number of increasing pressures on dairying systems in New Zealand (Clark et al., 2007). Any analysis of potential climate change adaptations needs to be seen in the context of this broader perspective, which can include, for example, increasing energy and fertilizer costs as well as environmental considerations.

4 CONCLUSIONS AND PERSPECTIVES

The impact analysis showed a negative effect of climate change on the model farms without adaptation, particularly in the North Island. This supports previous research (e.g. Zhang et al., 2007, Clark et al., 2001, Wratt et al., 2008) indicating that climatic change is an important variable to consider in developing management strategies for more productive and sustainable dairy systems in the future.

Some of the adaptations tested were able to compensate for the effect of climate change, and to improve productivity and income. This is consistent with the work of Dynes et al. (2010) showing that positive outcomes can be achieved under climate change scenarios using management strategies that are already well known and readily available to farmers. However some adaptation options, such as reducing stocking rates, showed negative effects on farm productivity and profitability under a future climate. This highlights the need for caution for potential unintended negative consequences of positively motivated adaptations. More in-depth consideration is also required of the effects of different stocking rates under climate change scenarios.

There is considerable diversity in current management practices, reflecting both the local climate and resources available, and personal management choices of the farmers. The impacts and effects of each adaptation option depended on the local climate and current management practices, highlighting the need to assess farms individually.

Pasture production is the driving force in the New Zealand dairy system, resulting in small differences in pasture productivity reflecting proportionally larger differences in profit. Further investigative studies are needed on the potential advantage of tall fescue and other deep-rooting and drought resistant pasture species, including improved calibration of the WFM for such species. Further calibration work is also required for the representation of irrigation effects. Cropping options for dairy farms in the climate change context, for example crops available with different sowing and harvesting dates, may also offer advantages.

Modelling studies can be useful to ‘pre-test’ adaptation strategies and form the basis for future research. They can also contribute to awareness raising and sharing information on adaptation options. However, it is important to consider these studies as one tool for the analysis of adaptation strategies together with farmers, as part of a broader systems analysis including elements which may be beyond the scope of the model.

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