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Modelling farm-level adaptation of temperate, pasture-based dairy farms to climate change

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ABSTRACT

Projections indicate that climate change may exacerbate existing challenges to the productivity of New Zealand dairy farming systems. To assess the importance of these projections and understand adaptation challenges at farm level, detailed farm-scale model simulations of climate change impacts were undertaken for six representative pasture-based dairy farms located in the major dairying regions of New Zealand. The analysis suggested that without adaptation, climate change is likely to have a negative impact in most of the study locations. However, the level and type of impact depends to a large degree on regional climate variability as well as on the management practices of each farm. Under current management, responses to projected climate changes ranged from no change to an 18% decrease in average annual pasture production. A number of modelled adaptations demonstrated the potential to reduce climate change impacts under current management. The modelling work, together with farmers' responses, showed the adaptations' potential to provide both benefits and management challenges across different regions and climate conditions. In particular, it highlighted the need for the results of farm systems modelling under climate change scenarios to be considered in the context of their specific and localised climatic and management challenges.

1. Introduction

Climate is a defining feature of any agricultural production system, and in New Zealand, as in the rest of the world, the impacts of climate change are already becoming apparent in the form of rising average temperatures, and increased recurrence and intensity of extreme climate events (Clark and Tait, 2008; Harrison et al., 2016; Porteous and Mullan, 2013; Reisinger et al., 2014). The dairy industry is a cornerstone of the New Zealand economy, and has expanded steadily over the past 50 years (Clark et al., 2012; DairyNZ, 2014; KPMG, 2010; MPI, 2014, DairyNZ, 2016). New Zealand dairy farms run at lower input costs than, for example their European and North American counterparts, because they are pasture based (Hanson et al. 1998). However, they may be more vulnerable to climate fluctuations than northern hemisphere systems that rely on larger amounts of imported feed (Clark et al., 2012).

There has been a long-term warming trend in New Zealand of 1.1 °C between 1900 and 2009 (Renwick et al., 2010). Projections indicate that future climate change may extend beyond the present range of farmers' experience (Clark et al., 2012; Reisinger et al., 2014), bringing changes in weather patterns that exacerbate existing pressures on the productivity and resilience of New Zealand dairy farming systems such as volatility in milk price, high debt levels (DairyNZ, 2014) and pressure to improve environmental performance (Jay, 2007). However, such change will not be uniform. Its position in the mid-latitude westerly wind belt means that the main climatic influences for New Zealand come from changes in wind flow (Renwick et al., 2010), and New Zealand's rugged and mountainous terrain gives rise to considerable regional and localised climate variability (Clark et al., 2012).

Studies on potential climate change impacts on dairy farms in New Zealand and temperate areas of Australia have focused primarily on changes in pasture productivity, because farm profit in pasture-based dairy systems is closely related to the amount of dry matter consumed per hectare per year (Chapman et al., 2009). Changes in pasture growth and quality will be affected by complex interactions between factors such as changes in temperature, sunlight hours, water availability and atmospheric CO_2 (Lee et al., 2013, Roche et al., 2009). While annual changes in pasture productivity are often small under climate change scenarios, there may be large variability and regional variation (Clark et al., 2001; Cullen and Eckard, 2011; Phelan et al., 2014; Wratt et al.,

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2008; Zhang et al., 2007). Studies modelling seasonal changes have shown greater sensitivity to climate change impacts than those using annual production as a measure (Reisinger et al., 2014).

While pasture growth is arguably the most influential driver of profit in pasture-based dairy farms, in practice these farms are complex ecosystems (Bryant and Snow, 2008) with biophysical, management and financial components.

Over the past decade, improvements in farm systems models have meant that many of the complex interactions between biophysical and management systems can be simulated with some confidence. Examples of such studies in the climate change context include the work of Fitzgerald et al. (2009) on Irish dairy farms, and Dynes et al. (2010) in New Zealand. Fitzgerald et al. (2009) carried out an integrated, whole farm study using the "Dairy_sim" model, based on a scenario of future dairying systems that would produce the greatest output of milk on a particular land area. They suggested that Irish dairy production should be able to readily adapt and remain viable under projected climate change scenarios (Fitzgerald et al., 2009). In New Zealand, Dynes et al. (2010) applied a whole-of-systems perspective to the potential flow-on effects of climate-driven changes in pasture growth. In this study, a separate model was used to simulate pasture growth response (EcoMod), which then fed into a farming systems model (Farmax Dairy Pro). The study compared a specific set of adaptation management strategies (cow numbers, calving date, supplementary feeding and grazing strategies) under a mid-range climate scenario for a dairy farm in the lower central North Island (Manawatu). These strategies had the potential to turn a negative climate change impact into a financially positive outcome for the modelled farm.

Whole farm models are highly complex and detailed input is required for setting up farm scenarios. Consequently, previous studies have focussed on technically feasible but idealised modelled farms (Dynes et al., 2010; Fitzgerald et al., 2009) or paddock-scale modelling (Cullen et al., 2009). Models at larger scales tend to utilise more empirical approaches and often include assumptions that may not be valid under climate change conditions at farm scale (Kipling et al., 2016). Most of these studies have focussed on climatic averages. However, in practice, climatic variability and extreme events may be more important to farmers than changes in average temperature and precipitation (Harrison et al., 2016; Reisinger et al., 2014).

Farms are complex socio-economic systems (Bryant and Snow, 2008) and analysis of climate change adaptation options can best be approached at farm level, where the combined effects of these changes will be felt and must be addressed (Newton et al., 2008). While a number of studies have analysed potential impacts of climate change on New Zealand dairy farms (e.g. Baisden et al., 2010; Dynes et al., 2010; Warrick et al., 2001; Wratt et al., 2008), none of these have analysed actual working farms. In setting up modelled farms that mimic actual farming systems, the present study aims to enable a more realistic analysis of the potential for particular adaptations. By engaging farmers in discussion around the adaptation options in relation to their own farms, it aims to provide a more in-depth understanding of the practical implications of different management adaptations.

For farmers, adaptation to climate change is part of a continuous, iterative process of adapting to a number of changing pressures that affect farm management (Stokes and Howden, 2010, Reidsma et al. 2010). Understanding how climate change will impact farming practice, and which adaptation options show the most promise for farmers, requires an understanding of different environments and management strategies.

This study is part of a broader integrated analysis based on the framework articulated in Kalaugher et al. (2013). It assessed the potential localised impacts of climate change on temperate dairy systems by modelling six dairy farms from different regions using a detailed farm systems model. Following the impact assessment, the effects of changes to current management practices were examined with farms exposed to different climate change scenarios.

2. Methods

2.1. The whole farm model

For this analysis, a detailed farm systems model was required that allowed a broader suite of management practices to be examined than has been attempted previously. The DairyNZ whole farm model (WFM) was used as it allows the representation of a large range of New Zealand farm system configurations and management options. In addition, its flexible decision rules allow an analysis of the effects of different management strategies on interactions and feedbacks between climate, management, and cow and pasture production in a farming system (Beukes et al., 2011; Bryant and Snow, 2008).

The WFM provides outputs for pasture growth and animal production on a daily basis, and economic results on an annual basis. Daily weather inputs also allow for fine-scale simulation of climate effects. It is a continuously developing model that is used for a range of analyses of different farming systems (Beukes et al., 2005, 2010a, 2010b, 2011; Romera et al., 2009), and has been previously evaluated and reviewed (Beukes et al., 2008; Bryant and Snow, 2008). It is based on three fully integrated modules: a mechanistic model of cow metabolism (Molly, see Baldwin, 1995); a weather-driven pasture module (McCall, see Romera et al., 2009), and a management/economic module (Beukes et al., 2005). New components are added as and when there is a defined need and sufficient supporting data. For example, some of the crop growth parameters defined in this version of the model (5.0.r) are weather-driven, such as in the maize model that was provided by Plant and Food Research (described in Li et al., 2009). For other crops, such as chicory, the capacity of the model is still limited, and crop yields must be defined by the user.

One limitation of the WFM is that it does not simulate the effects of carbon dioxide (CO_2) fertilisation. This means that a modelling analysis that specifically includes CO_2 effects, such as those carried out by Cullen et al. (2009), Cullen and Eckard, (2011) and Phelan et al. (2014), was not possible in this study. In a review of published research, Lee et al. (2013) estimated that when climate and nutrients are non-limiting, CO_2 fertilisation may lead to a positive growth response between 4% and 14% in ryegrass-clover based swards that dominate New Zealand's dairy production systems. Li et al. (2014) suggested a strongly seasonal pattern in this response, with the highest increases in growth rate occurring in spring.

The modelling of plant responses to elevated CO_2 under variable environmental and management conditions is a major source of uncertainty in our understanding of how global change processes may be manifested at farm level (Li et al., 2014; Rötter et al., 2011; Soussana et al., 2010). Because of the challenges inherent in capturing the likely impacts of elevated CO_2 on ecosystem processes, some studies have omitted these impacts (e.g. Wratt et al., 2008; Zhang et al., 2007), while others have applied blanket fertility increases to their data (e.g. Fitzgerald et al., 2009; Baisden et al., 2010). The recent study by Li et al. (2014), the only study to date to compare responses from Free-Air CO_2 Enrichment (FACE) experiments with modelled data in New Zealand pastures, highlighted the potential for models, in this case AgPasture, to overestimate these effects due to poor representation of years with small or negative responses to CO_2 (Li et al., 2014).

The WFM provides an option for the pasture module to replicate CO_2 fertilisation by adjusting the fertility response curve. However, this would not adequately capture the known interactions between nitrogen and soil moisture status and the strength of CO_2 response at a seasonal time scale (see Lee et al. 2013). For this reason a fertility adjustment was not applied.

2.2. Case study farms

Case study farms were selected from six major dairying regions in New Zealand: Northland, Waikato, Bay of Plenty (BOP) and Taranaki