# **Chapter 3.** Dairy

*Adapting dairy farming systems in a changing climatic environment*


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# Abstract

Climate change is an emerging concern for the dairy sector given the direct exposure of grass-based systems, indirect exposure through feed costs and gearing of the dairy enterprise. While the impacts of climate change on pasture growth have been well studied in New Zealand, there is a narrower knowledge base around broader impacts and what profitable adaptations can be pursued. To identify viable adaptations, multiple climate stressors and their interaction with the dairy system should be considered in a whole farm approach.

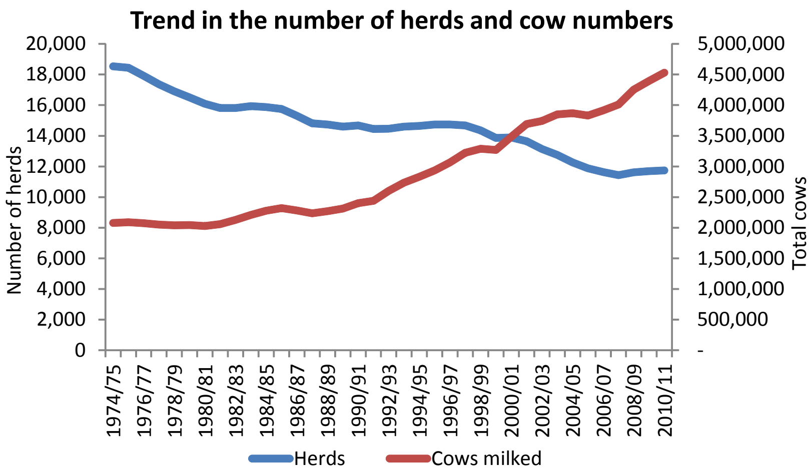
This chapter reviews available science and professional knowledge, as well as whole farm systems modelling under climate change scenarios. This approach to whole farm analysis identified a broad range of impacts, which, on the whole, point to both opportunities and challenges for the sector. It identified a degree of resilience and flexibility in the modern dairy system and a number of tactical, strategic, and transformational adaptation options. Focussing on the well quantified impacts on pasture productivity, there are opportunities to avoid losses or even improve operating position using well known tactical adaptations. There is also a need to remain vigilant to indirect impacts, or cumulative effects that cannot be readily quantified due to the complexity of dairy systems. Some of these like infrastructure, pest, and weed management as well as water resource management are described in Chapters 8 and 9.

# Contents

# 1 Introduction

The dairy sector is an important contributor to the New Zealand economy, earning NZ$12.1 billion in export income during the 2010–11 financial year, some 2.8 per cent of national GDP. The sector has undergone considerable change over the last 30 years, expanding in response to steady growth in the global demand for milk products (Kashtanova 2010). There have also been continued rises in input costs and structural changes like price deregulation. The sector has proven to be adaptable and resilient, with the dairy farming system evolving continually. Farmers have readily adjusted their economies of scale by increasing herd size and improving production efficiencies (Figure 3.1). The sector has been concentrated in some key North Island districts, but in recent years has expanded into the central North Island and lower South Island (KPMG 2010).

New Zealand's climatic environment is ideal for lower-input grass-based dairy systems, given reliable rainfall and temperate seasons. However, grass-based systems are also more vulnerable to climate fluctuations than those which use of imported feed. The high gearing of the modern dairy systems exacerbates this vulnerability, with increasing exposure to risk of events like drought and extreme weather to the farm business. Given this, the prospect of climate change and its associated impacts are an emerging concern for the sector. While an understanding of the general pasture impacts of climate change has been developed over recent years, there has been little specific assessment of the dairy system. At present there is a relatively narrow knowledge base concerning climate adaptations for the sector; and in particular, a limited understanding of what profitable actions can be taken to reduce climate exposure.



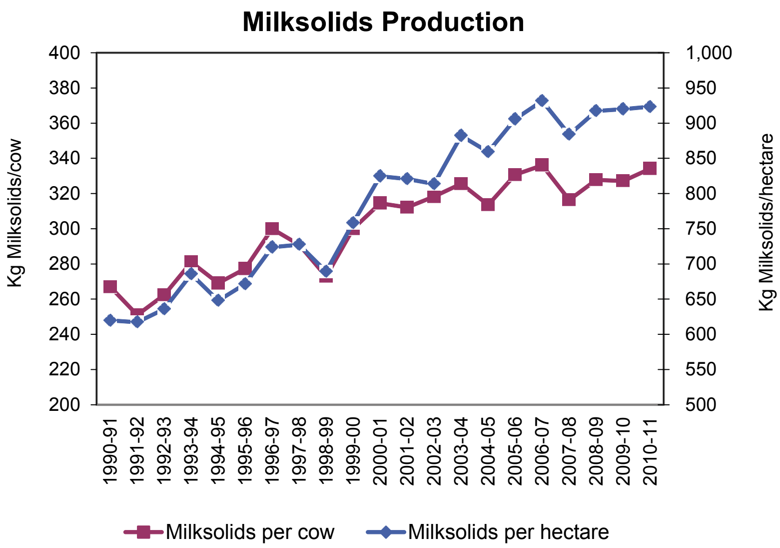




**Figure 3.1.** Trends in herd size (numbers of herds and numbers of cows) since 1980 (top) and trends in productivity (kg milk solids/cow and kg milk solids/ ha) since 1990 (bottom) in the New Zealand Dairy sector. Source New Zealand Dairy Statistics 2010 and LIC Dairy Statistics 2010.

This chapter is the first targeted review of climate change adaptation for the dairy sector. The objective is to improve the overall breadth and detail of understanding available, starting with an assessment of available information on climate impacts for pastures (Section 2.1) and the dairy cow (Section 2.2). This is followed by a targeted modelling study (Section 3) which takes a holistic approach to dairy system analysis, providing a quantified illustration of a sub-set of impacts and potential adaptations. This supports the identification of a broader set of adaptation options covering tactical, strategic and some transformational changes. The combination of review and modelling documents a wide range of adaptation options for the dairy system, identifying which appear to capture production benefits, and where knowledge gaps remain.

# 2 Impacts of climate change

## *2.1 Pasture in a changing climate*

In New Zealand 1.9 million hectares (ha) of land were used for dairy farming in 2007, with approximately 90% of that land sown in pasture species for grazing and 2% used to grow grain and seed crops for the dairy industry (Statistics New Zealand 2007). The main pasture and crop species are used by the New Zealand dairy industry are outlined in Table 3.1.

**Table 3.1.** Main pasture and crop species used by the New Zealand dairy industry (Charlton & Stewart 2000).

| ***Purpose*** | ***Type*** | ***$C_3$/$C_4$ species*** | ***Common name*** | ***Latin name*** |
|---|---|---|---|---|
| Pasture | Grass | $C_3$ | Perennial ryegrass | *Lolium perenne* L. |
| Pasture | Grass | $C_3$ | Italian ryegrass | *Lolium multiflorum* Lam. |
| Pasture | Grass | $C_3$ | Tall fescue | *Festuca arundinacea* Schreb. |
| Pasture | Grass | $C_3$ | Cocksfoot | *Dactylis glomerata* L. |
| Pasture | Grass | $C_3$ | Brome grasses | Bromus spp. |
| Pasture | Grass | $C_3$ | Timothy | *Phleum pratense* L. |
| Pasture | Grass | $C_3$ | Phalaris | *Phalaris aquatica* L. |
| Pasture | Grass | $C_4$ | Paspalum | *Paspalum dilatatum* |
| Pasture | Grass | $C_4$ | Kikuyu | *Pennisetum clandestinum* |
| Pasture | Legume | $C_3$ | White clover | *Trifolium repens* L. |
| Pasture | Legume | $C_3$ | Red clover | *Trifolium pratense* L. |
| Pasture | Legume | $C_3$ | Subterranean clover | *Trifolium subterraneum* L. |
| Pasture/crop | Legume | $C_3$ | Lucerne | *Medicago sativa* L. |
| Pasture | Herb | $C_3$ | Chicory | *Cichorium intybus* L. |
| Pasture | Herb | $C_3$ | Plantain | *Plantago lanceolata* L. |
| Crop | Cereal | $C_4$ | Maize | *Zea mays* L. |

There are a broad range of potential impact pathways for dairy pastures, and these are summarised in Table 3.2. This provides a linkage to some key climate drivers and range of future scenarios taken from Chapter 2 (Table 2.4). These are divided into direct impacts, where there are relatively straightforward linkages between climate and responses, and indirect impacts which are feedbacks in whole dairy or ecosystem system functions.

**Table 3.2.** Climate change impact knowledge summary for New Zealand dairy pastures (a) Direct impacts/ (b) Indirect impacts.

| ***Driver*** | ***Impacts*** | ***New Zealand*** | ***International*** |
|---|---|---|---|
| ***(a) Direct impacts*** | | | |
| Higher seasonal temperature | Changes to photosynthesis | Well established responses | Well established responses |
| | Changes to herbage yield | Well established responses | Well established responses |
| | Changes to gene expression/ possibility of some plants to adapt to increased temperature | No local studies | Emerging understanding |
| Changes to water availability | Changes to photosynthesis | Well established responses | Well established responses |
| | Differences between C3 (e.g., ryegrass/clover) and C4 (e.g., maize, kikuyu) species | | |
| | Changes to herbage yield<br>Both increases and decreases possible depending upon locality | Well established responses | Well established responses |
| | Changes to gene expression | Studies have been conducted but little published information available yet | International literature emerging |
| Increased extreme weather events leading to waterlogging and flooding | Reduced photosynthesis | Well established responses | Well established responses |
| | Reduced herbage growth | Well established responses | Well established responses |
| Increased carbon dioxide concentrations | Changes to photosynthesis and respiration | Well established responses | Well established responses |
| | Increased herbage yield | Well established responses | Well established responses |
| | Gene expression and evolutionary response of pastures | No New Zealand studies | Emerging knowledge based on 'model plants' |
| ***(b) Indirect impacts and system responses*** | | | |
| Interactions with increased carbon dioxide | Under temperature increase and rainfall limitations | New Zealand research available | Principles well established internationally |
| | Increased growth variability | | |
| | Nitrogen - increased demand from N pool to maintain or improve yield and quality | New Zealand research highlighting effects | Emerging knowledge |
| Botanical composition | Changes to C3:C4 mix<br>More favourable C4 environment to the north, e.g., increasing range of kikuyu | New Zealand studies highlighting potential under 1-4 degree average temperature shifts | Principles well established from field experiments |
| | Increased legume content | New Zealand studies available | Few models of sward competition for grazing systems |
| | Increased weed content | Few New Zealand studies completed | |
| Forage quality | Increased water-soluble carbohydrates<br>Decreased crude protein | Potential to push grass-based nutrition toward a more optimal balance<br>Uncertainty about timing, thresholds and seasonal effects | Principles well established internationally |
| Pests and diseases | Increased population turnover and vigour | Few studies done on main dairy pasture pests | Principles well established in research and field tests |
| | Expansion of geographic range | Few studies done on main dairy pasture pests | Principles well established in research and field tests |

Table 3.2 also provides information on the sources of knowledge (New Zealand or International), as well as some summary statements evaluating the depth of knowledge. A more in-depth summary of the scientific evidence that underpins Table 3.2 is provided in Sections 2.1.1–2.1.7.

### *2.1.1 Temperature*

#### *2.1.1.1 Photosynthesis*

In $C_3$ grass swards, rates of photosynthesis generally increase as temperatures rise from 5°C to 25°C (Charles-Edwards et al. 1971; Woledge & Parsons 1986). The photosynthetic enzyme ribulose 1, 5-bisphosphate carboxylase/oxygenase (Rubisco) catalyses both carboxylation and oxygenation reactions, which lead to photosynthesis and photorespiration, respectively. Increased temperatures favour oxygenation by decreasing the solubility of $CO_2$ and the specificity of Rubisco for $CO_2$ (Jordan & Ogren 1984), explaining why photosynthetic rates decline as temperatures rise above the optimum until, eventually, near the extreme end of the functional range, injury occurs and rates of photosynthesis are irrevocably affected (Sage & Kubien 2007). In comparison with $C_3$ plants, photosynthetic pathways in $C_4$ plants are better adapted to higher temperatures, for example, rates of photosynthesis in maize increase as temperatures rise up to 30°C (Labate et al. 1990).

In the model plant[1] Arabidopsis (***Arabidopsis thaliana*** L.), rubisco activase, an enzyme which activates Rubisco, was recently identified as one of the major limitations to photosynthesis under moderately high temperatures (>26°C; Kurek et al. 2007). Further research is required to determine whether this is the case in other plant species important to the dairy industry; and, if so, whether it is a potential target for conventional breeding or genetic manipulation to improve plant productivity under high temperatures.

#### *2.1.1.2 Herbage yield*

Plant species have different critical temperature ranges for growth and development, similar to those for rates of photosynthesis. The optimum temperature range for growth of cool temperate $C_3$ species is generally between 20°C and 25°C (Mitchell 1956; Davidson 1969; McKenzie et al. 2000), with minimal growth occurring below 8°C (or 5°C following vernalisation; Brereton et al. 1985). Optimal temperature ranges for warm temperate $C_3$ species (e.g., cocksfoot and phalaris) are slightly greater (20°C to 28°C; Davidson 1969); while $C_4$ plants (e.g., paspalum, kikuyu and maize) are well-suited to temperatures between 29°C and 35°C (Mitchell 1956; Fitzpatrick & Nix 1970; Kiniry & Bonhomme 1991).

As temperatures rise above the optimal range, reductions in plant growth are manifested through factors such as reduced leaf size, reduced tiller emergence, reduced root initiation, and partial death of the root system (Stuckey 1941; Mitchell 1956; Davies 1974; Langer 1979; Berry & Bjorkman 1980; Crafts-Brandner & Salvucci 2000). The temperature growth responses for some of the major species grown in New Zealand are shown in Figure 3.2. The response of the sub-tropical grass ***Brothriocloa*** is included, highlighting potential for the active response of grass species in warmer environments.

Over the next century, as long as temperatures remain lower than the upper threshold of the optimal range for each plant species, increased temperatures alone are unlikely to substantially reduce plant growth. In fact, during winter, increased temperatures are likely to result in greater plant growth as temperatures move closer to the optimal range and there is reduced frost-damage. These effects are well captured in primary production simulation models which are discussed in Section 3.

[1]The 'model plant' is used in research as it represents a broad range of functional responses and has been studied intensively. Results and knowledge based on the model plant can be extended to other species such as productive pasture. *Arabidopsis* was one of the first plants to have its entire genome sequenced.

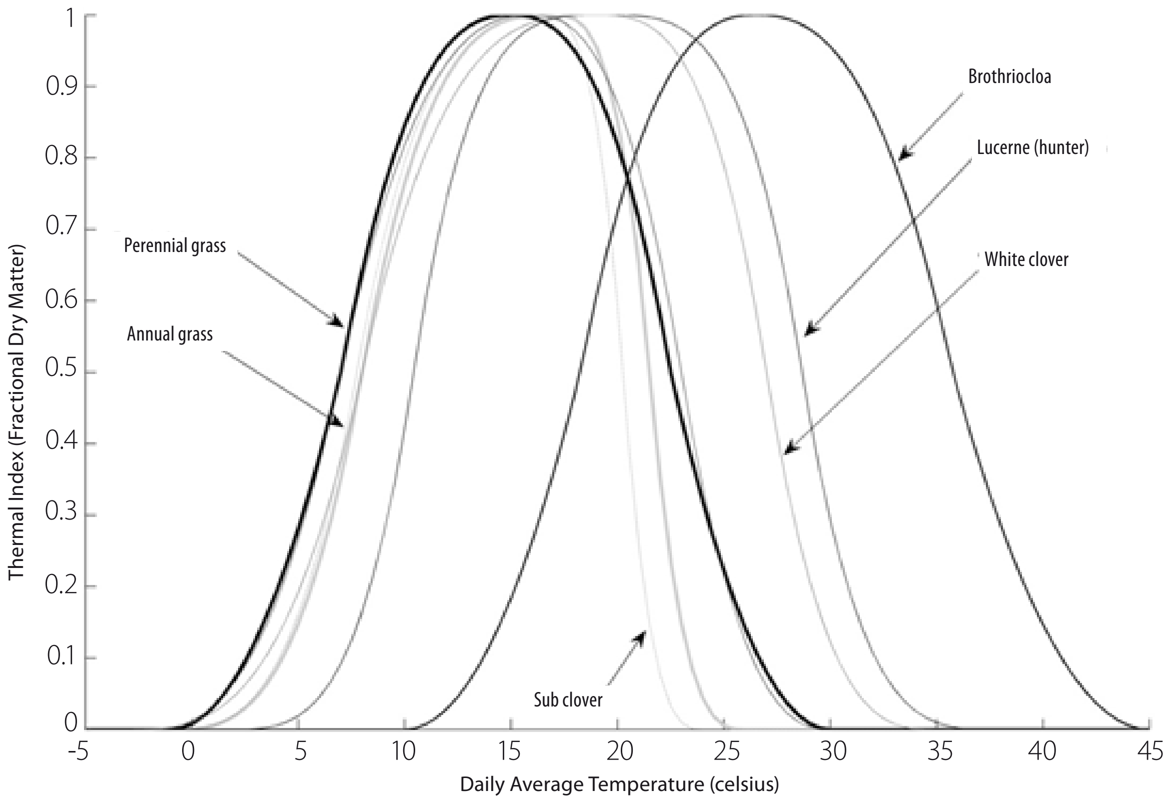



**Figure 3.2.** Fractional dry matter response of major pasture species grown in New Zealand, as well as of ***Brothriocloa***, a subtropical grass. Source: Adapted from Fitzpatrick & Nix 1980).

#### *2.1.1.3 Gene expression*

Emerging research shows that it is possible for plants to undergo biological adaptations that could reduce the impact of climate stress. Growth and development patterns, as well as molecular processes, may be altered under climate stresses like warmer temperatures. Knowledge of exactly how molecular processes are affected by climate stress is mounting, largely based on research using model plants. For example, Xu et al. (2011) recently decribed the presence of heat shock proteins (HSP) which enhance the tolerance of plants to high temperatures and maintain function under temperature stress (Schramm et al. 2008; Sarkar et al. 2009). In rice, high expression of the HSP gene successfully enhanced both heat tolerance and UV-B resistance (Murakami et al. 2004). Other components that are likely to be involved in protection from high temperatures include phospholipids, superoxide reductase, transcription factor ***DREB2A*** and S-nitrosoglutathione reductase (Lee et al. 2008; Schramm et al. 2008; Im et al. 2009; Mishkind et al. 2009). More research on pasture and crop plants important to the New Zealand dairy industry is required to determine whether similar responses to high temperature are evident.

### *2.1.2 Water availability*

#### *2.1.2.1 Photosynthesis*

Low water availability is a major environmental factor limiting the growth of numerous plant species. Water deficits reduce the photosynthetic capacity of $C_3$ plant leaves through both stomatal and metabolic limitations (Sheehy et al. 1975; Chaves et al. 2003). It is largely agreed that the main cause for reduced photosynthesis under water stress is reduced $CO_2$ diffusion from the atmosphere to site of carboxylation, caused by stomatal closure and reduced mesophyll conductance (Lawlor 2002; Lawlor & Cornic 2002; Flexas et al. 2006). Rates of photosynthesis normally recover rapidly following rehydration, but the impacts on plant metabolism can persist for some time (Lawlor 2002; Lawlor & Cornic 2002; Flexas et al. 2006).

$C_4$ plant photosynthesis is equally, or perhaps even more than $C_3$, sensitive to water stress, despite the greater capacity and water use efficiency (WUE) of their photosynthetic pathway (Ghannoum 2009). Under water deficit, $CO_2$ assimilation rates and stomatal conductance rapidly decline (Maroco et al. 2000; Ghannoum et al. 2003), and photosynthesis goes through three stages; an initial mainly stomatal phase, followed by a mixed stomatal and non-stomatal phase, then a mainly non-stomatal phase. The non-stomatal factors include reduced photosynthetic enzyme activity, nitrate assimilation inhibition, induction of early senescence, and changes to leaf anatomy and structure (Ghannoum 2009; and references therein).

Similalry, waterlogging after heavy rainfall events can also reduce plant photosynthesis, depending on the extent and duration of the waterlogging. When perennial ryegrass was grown under waterlogged conditions for 4 weeks, rates of photosynthesis were initially maintained, but declined to 70% on average by day 21 (McFarlane et al. 2003).

#### *2.1.2.2 Herbage yield*

Water deficits reduce the growth of numerous plant species, including pasture grasses (Carroll 1943; Thomas 1984), legumes (Thomas 1984; Peterson et al. 1992) and maize (Stone et al. 2001), largely due to reductions in the carbon balance as described above. Reductions in plant growth are manifested by reduced leaf appearance and extension rates (Barker et al. 1985; Volaire et al. 1998) and increased tiller and plant mortality (Barker et al. 1985; Volaire 1995; Boschma & Scott 2000).

The extent of the reduction in growth depends on factors such as the severity and duration of the water deficit, as well as the plant species. For example, in a field trial conducted in Palmerston North during 1981–1982 Barker et al. (1985) showed that there was no effect of water deficit on perennial ryegrass herbage yield for the first 35-days. There was a 31% reduction in total herbage accumulation over the 107-day deficit period, which ended in a deficit of 180 mm in the water-stressed treatment (Barker et al. 1985). In comparison, it took over four months for water deficit (simulated as 10th percentile seasonal rainfall) to affect growth rates of six pasture grasses in New South Wales, Australia (Boschma & Scott 2000).

Waterlogging is also likely to reduce plant growth. McFarlane et al. (2003) reported reduced leaf and root biomass in three perennial ryegrass genotypes after 2 weeks of waterlogging; while Dunbabin et al. (1997) recorded a 14% reduction in herbage DM production from an irrigated perennial ryegrass-white clover pasture after only 24 hours of waterlogging. Again, the reduction in plant growth will be dependent on the extent and duration, as well as the plant species.

In the future, changes in the seasonality of rainfall, with increased severity of summer droughts and increased intensity of rainfall events/flooding will alter both the availability of water and the plants demand for water (Chapter 2). This will probably be to the detriment of plant growth is some regions. However, the increased WUE under elevated $CO_2$ concentrations may compensate, at least in part, for reduced summer rainfall and increased evapotranspiration. This interaction is shown clearly in a range of modelling studies (Figure 3.4 in this chapter and Chapter 4 Sheep & Beef sector review).

#### *2.1.2.3 Gene expression*

Emerging research shows that some plants may have a degree of adaptive capacity to different stressors based on genetic and molecular-level responses. During water deficit, extensive gene expression changes occur that change the biochemical and proteomic machinery. Hundreds of genes have been identified that are either induced or depressed during events like droughts mainly in the model plant, ***Arabidopsis***, and rice. Drought stress-induced gene products can generally be classified into two groups:

- functional proteins including chaperones, proteases, water channel proteins, detoxification enzymes and key enzymes for osmolyte biosynthesis (Shinozaki & Yamaguchi-Shinozaki 2007)
- regulatory proteins encompassing transcription factors, protein kinases and phosphatases, enzymes involved in abscisic acid (ABA) biosynthesis and phospholipid metabolism (Shinozaki & Yamaguchi-Shinozaki 2007).

Further investigation into the role of drought-induced genes and integration of the molecular and cellular information with whole plant responses is still required in pasture species. Foito et al. (2009) have taken a step in this direction by identifying a ryegrass genotype that is more drought tolerant, together with a number of potential reasons why it may be more tolerant. Liu & Jiang (2010) also identified differences in a study of 20 ryegrass genotypes. Although these early studies highlight potential for selection for drought tolerance, more work is required to build a comprehensive picture of genotype diversity in ryegrass.

### *2.1.3 Carbon dioxide concentration*

#### *2.1.3.1 Photosynthesis and respiration*

Elevated $CO_2$ concentrations stimulate photosynthesis in $C_3$ plants (Sicher & Bunce 1997; Rogers et al. 1998; Clark et al. 1999; Isopp et al. 2000b; Newman et al. 2003; Ainsworth & Rogers 2007; Leakey et al. 2009). This occurs through increased carboxylation rates of Rubisco and competitive inhibition of oxygenation (Soussana et al. 1996; Drake et al. 1997). Over time, acclimation of photosynthesis to elevated $CO_2$ may reduce photosynthetic capacity, but rarely enough to compensate for the stimulated rate (Drake et al. 1997). Over two years, increasing the $CO_2$ concentration from 350 to 700 ppm increased gross canopy photosynthesis of perennial ryegrass pastures by 33% (from 19 to 25 t carbon/ha; Casella & Soussana 1997). This was an increase similar to those recorded for other $C_3$ grasses in free air $CO_2$ enrichment (FACE) studies (about 30–40%; for reviews see Long et al. 2004; Ainsworth & Long 2005).

In $C_4$ plants, Rubisco is located in the bundle sheath cell chloroplasts, where the concentration of $CO_2$ is between three and six times greater than in the atmosphere (Von Caemmerer & Furbank 2003). By doing this, $C_4$ plants avoid photorespiration, and are $CO_2$-saturated at current atmospheric $CO_2$ concentrations, explaining why the effects of elevated $CO_2$ may be negligible. For example, increasing the $CO_2$ concentrations from 376 to 542 ppm did not increase any photosynthetic parameters or yield in maize (Leakey et al. 2006). Other reviews have indicated that although photosynthesis in $C_4$ plants was enhanced by elevated concentrations of $CO_2$, it was not to the same extent as in $C_3$ species (Wand et al. 1999; Long et al. 2004; Ainsworth & Long 2005; Brouder & Volenec 2008; Cullen et al. 2009).

Unlike photosynthesis, there is little difference in the dark respiration response of $C_3$ and $C_4$ plants to elevated $CO_2$ (Brouder & Volenec 2008). When calculated on a tissue mass basis the response ranges from no influence of elevated $CO_2$ to a 40% reduction; while on a canopy basis there tends to be no effect of elevated $CO_2$ on dark respiration as the greater biomass is offset by greater photosynthesis (see review by Brouder & Volenec 2008).

#### *2.1.3.2 Resource use efficiency*

Elevated levels of $CO_2$ partially close stomata in plant leaves (Clark et al. 1999; Wand et al. 1999; Ward et al. 1999; Von Caemmerer et al. 2001; Leakey et al. 2006; Ainsworth & Rogers 2007; Leakey et al. 2009). This decrease in stomatal conductance reduces transpiration loss per unit of leaf area, increases WUE and may indirectly enhance growth by ameliorating water stress (Casella et al. 1996; Soussana et al. 1996; Drake et al. 1997; Schapendonk et al. 1997; Leakey et al. 2009). Decreased stomatal conductance also stimulates higher rates of photosynthesis and increases light use efficiency (dry matter (DM) production per unit of intercepted light; Drake et al. 1997).

As well as greater water and light use efficiency, plants grown in elevated $CO_2$ tend to have greater nitrogen (N) use efficiency (Drake et al. 1997; Stitt & Krapp 1999; Leakey et al. 2009), defined as either the rate of carbon assimilation per unit of N in the plant or the rate of growth per unit of N in the plant. Due to reduced photorespiration, plants grown in elevated $CO_2$ conditions can achieve a certain rate of photosynthesis with reduced activity of Rubisco and other enzymes (Stitt & Krapp 1999), allowing N to be reallocated from the N-intensive photosynthetic and photorespiratory pathways to alternative processes.

#### *2.1.3.3 Herbage yield*

Numerous studies confirm that as $CO_2$ concentrations increase above current levels under non-nutrient limiting conditions, yields of $C_3$ plants increase significantly (Casella et al. 1996; Soussana et al. 1996; Campbell et al. 1997; Schapendonk et al. 1997; Wand et al. 1999; Schneider et al. 2004). The growth responses are derived from stimulated photosynthesis and reduced stomatal conductance and are robust across a variety of experimental set-ups, including controlled environment chambers and FACE facilities.

Although there is agreement that elevated $CO_2$ levels will increase yield of $C_3$ plants, there is some debate as to exactly how much the growth response might be. A meta-analysis of previous FACE studies demonstrated an average increase in DM production from $C_3$ plants of 20% (Long et al. 2004). Baars & Rollo's (1990) modelling work predicted that annual pasture production under non-nutrient limiting conditions at five sites across New Zealand is likely to increase by between 7% and 26% over the next 50 years, with the greatest increases occurring during winter and autumn.

When data was compiled for pasture species used in New Zealand, the mean response to elevated $CO_2$ concentrations (to 600-700 ppm) was a 14% yield increase, but there was a broad range of from 4% to 33% (Figure 3.3; created from data from Newton et al. 1994; Casella et al. 1996; Soussana et al. 1996; Hebeisen et al. 1997; Schneider et al. 2004). Under limited N conditions, this response declines to about 4% (Kimball 2010).

Figure 3.3 draws on studies that investigate $CO_2$ effects in isolation, and a number of factors broaden the potential response range. Legumes tend to benefit more from increased $CO_2$ concentrations than non-fixing species (Gunn et al. 1999; Allard et al. 2003; Nowak et al. 2004), and the $CO_2$ response may also increase as the diversity of the pasture (i.e., number of pasture species) increases (Reich et al. 2001; Nowak et al. 2004). Interactions with climate stressors and nutrients are also important and will be covered in Section 2.1.4.

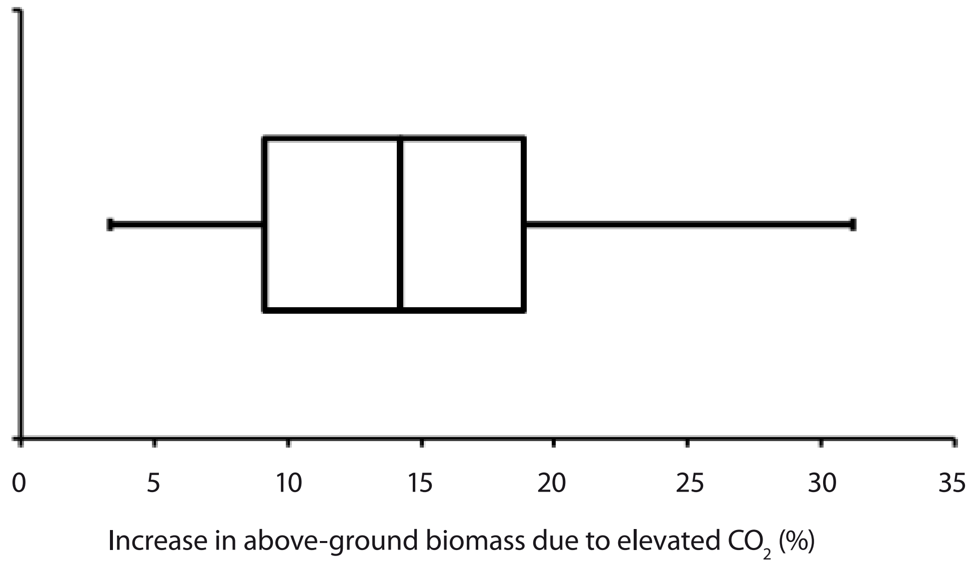



**Figure 3.3.** Variability in the annual above-ground biomass response of temperature pastures to elevated $CO_2$ under free air $CO_2$-enrichment conditions, displayed as ranges (whiskers), 25th percentile to the 75th percentile (boxes) and medians (lines).

In addition to above-ground yield, $CO_2$ elevation also increases root growth and mass of $C_3$ species (Newton et al. 1994; Soussana et al. 1996; Hebeisen et al. 1997; Schapendonk et al. 1997; Reich et al. 2001). This may occur through increased root diameter, total root length and/or altered root branching (Pritchard et al. 1999), alterations which are likely to change the roots' ability to obtain nutrients and water from soil.

There is contrasting evidence available about the response of $C_4$ plants to elevated $CO_2$ concentrations. Some studies suggest that $C_4$ plants will not demonstrate any response (Ainsworth & Long 2005), while others indicate that above- and below-ground yields of $C_4$ plants will also increase under elevated $CO_2$, although not to the same extent as $C_3$ plants (Newton 1991; Wand et al. 1999). Ghannoum et al. (2001) recorded increased whole plant biomass in response to elevated $CO_2$ concentrations in five out of 17 $C_4$ grasses tested under well-watered conditions.

#### *2.1.3.4 Gene expression*

Understanding at the genetic level of responses to climate change provides deeper insight into potential impacts; and also opens up opportunities for plant level adaptation which can be integrated into dairy systems. While numerous studies have examined the physiological and growth responses of plants to elevated $CO_2$, there are few studies that have investigated the transcriptome[2] responses, particularly in pasture plants. Ainsworth et al. (2006) identified 327 $CO_2$-responsive genes in soybean (***Glycine max***) leaves, with many belonging to the functional categories of cellular function, protein synthesis/degradation, photosynthesis/respiration, and carbon and nitrogen metabolism. The study also found increased levels of gene transcripts for several central carbon metabolic enzymes, indicating one potential mechanism behind the $CO_2$ fertilisation response. Although research in the area is in early stages, it is possible that $CO_2$ fertilisation effects may be enhanced through genetic level adaptations.

### *2.1.4 Carbon dioxide interactions*

#### *2.1.4.1 Carbon dioxide, temperature and rainfall*

Many experiments with $C_3$ species under different climatic conditions have shown that the positive yield response to increased levels of $CO_2$ is not uniform across a range of temperatures, and there are thresholds above and below which temperature overrides $CO_2$ fertilisation. This is because increasing $CO_2$ concentration reduces the ratio of photorespiratory carbon loss to photosynthetic carbon gain, while increasing temperature has the opposite effect. Across a wide range of $C_3$ plants, increased DM production responses to elevated $CO_2$ conditions have been recorded, with larger responses generally occurring at higher temperatures (Long 1991). In perennial ryegrass dominant pastures, Casella et al. (1996) predicted temperature thresholds, where between 14.5°C and 18.5°C, elevated $CO_2$ concentrations are likely to enhance pasture biomass accumulation. Above 18.5°C, however, the negative effects of increasing temperature may start to offset the positive effect of elevated $CO_2$. In New Zealand, yield of perennial ryegrass/white clover pastures was increased by 8% under elevated $CO_2$ conditions under temperature regimes of 16/10°C and 22/16°C day/night temperatures (Newton et al. 1994). In agreement with Casella et al. (1996), there was no increase in yield under elevated $CO_2$ concentrations at a temperature regime of 10/4°C.

There are also interactions between elevated $CO_2$ concentrations and water availability (Wall et al. 2006). Wall et al. (2006) investigated the effect of reduced water availability on wheat (***Triticum aestivum*** **L.**) grown under ambient and elevated $CO_2$ (370 and 550 ppm respectively). Under elevated $CO_2$ concentrations, the detrimental effects of drought were reduced, with plants demonstrating both greater drought tolerance (enhanced osmoregulation and adaptation of tissue), greater drought avoidance (lower stomatal conductance and transpiration rate, and development of a larger root system to enhance uptake of water and nutrients), resulting in greater above-ground biomass production.

The overall impact of elevated concentrations of $CO_2$, increased temperature and reduced rainfall on pasture production has been estimated by Cullen et al. (2009), who modelled three future climate scenarios for five sites in southeastern Australia. The three scenarios (2030, 2070-mid emission and 2070-high emission) represented a range of climate change effects (i.e., temperature increases of 0.7°C –1.2°C, 1.5°C –2.7°C and 2.5°C –4.4°C; altered rainfall by 0% to -8%, +1% to -17% and +1% to -28%; and $CO_2$ concentrations of 455 ppm, 581 ppm and 716 ppm for the 2030, 2070-mid- and 2070-high-emission scenarios, respectively). At three sites, the predicted average annual pasture production increased with each scenario, while at the other two sites, the predicted annual pasture production was greater than the baseline under the 2030 scenario, but reduced under both the 2070 scenarios. This indicates that over the next two decades the effect of climate change on pasture production is likely to be positive, particularly over the short term planning horizon, but longer-term effects are likely to be region- and species-specific.

#### *2.1.4.2 Carbon dioxide and nitrogen*

The potential for $CO_2$ fertilisation depends on the amount of N available for plants, meaning the supply of N may need to increase, creating more pressure on both nutrient and input cost management on dairy farms. Elevated $CO_2$ concentrations increase the carbon source capacity by increasing photosynthesis and

[2]This is the population of ribonucleic acid that DNA is transcribed to in a cell to express a gene. It is different to the genome, but critical in that it is used to tell when a gene (and subsequently a plant function like enhanced $CO_2$-response) is switched on or off.

carbohydrate synthesis. However, the ability to make use of the increased carbon depends on the sink capacity or development of new sinks; a process largely dependent on the N available for growth (Drake et al. 1997; Stitt & Krapp 1999).

In FACE facilities, regularly defoliated swards of perennial ryegrass have been growing for several years under different levels of $CO_2$ and N fertiliser. In these systems, elevated $CO_2$ increased photosynthesis, resulting in greater carbohydrate content during regrowth (Fischer et al. 1997; Rogers et al. 1998). High N promoted the positive growth response to elevated $CO_2$, possibly by shifting more carbon from the below-ground compartments towards the harvested shoots (Casella & Soussana 1997). When N was limiting, however, there was a marked decrease in the amount of active Rubisco (Rogers et al. 1998) and the $CO_2$ assimilation or uptake rate (Von Caemmerer et al. 2001; Ainsworth et al. 2003), resulting in either a restricted growth response (Schneider et al. 2004) or no response at all (Hebeisen et al. 1997).

### *2.1.5 Botanical composition*

The changing climate will affect the botanical composition of pastures, which in turn changes the timing of pasture growth responses and feed quality with flow through to milk production levels. In regions with strong temperature increases there could be decreased proportions of perennial ryegrass (or other C3 grasses) in warmer, drier regions and pest-prone areas (Campbell 1996). This has flow on effects to productivity in dairy systems. It is likely to be correlated with an increase in the proportion of more heat- and drought-tolerant species such as weeds (Rahman & Wardle 1990; Wardle & Rahman 1990) and subtropical C4 grasses (Baars & Rollo 1990; Field & Forde 1990; Thom 1990; Campbell et al. 1996). The proportion of legumes, such as white clover, may also increase as they are more responsive to elevated $CO_2$ than non-fixing species (Newton et al. 1994; Campbell et al. 1997; Hebeisen et al. 1997; Allard et al. 2003).

### *2.1.6 Pasture quality*

Projected climate changes will alter the nutritive value of pasture and crop plants. Long-term growth in elevated $CO_2$ conditions increases the carbohydrate content in $C_3$ plants (Soussana et al. 1996; Casella & Soussana 1997; Schapendonk et al. 1997; Cheng et al. 1998; Wand et al. 1999; Isopp et al. 2000a,b). In pasture plants water-soluble carbohydrates (WSC) are the main carbohydrate reserve, & consist largely of fructans, with smaller amounts of sucrose, glucose & fructose (Waite & Boyd 1953; Prud'homme et al. 1992). Fructans act as a storage pool for surplus carbohydrates and accumulate when carbon supply is increased (Farrar 1999), and are increased to a much greater extent than sucrose or hexose following exposure to elevated $CO_2$ (Casella & Soussana 1997).

In contrast to carbon, the protein and/or N content of leaf and root tissue decreases in plants grown under elevated $CO_2$ conditions (Soussana et al. 1996; Gifford et al. 2000; Isopp et al. 2000a). Declining N content in tissues, especially leaves, exposed to elevated $CO_2$ may occur via a metabolic down-regulation of photosynthesis-related enzymes as a regulatory response to $CO_2$-stimulated photosynthesis/high carbohydrate content, or a dilution effect with an accumulation of WSC reducing N concentration (Gifford et al. 2000). However, when the N concentration is recalculated on a WSC-free basis, then N was still reduced at elevated $CO_2$, suggesting that plants growing under elevated $CO_2$ conditions, contain less N due to a reduction in the amount of photosynthetic enzymes (Allard et al. 2003). This is supported by Cheng et al. (1998) who recorded substantially reduced amounts of Rubisco protein and abundance of ***rbcL*** and ***rbcS*** transcripts (i.e., the genes encoding the large and small subunits of Rubisco, respectively).

In New Zealand pastures the crude protein (CP) content of the herbage ranges between 9% and 35% DM, while the WSC content ranges between 7% and 25% DM (Kolver 2000; Roche et al. 2009a). As the CP content in pasture is generally greater than dairy cow requirements (12% to 24%; Kolver 2000), a reduction in N content as a result of increasing $CO_2$ concentrations is unlikely to have any detrimental impact on milk production. In fact, declining CP content combined with increasing WSC content may drive the WSC:CP ratio closer to the desired ratio of 1.5 (Parsons et al. 2010), thus achieving greater N use efficiency (NUE) by reducing the amount of urinary N deposited on the soil. Further work using New Zealand pastures is required to determine to what extent the CP and WSC content is altered, and if this has any subsequent environmental benefit.

These plant level responses in N and carbohydrate content need to be considered in association with reproductive and ecosystem level responses. Tait (2008) found an increase in the land area of New Zealand with mean annual growing degree days (GDDs; base temperature 10°C) greater than 1000 units from 1974–2003 to 2020–2049. Although the base temperature for perennial ryegrass is 0°C, this illustrates potential for more rapid development in dairy pastures under climate change. The prospect of earlier flowering and more rapid senescence results in a quality penalty with increased lignin content in available herbage. There is potential for the normal reductions in pasture quality expected in summer arriving earlier. These production impacts have yet to be studied systematically for dairy farm systems in New Zealand.

At the ecosystem level, increased legume content with warmer temperatures and elevated $CO_2$ is also likely to increase the nutritive value of pastures as legumes tend to be more nutritious, with greater CP and metabolisable energy (ME) content and reduced fibre (Harris et al. 1998). Under FACE conditions, increases in the digestibility of diverse pastures have been observed under elevated $CO_2$ (Allard et al. 2003), which is probably a result of increased legume proportions.

However, the negative effects of climate change may be greater than the positive, with reductions in nutritive value of pasture following an increase in the proportions of subtropical $C_4$ grasses and weeds (Cullen et al. 2009). These species have greater fibre content, and reduced CP, WSC and digestibility compared with $C_3$ species such as perennial ryegrass (Jackson et al. 1996). A higher incidence of extreme events, such as drought and high temperatures, is also likely to reduce the quality of pasture and crop plants. High temperatures reduce the WSC content and digestibility of grasses, and to a lesser extent, legumes, while increasing their fibre content (Deinum et al. 1968; Wilson 1981; Roche et al. 2009b).

### *2.1.7 Pests and diseases*

Climate change will affect the abundance and distribution of pasture pathogens, with both positive and negative implications for production. Numerous studies have documented changes due to climate change, including altered stages and rates of pathogen development, modified host resistance and changes in the physiology of host-pathogen interactions (Coakley et al. 2003 and references within).

The main pasture pests in New Zealand include Argentine stem weevil, black beetle, clover nematodes, clover root weevil, grass grub, Tasmanian grass grub, pasture mealy bug and porina. Although there is a paucity of research on the potential effects of climate change on these specific pasture pests, it is predicted that warmer temperatures may increase pest problems by increasing their geographical spread and reducing the time required for eggs to hatch and larvae to develop (Barker 1990; Prestidge 1990; Watson 1990; Willoughby & Addison 1997). However, this negative effect may be partially offset by increased larval and adult mortality at higher temperatures, particularly when combined with moisture deficits (Barker 1990; Prestidge 1990). The emergence of some pest populations and their abundance tend to be inversely associated with soil moisture (East et al. 1981; Gerard & Arnold 2002), either as a direct result on survival, or indirectly via the reduction in plant quality or the increased distribution of pathogens in the soil (Prestidge 1990).

Warmer temperatures may also increase the prevalence and geographic expansion of plant diseases (Coakley et al. 2003). Many of the fungal diseases that affect New Zealand pastures are favoured by warm, moist conditions (e.g., brown blight, crown rust, leaf spot) with most spores readily windborne. As well as increasing the incidence of disease, abiotic stresses such as heat may increase plant susceptibility to the diseases (Garrett et al. 2006).

Manning & von Tiedemann (1995) suggested that the increased canopy size and density resulting from elevated $CO_2$ levels, combined with increased canopy humidity, would promote foliar diseases such as rusts, powdery mildews, leaf spots and blights. This was confirmed in the field, with greater $CO_2$ increasing the fungal pathogen load of $C_3$ grasses – probably due to the increased leaf longevity and photosynthetic rate (Mitchell et al. 2003). However, in another study, there was a wide response to the effect of increasing $CO_2$ concentration on fungal disease severity, with the severity of some diseases increasing, while others decreased (Chakraborty et al. 2000).

### *2.1.8 Assessments of combined impacts*

A number of interpretative estimates of climate change impact have been made in New Zealand. Baars et al. (1990) suggested no change to annual yield in the North Island, with increases of 8% to 20% in the South Island. Campbell (1996) suggested potential increase in pasture production by 10% to 15% with regional variability. Clark et al. (1999) highlighted a range of 6% to 30% increase in annual pasture growth. Similarly the International Global Change Institute (IGCI 2001), suggested an 8% to 10% increase in pasture DM production in 2020, compared with 1990 figures. More recent estimates highlight improved production in Southland and Westland, and that average and worst-year production are likely to decline in east coast locations (EcoClimate 2008).

Results from a more recent analysis completed by Baisden et al. (2010) are provided in Figure 3.4 as an illustration of past studies. These highlight the general positive impacts of growth of a warmer climate for New Zealand identified in previous estimates, but also illustrate considerable regional and seasonal variability in the response. Generally, negative impacts occur in autumn and for some regions of the east coast during summer. During winter and spring when water limitations are not common, increasing temperatures and $CO_2$ fertilisation suggest strong increases to biomass production. The spatial distribution of impacts on summer and autumn reflect the known distribution of changes in projected drought reported in Chapter 2, where more severe drying occurs on the eastern seaboard.

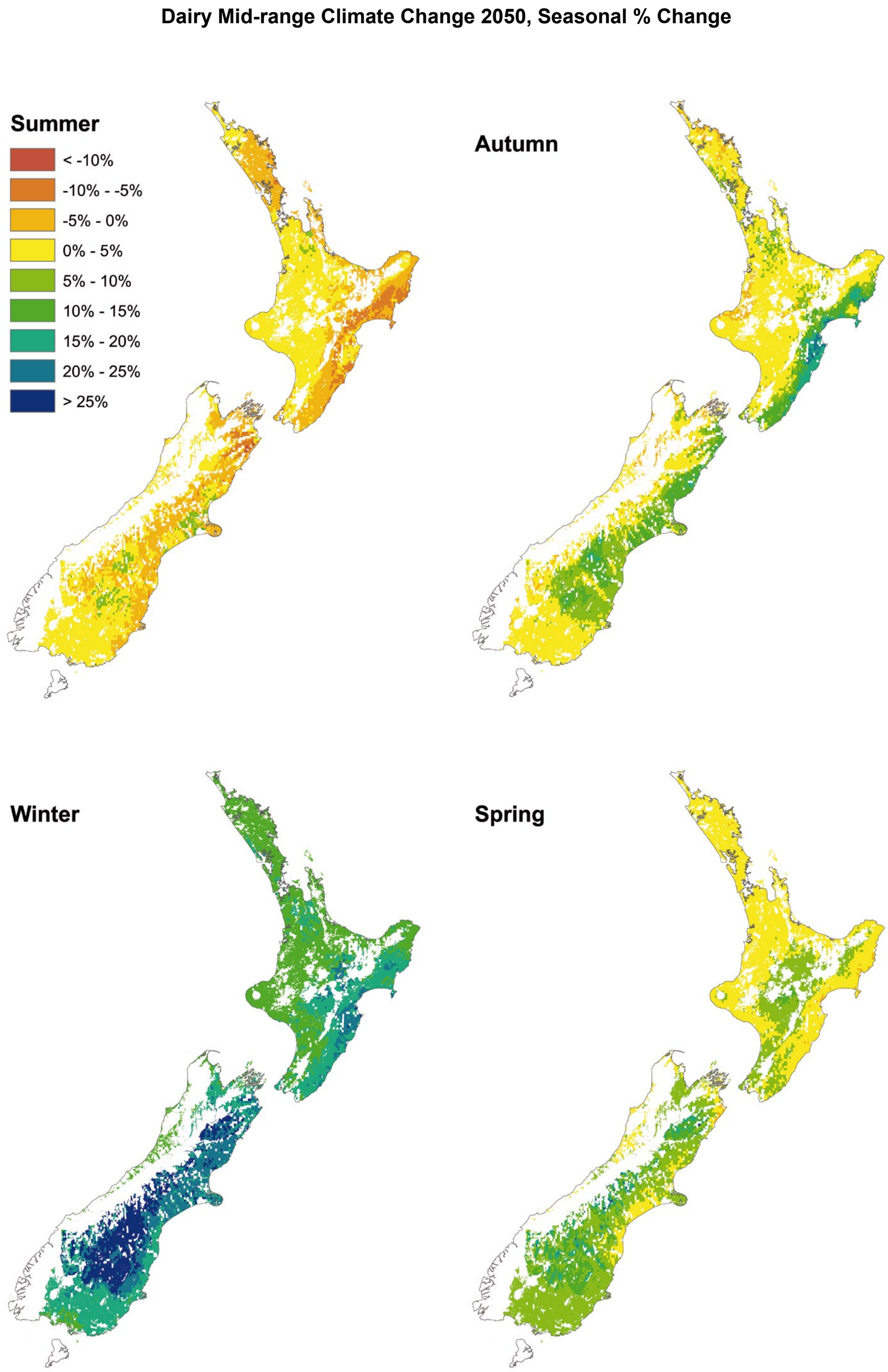



**Figure 3.4.** Percentage changes in pasture production for 2050 compared with 1980–1999 given a mid-range climate scenario. Source: Baisden et al. (2010). Updated figure courtesy of Baisden & Keller (2012).

## 2.2 Dairy cows in a changing climate

A summary of dairy cow impacts relating to some key climate drivers is provided in Table 3.3, and a detailed summary of the underlying science is provided in Sections 2.2.1–2.2.6. Thermal stress is the primary direct environmental challenge for the dairy cow in a changed climate, with associated increases in heat stress and corresponding deceases in cold stress under projected changes.

**Table 3.3.** Impact knowledge summary for dairy cows in a changed climatic environment, highlighting drivers currently experienced in New Zealand and those anticipated from international evaluations.

| ***Driver*** | ***Impact*** | ***New Zealand*** | ***International*** |
|---|---|---|---|
| Rising temperatures leading to more heat stress | Reduced intake<br>Reduced production | Known occurrence's but not well characterised | Very well established responses |
| Rising temperatures leading to reduction in cold stress | Inadequate feeding<br>Welfare concerns<br>Newborn safety | Mostly anecdotal or by inference with limited science | Knowledge limited to beef farming |
| Increased drought frequency in eastern and northern zones | Insufficient feeding<br>Lost production | Well established practical knowledge | Australian-based knowledge |
| Increased flood and storm intensities | Major disruption for all farm aspects at local levels | Practical experiences and contingency plans | |
| Animal disease threats | Animal health | Localised and sporadic | |

Much of the available knowledge is focussed on heat stress impacts and is derived from international sources. There are numerous reviews of heat stress (Morrison 1983; Wolfenson et al. 2000; Kadzere et al. 2002; De Rensis & Scaramuzzi, 2003; Jordon 2003; Collier et al. 2006, 2008; Nardone et al. 2010); with fewer literature reviews on cold stress – focusing primarily on beef cattle (Young 1980, 1983; Webster 1983). This is because dairy cattle have a high degree of cold tolerance due to the heat produced within the ruminant. In addition, large areas of production agriculture exist in regions more likely to experience heat stress than cold stress conditions for dairy cows. It is also relatively easier to measure and study heat stress in cattle.

### 2.2.1 Cow thermal response

In principle, dairy cattle have a thermoneutral zone (Curtis 1981; Webster 1983; Kadzere et al. 2002), which defines the environmental temperature range where animal heat production is minimal and core body temperature is normal (Figure 3.5).

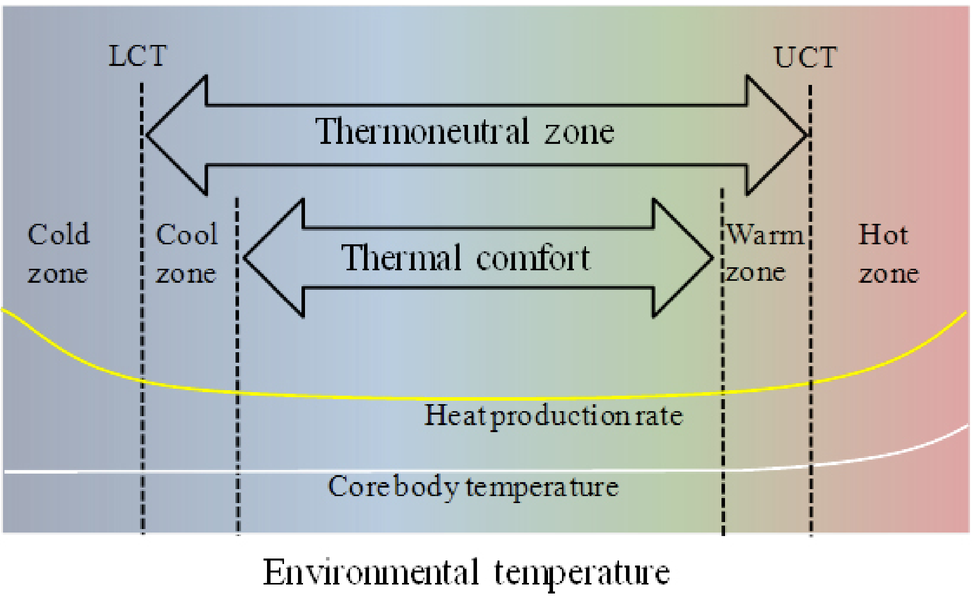



**Figure 3.5.** Schematic representation of the thermoneutral zone for cattle (adapted from Kadzere et al. 2002). LCT = lower critical temperature; UCT = upper critical temperature.

Within the thermoneutral zone, ruminants require no additional energy above maintenance to warm or cool the body (Johnson 1987). The boundaries of this thermoneutral zone are referred to as the lower critical temperature (LCT) and the upper critical temperature (UCT); these thresholds demarcate the cold and heat stress zones, respectively. Basal heat production increases in both cold- and heat-stressed states, while core body temperature rises when conditions exceed the UCT (Heat stress, red zone in Figure 3.5). Dairy cows have a number of production, clinical and reproductive responses when under thermal stress, and these are summarised in Section 2.2.2 (heat) and Section 2.2.3 (cold).

While there is agreement that the general model of the thermonuetral zone (Figure 3.5) operates for production cattle, the specific environmental temperatures that govern the thresholds are complex. This is because UCT and LCT are affected by dynamic animal-related factors such as age, breed, size and body insulation, milk yield, feed intake, diet composition, and previous state of acclimation (Kadzere et al. 2002). The combination of these variables and variability in the production environment probably explains some of the inconsistency reported. The temperature range for optimal performance, minimal performance losses, and the LCT and UCT for various ages and level of production for dairy cattle has been reviewed (Collier et al. 1982; Hahn 1999), and a summary of estimates is provided in Table 3.4.

**Table 3.4.** Summary of estimates of the dairy cattle thermoneutral zone (including source studies).

| ***Developmental stage*** | ***Age or condition*** | ***Thermoneutral zone*** | ***Reference*** |
|---|---|---|---|
| Calves | Newborn | 18 to 25°C | Collier et al. (1982) |
| | up to 1 month | 13 to 25°C | Hahn (1999) |
| Older calves | 1–5 months | -5 to 26°C | |
| | Peak performance | 5 to 15°C | Hahn (1999) |
| Cows | Non lactating, pregnant | -14 to 25°C | Collier et al. (1982) |
| Cows | Lactating | -30 to 25°C | Bryant et al. (2007a) |

### 2.2.2 Heat stress

#### 2.2.2.1 Measuring a heat stress environment

A number of climate-based indices have been developed to provide a general indicator of when a dairy cow is experiencing thermal stress. These are an indirect measure of climate impact as they do not, for example, quantify effects on animal intake or nutritional demand. A commonly used index for assessing heat stress risk is the temperature-humidity index (THI; Thom 1959). Relative humidity is a critical component of the THI in regions where air moisture is relatively high, but of less consequence in dry areas (e.g., Arizona, USA) with low ambient humidity (Bohmanova et al. 2007). Some estimates of THI do not account for solar radiation or wind speed, which are major environmental factors for grazing cattle. Gaughan et al. (2008) proposed a Heat Load Index (HLI) model for predicting heat stress in feedlot cattle that includes temperature, relative humidity and wind speed. This has been modified using data for dairy breeds in New Zealand (HLINZ) where it was found that incorporation of solar radiation was also important (Bryant et al. 2010b):

$$HLINZ = -49.05 + 1.40THI_{NRC} - 3.31WS + 0.146SR + 0.780T_{min} \qquad \text{Eq. 1}$$

$$THI_{NRC} = (1.8\ T_{max} + 32) - (0.55 - 0.0055RH) \times (1.8T_{max} - 26.8) \qquad \text{Eq. 2}$$

Where $THI_{NRC}$ is National Research THI equation used for US breeds (Dikmen et al. 2009), $T_{max}$ and $T_{min}$ are daily maximum and minimum temperature (°C/day); ***WS*** is mean daily wind speed (m/s/day); ***SR*** is accumulated daily solar radiation (MJ/$m^2$/day) and ***RH*** is average daily relative humidity (%).

Translating THI values into physiological and production responses is not straightforward. A study in Canterbury (Laird & Barrell 2010; Barrell 2010) reported that the THI value exceeded 72 on 10% of summer days; that internal body temperature increased in response to the THI exceeding 72, with a 120 minute lag time; but, that daily milk production levels were not affected by changes in THI. It is possible that night time THI values were sufficiently low to allow cows to unload heat accumulated during the day time. Minimum diurnal temperatures are more influential on the animal's thermo-neutrality status than diurnal maxima. More recent work indicated that a cool period of less than 21°C for 3 to 6 h ameliorates the negative effects of heat stress on milk production (Igono et al. 1992; West 2003). Studies examining the effects of heat stress should be mindful that ambient temperatures throughout the 24-hour period contribute to this condition, not just the periods when environmental heat stress conditions are maximal.

#### 2.2.2.2 Heat stress and milk production

The effects of heat stress on dairy cow productivity have been well characterised. Early studies (Ragsdale et al. 1949, 1951) reported that feed intake and milk production among a range of dairy breeds declines when air temperature exceeds 25°C. More recently, dynamic modelling of the relationship between milk yield and temperature recorded at the nearest meteorological station indicated that milk yield declines when average daily temperature exceeds 17.8°C (Andre et al. 2011). Milk production appears to be extra sensitive (compared to growth or wool) to thermal stress, and decreased yields of up to 40% are not uncommon (West 2003).

A study of 15,000 cows in Georgia, USA, showed that lactating cows become heat-stressed when the THI exceeds 72 (Morrison 1983; Armstrong 1994), where average daily milk yield is depressed by 0.2 kg for every THI unit increase above 72 (Ravagnolo et al. 2000). Zimbleman et al. (2009) recently revised the threshold to 68, and this is supported by behavioural observations (Cook et al. 2009). High-yielding cows are less tolerant to heat because basal-metabolic heat production increases with enhanced milk yield (Spiers et al. 2004) and this decreases the thermal gradient between the animal and its immediate surroundings. Modern cows are considerably heavier than their predecessors (without a linear increase in surface area) and this reduces the surface area:mass ratio, hindering effective heat dissipation. Genetic selection based on traditional production traits may increase animals' susceptibility to thermal stress.

There are complex genetic and metabolic responses in dairy cattle under heat stress, and identifying them is an important precursor to effective adaptation. In summary:

- The endocrine system changes its function under heat stress which may lead to behavioural responses such as reduction in intake (Bernabucci et al. 2010).
- Intracellular homeostasis is reprioritised and survival mechanisms are initiated by thermal stress (Collier et al. 2008) playing a role in acclimation and ultimately in reduced productivity.
- There are known gene expression responses to heat stress (Collier et al., 2008) including production of heat shock proteins that provide cellular protection during heat stress.
- As part of metabolic-genetic response, there is a decrease in synthesis of other proteins, an increase in glucose and amino acid oxidation while fatty acid metabolism is reduced, and an activation of both the endocrine and immune systems (Collier et al. 2008).
- Persistent heat stress results in an altered physiological state, an 'acclimation' process; cattle become more resilient to heat stress, driven by ongoing changes in the expression of responsive genes and largely regulated through endocrine signals (Collier et al. 2006).

Research suggests that the acclimation response is complex, a result of genetic factors, physiological state and both recent and historic environmental exposure. Kamal et al. (1962) reported that dairy heifers reared in ambient temperatures of around 27°C were heat stressed to a lesser extent when exposed to high temperature as lactating cows, when compared with heifers reared at about 10°C. More recent reports provide evidence that acclimation towards coping with heat load takes just a few days to several weeks, depending on differences in susceptibility among species, breed, and production levels (Bernabucci et al. 2010). Senft & Rittenhouse (1985) reported that the length of the acclimation period for Angus was 9 days, and 14 days for Poll Hereford. In summary, homeorhetic mechanisms provide some means for cattle to adjust to acute changes in ambient temperatures, and there is evidence that they can also acclimatise to longer-term changes, although the physiological mechanisms of longer-term adjustment are not well understood.

Similarly, reduced feed intake is a complex response to heat stress. It is probably a survival strategy as digesting (especially in ruminants) and processing nutrients generates further heat (i.e., the thermic effect of feed). Inadequate feed intake during heat stress was traditionally assumed to be responsible for decreased milk yields (West 2003). However, recent experiments demonstrate inconsistent patterns in feed intake and milk yield in response to severe heat stress (Shwartz et al. 2009). Because of the conflicting feed intake and milk yield relationships, it has been hypothesised that heat stress reduces milk synthesis by both direct and indirect (via reduced feed intake) mechanisms (Shwartz et al. 2009). A series of pair-feeding experiments enabled an evaluation of thermal stress to be conducted while eliminating the confounding effects of dissimilar nutrient intake. These types of experiments are required to differentiate between direct and indirect effects of heat stress, because both heat stress and low intake reduce milk yield. Incorporating this experimental design has allowed for discoveries indicating that reduced feed intake only explains about 35% to 50% of the decreased milk yield during environmental-induced hyperthermia (Wheelock et al. 2010).

Heat stress has long been known to adversely affect rumen health. One way cows dissipate heat is via panting (which through a complex pathway leads to abnormal rumen pH levels and ultimately loss of body condition).The increased respiration rate from panting, results in more $CO_2$ being exhaled. This alters the HCO3- (bicarbonate) to $CO_2$ ratio in the blood, reducing the effectiveness of blood pH buffering. To compensate, the kidney secretes $HCO_3$- and this reduces the amount of $HCO_3$- available (via saliva) to maintain a healthy rumen pH. Panting cows also drool, and this further reduces the quantity of saliva swallowed in the rumen. Heat-stressed cows ruminate less due to reduce feed intake and therefore generate less saliva. The reductions in the amount of saliva, and salivary $HCO_3$- content, plus the decreased amount of saliva entering the rumen make the heat-stressed cow much more susceptible to sub-clinical and acute rumen acidosis (Kadzere et al. 2002).

When cows begin to accumulate heat, there is also a redistribution of blood to the extremities in an attempt to dissipate internal energy. As a consequence, there is reduced blood flow to the gastrointestinal tract and nutrient (i.e., volatile fatty acid) uptake may be compromised (McGuire et al. 1989) due to a reduction in the concentration gradient between the lumen and enterocytes. Coupling the blood acid-base balance dynamics, intestinal blood flow patterns and cow behavioural changes (i.e., to meal frequency, drooling, etc.) together, creates a situation where rumen health is seriously jeopardised.

Reduced albumin concentrations in circulation and a concomitant increase in globulin were reported for dairy cows with the onset of seasonally hot temperatures (Roussel et al. 1972). This physiological response (i.e., reduced albumin:globulin ratio) is indicative of liver challenge and possibly also of systemic inflammation. Such responses are evident in other stress-induced conditions associated with poorer health during the transitional calving period. It can be assumed, therefore, that excessive heat invokes a physiological response that supports a 'stressed-state' in the animal; and that all aspects of animal performance could be compromised by excessive heat.

#### *2.2.2.3 Heat stress and reproduction*

From the literature, it is clear that conception rates are reduced by heat stress, although the risk period for heat stress under climate change will continue to come later than the period for breeding dairy cows in most seasonal, pasture-based systems. Ingraham et al. (1974) reported that conception rate declined from 67% to 21% when average daily THI of less than 66 was increased to greater than 76. They also reported that the THI two days before insemination was most highly correlated with the effect of THI on conception rate. An increase in THI from 70 to 84 two days before insemination reduced conception rate from 55% to 10%. Thatcher et al. (1974) reported that heat stress conditions in Florida reduced conception rate from 39% among cows managed within an artificially cooled environment to 28% among cows exposed to ambient conditions. Similarly, Australian data demonstrate a strong relationship between conception rates and THI (Morton et al. 2007). In this study, monthly conception rates declined in a quadratic fashion from 46% to 26% as average daily maximum THI increased from 66 to 78.

A variety of potential underlying reasons for a reduction in conception rates during heat stress conditions has been reported (Wolfenson et al. 2000; De Rensis & Scaramuzzi 2003; Jordon 2003). These include reduced duration and intensity of oestrus (Nebel et al. 1997; Cartmill et al. 2001) and poorer ovarian follicular and oocyte quality (Monty & Racowsky 1987; Badinga et al. 1993; Al-Katanani et al. 1998). These poorer quality oocytes have a delayed cleavage rate to the 2- and 4-cell embryonic stage, perhaps due to a transcription deficiency of the POU5F1 gene responsible for maintenance of pluripotency of the embryonic stem cells. An increased rate of early (on day 7; Putney et al. 1989) and late embryonic losses (days 8 to 16; Biggers et al. 1987) are also evident for those cows that were successfully fertilised during heat stress conditions. Embryonic losses may be a result of a disrupted balance of signals between the conceptus and uterus (Putney et al. 1988); namely, reduced production of the pregnancy signal protein, interferon-tau, by the conceptus, as well as increased secretion of prostaglandin-F2α (luteolytic signal) from the uterus. We can conclude that there are numerous points within the female reproductive processes that are required to establish a viable pregnancy at which heat stress can have deleterious effects.

Bull fertility is also reduced by heat stress. Results from an environmental chamber study indicated that 5 weeks of exposure to temperatures exceeding 29.4°C reduced sperm motility and concentration (Casady et al. 1953). Ax et al. (1987) additionally reported that a high frequency of abnormal sperm is ejaculated following heat stress conditions. Meyerhoeffer et al. (1985) reported that exposing bulls to between 31°C and 35°C for 8 weeks reduced sperm motility from about 78% to as low as 50%; and that a cooler recovery period of 8 weeks was required before semen quality returned to normal. Semen for AI is likely to be at less risk because the timing of semen collection can be limited to cooler periods, or precedes the summer months in the case of fresh extended semen. In contrast, the period of natural mating in seasonally mated herds can coincide with heat stress conditions, and would appear to present a more likely risk with the predicted rise in ambient temperatures.

#### *2.2.2.4 Heat stress and young stock*

Heat stress can have detrimental effects at any stage of the animal's life-cycle, even before it is born. The health of newborn calves is critically dependent on access to sufficient, high quality colostrum (i.e., the cow's first milk). Nardone et al. (1997) reported that cows suffering heat stress in late pregnancy produced colostrum that was weaker in immunoglobulins and lower in protein. Poor quality colostrum has the potential to reduce the transfer of passive immunity, making the calves more susceptible to disease (Nardone et al. 1997). After birth, newborn calves exposed to hotter environments have higher mortality, higher serum corticosteroid concentration, and lower serum immunoglobulin IgGl at 2 and 10 days after birth (Stott et al. 1976). The growth rate of young cattle is also affected by heat stress. Young bulls had a reduction in dry matter intake and growth rates when exposed to temperatures between 29°C and 40°C for 9 days (O'Brien et al. 2010). Growing heifers exposed to heat stress had greater feed intake per unit weight gain. This effect was transient, however, as the heifers attained projected body weights 3 to 4 weeks after returning to normal (thermoneutral) conditions (Baccari et al. 1983 cited in O'Brien et al. 2010). From this body of evidence, we can conclude that young stock are susceptible to heat stress, although it would be logical to assume that their lower metabolic rate and larger surface area relative to body mass would transfer a higher tolerance compared with the lactating cow.

#### *2.2.2.5 Heat stress and health and welfare*

Hot climatic conditions impact on cattle welfare, as evidenced by the physiological and behavioural changes occurring in cattle in these conditions. Cattle in warm temperate summers (>25°C) employ a number of behavioural strategies to enable them to reduce heat load and thermoregulate more effectively. These include changes in posture, seeking shade or cooler microclimates, changing times of grazing, increasing water consumption, and making use of cow showers if available (Schutz et al 2011). Heat-induced changes in behaviour occur before changes in production, and can be indicators that production may decline and heat stress may ensue if the conditions continue. To assess motivation for shade, dairy cows deprived of lying for 0, 3, or 12 hours were given a mutually-exclusive choice between lying and access to shade under a range of warm to hot conditions (<25°C, 25-30°C, >30°C). Shade use increased as ambient air temperature increased, and cows chose to stand in shade in high ambient temperatures rather than lying in non-shaded areas after 12 hours of lying deprivation (Schutz et al. 2011). Further research confirmed these results, indicating that motivation to access shade increased when the $HLI_{NZ}$ exceeded 66 and the temperature reached 29°C. At that temperature, cows that had been deprived of lying for 24 hours decreased their lying time by 49% in order to access shade (Matthews & Arnold, unpublished data). Lying is highly valued by cattle so the strong motivation to access shade in high temperatures, particularly when deprived of another highly-valued activity (access to lying), indicates that the requirement for shade during hot conditions is relatively high (Schutz et al. 2011; Matthews & Arnold, unpublished data). These results, together with the physiological effects of excessive heat described earlier, suggest that cattle may be experiencing compromised welfare in temperatures exceeding 25°C and particularly above 29°C, and therefore measures should be taken to mitigate the effects of hot conditions on cattle.

### *2.2.3 Cold stress*

#### *2.2.3.1 Measuring a cold stress environment*

A cold stress index (CSI) based of the NRC model (Fox & Tylutki 1998) has been validated for New Zealand conditions (Bryant et al. 2010b). The CSI accounts for body surface area, body condition score, feeding level, coat length, wind speed, temperature and rainfall. Using this CSI, Bryant et al. (2010b) predicted that the LCT for a New Zealand herd of non-lactating dairy cows fed to requirements for maintenance and pregnancy, would be -13°C under calm, dry conditions. The LCT increases markedly when there is rain (to 0°C), strong wind but no rain (to 4°C) or both wind and rain (to 7.5°C) in this model. It has been reported that the NRC CSI corroborates with behavioural preferences in cattle for seeking shelter from the cold (Mathews & Bryant 2010). The level of cold stress experienced by the animal, however, is dependent on level of milk production or metabolic rate, breed, intake, and degree of acclimation to cold conditions. Dairy cattle are able to adjust to short- or long-term cold conditions by eliciting a series of changes as described by Johnson (1976) and Slee (1971).

#### *2.2.3.2 Cold stress and milk production*

Milk production is reported to decline when temperature falls below -5°C; with the magnitude depending on breed, feed intake and acclimation (Brouček et al. 1991). There were dramatic losses in milk yield when cows were kept below -23°C, and high producing dairy cows, with high metabolic heat production, only reduced production when temperature dropped below -30°C (Young 1983) and -45°C (Christopherson & Young 1986). Cattle exposed to colder conditions than their thermoneutral zone will increase intake (if available) and energy expenditure, perhaps at the expense of growth and milk production because more energy may be diverted from production to maintenance functions. In addition, cold stress appears to affect digestive function in lactating cattle, by increasing intestinal motility which reduces turnover time and digestibility of the digesta.

However, highly degradable feedstuff is less affected by shorter turn over time compared with feed components that had lower digestibility (Christopherson 1976).

Physiological adaptations in cows exposed to cold stress included greater heart rate, hematocrit, and concentrations of plasma free FA and glucose (Shijimaya et al. 1985). Thyroid and adrenal corticoid hormones were also affected by acute and chronic cold stress, though these mechanisms are not fully understood. Some physiological responses to cold stress have been reported, including trends in blood glucose, free fatty acids, thyroid function and minerals. Cattle exposed to adverse winter conditions (cold, rainy, and windy) had greater intake but grew slower and produced less milk (Martin et al. 1975).

#### *2.2.3.3 Cold stress and reproduction*

A review by Collier et al. (2006) reported that cold stress has little effect on reproduction in dairy cattle, and is of little or no consequence compared with the losses due to heat stress. There is no strong evidence of a temporal link between cold stress and cow fertility, although there is anecdotal evidence from farmers that 'cows are less likely to cycle' during inclement weather in early spring. There is no real scientific evidence to support this perception, but it is possible that oestrus is more difficult for famers to detect when it is raining and cold. A report by Kilgour et al. (1997) indicated that the intensity of behavioural oestrus is lessened during inclement weather. Large-scale studies that link local weather conditions to measures of reproductive performance would be required to provide an evidenced-based assessment of the spatial and temporal associations between weather conditions and reproductive performance.

While there is only scant evidence of an immediate and deleterious effect of cold stress on reproduction, it is well known that cold, wet winters can be detrimental to fertility. During a harsh winter, it is more likely that body tissue reserves are not sufficiently accumulated to achieve the levels known to promote an early resumption of oestrus cycles after calving (e.g., body condition scores of 5.0 to 5.5 among 85% of the herd at calving). These effects could be considered indirect; a consequence of an unfavourable nutritional balance through the cooler wintering seasons, and partly driven through managerial decisions and actions. The likely decline in reproductive performance due to sub-optimal body condition at calving can be assessed using the DairyNZ InCalf Herd Assessment Pack tools.

#### *2.2.3.4 Cold stress and young stock*

The LCT of the thermoneutral zone for newborn calves is 13°C, but declines to -5°C for juvenile calves (Collier et al. 1982; Hahn 1999). Cold stress reduces the ability of newborn calves to absorb colostral immunoglobulins (Olson et al. 1980), thus reducing the passive immunity of the newborn to infectious disease. Calves with reduced resistance to disease have a higher risk of mortality up to 6 months of age. Breed contributed to cold stress resistance, and compared with Jersey calves, Friesian-Holsteins were less susceptible and had 14% greater body insulation (Holmes & McLean 1974). Newborn calves are most vulnerable during periods of extreme cold, and must consume sufficient quantities of high-quality colostrum to project against the greater risk of disease. This is particularly important for smaller breed calves, such as Jersey.

In addition to increased risk of disease, growth rates are reduced in newborn and juvenile calves during periods of cold stress, as nutrients are partitioned away from protein synthesis for muscle, towards internal organs and the generation of heat (Scott et al. 1976). Cold stress increases the metabolic rate of the animal to maintain its body function. For instance, brown adipose tissue (BAT) of the newborn is catabolised to maintain body temperature and this mechanism is critical to maintain thermogenesis and calf survival (Carstens et al. 1997). These reduced growth rates can be reversed by increasing the feed available to cold-stressed calves. Calves housed in cold conditions (<5°C) were reported to have similar growth rates compared to calves housed in warmer conditions (15°C to 16°C) although calves under cold conditions had greater feed intakes. The effect of cold stress on calves can be negated through adequate nutrition and shelter.

#### *2.2.3.5 Cold stress and health and welfare*

Cattle in cold conditions adopt a number of behavioural strategies to minimise heat loss and increase heat production. These strategies include changes in activity, posture and body orientation in relation to the weather conditions, shivering, and seeking shelter from wind and rain (Schutz et al. 2010). Dairy cattle exposed to wind and rain for seven days were reported to have reduced lying times, greater increases in plasma and faecal cortisol levels, greater total thyroxine (T4), greater NEFA concentrations, and lower total white blood cell numbers than when housed indoors. These changes indicated activation of the stress axis as well as physiological and behavioural adaptations, potentially leading to a reduction in welfare (Webster et al. 2008). Furthermore, the greater metabolic requirements and reduced intake induced by cold, wet and windy conditions may cause hunger in the short term; and, if conditions persist, loss of body condition in the long term, thus compromising welfare (Schutz et al. 2010).

To assess the effects of cold conditions on dairy cattle and their motivation to access shelter, Mathews & Bryant (2010) created a trade-off between access to shelter and access to lying, which is a highly valued activity for dairy cattle. When given the choice between rest and shelter, rest-deprived cows exposed to cold conditions (lower than the LCT) for 48 hours, spent a significantly greater proportion of their time in shelter compared to cows exposed to moderate (-5°C of LCT) or warm (>5°C above LCT) conditions (Mathews & Bryant 2010). This suggests that cattle place a high value on shelter in cold conditions, and may be experiencing hypothermic distress resulting in compromised welfare when exposed to cold conditions (lower than LCT) without shelter.

### *2.2.4 Severe weather events*

Although New Zealand has a naturally variable climate, extreme weather events still have a significant impact (Paine et al. 1998). Extreme events cause disruption to production in dairy systems, usually of a temporary nature. However, in some cases permanent damage to the land or farm and/or regional infrastructure occurs and will have longer run impacts. Variability and extremes are expected to increase in a warming climate. Subject to uncertainties described in Chapter 2, these expectations include longer and more intense droughts, higher temperatures, increased frequency of extreme daily rainfall, and potentially an increase in strong winds.

While the importance of extreme events under climate change is widely recognised (IPCC 2007), in practical terms it is difficult to assess their impact on ecological processes, including agricultural systems, because they are high impact events with extremely low occurrence and short duration. (Jentsch et al. 2007). As with the climate projections (Chapter 2), modelling of the resulting ecological effects is very limited and subject to considerable uncertainty, with a strong tendency toward underestimating extremes (Katz et al. 2005; Quiggin 2007).

The projections of major agricultural droughts (highlighted in Chapter 2) and associated high temperatures would lead to more frequent and widespread feed shortages (Section 3.2) and animal stress events. Extreme heat waves can be devastating and cause significant economic loss (Nardone et al. 2010), particularly if they are unseasonal and arrive abruptly, giving animals little opportunity to acclimatise (Nienaber & Hahn 2007). Effects can be exacerbated by water shortages, as heat-stressed animals can require two to three times as much drinking water as normal (Nardone et al. 2010); and some heat stress relief mechanisms, such as sprinkler cooling rely on water availability (Igono et al. 1985; Urdaz et al. 2006; Ghosh & Shiv 2007).

Flooding is a common adverse weather event for flood-prone dairy regions. Wet and muddy conditions have been shown to negatively impact animal welfare indicators such as skin temperature, lying time and feed intake (Webster et al. 2008; Schulz et al. 2010; (Tucker et al. 2010)) and may increase the risk of mastitis and lameness. Flooding can also facilitate the spread of parasites, faecal pollution and associated pathogens (Brunsdon 1962; Vermunt 1994; Muirhead et al. 2004; Davies-Colley et al. 2008).

The impact of potential increases in wind strength will depend on seasonality. There is presently a tendency for wind force to be highest during the summer (Roche et al. 2009c) which may help to relieve heat stress in cattle through evaporative cooling (Brown-Brandl et al. 2005). However, it may also exacerbate drought effects, by increasing moisture loss from the ground and potentially speeding up the onset of drought conditions (Mullan et al. 2005). In winter, increased wind force may exacerbate the negative effects of wet conditions on animal feeding behaviour (Schutz et al. 2010).

Extreme weather events can increase the vulnerability of the farming system to pests and diseases. From an ecological perspective, they can destabilise ecosystems and create conditions conducive to changes in species composition and distribution (Jentsch et al. 2007; Harley & Paine 2009) and hence pest and disease outbreaks. This effect is exacerbated when a number of extreme events occur in rapid succession. While the role of such disturbances in weakening a community's resistance to invasion is well recognised in the ecological literature (Denny et al. 2009), little attention has so far been paid in the dairy literature to potential compounding effects under extreme weather events such as: the impact of severe environmental stress on cow immune systems, reduced pasture quality and increased invasive potential of pests and diseases.

### 2.2.5 Animal disease threats

Climate change provides potential for increased disease prevalence and severity from existing or novel sources. New diseases are introduced by incursion (from foreign source), emergence (newly developed) or evolution (from a pre-existing source; Morris, 2008). Morris (2008) concluded that a shortage of skills, resources and adequate backing by key people at national level were current weaknesses in preparedness for mitigating disease outbreaks in New Zealand.

Not only may altered climatic conditions be favourable for disease agents, resistance to disease may be concomitantly eroded if the altered condition is stressful on the animal (Nardone et al. 1997). An example is the reported increase in the incidence of mastitis during hot conditions, potentially due to a favourable environment for pathogenic attack (Hogan et al. 1989; Chirico et al. 1997) and a weakened immune system within the heat-stressed cow (Giesecke 1985; Lacetera et al. 2005).

An increased challenge on dairy cow health may come from fungi-related (mycotoxic) diseases if climate change results in a greater prevalence of warm, humid weather; conditions suited to rapid fungus growth – particularly after light rain episodes (Smith & Towers 2002). The most prominent of these diseases is pithomycotoxicosis (facial eczema) where high levels of ingested toxin, sporadesmin, results in liver injury, occlusion of the bile ducts and photosensitisation (Smith & Towers 2002). Affected animals also become less immune competent (Smith & Payne 1991). Other significant mycotoxins on grazed pastures include lolitrem-B and ergovaline; the causative agents in ryegrass staggers (Gallagher et al. 1981, 1984) and tall fescue toxicosis (Schmidt & Osbourn 1993), respectively. Further mycotoxin-related toxic disorders known to occur in New Zealand include ergotism and paspalum staggers (Smith & Towers 2002). Yet another mycotoxin is zearaleone, a phyto-estrogenic compound capable is causing infertility in sheep (Smith & Towers 2002) because the risk period for high levels of zearaleone ingestion coincides with ewe breeding (autumn). Although cattle are considered susceptible, spring breeding practices for cattle in New Zealand avoid this high risk period for zearaleone influence.

Animals are more at risk to ryegrass staggers in hot, dry summers when limited plant growth forces them to graze down into the basal sheath of the plant where lolitrem-B concentrations are highest (Smith & Towers 2002). Incidence of suspected tall fescue toxicosis are infrequent in New Zealand (Brookbanks et al. 1985; Kearns 1987). However, the nature of ergovaline – which is to make animals more susceptible to heat stress – poses an additional threat in the context of the predicted increases in temperature.

### 2.2.6 Feed supply and quality

The direct impacts of climate change on pasture growth and quality reviewed in Section 2.1 of this chapter, highlight potential for both positive and negative changes to the feed base under climate change. Through animal intake and feed nutrition, these have flow on effects to the animal metabolism and ultimately milk production. A weakness of previous climate change assessments is that they tend to focus on one or two climate drivers. When impacts are considered, they examine the pasture and animal separately at best, or have not considered the animal at all (for example the assessments described in Section 2.1.8). To adequately consider feed supply and quality impacts on the dairy cow, and ultimately production, a more holistic approach is needed.

Roche et al. (2009a–d) conducted one of the first whole-dairy system response experiments under open field conditions in New Zealand, where climate variability was traced through to milk solids production. The results highlight the cyclical nature of weather patterns on pasture growth dependencies (Roche et al. 2009a), temporal patterns in pasture quality through the season (Roche et al. 2009b), influence of weather on pasture growth and quality (Roche et al. 2009c), and the effects of weather-dependent pasture supply characteristics on dairy cattle productivity (Roche et al. 2009d). For example, there is a strong positive relationship between herbage quality, as driven by radiation and temperature, and milk protein content. However, the effect is small, at least in a well-managed dairy system where pasture quality is not allowed to vary greatly through optimal tactical grazing. This provides experimental evidence that farm management is able to modify weather-dependent seasonal influence on pasture-animal relationship in open field conditions.

A key insight provided by the experimental work of Roche et al. (2009a–d) is the nature of the complex plant, animal and management relationships that occur in a dairy grazing system. By considering only one climatic driver in isolation, there is considerable scope to misinterpret the risks posed by climate variability and change. Taking a whole-farm systems approach is critical to improving understanding of both climate impacts and adaptations (Dynes et al. 2010). While experimental work is one important approach to improving systems understanding, the use of dynamic whole-farm modelling provides a complementary way to examine these relationships. It also opens up the ability to extrapolate forward, and examine the dairy system under a range of future climatic conditions.

# 3 Modelling the dairy system in a changed climate

## *3.1 Past estimates of combined impact*

Model-based studies of climate impact carried out in New Zealand have largely focussed on climate change effects on pasture growth and abundance, representing the effects of climate and $CO_2$ exchange on photosynthesis (Section 2.1.8). Holistic system-wide responses – like interactions between pasture abundance, feed quality, and the cows, given a shifting physiological state –have not been comprehensively examined. Climate change impact analyses that also include management actions, and or the economic and business aspects of a farm, are similarly uncommon.

Two previous studies have taken a more holistic approach, a case study within Kenny et al. 1995 and Dynes et al. (2010). While both studies include interactions, they focus on gross effects on pasture yield (and in the case of Dynes et al. 2010, report economic indicators). Both are single-site studies in the Waikato and Manawatu respectively. Like the experiments of Roche et al. (2009a–d) described above, both studies illustrate that there are management effects, which could provide a way of turning potential negative climate change impacts into a positive outcomes. This study, along with similar efforts carried out in Australia (Cullen et al. 2009; Holz et al. 2010) and in Ireland (Fitzgerald et al. 2009,) highlight the potential for careful application of dynamic system models when assessing grazing impacts, to explore the complex management-climate-system interactions. The general approach is expanded here using the Primary Sector Adaptation Scenarios (PSAS) described in Chapter 2.

## *3.2 Whole farm modelling*

The DairyNZ Whole Farm Model (WFM) developed by Beukes et al. (2008) is used to simulate the response of the dairy system in past (1980-99) and future climates (a high and low scenario at 2030–49). The WFM represents a pasture-based dairy farm with individual paddocks and cows simulated on a daily time-step. The WFM framework is under continual development for use by the dairy sector, but for this application three main modules have been integrated:

***Molly*** is a mechanistic model of cow metabolism which represents the critical elements of digestion and metabolism. The cow's production is influenced by the quantity and quality of feed and by her metabolic capacity to absorb and convert nutrients into milk (i.e., genetic merit). Molly's feed intake is driven by metabolic demand. Feed quality is described in a feed composition table in the WFM, where the user defines feed fractions for all feeds used in the farm system. The feed fractions are processed through Molly's digestive system and nutrients absorbed into the bloodstream. The metabolic energy content of the feed is, therefore, not an input, but a product of digestion and absorption. Molly predicts enteric methane (CH4), urinary-N, faecal-N, milk, live weight and body condition changes, milk solids (MS = fat + protein) and milk urea-N.

The ***pasture module*** is a weather-driven ecophysiological model of herbage yield coupled to a two-layer soil-water balance. It is the key linkage with climate variability, as it is driven by daily rainfall, temperature radiation and potential evaporation. The pasture module is fully integrated with Molly via an energy and plant herbage mass balance. It has been parameterised for the major pasture species currently used in production (Ryegrass-clover swards), as well as some alternatives like tall fescue.

The ***management/economic module*** is integrated with the biophysical modules and flexible enough to represent the major dairy production systems. It has been developed with high levels of feedback from farm operators, so as to represent the key decisions and strategies of dairy operators. For example, it is able to represent the widely used grass-based system (Dairy system 3), as well as different levels of reliance of purchased feed (systems 1–2 and 4–5). Different milking block/support block designs can be simulated, as well as grazing intensities, strategies and milking timeframes (both seasonal and daily). The module also calculates farm economic returns, integrating climate-production and market risks. For this study, the market risks (input and output prices) remain static, set at the 2010/11 financial year level.

### *3.2.1 Simulating adaptations*

The strength of the WFM for analysis of climate change adaptation is the detailed and realistic way in which management and technologies are represented. The management-economic module is set up with a mix of internal decision rules and inputs. A limitation of many simulation models is that management is represented statically, whereas in an operating system there is a degree of flexibility around decisions. For example in a given WFM simulation, the model can be set up to purchase feed up to a critical economic threshold defined for the farm business, or to graze the paddock to a specified residual. It is important to recognise that the WFM simulations based on 'current management' reflect the dynamic decision making environment of a farm operation given known levels of flexibility.

Changes to current management can also be represented, providing a way of quantifying a subset of the range of potential new adaptations. Some of the main management factors represented by the WFM include:

- Pasture growth response to N applied as either mineral fertilizer or irrigated effluent N.
- Some or all paddocks can be irrigated according to a user-defined irrigation policy.
- Pasture response to irrigation water is determined by soil moisture levels at the time of irrigation.
- Paddocks are grazed rotationally.
- Post-grazing herbage mass influences pasture regrowth.
- Paddocks can be eliminated from the grazing rotation for all or part of the year as part of a cropping policy e.g., maize, cereal or brassica crops.
- Supplements (home-grown or bought) can be fed to cows according to policies created by the user. Other user-defined policies related to cow management include breeding, grazing off the farm, drying off, culling and replacement.

Based on the broad range of adaptation options that have been identified in this review (Section 4.1, Table 3.6), a subset of adaptations have been tested in WFM framework under past and future climates. These follow the broad adaptation classification detailed in Chapter 1, where:

**Current management** is based on producer profiles, and an overview is provided for each region in site reports 1–5 (Section 3.5). This forms a baseline climate impact analysis.

**Tactical adaptations** are well known responses that are currently part of day-to-day management options for farm operators. In this case a standard well understood farm management approach to managing variations in forage supply is used.

**Strategic adaptations** are system-wide changes, based on proven approaches from other districts or systems. In the WFM experiments, the examples selected were irrigation, pasture species change and reducing stocking rate.

The specific site-level tactical and strategic level adaptations used in the modelling are summarised as follows:

**Southland:** no tactical adaptations were assessed. A strategic change was made to the system where allocation of effluent irrigation was used in shoulder seasons. A second change was investigated reducing system intensity by a 15 per cent reduction is stocking rate.

**Canterbury:** a tactical adaptation was examined where feed flexibility was built into the systems. This included widening the forage conservation time window establishing more conservation paddocks; making silage when biomass in a paddock went over 4000kg/ha and feeding cows to demand whenever there is silage in the feed store. In this system irrigation was removed as a strategic adaptation. Tall fescue was introduced to investigate the effect of a strategic change (along with removal of irrigation). Lowering system intensity (15% reduction in stocking rate) was also examined.

**Taranaki:** the same set of adaptations were investigated here, except that irrigation was included a strategic adaptation. The rule was to irrigate 6mm/ha when soil moisture goes is 75% of field capacity between Oct-Apr.

**Waikato:** explored the same set of adaptations as the Taranaki system.

**Northland:** explored the same set of adaptations as Waikato and Taranaki.

### *3.2.2 Assessing system and cumulative impacts*

A key decision in climate change impact analysis is the choice of farm performance indicator. This depends on use and experimental design; whether specific diagnosis of the effects of individual climate drivers is required; whether the implications of the broader operating environments are to be considered; or whether a direct impact indicator is needed or a more holistic system response. The WFM simulates a wide range of metrics that allow the response of the dairy system to be tracked comprehensively. To conveniently analyse the question of productivity benefits, a set of farm performance indicators were selected from this broad range:

**Pasture growth**. This provides a generalised indicator of the direct impacts of change, integrating the combined effect of climate drivers on the farm biophysical ecosystem.

**Milk solids production**. This provides an integrated view of the combined production effects on the dairy cow and pasture system.

**Farm operating profit** .This is used as holistic system response indicator. Through input and output pricing, this also integrates the broader operating environment into the analysis given pricing levels at 2010/11.

A key alteration made to the WFM for this study was to introduce a degree of inter-annual carryover within the management module. This quantifies some of the cumulative impacts of climate change in terms of a farms operating position. To achieve this, the twenty year current (1980–99) and future (2030–49) periods were divided into two separate 10-year model runs, with the results amalgamated. Effects like carry-over from drought and year to year financial operating position are included in the analysis of farm financial indicators. Some cumulative biophysical impacts were not, such as cow body condition and corresponding stocking rate adjustments. These were re-set every year to average levels.

### 3.2.3 *Regional design*

To support a comprehensive analysis, the WFM was set-up for five representative farms across the main dairy regions of New Zealand (Figure 3.6). This was achieved with the aid of farm managers and parameterisation using available production data. When benchmarked with the DAIRYBASE data sets each farm represented the mid to upper quartile of management performance, thereby providing a baseline of current management practice in each region.

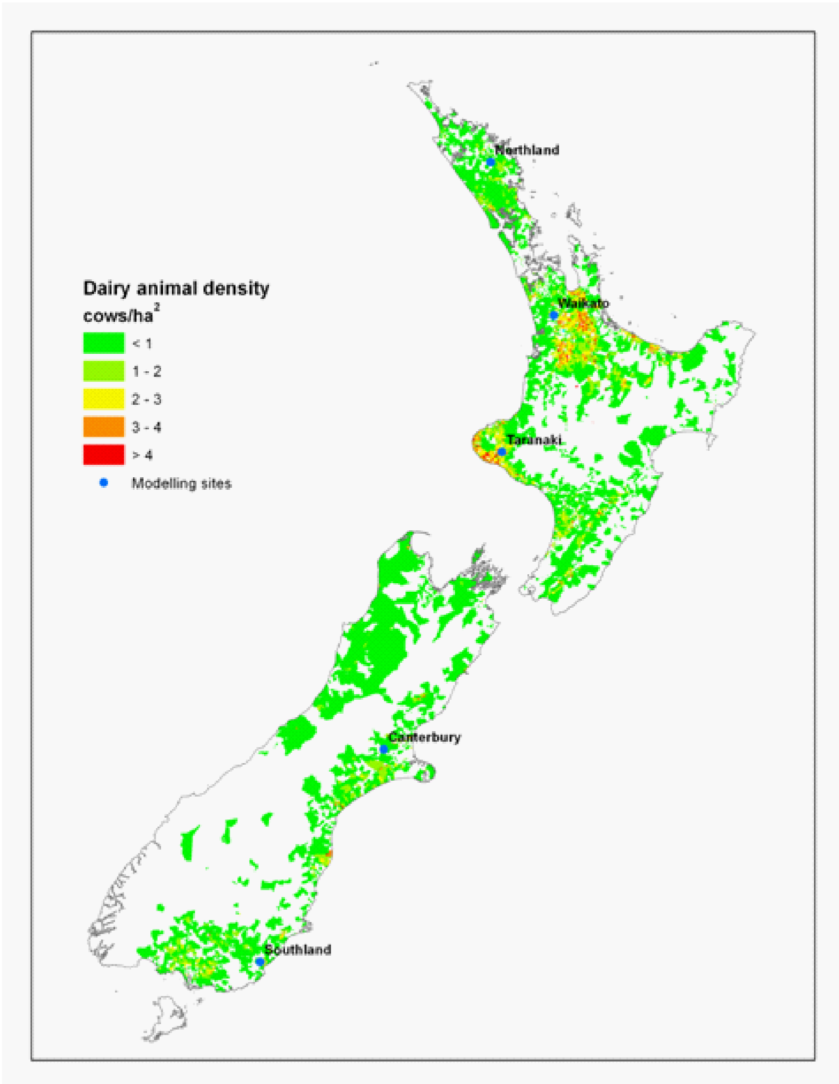



**Figure 3.6.** The five modelling sites used in this study to represent regional effects. Data on stock density is sourced from based on the 2007 Agricultural Census.

## 3.3 *Sector overview*

To provide a broad level summary of gross effects across the dairy sector, the operating profit data is pooled across all sites and classified according to the general adaptation levels. A plot summarising the variability in response across all years and sites is presented in Figure 3.7. Small but negative changes in the median operating profit are evident between the past (1980–99) and both future (2030–49 high and low) climate scenarios under current management. However, there are more important changes when the variability of operating profit response is considered. The future period under current management has a shift toward more negative or low income years when compared with current climate. Although not shown, there is an increase (approaching a doubling) in the number of negative outliers in the future climate under current management than under recent conditions. This is consistent with an increase in the frequency of the type of drought in the future climatic regime that would lead to financial losses for the farm business.

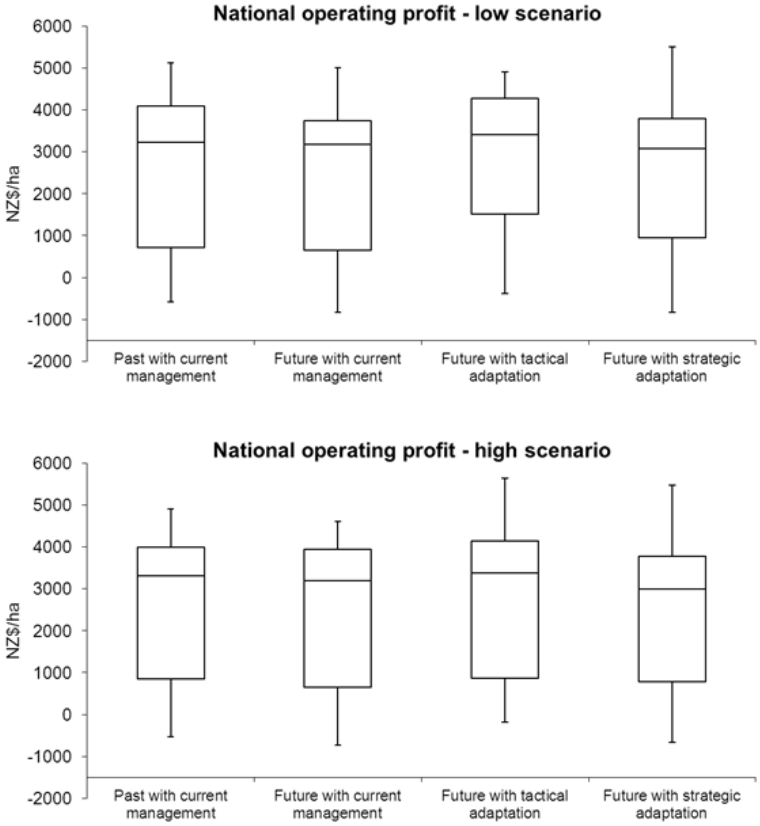



**Figure 3.7.** Average responses across 5 sites and for general adaptation categories. Responses in farm operating profit under past (1980–99) and future climates (2030–49, high and low scenarios) with tactical and strategic adaptation. Line is the median, boxes are the inter-quartile range and whiskers show 1.5 times the inter-quartile range.

Under future climate conditions, and when the farm implements tactical adaptation (optimal grazing management and conservation), there is a lift in median operating profit in the future climate. The impacts on operating profit from droughts under current management reported above are seemingly reduced or avoided. This adaptation also enables the farming system to capitalise on good years, with a dramatic increase in the upper quartile of operating profit.

When data from all three strategic adaptations are pooled, there is a wide spread of results. There is a small negative change in median operating profit compared with past climate under current management. Many of the drought effects remain, with similar levels of negative profit years with current management (past and future climate). At the other end of the scale, the strategic adaptations were also able to capture more profit in good years similar to those described for tactical adaptation.

These results provide further ratification of the principle that management can be configured in a way to reduce negative impacts and capture opportunities presented by climate variability expected in the future, at least the ones encapsulated in the PSAS. While examination of results by pooling data across all sites provides a sector overview, it also masks some of the important detail that is experienced at the regional level and within the farm system.

## *3.4 Seasonal agronomic change*

An informative way to track the agronomic level impact of climate change on dairy systems is to examine changes in the seasonal profile of pasture production. The deviations in future climate (2030–49) from past climate (1980–99) under current management in 'on average' seasonal pasture growth are shown in Figure 3.8. Although these reflect the complex seasonal interactions between temperature and water limitation on growth, as a general rule climate change brings some challenges to production timing by changing the length of the season and also increasing or reducing potential yield at different times. The seasonal changes reported at a site level in Figure 3.8 are consistent with the seasonal changes mapped across the country in Figure 3.4 – the latter providing a reasonable guide for those wishing to interpret specific results for their local area and transfer some of the core principles found in this more detailed approach to modelling. These agronomic shifts are also consistent with changes reported in previous modelling studies and interpretive reviews (for example Clark et al. 1999; Dynes 2010 and pasture simulations in Chapter 4).

When considered on a site by-site basis, these changes are complex and there are subtle but important whole system responses. For example in Northland, pastures growing under future climatic conditions would increase yields when temperatures are optimal for growth, but experience an earlier and more pronounced summer, with this effect exacerbated in the high (warmer) climate. As shown in Site report 1 in Section 3.5, current management allows this summer feed gap to be compensated for by supplementary feeding, with negative production impacts (milk solids) under the high climate scenario (a significantly shorter milking season); but there are positive production impacts under the low scenario (less intense change in summer, and more growth in late spring).

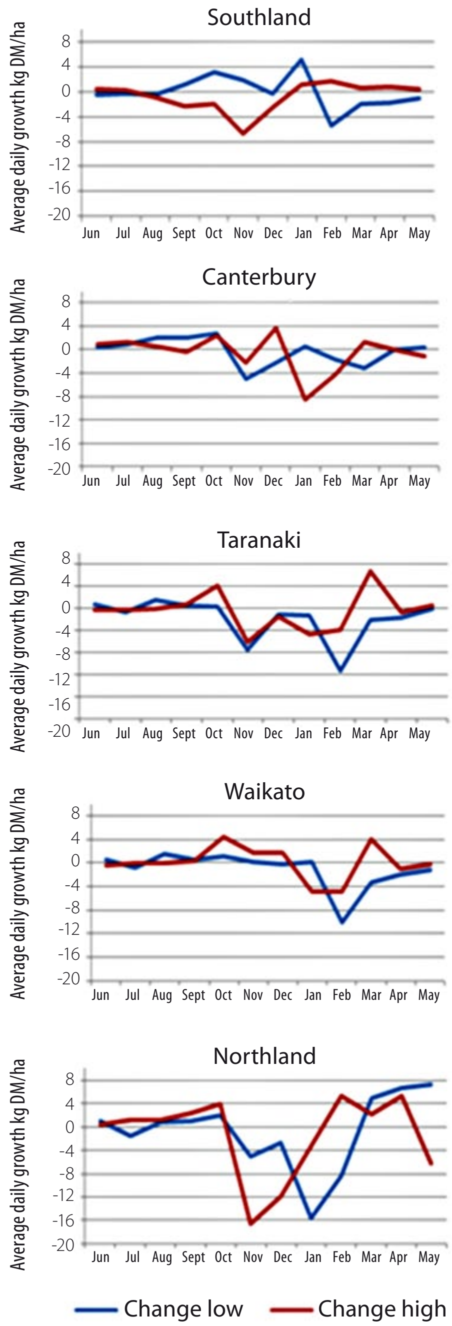



**Figure 3.8.** Pasture growth rate differences in 2030–49 from past (1980–99) climate under current management. Change low and Change high are the Primary Sector Adaptation Scenarios (PSAS).

## 3.5 *Regional profiles*

Regional analysis and interpretation of the WFM modelling results are provided in Site reports 1–5 below. These are accompanied by interpretations which provide a specific site-by-site level guide to the complex effects and responses that occur in a dairy farming system under climate change. A simple overview assessment is provided in Table 3.5 considering the direction of change from past climate (1980–99) across all farm performance indicators under the two future climate scenarios. This presents a classification of the results, according to where there is consistent evidence around the direction of change given this range of factors.

**Table 3.5.** Overall assessment of dairy productivity and profitability indicators given current management, tactical and strategic adaptations under future climate scenarios (high, low). Dairy performance indicators are simulated by the DairyNZ Whole Farm Model (WFM).

| *Impact analysis* | *Management profile* | *Southland* | *Canterbury* | *Taranaki* | *Waikato* | *Northland* |
|---|---|---|---|---|---|---|
| | Current management | (red) | (red) | (red) | (red) | (orange) |
| **Tactical adaptation** | Silage conservation & targeted grazing | (black) | (light blue) | (green) | (orange) | (green) |
| **Strategic adaptations** | Irrigation | (green) | (red) * | (red) | (orange) | (light blue) |
| | Pasture species change | (black) | (green) * | (green) | (green) | (light blue) |
| | Reduced stocking rate | (light blue) | (red) | (red) | (red) | (red) |

Key:

| | |
|---|---|
| (green) | Consistently positive under the climate scenario tested |
| (light blue) | Majority of indicators positive under most climate change projections |
| (orange) | Majority of indicators neutral or negative in most climate change projections |
| (red) | Consistently negative across many indicators under a range of climate change projections |
| * | is removal of irrigation from the Canterbury system |
| (black) | Not assessed |

Considering the summary classification in Table 3.5 and the more detailed analyses in Site reports 1–5, an overview highlighting the main strategic level insights from the WFM modelling is provided here:

- Across all sites, there was a mild to moderate negative effect on production and profitability under climate change when current management is pursued.
- Understanding the complex seasonal changes in pasture production is critical to understanding the impact of climate change. The modern dairy system is geared toward high levels of pasture utilisation, so even small changes to the variability of feed from on-farm pastures can lead to large changes in operating profit
- The tactical adaptation tested (conservation paddocks and optimal utilisation of surplus pasture) is an illustration of a standard risk management strategy to manage seasonal feed deficits, increasing flexibility around 'animal nutrition'. It is one way of reducing the vulnerability of a grass-based system to climate-induced feed deficits. The specific example tested in the modelling was not only able to compensate for the effect of climate change, but continued to improve productivity and profitability across all sites and climate scenarios. As described in Section 4, this is one of a broad range of tactical adaptation options available to New Zealand dairy farmers that would increase flexibility around home-grown feed.
- The mixed results found across the three strategic adaptations demonstrate that it is also possible to pursue a both a 'more' or a 'less' optimal course of adaptation under climate change. For example, a

blanket policy aimed at reducing stocking rates alone would place downward pressure on profitability, leading to negative downside risks for a farm business. This is arguably a form of 'maladaptation', at least in terms of farm profitability in current market settings, where a series of unintended consequences arise from a positively motivated change. Although some adaptation options ameliorate production losses, they are not always cost-effective solutions. Care needs to be taken when moving adaptation toward on-farm implementation. It needs to be supported by sound analysis within an adaptive management framework.

- The modelling experiments have followed a number of illustrative examples and it is important to recognise the role of context in farm management and change. Personal preferences, attitudes to risk, skills, resources available, market risk, environmental goals and regulatory constraints all influence current management settings and the viability of adaptation options. While it is possible to highlight strategic directions for the Dairy farming system (for example 'flexibility around home grown feed'), it is not possible to make specific blanket recommendations about technologies and practices – as the choice of appropriate adaptation strategies will depend on individual farm circumstances.

# Site report 1: NORTHLAND

## Current management

**Support block:** includes dry stock

**Milking platform:** 75 ha

**Stocking rate:** 2.4 cows/ha

**Milking:** Once a day

**Crop:** Turnip brassica

**Irrigation:** None

**Silage:** No

**N Fertiliser:** 200kg N/ha

**Drying off:** 10 May, earlier if covers are low

**Calving starts:** 14 July

**Purchase supplements:** Palm kernel, silage

## Tactical adaptations

Increased silage production
Cut paddocks when cover over 4000kg/ha
Conservation paddocks (Oct-Apr)
Cows fed to demand

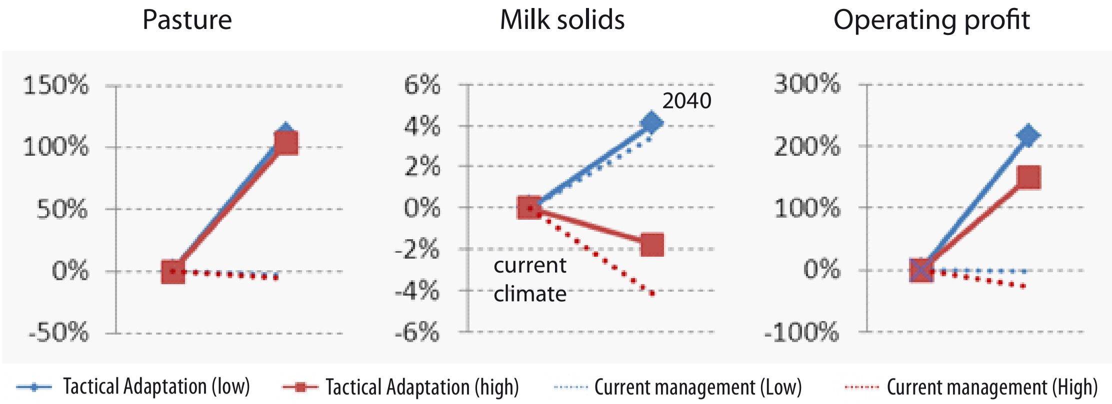
## Strategic adaptations

Irrigate
6mm/ha if soil moisture blow 75% field capacity

Change pasture species
Tall fescue

Reduce stocking rate
15% (2 cows/ha)

## Current management, tactical and strategic adaptations under future low and high climate scenarios




% changes in 20 year averages from current climate (1980-99) (red) at 2040 (2030-49) (blue)

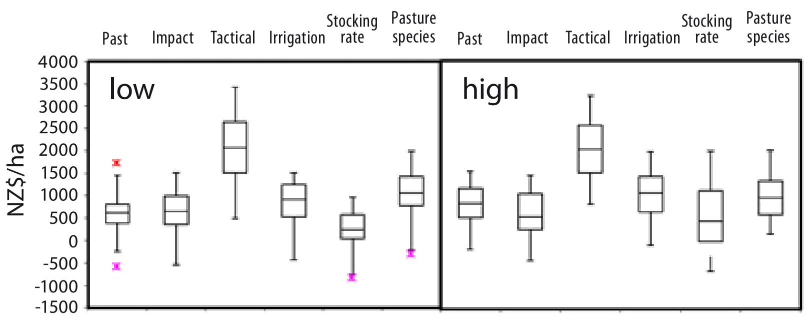
**Current management:** results in negative mean pasture production in a future climate, with different seasonal shifts between high and low. Increased milk solids in low climate due to extension of milk production window under temperature change. Current policy of purchasing feed at times of deficit creates downward pressure on farm profitability. Increased variability in profit, with slightly higher risk of negative profit.

**Tactical adaptation:** conservative timely grazing with a cost effective/flexible feed source lifted productivity. Strong upward pressure on farm profitability across the range of changed climate. Decreased likelihood of negative profit years.

Strategic adaptations:

- *Reduced stocking* lowered performance
- Introducing *irrigation* and a *new pasture species* lifted productive performance and profitability. No reduction in risk of negative profit years
- Outcomes hold across the range of future climate change

### Variability in operating profit




*Impact is current management
Assumes 2010/11 input costs and prices

## Site report 2: WAIKATO

**Current management**

**Support block:** 30 ha

**Milking platform:** 175 ha

**Stocking rate:** 3.7 cows/ha

**Milking:** Twice a day

**Crop:** Maize

**Irrigation:** Effluent

**Silage:** No

**N Fertiliser:** 180kg N/ha

**Drying off:** Depends on May milk yield

**Calving starts:** 7 July

**Purchase supplements:** Palm kernel, maize silage

**Tactical adaptations**

Conservation paddocks
Cut paddocks when cover over 4000kg/ha
Cows fed to demand

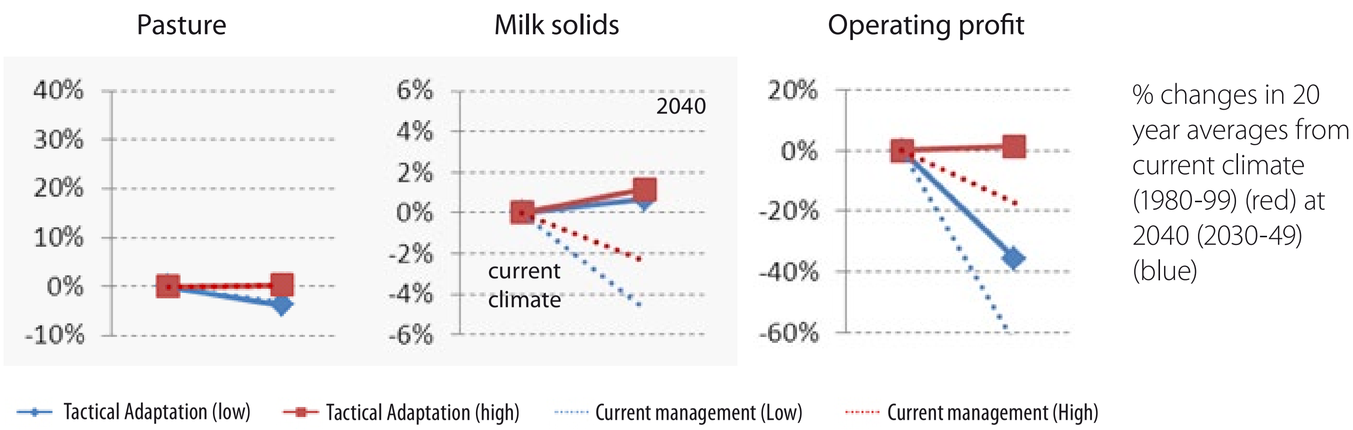
**Strategic adaptations**

Irrigate
6mm/ha if soil moisture blow 75% field capacity

Change pasture species
Tall fescue

Reduce stocking rate
-15% (3.1 cows/ha)

### Current management, tactical and strategic adaptations under future low and high climate scenarios



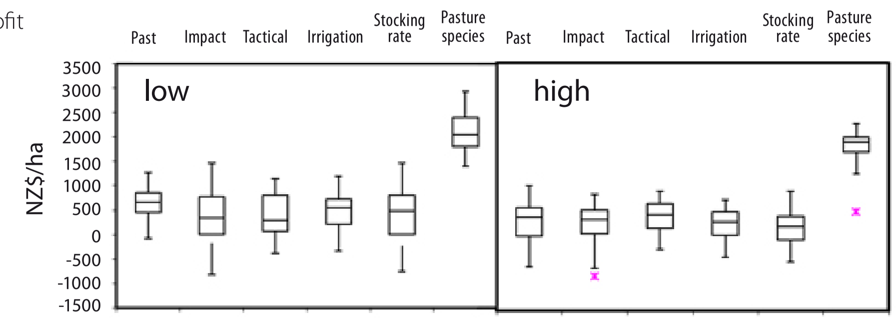

**Current management:** negative mean pasture production in a low future climate with minimal change in the high climate due to warmer temperatures. The current system relies on maize imports to manage feed deficits, but not enough could be imported due to current policies and an overall reduction in milk production occurred. Strong downward pressure on profit with increased exposure to risk of negative profit.

**Tactical adaptation:** using conservation paddocks and making silage lifted productivity. This was not profitable in the low climate and risk of negative profit years remained. It was profit neutral in the high climate scenario and negative profit risk is around current levels.

Strategic adaptations:

- *Reduced stocking* lowered average profit and increased risk
- Introducing *irrigation* was profit and production neutral
- Introducing a *new pasture species lifted* productive performance and profitability, reducing risk of negative profit years
- Outcomes hold across the range of future climate change

### Variability in operating profit



## Site report 3: TARANAKI

### Current management

**Support block:** 53 ha

**Milking platform:** 104 ha

**Stocking rate:** 3.6 cows/ha

**Milking:** Twice a day

**Crop:** No

**Irrigation:** Effluent

**Silage:** No

**N Fertiliser:** 200kg N/ha

**Drying off:** Depends on May pasture cover

**Calving starts:**19 July

**Purchase supplements:** Palm kernel, maize, silage, molasses

### Tactical adaptations

Conservation paddocks
 Cut paddocks when cover over 4000kg/ha
 Cows fed to demand

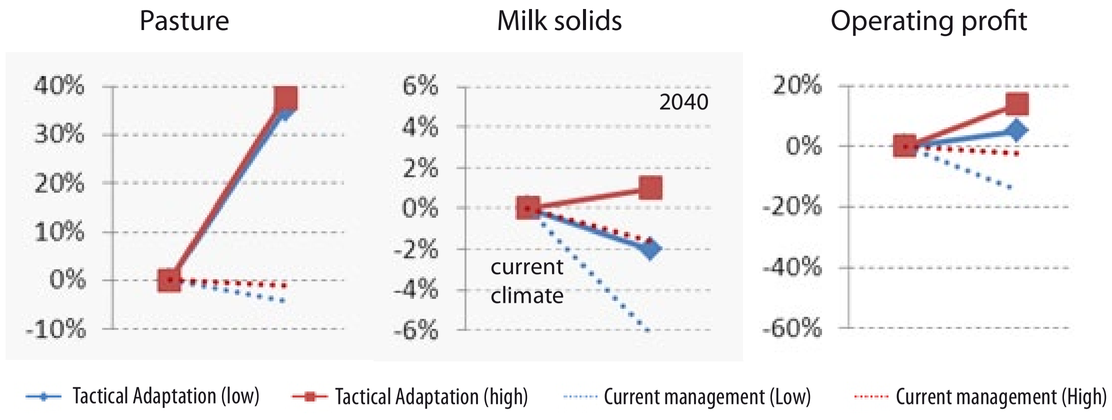
### Strategic adaptations

Irrigate
 6mm/ha if soil moisture blow 75% field capacity

Change pasture species
 Tall fescue

Reduce stocking rate
 -15% (3.0 cows/ha)

## Current management, tactical and strategic adaptations under future low and high climate scenarios




% changes in 20 year averages from current climate (1980-99) (red) at 2040 (2030-49) (blue)

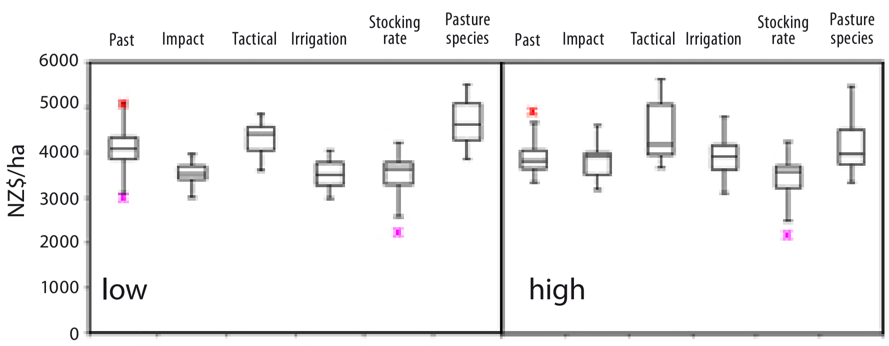
**Current management:** in a changed climate results in negative mean pasture production, milk solids and operating profit, increasing the risk of low income years. This occurs across the range of climate change.

**Tactical adaptation:** using conservation paddocks and feeding silage to demand lifted overall pasture performance, lifting milk solids in a high but not in a low degree of climate change. There is upward pressure on operating profit in across the range of climate change. Higher average profits and the increasing chance of high profit years in the high climate are because the warmer temperatures open up new production opportunities.

Strategic adaptations:

- *Reduced stocking* and irrigation lower profitability and increased risk
- Introducing a *new pasture species* lifted productive performance and profitability, reducing risk of negative profit years. This effect was stronger in the low climate scenario

### Variability in operating profit



# Site report 4: CANTERBURY

**Current management**

**Support block:** part of large operation

**Milking platform:** 141 ha

**Stocking rate:** 3.8 cows/ha

**Milking:** Twice a day

**Crop:** No

**Irrigation:** Uses full allocation

**Silage:** No

**N Fertiliser:** 200kg N/ha

**Drying off:** 25 May, earlier cows are in low body condition score

**Calving starts:** 1 August

**Purchase supplements:** Palm kernel, silage

**Tactical adaptations**

Conservation paddocks
Cut paddocks when cover over 4000kg/ha
Cows fed to demand

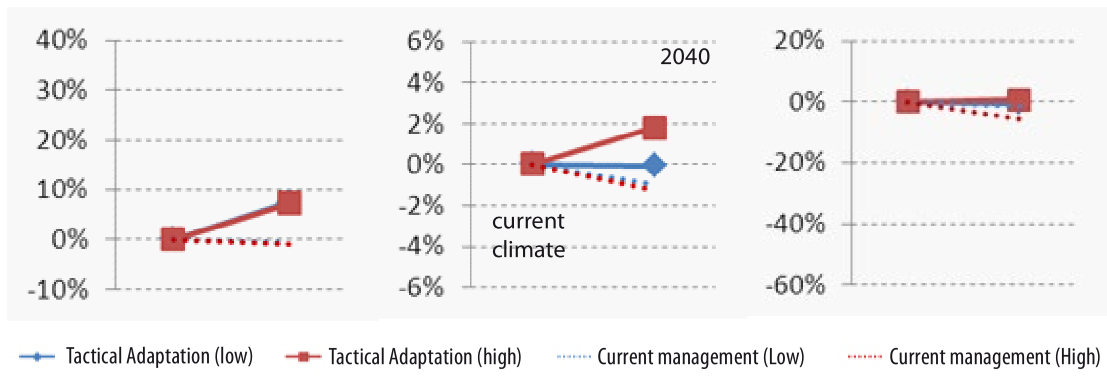
**Strategic adaptations**

Remove irrigation

Change pasture species
Tall fescue with no irrigation

Reduce stocking rate
-15% (3.3 cows/ha) with irrigation

## Current management, tactical and strategic adaptations under future low and high climate scenarios




% changes in 20 year averages from current climate (1980-99) (red) at 2040 (2030-49) (blue)

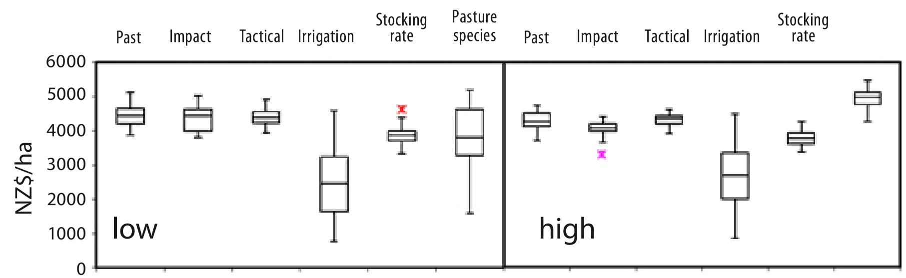
**Current management:** in a changed climate results in negative mean pasture production, milk solids and operating profit, increasing the risk of low income years, particularly in the high climate.

**Tactical adaptation:**using conservation paddocks and feeding silage to demand lifted overall pasture performance, lifting milk solids under climate change. This avoided the downward pressure on average profitability under current management, bringing it back to present levels. There was an identifiable reduction in low profit years, particularly in the high climate scenario.

**Strategic adaptations:**

- *Removing irrigation* lowers profitability and heightens risk, and is a mal-adaptation. Similar effects occur with the *new pastures species (irrigation removed)* in the low climate change scenario and to a lesser extent *lowering stocking rate*
- Introducing a *new pasture species* lifted productive performance and profitability in a high climate, despite the removal or irrigation, taking advantage of higher temperatures and changed rainfall patterns

### Variability in operating profit



# Site report 5: SOUTHLAND

## Current management

**Support block:** 88ha.

**Milking platform:** 166 ha

**Stocking rate:** 2.9 cows/ha

**Milking:** Twice a day

**Crop:** Turnip, swedes

**Irrigation:** Effluent

**Silage:** Yes, conservation blocks

**N Fertiliser:** 140kg N/ha

**Drying off:** based on milk yields and pugging risk.

**Calving starts:** 9 August

**Purchase supplements:** Silage, maize

## Tactical adaptations

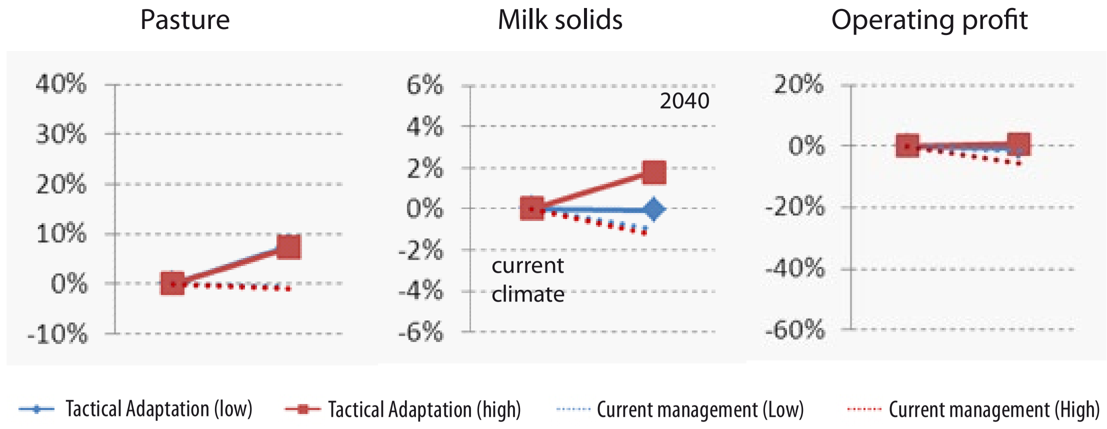
Increased silage production is current practice

## Strategic adaptations

Irrigate
6mm/ha if soil moisture blow 75% field capacity

Reduce stocking rate
15% (2 cows/ha)

## Current management, tactical and strategic adaptations under future low and high climate scenarios



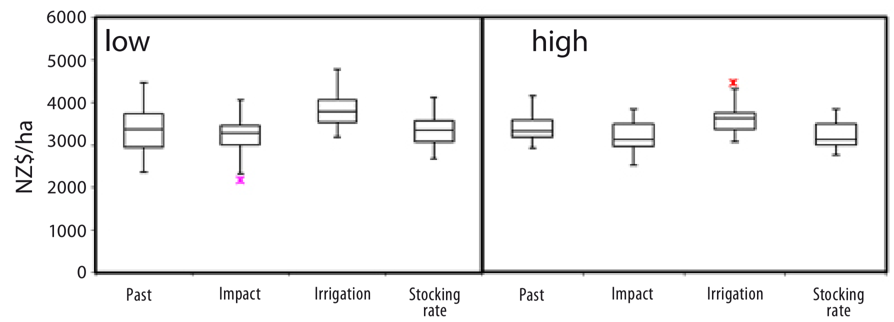

% changes in 20 year averages from current climate (1980-99) (red) at 2040 (2030-49) (blue)

**Current management:** results in small reductions in mean pasture, milk solids and operating profit. There is increased variability Increased variability in profit, with slightly higher risk of negative profit years.

Strategic adaptations:

- *Reduced stocking* resulted in no overall shift in mean performance, but did reduce the risk of low operating profit, although opportunities were also missed in in good years
- Introducing targeted *irrigation* (possibly with effluent) allowed some new 'shoulder season' production opportunities to be exploited as temperatures rise. The practice increased average profit, lowered risk in poor years and increased profits in good years. This occurred across the range of climate outcomes

### Variability in operating profit



## 3.6 Using model-based assessments

Modelling the complex responses of whole farm systems under climate change provides an illustration of what could happen under a range of future climate and management scenarios. This is a quantitative method to examine the function of a complex system like a dairy farm. It is able to provide a more holistic analysis of climate change than is possible through the more common approach of assessing individual climate variables and responses in only part of the farm system. Careful interpretation allows some key strategic insights to be developed, as well as providing another line of evidence to test the degree to which management influences the level of impact under climate change.

However, modelling studies have their limitations and it is important to consider the WFM experiments carried out here in a broader context. There are biological processes and management options that cannot be modelled effectively given current techniques. For example, changes to pasture composition in a competitive sward are not modelled in the current framework, so the prospect of increasing abundance of kikuyu grass to in northern dairy pasture swards has not been assessed. Similarly, existing modelling architectures does not support analysis of pests, diseases and animal health effects. There are also a number of specific potential adaptation options that the WFM can investigate which were not examined in this study, for example the use of imported feeds to manage seasonal nutrition deficits.

The most important limitation when applying farm systems models to climate change and variability analyses, are their inability to quantify the full range of cumulative impacts. For example, while the modelling study accounted for financial year-to year carryover from changed drought and grass production seasonality, it did not quantify the cumulative impacts from a succession hazardous events. Quantifying cumulative impacts under climate change remains elusive at the climate (frequency) and at the biological/land system levels. The on-going costs and its implications for farm financial performance have not been studied.

For these reasons, it is important to recognise both the benefits and limitations of holistic farm model analysis and to use them in a broader context. In this chapter, these model results should be considered within the broader review of dairy system adaptation options (Section 4). In terms of further implementation, the results serve as a useful piece of information for illustrating some general principles as part of discussion with rural professionals and farmers, but do not allow the formation of 'management prescriptions' around adaptations to pursue at the regional and farm level.

# 4 Adapting the dairy system

## 4.1 Adaptation summary

Production and farm management information related to climate variability and change has been reviewed for dairy farming systems in New Zealand. This review draws on a range of scientific and professional literature, as well as numerous industry programmes, initiatives and decision support systems. Although climate variability is a factor in farm management, this body of material does not always consider seasonal variations and longer-term climate change specifically, nor has the climate change impact community fully accessed the depth of knowledge available on farm management. This section provides a step toward a more integrated approach, by reviewing the relevant mainstream production system knowledge and identifying key potential climate adaptations. These adaptations are classified according to different adaptation levels defined in Chapter 1 (and used in the modelling experiments in Section 3). A summary of the key adaptation options identified is provided in Table 3.6, while Sections 4.2 to 4.4 describe them in more detail.

**Table 3.6.** Adaptation knowledge summary for the dairy sector.

| ***Driver*** | ***Impact*** | ***Tactical*** | ***Strategic*** | ***Transformational*** |
|---|---|---|---|---|
| Higher seasonal temperature | • Changes to seasonal herbage yield<br>• Earlier reproductive development<br>• Increased weed and subtropical $C_4$ grass ingress into pastures<br>• Reduced herbage quality<br>• Increased geographical spread of pests and diseases | • Change stocking rates<br>• Lengthen lactations<br>• Produce more silage/hay<br>• Alter calving patterns<br>• Alter grazing rotation lengths<br>• Improve pasture assessment and monitoring<br>• Use alternative pasture/crop species that are more heat-tolerant<br>• Sow endophyte-containing species<br>• Use crops to break pest cycles | • Use newly developed plants adapted to warmer temperatures | • Use newly developed plants adapted to warmer temperatures<br>• Invest in research to genetically modify plants for increased heat-tolerance |
| Heat stress | • Reduced intake<br>• Reduced production | • Alleviate by cooling during milking<br>• Minimise animal movement during the day | • Outdoor shades<br>• Cow selection for heat tolerance | • Move away from heat stress regions |
| Cold stress | • Improved cow welfare<br>• Reduced feed efficiency | • Shelter | • Wintering systems for supplement feeding | • Winter housing in cold regions |
| Low water availability | • Reduced herbage yield<br>• Reduced pasture persistence<br>• Increased weed and subtropical $C_4$ grass ingress into pastures<br>• Reduced herbage quality | • Use irrigation where available<br>• Use alternative pasture/ crop species that are more drought-tolerant/water use efficient<br>• Reduce stocking rates<br>• Improve pasture assessment and monitoring<br>• Use supplementary feed to fill feed deficits<br>• Conduct pasture renewal | • Use newly developed plants adapted to drought or that are more water use efficient<br>• Invest in new irrigation infrastructure<br>• Invest in infrastructure required to store and distribute supplementary feeds<br>• Revegetation and soil organic carbon management to improve groundwater recharge and maintain soil moisture | • Use newly developed plants adapted to drought or that are more water use efficient<br>• Invest in research to genetically modify plants for increased drought-tolerance and/or water use efficiency |
| Waterlogging and flooding | • Reduced herbage yield<br>• Reduced pasture persistence<br>• Increased weed and subtropical $C_4$ grass ingress into pastures<br>• Reduced herbage quality | • Reduce stocking rates in prone regions<br>• Improve pasture assessment and monitoring<br>• Use more supplementary feed to fill feed deficits<br>• Conduct pasture renewal | • Invest in infrastructure required to store and distribute supplementary feeds | |
| Increased $CO_2$ concentrations | • Increased herbage yield (potential depends on N available to plants)<br>• Increased legume content in pastures<br>• Increased water use efficiency | • Increase stocking rates<br>• Lengthen lactation period<br>• Produce more silage/hay<br>• Alter calving patterns<br>• Increase pasture diversity<br>• Increase fertiliser applied | | |

## 4.2 Tactical adaptations

Tactical adaptation involves modifying the existing production system using current well known management practices. Adoption of these options would extend the current levels of adaptive capacity to its full potential given the limits of current knowledge and skills. These are the management responses that dairy operators can readily adjust now with good levels of confidence, high levels of knowledge and relatively minimal investment. They have wide appeal because they are tangible, visible and familiar and may be an effective response at low levels of exposure to climate change.

### 4.2.1 Farm management

The prospects of increased feed variability and seasonal shifts under climate change are well identified, and potentially the most significant impacts of climate change for the sector. New Zealand dairy systems have a range of farm management tools that provide a means of adapting, and a general overview is provided in Table 3.7.

New Zealand dairy pastures are grazed with emphasis on paddock rotation, where the return period is long to begin with, hastening as demand increases post-calving and during lactation. This creates a 'feed wedge' where pastures in individual paddocks are in a different state of regrowth, keeping them in an optimal growth rate. At some point in the season demand will match supply: this is around 20 September in the Waikato up to the 20 October in Southland, but this varies depending upon seasonal constraints. For grass-based production, calving date is generally around 50–70 days before the balance date. This system can be adjusted depending upon seasonal conditions, where in times of pasture surplus, farm managers readily increase stocking rates, alter calving patterns, extend lactations and/or produce silage/hay. Conversely, in times of pasture deficit farmers tactically reduce the systems intensity and make numerous timing adjustments. Temporarily shifting the farming system away from its reliance on grass-based feeds is also a form of seasonal adjustment. The industry is rich in technical information on these approaches (for example the Agri-Seeds 2012). There are also ongoing programmes of farm benchmarking, farm field days and others that support information transfer. This level of description has not been repeated here, but a shortened guide to some of the underlying science is provided in Box 3.1.

**Table 3.7.** Overview of existing farm management options (tactical and strategic adaptations) to cope with changes in seasons and temporary feed deficits.

| | ***Tactical*** (temporarily reduce exposure) | ***Strategic*** (shift seasonal timing and intensity) |
|---|---|---|
| Times of increased feed (e.g., higher growth in spring) | Buy in and store grain or supplements at times of surplus when they are cheaper | Increasing stocking rates |
| | Adjusting rotation planning (pasture wedge) | Extension of lactation |
| | Establish conservation paddocks | Bring forward calving |
| | Growth of forage crops to increase feed reserves | Production of more silage/hay |
| Times of feed deficit (e.g., longer, more severe summer, autumn droughts) | Emergency purchase of feed | Decreased stocking rate |
| | Adjusting rotation planning (pasture wedge) | Early dry-off |
| | Utilisation of conserved fodder/crops | Delayed calving |
| | Wintering off farm | Utilise stored feed |

Testing the limits of current farm management tools under a range of climate scenarios provides important guidance around the degree of exposure of current systems and their inbuilt levels of resilience. Modelling studies in southeastern Australia and Tasmania (Cullen et al. 2009), Europe (Baars & Rollo 1990) and Ireland (Fitzgerald et al. 2009) all highlight that current dairy farm management adjustments provide an effective response under climate change scenarios. Modelling highlights similar potential in the New Zealand context (Section 3), also factoring in a number of carryover effects from multiple cumulative impacts. However, because of limitations in both climate and production systems modelling, it is also important to consider the need to reduce the overall exposure by making more permanent shifts away from current systems. These shifts could include, for instance, reducing overall intensity or increasing it. This more strategic level of response is reviewed in Section 4.3.

**Box 3.1.** The science of dairy farm management.

### Rotation length

More precise grazing is another adaptation to shifts in feed supply and demand. For optimal management of dairy systems farmers often base grazing intervals or rotation lengths on grass leaf appearance rates. In well-utilised, rotationally grazed pastures, perennial ryegrass regrowth has been observed to follow the stages presented in Figure 3.9.

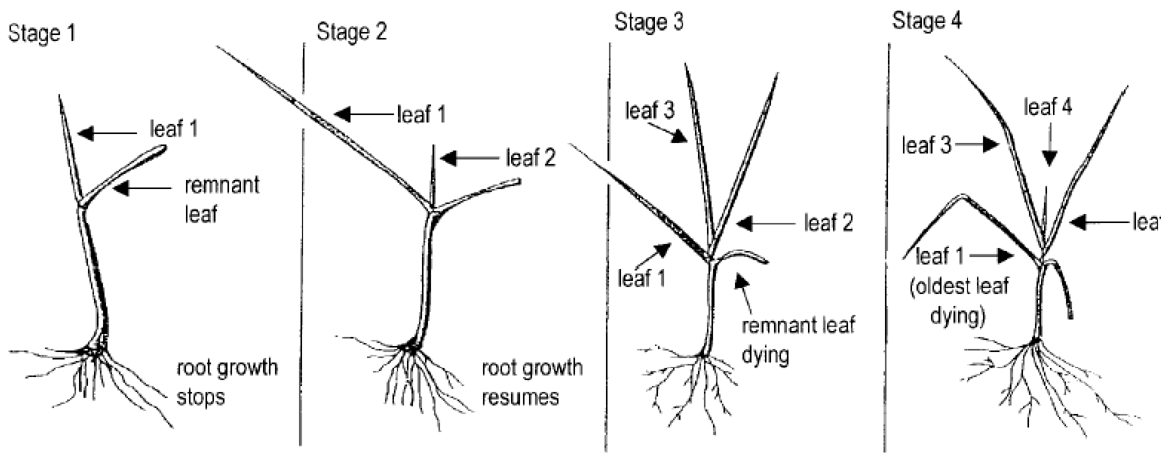



**Figure 3.9.** Regrowth stages of a perennial ryegrass tiller following defoliation. (Source: Donaghy 1998).

The optimal time for grazing perennial ryegrass pastures is between when two and three new leaves have fully emerged post-grazing, i.e., between the 2- and 3-leaf stages of regrowth (Fulkerson & Donaghy 2001). This is during the period of maximum pasture growth but before senescence begins, thus ensuring high pasture quality. Similar leaf stage-based grazing recommendations are available for tall fescue (between the 2- and 4-leaf stages; Donaghy et al. 2008), cocksfoot (4-leaf stage; Rawnsley et al. 2002; Turner et al. 2006a) and prairie grass (4-leaf stage; Turner et al. 2006b; 2007).

As the temperature increases over the next century, grass leaves are likely to appear more quickly because temperature is the major determinant of leaf emergence under sufficient moisture availability (Mitchell 1953; Silsbury 1970). This increase in the rate of leaf appearance will likely mean that grass-based pastures will reach the optimal stage for grazing (between the 2- and 4-leaf stages of regrowth depending on the predominant grass species) more quickly. Thus shortening rotation lengths in the future should ensure that pastures are grazed during their period of optimal growth and nutritive value.

### Timing adjustments

Day-to-day adjustment (e.g., avoid hot midday period), through to seasonal ones (e.g., avoid summer) can be made to managerial routines/systems to reduce the deleterious impacts of environmental extremes on cow production and reproduction. Infrared thermal imaging studies have demonstrated that walking to the dairy shed for the afternoon milking increases the heat loading on cows; longer walking distances result in greater body temperature increases and respiration rates (Verkerk et al. 2006). In addition to providing shade and water sprinkling during milking, possible adaptation options include once-daily milking, delaying the timing of the afternoon milking until the heat-stress risk has reduced, and having cows graze closer to the dairy shed during the hottest days. Survey data (Tucker et al. 2005) indicated these are options sometimes used by farmers during particularly hot summer periods.

A heat or cold stress forecasting service based on a thermal stress model may be available to New Zealand farmers in the near future (Bryant et al. 2010b). This service would forewarn farmers of impending thermal risk, and give them time to take whatever precautionary actions are available. For example, DairyNZ has produced a guide for farmers to support them in preparing and responding to floods. For animal welfare management, the key messages from this guide are: to heed weather warnings and move stock to higher ground, ensure supplemental feed is available and stored above the flood level, and have enough flexibility to be able to off-load cows from the farm.

Skills for adaptation

Improvement in pasture assessment skills and monitoring systems to support more detailed feed budgets has been a goal of the industry for some time. Feed wedge management software, which is driven by detailed pasture observation and monitoring, is now commonplace on most research farms – and increasingly used in the operational environment. Continued focus on these skills, in line with more precise grazing rotations to optimise herbage yield, will be important adaptations in a more variable and warmer climatic environment.

### *4.2.2 Use of endophytes*

If pasture pests spread and/or become more prevalent in certain regions it will become more important to use current pasture plants that offer some level of protection against those pests, for example plants which harbour endophytes (Barker 1990; Thom 2010). Endophytes are fungi that grow between plant cells and produce a range of compounds (e.g., lolitrem B, ergovaline, peramine, epoxy-janthitrems) that are toxic to various pests.

Of the current ryegrass endophytes available, AR37 provides good control against black beetle (***Heteronychus arator***) adults, pasture mealy bug (***Balanococcus poae),*** root aphid (***Aploneura lentisci***), porina (***Wiseana cervinata***) and Argentine stem weevil (ASW; ***Listronotus bonariensis***) larvae. Endo5 provides good control against black beetle adults, pasture mealy bug and ASW larvae, AR1 controls against attack from ASW and pasture mealy bug, and NEA2 provides good control of black beetle adults and moderate control of ASW larvae (Popay & Hume 2011).

In tall fescue, the MaxP™ endophyte provides protection against adult black beetle, ASW, pasture mealy bug and root aphid (Pennell & Ball 1999; Popay et al. 2005; Jensen & Popay 2007). There are still some pasture pests that endophytes do not yet provide protection against. Identification of new endophytes with enhanced protection against insects or covering a wider spectrum of insects found in New Zealand will be important in protecting plants in the future.

### *4.2.3 Use of fertiliser*

To gain any beneficial effect from elevated $CO_2$ concentrations plant production and quality, it will be necessary to ensure that nutrients are not limiting, particularly N, otherwise the growth response will be limited. This may require increases in annual fertiliser application. This highlights the importance of current industry efforts to improve the efficiency of fertilisers and the recycling of N through effluent application for both environmental and production outcomes.

### *4.2.4 Herd management*

Under the New Zealand Animal Welfare Act 1999, dairy farmers are legally required to meet minimum standard No. 6 for providing shelter to dairy cattle. All animal classes must be provided with a means to minimise the effects of adverse weather, sick animals and calves removed from the cow must be sheltered, and remedial action is required when cattle develop health problems associated with adverse weather. This means reducing overall exposure to thermal stress.

A number of management options are currently available to reduce the effects of heat and cold stress in dairy cattle, including infrastructural modifications such as shade, evaporative cooling, and cooled drinking water for heat stress; and windbreaks, housing, and animal covers for cold stress. In addition, nutritional adjustments, changes to routines, systems, and milking frequencies, and animal selection can potentially play a role in reducing heat stress and cold stress in dairy cattle.

## *4.3 Strategic adaptations*

Strategic adaptations involve changing to another known production system, or making substantive changes to current systems, where practices and technologies are well known. This level of change may be warranted given mid to high level climate change. It happens now as a response to market adjustments, given relative pricing of input costs, regional climate variability, land use capability and seasonal conditions. There is also a tendency for managers to import and adapt practices from other sectors, regions or countries. There is a higher degree of risk involved, with more capital investment required to make strategic change.

### *4.3.1 Farming system changes*

Currently there is a spectrum of dairy farming systems in New Zealand. This spectrum provides a range of exposure to the direct and indirect effects of climate change and other risks. These range from very low input, pasture-only dairy production systems (System 1) to high input systems which incorporate up to 60% of the cows' diet as purchased supplements (System 5). These are described in more detail in Table 3.8 with some baseline information about performance and gearing for a benchmark operation in the Waikato. The recent expansion of dairying in the colder southern environment has seen the development of a specific 'Southern Wintering System', which relies on 'off farm feed' by transporting cows to alternative locations during the harsh June–July period.

Both profitable and non-profitable farms exist across this spectrum of farming systems. The level of profitability and relates more to farm management rather than choice of a given system. High pasture growth and feed utilisation levels are possibly the most important agronomic driver's profitability, and depend on a number of factors. However, stocking rate, calving date and calving spread are probably the management decisions that have the greatest impact on profitability.

All systems are represented in the sector, with System 5 farms being the least common. During 2010/11 the majority of the national herds were managed under Systems 2 and 3. There are more System 4 farms in the South Island, particularly in Canterbury, given the close proximity with the broad acre cropping sector. Grass-based (System 1) dairies are more common on the North Island, particularly in Taranaki and Northland. As described previously, farmers are faced with trade-offs between direct exposure to climate variability and the different risks (inclusive of input price variability for imported feeds) of operating each system. These choices hinge upon personal preferences, attitudes to risk, skills, resources available, market risk, environmental goals and regulatory constraints.

Systematic study of the performance of these systems in a changed climate has yet to be carried out. In general, System 1 farms will be highly sensitive to shifts in pasture growth variability, and System 5 farms will have low levels of exposure. However, this conclusion does not consider the indirect effects of the cross-sector impact of major droughts - where there will be concurrent grain and fodder crop yield reductions, shortage of feed and heightening of input prices.

While Systems 1-5 provide a degree flexibility across a range of climate exposures, there are a number of components of these systems that are under constant state of change through benchmarking, as well as underlying improvements to pasture and animal biological technologies. There are also a number of more direct changes that that target climate change that are adaptations.

**Table 3.8.** Key features (and a subset of performance benchmarks) for the five main dairy systems in New Zealand. Benchmarks are based on a best-practice farm in the Waikato. OE = operating expenses (NZ$); EFS = effective operating surplus (NZ$). (Source: Hedley et al. 2006).

| | | ***System 1*** | ***System 2*** | ***System 3*** | ***System 4*** | ***System 5*** |
|---|---|---|---|---|---|---|
| Key features | | All grass | Feed for dry cows (4-15%) | Feed imported to extend lactation (10-20%) | Feed imported to bring forward and extent lactation (20-30%) | Feed used all year (30 up to 60 %) |
| Pasture | Cows/ha | 3.4 | 3.6 | 3.9 | 4.2 | 4.5 |
| 19t/ha/year | OE($) | 2820 | 3066 | 3637 | 4798 | 6586 |
| | EFS($) | 2350 | 2482 | 2691 | 3100 | 3395 |
| Pasture | Cows/ha | 2.7 | 2.9 | 3.1 | 3.4 | 3.6 |
| 15t/ha/year | OE($) | 2400 | 2656 | 3182 | 4107 | 5422 |
| | EFS($) | 1712 | 1771 | 1906 | 2264 | 2457 |
| Direct exposure to climate variability | | Totally reliant on seasonal conditions | Moderate to high exposure | Reduced exposure | Low exposure | Not sensitive to seasonal variability |

Supplement price 19c/kg DM for System 2 to 21.5c/kg DM for System 5.

### *4.3.2 Pasture species*

Alternative pasture species are a viable and practical climate change adaptation for the dairy sector. Perennial ryegrass is the optimal grass for dairy cow production and is widely distributed across New Zealand (Kemp et al. 2000). However, over the next century, alternative species that are better adapted to higher temperatures, have greater WUE or that demonstrate greater responses to elevated $CO_2$ levels, may become increasingly important. Candidate pasture species include tall fescue (Martin et al. 2008; Neal et al. 2009), cocksfoot (Jensen et al. 2002; Neal et al. 2009), phalaris (Boschma & Scott 2000), annual ryegrass (Callow & Kenma 2004), kikuyu (Neal et al. 2009), prairie grass (Neal et al. 2009), lucerne (Neal et al. 2009), chicory (Li et al. 2010) and plantain (Stewart 1996).

Changing the species base is not straightforward on-farm, and requires careful consideration of growth patterns and production/economic trade-offs. Substantial and on-going research is required on the performance of alternative pasture species in temperate dairying regions to determine their positive and negative attributes. For example, tall fescue is slower to establish than ryegrass, which can result in reduced pasture accumulation during the first year (Nie et al. 2004; Tharmaraj et al. 2008). In successive years, greater annual and/or summer pasture accumulation is achievable, particularly when soil moisture is low and/or temperatures are high (Nie et al. 2004; Tharmaraj et al. 2008; Minneé 2011). Preliminary results from the Waikato indicate that basing pastures predominantly on tall fescue rather than ryegrass did not compromise milk solids production per hectare (Clark et al. 2010). In fact, the seasonal growth pattern of tall fescue-dominant pastures recorded by Tharmaraj et al. (2008) was predicted to result in an overall gain in gross returns of NZ $127/ha and NZ $256/ha compared with ryegrass, depending on whether the farm was 'average' or within the top 10% of farms ranked according to profitability (Chapman et al. 2011).

Increasing pasture diversity, by maintaining swards with four or more species that have differing $CO_2$, water and temperature thresholds, is a highly promising adaptive response to climate change (Reich et al. 2001). At two sites in New Zealand, diverse pastures containing between two and eight plant species are being evaluated under cow grazing to determine herbage DM production and nutritive value, species survival and milk production (S.L. Woodward, pers. comm 2011.). Information such as this will provide a starting point for farmers wishing to establish diverse pastures in the future, although the experiment may need to be repeated under future climatic conditions for confirmation.

### *4.3.3 Irrigation*

Modelling work predicts that summer soil moisture deficits will probably occur more frequently in New Zealand in the future (Chapter 2). Irrigation requirements in many regions are likely to increase to ensure adequate water supply throughout the year. In other regions, the annual water supply may increase (e.g., from the Southern Alps due to increased winter rainfall and snow melt). However, the increased supply may not fully compensate for the increased demand (see Chapter 8 and Palmer 2009). Farms that do not currently have irrigation systems may choose to install such infrastructure to reduce the detrimental impact of moisture deficits (Palmer 2009; Wratt 2009).

### *4.3.4 Pasture renewal and cropping*

Given or sward, or feed quantity and quality, responses like increased weed content, farmers can increase their rates of pasture renewal to maintain, or even increase farm profitability. This will also have the added value of allowing farmers to use the latest genetic material, which is likely to have enhanced attributes compared with older cultivars, for example, new and improved endophytes. For pasture renewal to be effective, key issues include the selection of appropriate species and management practices, and careful cost-benefit analyses.

Farmers can also use more crop species on-farm, either before pasture renewal to break pest and weed cycles and reduce the pressure placed on subsequent pastures (Kenny 2010); or simply to improve DM production by using plants which are more water use-efficient or drought-tolerant. Increases in annual DM production may be substantial, with yields of more than 40 t DM/ha/year possible using triple- or double-cropping systems with irrigation and N fertiliser (i.e., 42.3 t DM/ha/year, Garcia et al. 2008; 48.9 t DM/ha/year, Minneé et al. 2009). Cullen et al. (2010) highlighted lucerne, a maize/annual ryegrass double crop and a maize/brassica (***Brassica napus***)/field pea (***Pisum sativum***) triple crop as having greater DM yields and WUE than irrigated perennial ryegrass/white clover pastures.

Studies such as these indicate that modifying the feed base by using different crops may be an effective way of using water more efficiently and achieving greater DM production than traditional perennial ryegrass/white clover pastures. However, there are some downsides and risks to cropping systems that need to be taken into account. Cropping systems increase the total cost of milk production (Dillon et al. 2005), which may reduce profitability. There is also the risk of crop failure in dry conditions – and growing a crop means reducing the effective area of the farm, thereby increasing risk of feed deficit in drought. As with other adaptations, there are important trade-offs that must be considered before they are implemented on-farm.

### *4.3.5 Reducing heat stress*

There are many published reviews on potential ways to reduce heat stress in lactating dairy cows (Morrison 1983; Hansen & Aréchiga 1999; West 2003; Collier et al. 2006). Most reports are focussed on the intensive dairy systems where cows are housed, and therefore assume that artificial cooling systems are a practical option. Cooling strategies are limited for an extensive outdoors dairy systems, but there are some options which are available and commonly used (Verkerk et al. 2006). These are summarised below:

- Providing shade to pasture-grazed dairy cows while held in the yard waiting for the afternoon milking reduced their respiration rate by 30% and their body temperature by 0.3°C, as compared with un-cooled control animals (Kendall et al. 2007). In another study, Schutz et al. (2011) reported that behavioural observations indicated that cattle prefer shade than water sprinklers as a method for cooling, even though sprinklers were more efficient in decreasing respiration rate, body surface temperature and insect nuisance.

- Brown-Brandl et al. (2005) reported that increasing air movement accounted for reduction in heat stress in feedlot cattle; and Holmes et al. (1993) reported that wind speed significantly increased heat loss in dairy cattle under New Zealand climatic conditions. Forced air movement within a shaded environment is sufficient for reducing head loading at moderate ambient temperatures (Berman et al. 1985), but an evaporative cooling of the animals microclimate is required to alleviate the discomfort of higher air temperatures (McArthur 1987; Her et al. 1988). Kendall et al. (2007) demonstrated that water sprinkling of cows held in yards awaiting the afternoon milking within a pasture-grazed system, alleviated the symptoms of heat loading and fly nuisance, compared to un-cooled animals; and more so than by provision of shade only.

- Sprinkler systems to wet the animal may be a way to reduce core body temperatures below critical limits (Kibler & Brody 1950; Berman 2010) However, this practice becomes progressively less efficient with increasing humidity (Ragsdale et al. 1953), and is practically ineffective when relative humidity exceeds 55% (Berman 2009).
- Providing pooled drinking water is one potential practice that may alleviate heat stress (Ittner et al. 1954; Morrison 1983). Stermer et al. (1986) reported a 0.75°C reduction in body temperature when cows drank water at 10°C, compared with a lower reduction of 0.46°C when they drank water at 28°C. Respiration rate was also reduced with the cooler drinking water, but the cooling effect only lasted 2 hours, which was not long enough to prevent the risk of cows exceeding the critical threshold of thermoneutrality for some period of the day.

### *4.3.6 Reducing cold stress*

Ruminants have a high degree of tolerance to cold conditions and cold stress is much less prevalent than heat stress, even in New Zealand where cold winters and mild summers is a characteristic (Verkerk et al. 2006). There are fewer reports in the literature on cold stress in dairy cattle than for heat stress. Verkerk et al. (2006) described heat and cold stress and how these stresses may be reduced from a dairy cow welfare viewpoint in New Zealand.

Quam et al. (1994) reported on the practical aspects of reducing wind chill through the use of windbreaks in the United States. Wind chill is a function of air temperature and wind speed. Their information for beef cattle indicates that beef cattle can withstand a wind chill temperature of -30°C with little risk of cold stress. In a wind chill of between -30°C and -60°C, there is increasing danger of exposed regions of the body (e.g., teats and scrotum) freezing; and also of cold stress causing latent disease to appear. Beyond -60°C, there is extreme danger, especially for young stock. Windbreaks may be a practical means for reducing wind speed, and thus wind chill.

From the 'animal wind chill chart' (Table 3.9), the equivalent wind chill temperature would reduce from -21°C to -9°C when air temperature is -1°C. The estimated digestible energy requirement was reduced from 31.6 to 26.1 Mcal/d at 0°C, and from 37.8 to 32.3 Mcal/d at -30°C. In a Montana (United States) study, where pregnant beef cows were wintered with or without access to windbreaks, Olson et al. (2000) reported a slight benefit in immune response and back fat thickness among windbreak sheltered cows, but no differences in productivity or reproductive measures. Similarly, McCarrick & Drennan (1972a, b) found no productivity benefit of providing shelter for growing beef cattle under Irish wintering conditions.

**Table 3.9.** 'Animal windchill chart' adapted from Quam et al. 1994. Wind speed is depicted on the vertical axis and air temperature is depicted on the horizontal axis. This chart was designed for cold dry climates and ignores the additive effect of rain.

| | | F | 50 | 40 | 30 | 20 | 10 | 0 | -10 | -20 | -30 | -40 | -50 | -60 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **C** | **10.0** | **4.4** | **-1.1** | **-6.7** | **-12.2** | **-17.8** | **-23.3** | **-28.9** | **-34.4** | **-40.0** | **-45.6** | **-51.1** |
| mph | **km/h** | m/s | Equivalent temperature (°C) | | | | | | | | | | | |
| 0 | **0.0** | 0.0 | 10 | 4 | -1 | -7 | -12 | -18 | -23 | -29 | -34 | -40 | -46 | -51 |
| 5 | **8.0** | 2.2 | 9 | 3 | -3 | -9 | -14 | -21 | -26 | -32 | -37 | -44 | -49 | -56 |
| 10 | **16.1** | 4.5 | 4 | -2 | -9 | -16 | -23 | -30 | -37 | -43 | -50 | -57 | -64 | -71 |
| 15 | **24.1** | 6.7 | 2 | -6 | -13 | -21 | -28 | -35 | -43 | -50 | -58 | -65 | -73 | -80 |
| 20 | **32.2** | 8.9 | 0 | -8 | -16 | -23 | -31 | -39 | -47 | -55 | -63 | -71 | -79 | -89 |
| 25 | **40.2** | 11.2 | -1 | -9 | -17 | -26 | -34 | -42 | -51 | -59 | -67 | -75 | -83 | -92 |
| 30 | **48.3** | 13.4 | -2 | -11 | -19 | -28 | -36 | -45 | -53 | -62 | -69 | -78 | -87 | -96 |
| 35 | **56.3** | 15.6 | -3 | -12 | -20 | -29 | -37 | -47 | -55 | -63 | -72 | -81 | -89 | -98 |
| 40 | **64.4** | 17.9 | -3 | -12 | -21 | -29 | -38 | -47 | -56 | -64 | -73 | -82 | -91 | -100 |
| 45 | **72.4** | 20.1 | -4 | -13 | -21 | -30 | -39 | -48 | -57 | -65 | -74 | -83 | -93 | -101 |

Little danger to mature animals

Increased danger; will freeze exposed regions such as teats and scrotum. Will stress animals causing latent diseaes to appear.

Great danger especially to young animals

Young (1983) noted that, from practical experience, moisture exacerbates wind chill, but that no controlled studies had been conducted to specifically investigate this effect of moisture. Notwithstanding the additive effect of rain, it is apparent from the 'animal wind chill chart', that conditions experienced in New Zealand are substantially less severe than those indicated for North America. In fact, this information suggests that cold stress in mature domestic ruminants in New Zealand would be a rare event. However, there is substantial anecdotal evidence that wintering cows outdoors is a challenge, particularly in southern regions. Inadequate feed intake due to insufficient feed allowance or poor feed utilisation and pasture damage during wet periods are more likely to be the key issues in this situation (Longhurst et al. 2006 a, b).

Although the vast majority of cattle are managed outdoors all year round, there is some temporary housing of dairy cows in New Zealand. 'Herd Homes'® are a commercial example of cow housing (Longhurst et al. 2006 a), with a greenhouse-like roof over slatted floors (Longhurst & Lambourne 2006). A farmer survey noted that climatic issues and cow welfare were among the reasons farmers chose to invest in roofed-housing, with the main reason being to reduce pugging damage to soils and pasture during wet conditions (Care & Hedley 2008). Other perceived benefits are that "cows hold weight better and are more relaxed in a herd home" that is 5-6°C cooler than outside temperatures in summer (Riemersma et al. 2007), and 2-3°C warmer in the winter (Longhurst & Lambourne 2006).

Verkerk et al. (2006) provided experimental evidence that winter housing of dairy cattle reduces the diurnal body temperature fluctuations experienced when cows are managed outdoors. During winter, the average body temperature of housed cows ranged from a peak of about 38.6°C at 3 pm to a nadir of about 38.3°C at 9 am. Cows managed outdoors at this same location had an average body temperature peak and nadir at the same times, but the peak was 38.8°C and the nadir was about 38.1°C. The thermal comfort zone for dairy cattle centres around 38.6°C, with lower and upper critical limits of 36.5°C and 40.5°C, respectively (see Verkerk et al. 2006). On this basis, outdoor management of dairy cows with minimum and maximum air temperatures being -3.7 and +10.3°C, respectively, and a -0.3°C wind chill, did not result in these cows having average body temperatures beyond their thermal comfort zone. However, it was noted that cows adopted postures to reduce heat loss and shivered to generate heat during cooler periods of this two-year study (i.e., cold-stress responses were activated to maintain normal body temperature).

Dairy calves exposed to cold conditions consumed a large amount of oxygen to maintain body temperature. However, calves exposed to cold conditions for a short time (9°C and 8 km/h wind) reduced oxygen consumption by 40% when wearing polyethylene body covers (Holmes et al. 1993). From field studies, Macdonald & Penno (1996) reported no apparent benefit of fitting covers to calves, yearlings or mature cows.

### *4.3.7 Nutritional adjustments for the cow*

One way of increasing overall production is to maximise milk solids output per cow by moving the system into one which is more reliant on imported feeds using high energy rations. Systems with higher flow through, and total feed utilisation, are more common in the USA and subtropical dairy systems where pasture growth is less reliable than in New Zealand. Development of extremely high input dairy systems is in its early phases in the New Zealand context, but provides one avenue to decrease overall exposure to climate variability.

There are also several nutritional strategies that target cold and heat stress. A common strategy is to increase the energy and nutrient density (reduced fibre, increased concentrates and supplemental fat) of the diet as feed intake is markedly decreased during heat stress. In addition to the energy balance concern, reducing the fibre content of the diet is thought to improve the cow's thermal balance and may reduce body temperature. Therefore, different approaches to mitigate heat load are discussed in this section. They include:

- Reducing the amount of fibre in the diet, which limits heat stress by lowering ruminant temperatures; but care needs to be taken not to damage ruminant health with around a 60% Neutral Detergent Fibre (NDF) value being ideal.
- Increasing rumen degradable forms of dietary protein levels during heat stress to cope with reduced intake (West 1999).
- Increasing the amount of dietary fat. This has been a widely accepted strategy in US dairies in order to reduce basal metabolic heat production, although there are few experiments demonstrating benefits from this practice.

- Keeping water tanks clear of feed debris and algae. This is a simple and cheap strategy to help cows remain cool. Water intake is vital for milk production (milk is ~87% water) but it is also essential for thermal homeostasis.
- Taking into account the buffering capacity of the heat-stressed animal to control acidosis and metabolism changes. Increased $CO_2$ concentrations at a sward level could induce hyperventilation and thus alter the carbonic acid:bicarbonate ratio in circulation. This could heighten the risk of acidosis and associated disease states (Nardone et al. 2010).
- Having a negative dietary cation-anion difference (DCAD) during the dry period and a positive DCAD during lactation. This is a good strategy to maintain health and maximise production under heat stress.

Altering nutrient intakes of the dam in late pregnancy affected the offspring and its ability to adjust to cold conditions. It was reported that feed restriction during the pre-partum period, reduced the thermogenic ability of the newborn to cope with low environmental temperature. Feeding a fatty diet to cows during late gestation conferred an increased resistance to cold stress in the newborn calf (Lammoglia et al. 1999). Dietz et al. (2003) concluded that a high fat diet for the late gestation cow could provide a benefit to calves during a cold calving season.

## 4.4 Transformational changes

Transformational change involves innovation to develop completely new production systems or even industries. This is the least well defined level of adaptation as the knowledge is not fully developed – let alone realised as adaptive capacity. This type of adaptation may be necessary for extreme levels of climate change – where there is clear evidence that climate has moved to a new regime where current practices are not viable. New knowledge and practices are developed as collaboration between producers, researchers and specialists. Larger levels of investment are required to develop new adaptations with more risk. Investment should be justified on the grounds of strategic advantage. This type of adaptation could take five to twenty or more years to realise as adaptive capacity.

### 4.4.1 Plant traits

Traditional ryegrass and white clover plant breeders are likely to continue to make genetic improvements of up to 1% per annum in DM yield. In the long term, biotechnology offers the prospect of increasing pasture yields by 20% from the current level of 20 t DM/ha per year, up to 25 t DM/ha per year. This potential increase is as a result of fundamental changes in photosynthetic mechanisms (Clark et al. 2010).

#### 4.4.1.1 Plant morphology

There may be some plant morphological and physiological traits that can be altered using plant breeding techniques to enable better adaptation to future climatic conditions. In modelling studies, increasing the root depth and heat tolerance of perennial ryegrass under a 2070 high-emission scenario increased pasture production compared with shallower rooting or less-heat tolerant plants (Cullen et al. 2009, 2010). This indicates that although high temperatures and limited soil moisture are both likely to limit pasture production under high-emission scenarios, these factors may be overcome by modifying certain traits during plant breeding.

#### 4.4.1.2 Phenotypic plasticity

Phenotypic plasticity is the ability of a plant to modify its phenotype, and subsequently physiological responses, to a given environmental stress like climate change (Strand & Weisner 2004). Some species demonstrate greater phenotypic plasticity than others: for example lucerne demonstrates high genotypic and phenotypic plasticity, which enables it to better adapt to many different regions and climates than some other species (Baron & Belanger 2007). Nicotra et al. (2010) posed a number of questions regarding plasticity and the response of plants to climate change. The questions of particular relevance to this review include:

- What is the genetic control of plasticity and how is it linked to epigenetics?
- Can plasticity genes be identified and, if so, does this improve our ability to predict long-term responses of plant traits and species to climate change?

- What plant traits are likely to show adaptive plasticity and is this plasticity important in determining the response to climate change?
- How much variation is there for plasticity and how does it respond to selection?
- Is it possible to breed for plasticity in key traits to improve yield stability under climate change?

Multidisciplinary investigation into these and other crucial questions surrounding plasticity is likely to highlight opportunities to breed more resilient plants capable of greater survival and/or yield in future environments (Nicotra et al. 2010; Nicotra & Davidson 2010).

### *4.4.2 Evolving the dairy cow*

There is potential to change cattle physiology (through breeding) over time to reduce their susceptibility to both heat and cold stress. The principle is well founded in beef cattle where there are both heat-tolerant (***Bos indicus***) and cold-tolerant species (***Bos taurus***) breeds. Across the New Zealand dairy herd, Holstein Fresians are more sensitive to heat and cold stress than Jerseys (Bryant et al. 2007a); heat stress conditions are common in New Zealand (between 17% and 20% of lactation days), but cold stress conditions are rare (<1 % of lactation days) (Bryant et al. 2007a). The nature of breeding ability and environment interactions vary, and definite conclusions on environment-dependent expression cannot be made (Bryant et al. 2007b).

The national breeding objective for New Zealand dairy cows is to identify animals whose progeny will be the most efficient converters of feed into farmer profit. Only traits of economic importance, and with measurable genetic variability, are included in the New Zealand Breeding Worth index (NZBW index). Currently, these are milk protein, fat, and volume, cow live weight, fertility, residual survival and somatic cell count. Based on this current selection index, Bryant et al. (2007c) reported that the environmental extremes in New Zealand are not large enough to warrant separate breeding indices for different environments. The status quo would mean any required genetic adaptation to climate change would occur via selection pressure on these traits, notwithstanding future alterations to trait inclusion in the NZBW index.

Resistance to heat stress and disease can also be advanced through the genetic selection approach. For example, Frisch (1981) reported that selection for growth rate within a hot environment produced cattle with an increased degree of heat tolerance. In another example, Morris et al. (1991) demonstrated that resistance or susceptibility to sporidesmin (the causative mycotoxin in facial eczema), in dairy cattle, is a highly heritable trait. Progeny of widely used dairy sires were tested for susceptibility to facial eczema using gamma-glutamyltransferase (GGT) and glutamate dehydrogenase (GDH) as indicators for liver damage (Cullen et al. 2006). The heritability estimates ranged from 0.32 to 0.47 among Holstein-Friesian and Jersey sires. Some candidate genes involved with susceptibility to facial eczema have been identified, and there is genetic evidence that the biochemical detoxification pathway of ingested sporidesmin has commonality for detoxifying other mycotoxins, such as lolitrem-B and ergovaline (Morris et al. 2004). Should climate change result in significantly warmer, more humid weather conditions that warrant increased animal resistance to mycotoxic challenges, then genomic marker assistant selection appears to offer a feasible approach for such adaptation (Morris et al. 2004).

### *4.4.3 Genomic opportunities for genetic selection*

Animal selection based on genomic markers is a rapidly progressing technology. This technique offers a powerful tool for selection of animals with superior traits (Hayes & Goddard 2007; Pryce et al. 2010), including those that may accelerate adaptation to climate change should current trait performance be deemed inadequate (Hayes et al. 2009). An Australian report (Hayes et al. 2009) utilised the diversity of dairy farm system types and climatic conditions to establish a genomic basis for selecting cows with greater tolerance to elevated THI and to reduced feed supply. They reported finding markers for chromosomes 9 and 29, respectively, and two promising candidate genes to pursue. ***Bos indicus*** are more tolerant to heat than ***Bos Taurus*** cattle due to activation of thermotolerance genes (Hansen 2004).

One previously identified marker of heat tolerance is the 'slick hair' gene, firstly identified in Senepol cattle (Hammond et al. 1996), and later in other breeds, including Carora cattle, which are a composite of Brown Swiss and a Venezuelan criollo breed (Olson et al. 2003). The slick hair gene is a major dominant gene with a phenotype that has superior tolerance to heat stress conditions as compared with normal-hair phenotypes (Olson et al. 2003). Dikmen et al. (2008) showed that the slick gene phenotype was able to achieve a greater sweating rate, and attributed this ability as at least one of the heat tolerance mechanisms. However, it does appear that slick hair per se is what confers some advantage in heat tolerance; normal-haired cows that had their coats clipped had a lower body temperature and greater milk yield compared with unclipped normal-haired cows under heat stress conditions (Mejía et al. 2010).

## *4.5 Key knowledge gaps*

The impact of increasing $CO_2$ concentrations, and changing temperature and rainfall patterns on New Zealand pasture and crop plants is not fully understood: particularly as regards the potential interactive effects between the three variables. Furthermore, research into the effect of these variables on plant molecular processes is still in its infancy, or not yet begun, in many pasture species. Development of more stress-tolerant plants is likely to become one method of adapting to climate change. Certain genes are directly involved in the plants' adaptive responses to changes in climate, and pest and disease attack. These genes can be elucidated through quantitative trait loci (QTL) mapping and/or gene expression profiling techniques thus providing opportunities for plant breeding. A number of genes have been identified in species such as ***Arabidopsis***, rice and maize that modulate plant responses to abiotic stresses (Achard et al. 2006; Castiglioni et al. 2008; Huang et al. 2009). Similar investigation into pasture species may highlight opportunities for conventional breeding and/or genetic modification. This is a long-term strategy for adaptation. In the short term, farmers are likely to investigate alternative pasture and/or crop species. Information that would be useful to them is likely to include:

- comparisons of seasonal trends in plant quality and yield for a number of different species in a range of environments
- comparisons between seasonal milk production responses to alternative species and perennial ryegrass
- investigations into the compatibility and benefits of different species within a diverse pasture in a range of environments
- understanding how these changes integrate with current nutrient and water use efficiency goals as well as the role of soil carbon.

By itself, projected increases in average temperature of 2°C would seem to pose little or no ***direct*** environmental threat to health and productivity of dairy cows. This is because ruminants have a wide thermoneutral zone and an ability to shift this zone through physiological acclimation mechanisms. Breeding will improve over time as more traits are identified and are measurable. Advances in genomic selection may ameliorate this time-lag disadvantage. A gradual change in climatic condition, rather than a precipitous change, would assist with this acclimation process.

Predicted climate changes are more likely to threaten dairy performance through ***indirect*** effects on disease, feed supply and quantity, and extreme weather events. The consequences of these were discussed (see Section 4.2) with the key points being:

- a warmer climate will favour warm species grasses which are of less nutritive quality per kg consumed, provide poor year-round consistency of feed supply and are difficult to manage
- rainfall change may exacerbate the 'too dry' and 'too wet' extremes
- plant and animal diseases become a greater threat.

Some of the impacts of these changes like infrastructure, pest, and weed management as well as water resource management are described in Chapters 8 and 9. Key innovations into the future will revolve around feed flexibility, practices, and strategies that allow dairy farms to capitalise on excess biomass when it is available and avoid losses associated with climate induced downturns in production.

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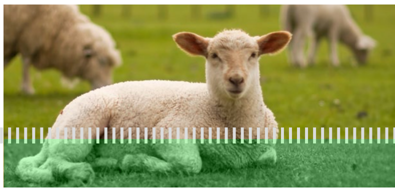
# **Chapter 4.** Sheep & Beef

*Hill country sheep and beef: impacts and adaptations to climate change*

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