

Pathways to climate resilience: Adaptation of dairy farm systems in response to climate changes

Callum R. EASTWOOD¹, Elena M.K. MINNEE^{1*} and Anita B. WREFORD²

¹*DairyNZ, Hamilton, New Zealand*

²*AERU and Faculty of Environment, Society and Design, Lincoln University, Lincoln, New Zealand*

*Corresponding author: Elena.Minnee@dairyNZ.co.nz

Abstract

Changes in climate across New Zealand (NZ) require ongoing adaptation strategies for pasture-based dairy farmers to remain productive, resilient and economically viable. In this study we explored strategies that NZ dairy farmers are using to adapt their systems to changes in regional climate. This research used a qualitative semi-structured interviews to conduct case study research on seven dairy farms throughout NZ. The case study farmers noted more variable regional climate with changes such as warmer winters with less frosts, more frequent and serious flooding events, longer dry periods interspersed with more intense rainfall events, heat in summer, and increased wind intensity during storms. They used a range of adaptation strategies in response to regional climate changes. These strategies can be classified as a) enhancing system robustness through lowering stocking rates to increase feed buffers, b) increased adaptability through greater responsiveness to significant events such as floods, or c) transformative change such as moving to whole season once-a-day milking or investing in housing infrastructure. The case studies highlight that farmers already need support from agricultural research, extension and policy to increase their adaptive capacity to more variable and extreme weather; this is now a current, rather than future, issue.

Keywords: adaptive capacity, incremental, reversibility, transformation

Introduction

New Zealand's farmers are facing changes in climate, from increased summer dry, warmer winters, to more intense weather events (Keller et al. 2021). Climate changes are projected to, and in many cases already are, impact aspects of the farm system such as pasture persistence and seasonal growth patterns (Lee et al. 2013; Marmont et al. 2024a; Chapman et al. 2025), management of intense wet periods (Edwards et al. 2017), increased pest and disease risks (Mansfield et al. 2021) and risks of livestock heat stress (Woodward et al. 2025). This requires on farm adaptation to maintain a productive feed base and healthy productive animals.

In managing complex biological systems within a dynamic environment, farmers face constant internal

and external forces that can necessitate adaptation at operational, tactical or strategic level (Eastwood et al. 2017). Adaptation in response to, or anticipation of, climate change requires farmers to make decisions while there is significant uncertainty of longer-term climate impacts (Keshavarz & Karami 2014; Knook et al. 2023). Any farm system adaptation implemented in this context depends not only on the external challenge (i.e. change in climate) but farmer-specific factors such as worldview, values, appetite for risk, skills and ability to adapt (Parminter 2019) and therefore different farmers may make different decisions when faced with a similar problem (Keshavarz & Karami 2014). Also, farmers manage within a wider socio-economic-technical innovation system (Romera et al. 2020) and change is subject to niche-regime tensions, where the regime is the dominant system and a niche is the space where new approaches are created and tested (Ingram 2015).

Farm adaptation can range from minor adjustments to significant investment of time and capital and transformative change. The motivation and triggers for change and adoption of practices have been widely studied (Montes de Oca Munguia et al. 2021b; Marmont et al. 2024b; Yeo & Keske 2024). These studies highlight that the triggers for change are highly context specific, and that feedback loops during or after the adaptation influence the longevity of change (Montes de Oca Munguia et al. 2021b). Confidence, in both the justification for change and the outcome of change, is an important component of the decision-making trigger. For farmers, awareness and confidence can be built from seeing experiences of other farmers (Ingram 2015; Montes de Oca Munguia et al. 2021a). Therefore, the aim of this study was to understand strategies that dairy farmers in different regions of NZ are using to adapt to climate changes, what the drivers for change were, and the farmer experiences of the adaptation process and outcomes. This information will be valuable for other farmers as they consider their adaptation options in response to a changing climate.

Methods

Seven dairy farming case studies were undertaken on farms in the Northland, Waikato, Bay of Plenty,

Canterbury, and Southland regions using a qualitative research approach. Case study participants were identified through professional networks of the researchers and DairyNZ staff. Selection criteria were farmers who had implemented adaptations to their farm system over the past decade that were primarily related to a changing climate (e.g. increased droughts, more intense rainfall events, changing winter conditions). The number of case studies was chosen to reflect a range of farmer experiences throughout NZ, and as we did not seek to achieve data saturation through this methodology, it falls within the 4-10 case study range suggested by Ahmed (2025). Potential limitations of this methodology are bias around selection of participants, and lack of ability to widely extrapolate findings. Therefore, the results of this research should be viewed as providing exploratory insights in potential issues farmers are facing that require further research. Approval to conduct the research was obtained from the Lincoln University Human Ethics Committee (HEC2023-48).

Farmers were interviewed in person by the two lead authors using a semi-structured interview method. The interview questions focussed on participant's experience

of any regional climate changes, implications for their farm system, adaptations implemented and the decision-making processes, consequences of adaptation in terms of efficacy, financial and system implications, and unintended outcomes. Interviews were conducted between January to July 2024, and ranged from 1.5 to 2 hours in duration, and were recorded and transcribed for analysis. Thematic coding was undertaken using ATLAS.ti Web (version v9.17.1) qualitative analysis software. The results of the theming, where similar aspects (codes) related to adaptation across farmer participants were identified, are presented in the next section. The main codes used were: regional climate observations and issues, adaptation drivers and triggers, implications of adaptation, information sources and advisors, feedbase and crops, and future outlook. In this paper, farmer names are not used, and some farm data is rounded for anonymity.

Results

In this section, we provide an overview of each case study including their perceived climate challenges, adaptation they have implemented in the past decade, any implications of the adaptation, and their

Table 1 Summary of case study farms, climate challenges and adaptation

| Farm | Farm details | Regional climate changes noted by farmers | | | | | | | Adaptation strategies |
|------|--|---|---------|----------------|----------------|----------------|------------------|----------|--|
| | | Weather variability | Drought | Thermal stress | Reduced frosts | Milder winters | Intense rainfall | Flooding | |
| 1 | Northland dairy farm: 350 cows, System 5. | X | X | X | X | X | X | X | Housing infrastructure to reduce pugging risks and heat stress, summer crop, extended lactation. |
| 2 | Northland dairy farm: 270 cows, System 3. | X | X | X | X | X | X | X | Diverse pasture base, summer crop, milking interval (from twice-a-day (TAD) milking to once-a-day (OAD) milking), responsive management of floods. |
| 3 | Waikato dairy farm: 220 cows, System 3. | X | X | X | X | X | | | Diverse pasture base, multispecies summer crop. |
| 4 | Bay of Plenty dairy farm: 430 cows, System 3. | X | X | X | X | X | X | X | Tactical flood response, summer cropping, earlier calving date. |
| 5 | Canterbury non-irrigated dairy support block: 180ha. | X | X | | X | X | X | | Diverse pasture base, replaced winter crop with permanent pasture |
| 6 | Southland dairy farm: 450 cows, System 4. | X | X | X | X | X | X | X | OAD milking first 2-3 weeks in the lactation, 3-in-2 milking post December, tactical use of 3-in-2 during cold/snow weather events pre-December |
| 7 | Southland dairy farm: 600 cows, System 4. | X | X | | X | X | X | X | Full season OAD milking, winter on pasture and small area of kale |

thoughts about future climate changes and adaptation opportunities. A brief overview of each farm is provided in Table 1.

Regional climate changes observed by case study farmers

There were a range of climate changes observed by farmers, influenced by region. In Northland, Farmers 1 and 2 noted more variable weather patterns with more extremes (e.g. cyclones, droughts), change from some 'hefty' frosts 30+ years ago to only the odd light frost in recent years, and milder but wetter 'almost tropical' winters with increased grass growth. Summers seem hotter and more humid with some 'intense' hot periods and tropical-style downpours, which can start in October or November and go right through to March. There was increased uncertainty for these farmers due to the variability and with 'normal' spring conditions often occurring later than before.

The farmers in Waikato and Bay of Plenty (Farmers 3 and 4) identified drought as the biggest issue and while annual rainfall may be similar to historical averages there appears to be more intense rainfall periods followed by longer dry periods in between "going from boom to bust" (Farmer 4). Farmer 3 noted this can cause an issue for water absorption, particularly on peat soils. The farmers also noted warmer winters where there is still grass growth, and fewer frosts. Farmer 4 was seeing more frequent flooding, and around a third of the farm can be flooded.

In Canterbury, Farmer 5 noted it has become milder with no large snowfalls in the past 15-20 years that caused problems for feeding and power supply. Average rainfall hasn't changed but seems like more intense rain events (e.g. 120 mm in a day) and longer dry periods. They consider autumn droughts to be the weak point of their system, although in recent years they hadn't had a dry autumn.

The two Southland farmers also noted increased climate variability and while wet summers do occur, the trend is toward drier summers; in recent years there have been two declared droughts, and "in the last ten years we've certainly seen way harder dries than we ever have" (Farmer 6). Farmer 7 noted that summer dry periods seem to be longer, up from around 5 weeks to sometimes 10 weeks long and occurring later in the season around March to May. Flooding was an issue for both farms, a recent large flood covered 50% of Farm 6 and up to three-quarters of Farm 7 can flood. Farmer 7 noted that in recent years, the floods arrive quicker and from less rain, possibly related to land use change further up the catchment. Flooding is more variable and now happens in winter as well as summer; there can be three floods per season but there hadn't been many in the past 3 years.

"We always used to say you usually would flood in summer because if they get thunderstorms and the ground is so hard and it's been dry, it just comes off. But now we're getting floods kind of in winter as well ...you can just get a flood anytime now." Farmer 7 (2024).

Additionally, farmer 7 used to expect two snowfalls on the ground per winter, but snow events are less regular lately. Winters are warmer and they can get some grass growth over winter when previously there was none; Farmer 6 also noted better grass growth in the shoulders of spring and autumn.

Impacts of climate changes and triggers for change

North Island farmers noted the impacts of changes in climate on pasture and crop persistence and productivity. Warmer conditions, with reduced frost events or increased humidity, have increased incidence of pest and disease in maize crops (e.g. fall army worm, maize rust (*Puccinia sorghi*). Additionally, the lack of frost chilling is contributing to a higher pasture weed burden on Farm 4, where thistles now grow through winter without being killed off by frost. Increased summer temperatures that are above the optima for ryegrass-based pastures combined with extended dry periods are reducing pasture persistence. Farmer 3 needing to resow 75-80% of pastures on farm following droughts, and Farmers 1 and 4 said over the last 20 years they have seen increased ingress of paspalum (*Paspalum dilatatum*), a warm season C4 species, into pastures and a reduction in clover growth in summer. Farmer 2 was also concerned about hot and humid conditions increasing risk of facial eczema.

In the South Island, farmers cited climate change impacts such as warmer winters, management of wet soils, and flood events. For the two Southland farmers, increased risk of flooding was a major trigger for changes around the winter feedbase and milking frequency. Dry summers and increased heat were a trigger for the change to using 3 in 2 milking on Farm 6.

Adaptation responses by case study farmers

Case study farmers were using a range of responses to the regional climate changes they faced, summarised below.

Infrastructure investments

On Farm 1, the main adaptation was the investment in livestock housing infrastructure in the late 2010s. Major triggers for the investment were recent very wet spring periods and an aim to prevent pugging of pastures and improve the welfare of the animals. Prior to investment the farmers looked at all options for housed/shelter systems and were actively involved in design and overseeing construction, including talking to farmers using similar systems to gather insights

and advice. Farm 2 had a covered feed pad which was useful during wet periods, and Farm 3 an uncovered pad to feed cows off pasture during dry seasons. Farms 6 and 7 had considered housing infrastructure but had not invested primarily due to cost.

Adaptation of feedbase and pasture species

A major area for adaptation was around adjusting the farm feedbase to match the local climate. On Farm 2, adaptation centred on identifying the most appropriate pasture species and fodder crops to match the different micro-climate, soil and topographical zones on the farm. For this farm it has been a gradual, evolving process over many years, driven by information seeking, experimentation, and observation, rather than a single trigger event. A key to successful adaptation has been the farmers' deep understanding of their land. For example, lucerne has proved effective in drier zones, where ryegrass performs better in wetter areas. Participation in pasture trials testing species such as fescue, cocksfoot, and ryegrass revealed that fescue performed particularly well in hot summer conditions. Although it was initially slow to establish, it thrived once established, and through the development of a tailored management approach persists for up to 14 years. Dry tolerant species, cocksfoot and chicory are included in most pasture mixes.

Farm 3 utilises multispecies pastures and crops to maintain more reliable and stable growth under variable growth conditions, combining species with greater drought tolerance or seasonal different growth patterns for example. Four years ago, following variable success with monoculture summer crops, the farmers planted a 17-species summer crop which has since been refined to around 11 species. They are happy with the performance of their current system and noted *"It would have to be a pretty strong argument to change what we're doing at this point"*. In terms of management, they often go to zero grazing in dry summers to avoid overgrazing pastures, keeping the herd in one sacrifice paddock and using supplement and grazing the multispecies summer crop. This allows pastures on the rest of the farm to rebound quickly when it rains in autumn.

On Farm 4, the farmers have adapted the feedbase to include around 8 ha of maize, yielding 28 – 30 t DM/ha as maize silage, to fill feed gaps and support pasture renovation. For these farmers, adaptation means ensuring a homegrown feed supply, with maize to provide confidence and resilience, but they acknowledge this approach still carries risk: *"Where you talk about that adaptation, ... maize was our kind of saviour to a degree in our autumns and guarantees our production and it means that we can keep going and put condition on cows. But if we have years where those [maize crops] failed..."* – Farmer 4 (2024)

On Farm 5 the focus has been on finding a feed base that works with the local climate, is resilient, and simple to implement. They had a previous system that involved a fodder beet-oats-kale-grass cropping programme with 2–3-year re-grassing. Cow health issues were increasing (e.g. metabolic disorders such as ketosis, and metritis), weed and disease control was becoming more of a problem in the fodder beet, and variable yields in the crops could lead to feed supply issues that last for 18 months. When there was a surplus from high crop yields at the end of winter grazing, there was a tension between moving pre-calving cows back to the dairy farm or keeping them on the grazing block longer to use the surplus feed. They felt there must be a better, more simple system, and through advisor and networks they explored how cocksfoot might fit. Their new system is mostly pasture with about a quarter of the pasture area in fescue and three-quarters in cocksfoot, that the farmers find to be reliably productive and persistent to climate and pests. Prairie grass, white and red clover and timothy are also used in the mixes. Around 15% of the farm is now in a fodder beet or kale crop (down from 40%) which fits in with a 6-year renewal for the cocksfoot pastures. Barley (6-7 ha) is also grown for whole crop baleage to either use on the dairy farm or to be fed out with the kale crop.

An area of adaptation on Farm 7 has been the wintering strategy. Initially, they wintered stock on a lease block with crops, then moved to the home farm using a multispecies mix including sunflowers, linseed, buckwheat, kale, and others. After two years, they realised the mix lacked sufficient protein, so they switched to growing only kale, supplemented with baleage in the paddock which suited the cows but didn't suit the flood-prone paddocks *"you can't put your baleage out in the paddock pre-winter like you see all around the place on the hills because baleage floats"* – Farmer 7 (2024). They then trialled fodder beet, which went well until a stock breakout led to severe acidosis, lameness, and mastitis. After that, they decided fodder beet was too risky. Their current system involves wintering on pasture, enabled by warmer temperatures that support pasture growth, and feeding silage, with one paddock of kale for the in-calf heifers. The silage-based wintering system provides much more flexibility with floods and is also much simpler to manage at low cost. It allows them to capture any feed surplus during the year and go into winter knowing they have enough silage to get through. Any extra growth from warmer winters would help with building pasture covers and feed buffers prior to calving.

Farm system adaptation

Farmers were also adjusting their wider farm system, such as calving dates and milking schedules. A change

in calving date from 16 July to 23 June had been implemented on Farm 3, in part due to modelling work conducted by DairyNZ as part of a project, that indicated a benefit for moving calving date six weeks earlier. A move to full autumn calving was discounted due to modelling showing it wouldn't provide any more production benefits and may negatively impact in-calf rate. On Farm 4, strategies included lowering the stocking rate and shifting start of calving from 30th July to 25th July to minimise the risk of early feed deficits. While some local farmers calve earlier, the case study farmers observed this often increases reliance on supplementary feed.

Managing the paspalum-dominant pastures necessitated farm system adaptation on Farm 4. They use a 21-day rotation; however, this may not be fast enough when the paspalum is growing rapidly and can lead to feed quality loss. A 14-to-16-day rotation from mid-December may be more effective, but the farmers are hesitant due to limited information on how this change would perform under variable weather conditions or its potential flow-on effects across the farm system. Paspalum, an invasive summer grass, stops growing when night temperatures cool. This used to happen in late March, but now more often occurs in early April, creating a feed gap the farmers currently fill with maize silage. They are concerned that if the weather shifts suddenly, pasture growth may slow or utilisation may decline, making their faster rotation strategy riskier. Additionally, effective implementation and particularly aggressive paspalum management, requires a skilled farm team, which adds a layer of complexity and risk to the approach.

On Farm 6 they have constantly been adapting to find a system that matches both their business goals and the feed supply and weather variability. Adaptation on the farm has involved adjusting the herd size which a few years ago was 500, progressively down to 450. The goal of the lower stocking rate is partially to have more consistent production and feed costs between seasons, but also to be more resilient to adverse weather events without dropping production or having to spend on purchased feed. It also allows another 115 t DM pasture or crop to utilise across the season to limit the risk of pushing into a feed deficit. January and February, sometimes into March, are usually the hardest months for pasture growth so they have evolved their system to include summer turnips and in-shed feeding to cover feed gaps. They have recently increased from 6 to 9 ha of turnips, and use a pasture mix of ryegrass, white and red clover, and plantain. The farmers try to run a system where they have more feed buffer and options for wet or dry seasons. They aim to be proactive, utilising a feed wedge and identifying feed deficits up to 5 weeks out. Flexibility around milking schedules include use of

OAD milking for 2-3 weeks at the start of lactation in August, then TAD milking until late December before switching to 3-in-2 milking. When there is dry weather at the end of the season, they aim to be proactive culling non-pregnant and unwanted cows.

Full-season OAD milking has been adopted in Farm 7 after they previously used part-season OAD and 3-in-2 milking. Flood risk was a key driver, as OAD milking makes managing flood events and feeding cows easier due to lessened need for moving cows. They started with 700 cows, allowing for heavy culling in the first season to suit the system, and now peak milk around 600 cows. Production initially dropped from 450 to 365 kg MS/cow after adopting OAD milking but has since improved to 460 kg MS/cow through increased days in milk from use of short gestation semen to achieve and tighter calving pattern. Additionally, because floodwaters usually clear within 24 hours with minimal silt, and they prioritise faster-drying paddocks to return cows to pasture quickly.

"We thought maybe these cows can do it and so we came to that discussion group and as they said well what...it's not a major change, you're not pouring concrete, you're not doing anything, if you don't like it you just milk them twice again, doesn't matter, give it a crack so that's what we did and haven't looked back."
Farmer 7 (2024)

On Farm 7, they have proactive policies around culling if there is a dry autumn, and the recent investment in in-shed feeding allows palm kernel feeding to cover feed gaps. Their reduced stocking rate and the use of OAD milking allows them greater flexibility with feed supply changes. The farmers also noted that better information about cow rumination changes from their on-animal sensors ('wearables') can be useful in both cold and heat stress periods to provide insights on real-time cow experience and whether shelter or feed is needed.

Responsive management approaches

The final area of adaptation was based around farmers developing more responsive management, primarily in relation to unpredictable flooding events. Farm 2, the farmers have a plan where if a high rainfall event is predicted they start preparing, for example immediately ordering seed and fertiliser, and as soon as it is dry enough, they over-sow pastures with an aim to go from "seed to feed" in 6 weeks. They have recently started using palm kernel due to the increased flooding as it helps with the feed gap when so much of the farm is out of action.

"Your biggest thing is changing your management within that period and within the seasons. You've just got to be prepared and flexible to change like we do, got to speed up, ... have to slow down now or do whatever"
– Farmer 2 (2024)

On Farm 4, flooding on one third of the farm can deposit heavy silt in pastures, so the farmers have developed a tactical adaptation strategy to minimise damage, including: if forewarned they graze the pastures on flood prone areas to promote rapid pasture recovery, then move the stock to higher ground. Post-flood, cows may be used to break up light silt layers, but if silt exceeds 10 cm, it is usually ploughed in, and the paddock is left for maize planting the following year.

Floods can happen any time of year on Farm 6, and the farmers said that while they may have 18 hours warning, they have learned to be wary under certain weather patterns, but they still can get caught out. If they get a flood, they have tactics related to where to move the cows, changing to 3-in-2 milking to reduce the energy demand for cows, and having a back-up generator.

"I guess for us it's just trying to ... have contingencies in place. We've got our summer sorted, we know how to manage through a bad spring and just keeping your sort of eye on these weather events that are coming" – Farmer 6 (2024)

Implications of adaptation and outlook

The case study farmers noted outcomes from their adaptations such as enhanced flexibility and resilience, greater simplicity of management, and the value of incremental improvement. Some of the farmers were also considering the next adaptation options for when climate and/or financial factors changed, as outlined below.

The investment in off-paddock infrastructure on Farm 1 gave the farmers much greater control during wet periods but an unintended benefit was it also provided shelter for animals in hot or cold conditions. Where previously milk production dropped during major weather events (e.g. storms or droughts), the farmers noted it is virtually unaffected now. Alongside the infrastructure change, the farm has increased supplementary feed use, in part due to the ability to feed with less wastage through the housing and to de-risk the variability in pasture growth in wet spring and dry periods. Around 25ha of maize is now grown on farm, and effluent from the housing is applied by contractor twice a year, particularly into maize crops. These adaptations have reduced the fertiliser use on farm, per cow production has increased from around 400 kg MS/cow to over 500 and enabled an extended lactation system with 6-week AI-only mating. The farmers on Farms 6 and 7 had seriously considered composting barns for benefits such as flexibility around weather and flooding and being able to calve inside, however cost, sourcing cost-effective sawdust and managing effluent were the major deterrents.

Farm 5 expected climate trends to exacerbate with

extended dry periods and higher temperatures. They feel that their current system provides flexibility, and while increased droughts will put pressure on the system, they may be able to recoup this with increased growth through warmer winters, as outlined below.

"If we are going to end up warmer in the winter, we're going to grow more grass in the winter so therefore we don't necessarily need to be able to stack as much aside. So, I think with fescues and cocksfoot, we certainly are well equipped to handle heat and they're as good as any grass as far as hacking your dry spells" – Farmer 5 (2024)

The farmers on Farm 5 believe their support block system adaptation is a much simpler system and has increased resilience through being better and faster for people feeding cows on drier pasture paddocks, better for the cows through a balanced diet with reduced metabolic, metritis and lameness issues along with a slight improvement in reproduction. Compared to their previous system it's more resilient in terms of profit. Environmentally, it has reduced estimated nitrogen losses, which meant reduced compliance requirements around intensive winter grazing regulations, and less estimated greenhouse gas emissions. The system is also a lot more flexible and not as reliant on growing feed at specific times of the year, however it has increased autumn drought susceptibility.

On Farm 4, the adaptation approach focused on incremental adjustments rather than major system or infrastructure changes. By altering one aspect at a time, they could evaluate what worked effectively. Future adjustments they identified were a larger feed buffer as weather becomes more variable, installing irrigation (however currently the cost of water and consents were deterrents), winter milking (brings a high risk around paddock management in wet winters), and improved housing infrastructure (they felt this would lock in costs and system change). Similarly on Farm 6, the farmers noted they will continue finetuning and evolving and keep looking out for advances that help resilience like pasture varieties that are more productive and will 'hang on' a bit longer in the dry.

Discussion

In this paper, we aimed to understand strategies that dairy farmers in different regions of NZ are using to adapt to climate changes, what the drivers for change were, and the farmer experiences of the adaptation process and outcomes. The case studies highlight the wide range of changes, and subsequent uncertainty, that farmers are experiencing in terms of their local climate and pasture and crop growth patterns, aligning with projections by Keller et al. (2021) and recent research on pasture growth trends (Mackay et al. 2023b; Mackay et al. 2023a). The changes noticed

by farmers included warmer winters with less frosts, more frequent and extensive flooding events, longer dry periods interspersed with more intense rainfall events, heat in summer, and increased wind intensity during storms. These changes align with studies of climate and pasture growth data and the impact on pasture productivity expected due to regional climate change (Lee et al. 2013; Garcia et al. 2021; Glassey et al. 2021; Mansfield et al. 2021). While only a small snapshot of farms, the northern farmers seemed to face more urgency for adaptation than southern farmers. Farmers reported several climate-related impacts, including increased heat stress for livestock and risks to pasture productivity and feed supply due to moisture deficits, temperatures exceeding ryegrass tolerance, and challenges with wet soils. Flooding was a common issue across many case study farms, though this may reflect the selection criteria used. Warmer winters and fewer frosts were seen to offer potential benefits for feed production but were also associated with increased pest and weed pressure, consistent with findings by Lee et al. (2013) and Mansfield et al. (2021).

A feature of adaptation to climate changes in the case studies was the uncertainty in the extent and pace of changes, regional nuance, and the highly variable and non-linear nature of change. Decision-making under uncertainty is an inherent feature of farming (Beukes et al. 2019; Eastwood & Renwick 2020). However, uncertainty within longer term strategic decisions can require good foresight and sensemaking skills of farmers; foresight can be learned through training to interpret the business environment (Lahnamäki-Kivelä 2022). Decreasing the uncertainty of climate changes will be vital to build farmer confidence in adaptation. While decreasing the uncertainty in climate projections itself is not straightforward, better communication of regional projections, e.g. Keller et al. (2021), sharing stories like in this study, and peer-to-peer discussions on adaptation strategies and their ramifications can all generate confidence for implementing adaptations.

The adaptation processes implemented by the case study farmers highlighted a range of approaches. These included significant long-term investments in housing infrastructure to manage wet (and heat) periods, system adaptations such as changes in calving dates and milking schedules such as full season OAD or 3-in-2 milking (Eastwood et al. 2022), and evolution in pastures and crops grown to match climate conditions. Based on the case studies, this tension between incremental versus transformative change can be linked to scale of the challenge being addressed but also to factors such as cost, reversibility, certainty about success, and capability within the farm team to implement change. It may also be linked to the investment horizon for farmers, for example whether their planning focusses

on the next five or fifty years. There is also a niche-regime interaction (Ingram 2015; Nettle et al. 2025) to be aware of, such as access to drought resilient cultivars and winter milk contracts when changing calving patterns. Incremental changes represent a form of path dependency where farmers make small operational or tactical changes such as changing stocking rate but stay on the same general trajectory; transformative change can require a major ‘trigger’ event where farmers consider wider system change (Kirk et al. 2022). Trigger events observed in the case studies included very wet springs for Farm 1, system modelling in Farm 3, observation of success on other farms for Farm 5, and a very large flood event for Farm 7. Conversely, the variable and uncertain nature of regional climate change can mean a lack of obvious trigger points for farmers, leading to a feeling that complex and/or costly system changes are too hard to justify, leading to path dependency within existing farm system boundaries.

Many of the farmers in this study were ‘feeling their way through’ adaptation pathways that often involved ‘tinkering’ (Comi 2023) with their system through successive changes in pasture species, crops, or wintering practices. Stringer et al. (2020) note that such pathways are not smooth and may be adaptive or maladaptive, the latter being where changes lead to undesirable or worse states, e.g. the fodder beet experience on Farm 7. Partial adoption or dis-adoption (Montes de Oca Munguia et al. 2021b) are other aspects to be aware of as the sector evaluates change, as adaptation strategies will not fit every farm. There is a role for advisors and the broader sector to understand the options available to farmers, and any potential pitfalls, to help farmers avoid maladaptation as they navigate the adaptation pathways (Vermeulen et al. 2018). From the case studies, it appears there is poor visibility among farmers of which adaptation strategies work, why and where.

Finally, the experiences of the case study farmers can be viewed in terms of the three resilience capacities, where they have implemented practices to enhance the farm system robustness (coping with shocks), adaptability (capacity of actors, responsiveness) or transformability (significant change to structure) (Shadbolt et al. 2013; Knook et al. 2023). Changes such as lowering stocking rate to have a larger feed buffer (Farm 6) or changing grazing management to optimise paspalum productivity (Farm 4) are examples of enhancing robustness capacity, whereas moving to full season OAD milking (Farm 7) or reorientating the farm around housing infrastructure (Farm 1) are examples of building transformative capacity. There was also enhanced responsiveness, with adoption of operational plans to respond quickly to events, particularly floods, enabling farms to recover rapidly. This responsiveness

represents increased adaptability capacity and will be increasingly important for farmers in a highly variable climate. The higher resilience of farm systems that have greater ability to respond to unfavourable or favourable conditions has been highlighted in prior research into the NZ dairy sector (Shadbolt et al. 2013). Adaptive capacity, or the potential of farmers and their farm systems to enhance resilience in a changing environment (Sundstrom et al. 2025), will be increasingly important as farmers face climate change. The case study farmers were purposely selected to highlight those making changes, but there will be a large proportion of farmers whose adaptive capacity is currently low, due to factors discussed in this paper such as uncertainty, lack of clear trigger points, and path dependency. Addressing these factors needs to be a focus for agricultural research, extension and policy.

Conclusions

Increasingly variable climates are having implications for dairy farmers that differ between regions across NZ. The farmers studied in this project were implementing adaptation to changes such as longer dry periods, increased rainfall intensity and flooding risk, and warmer winters. This increased variability meant there were a range of responses from incremental to transformative, and that the farmers took their own pathway to enhanced system resilience. The case study farmers represent those most open and able to change, however adaptive capacity should be a focus for capability building across the sector. Lessons from this study and similar research on adaptation can be used to inform other farmers looking to implement adaptation strategies, and the importance of adaptation to policy makers. Actions taken by farmers in this study will provide ideas and inspiration for other farmers dealing with climate changes.

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