Research Article

Genetic Improvement as Adaptation Option for Climate Change in Dairy Farms in South Eastern Australia

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Abstract | The dairy industry has to increase production while overcoming the effects of climate change. This project assessed these challenges by adopting genetic advancements in dairy farms in order to adapt the systems to climate change. Historical and prospected climate scenarios were simulated by using daily climate data from the SILO meteorology database. The different handling styles and climate fluctuations of two farms were simulated using DairyMod. Using current pasture species and livestock, it first was modelled the effects of climate change in 2050 and 2080 on pasture growth, feed consumption, and milk production. Afterward, it was modelled better adapted pastures (deeply rooted, or "DR" and heat-tolerant, or "HR"), as well as livestock (with higher feed conversion efficiency, or "FCE"). The growth patterns of pastures will be impacted by climate change as the spring growing season will be shorter. Climate change will also result in less milk production and less feed consumption. The combined adapted perennial ryegrass DR+HT is the most effective adaptation alternative to counteract the effects of climate change on pasture growth. The combined adapted perennial ryegrass DR+HT and the multiple adaptations FCE+DR+HT are the most effective ways to counteract the effects on overall feed consumption. The best adaptation strategy to combat the decline in milk production is to use the multiple adaptations FCE+DR+HT. The use of genetically modified dairy cattle with ryegrass can increase milk supply by up to 5% until 2050. These findings suggest that genetically modified dairy cattle and genetically modified ryegrass must be introduced together in order to adapt a dairy system.

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Introduction

The dairy sector needs to become more efficient in the future. Milk is one of the most vital foods for humans, its production will need to more than double in the coming years to meet the demands of an expanding population. However, the dairy sector needs to lessen its environmental impact, overcome the effects of future climate change, and become more sustainable (Steinfeld *et al*., 2006; Berry and Crowly, 2013). According to future climate projections, Australia will see higher temperatures and CO_2 levels, less rainfall, a more variable climate, and a rise in the frequency of extreme weather events. As a result, there will be significant losses in dairy production due to declining pasture yield and quality, declining animal performance, rising pest and disease incidence, and increasing soil degradation (Howden and Stokes, 2009).

Adaptation strategies must cope with the degrees of uncertainty surrounding the changes that will take place in each region in order to guarantee food security in the future (Howden and Stokes, 2009). To increase dairy production's efficiency and prepare it for future climate change, the genetic improvement of plants and animals is a crucial adaptation strategy (Moore and Ghahramani, 2013). In the case of dairy cattle genetic progress has been the main driver for the rising production of the last decades by improving feed efficiency, which is the main indicator of animal profitability (Oltenacu and Broom, 2010). In the case of pastures (perennial ryegrass), the advance in genetic has great importance for future pasture profitability, because maintaining pasture quality and yield in the face of future climate change will be challenging by using only management changes and fertilization (Parsons *et al*., 2011). In order to mitigate the negative effects of a warmer and drier climate, the project aims to evaluate the effects of climate change on dairy farms through the use of two case studies in southeast Australia. DairyMod, a dairy production system model that uses daily climate data to simulate pasture and animal production for pasture-based systems, was used to model the impacts and adaptations of climate change (Johnson *et al*, 2008).

Using herd recording data, a mathematical model that predicts milk production can be used to model future milk yield and predict the value of a dairy cow's milk production in the future (Græsbøll *et al*., 2017). Models can also predict the interaction of genetic variances and feed efficiency (Bouquet *et al*., 2022). There are models that predicts feed intake such, nutrients requirements and utilization, milk production and growth (Hulme *et al*., 1986; Freer *et al*., 1997; Krizsan *et al*., 2014).

Materials and Methods

Case studies simulation

DairyMod, a dairy production system model that uses daily climate data to simulate pasture and animal production for pasture-based systems, was used to conduct the farm study simulations (Johnson *et al*., 2008). The case studies were based on real farms in Gippsland and South Australia. The Gippsland farm was located near Moe. The farm was stocked at 3.2 cows/ha with a spring calving pattern (Cows calf from September to November). Annual concentrate feeding averaged at approximately 1 t/cow. The South Australian farm was located in the Fluerieu Peninsula. It had a lower stocking rate and an autumn calving pattern (Cows calf from March to May). Concentrate feeding levels were higher on this farm, averaging approximately 1.6 t/cow/annual.

The stock breed in both farms is mainly Holstein-Friesian. Perennial ryegrass (*Lolium perenne*) was use in both farms. The nitrogen (N) fertilization management was fixed at 50 kg N/ha applied every time the paddock was grazed or cut. No irrigation was used on either farm. In this paper, irrigation was not implemented because in the farms where the project was performed, they have a seasonal milk production whereby cows are mated during the height of pasture availability in order for them to calve and lactate. In this case rainfall supply enough water for pasture production (Hogan *et al*., 2005).

Climate change simulation

Daily climate information from the SILO meteorology database was used to simulate the farms under the past and future climate in every location. The historical climate based used measured data from 1975 to 2013. Future climate projections were based on the Representative Concentration Pathway 8.5 (World Meteorological Organization, 2015) using six Global Climate Models for projections at 2050 and 2080 (IPCC, 2013). To create the future climate scenarios monthly change factors for temperature (°C) and rainfall (mm) were applied to the historical climate, following the procedure of Cullen *et al*. (2009). A representation of the variation in projections across the global climate models low, medium and high change scenarios were developed for the years 2050 and 2080.

At both sites the climate projections indicated warmer temperatures but there was substantial variation in predictions for rainfall change. In Gippsland the average annual rainfall in the historical base was 936 mm with a range of temperature from around

9 to 19°C. By 2050 the average annual rainfall was 1012 mm, 906 mm, and 792 mm in the low, medium and high scenarios, respectively, with a range of temperature from around 10 to 21 °C. By 2080 the average annual rainfall was 1072 mm, 882 mm, and 677 mm in the low, medium and high scenarios respectively, with a range of temperature from around 11 to 22 °C. In South Australia the average annual rainfall in the historical base was 938 mm with a range of temperature from 10 to 17°C. By 2050 the average annual rainfall was 989 mm, 882 mm, and 782 mm in the low, medium and high scenarios respectively with a range of temperature from around 11 to 19 °C. By 2080 the average annual rainfall was 1029 mm, 836 mm, and 658 mm in the low, medium and high scenarios respectively, with a range of temperature from around 12 to 20°C.

In the two case studies, in the case of the atmospheric CO_2 concentration (ppm) in the historical data, a constant base of 380 ppm was used. For future climate impacts the atmospheric CO_2 concentration was changed in 2050 the CO_2 concentration was 540 ppm, and in 2080 the CO_2 concentration was 758 ppm.

Simulation of impacts

The impacts of future climate change were assessed by simulating the farms in the future climate scenarios without changing the farm systems. The impacts that were assessed in pasture and dairy production were: the growth pattern of the pasture measured as pasture growth rate expressed in (kg/ha)/d, feed consumption expressed in (kg/animal)/year split in pasture intake, concentrate intake and forage intake and total lactation expressed in (kg solids/animal)/year.

For each farm, historical climate data from 40 years prior to the study and climate variables for 2050 and 2080 for low, medium and high scenarios were inserted into the DairyMod software.

Simulation of adaptation options

To assess the effectiveness of adaptation options pasture and livestock parameters were changed in DairyMod and run under the same future climate scenarios.

For each case study, five adaptation options due to genetic improvements were applied as follows:

Perennial ryegrass with deeper root (DR): The pasture root length was 40 cm and 50% of its root distribution was found in the first 15 cm. The maximum root length of the adapted root deep perennial ryegrass (DR) was 60 cm and 50% of root distribution was found in the first 25 cm. A study of perennial ryegrass traits served as the basis for the modification of the root parameters (Crush *et al.* 2007; Cullen *et al.* 2014).

Heat tolerant perennial ryegrass (HT): In order to model a heat tolerant pasture, the initial temperature in which the plant heat stress starts to occur was changed by 2 °C, from 28 °C to 30 °C in the heat tolerant perennial ryegrass (HT). The temperature in which the plant experienced a full cessation of growth was also changed by 2 °C, from 35 °C to 37 °C in the heat tolerant perennial ryegrass (HT).

Combined adapted perennial ryegrass (DR+HT): The pasture has the two traits combined: Perennial Ryegrass with Deeper Root (DR) + Heat Tolerant Perennial Ryegrass (HT).

Better-feed conversion efficient dairy cattle (FCE): To increase the livestock's conversion efficiency in the stock's biophysics, the production efficiency was changed by 5 units in the case of Gippsland cows from 55 to 60 units, and in the case of South Australian cows it changed from 50 to 55 units. These changes increased feed conversion efficiency by 10%. In several studies the milk yield in cows increased approximately 1% per year and most of this increment is due to genetic improvement especially in the last 3 decades (Oltenacu and Broom, 2010; Hayes *et al.*, 2013). Milk production and feed intake are highly genetically correlated (Connor *et al.*, 2012) for this reason genetic improvement in feed conversion efficiency is the main driver for improving milk production (Berry and Crowley, 2013). In this study the 10% in improvement in FCE is a conservative improvement. Even if genomic selection and future reproduction biotechnologies would lead a future increase in genetic improvement, it is important to take into account the dairy cattle genetic potential (Niemann, 2011).

Multiple adaptations (FCE+DR+HT): In this case the pasture has the two traits combined and the dairy cattle has 10% better FCE. Perennial Ryegrass with Deeper Root (DR) + Heat Tolerant Perennial Ryegrass (HT) + Better-Feed Conversion Efficient Dairy Cattle (FCE).

The degree to which genetic improvements will contribute to mitigating future climate change impacts in the two case studies by the years 2050 and 2080 was assessed by comparing how climate change affects milk production without genetic improvements and with genetic improvements using box-and-whiskers plots.

A stacked column was utilized to show the distribution and percentage of pasture, concentrate, and forage intake in the case of feed consumption. A line chart was utilized to illustrate the data's tendency in the pasture growth rate case.

Results and Discussion

Impacts of future climate change on pastures and dairy production

Future climate change increase pasture growth patterns rates in winter (June to August) and early spring (September to October), but shorten the springtime growing season (Figures 1 and 2). Figures 1 and 2 indicates that across the future climate scenarios there is a higher peak of pasture growth rate, where the highest peak is in the high emissions scenario for 2080. When the pasture growth rate is higher, there is an accumulation of pasture in the time that the pasture is cut, however, in November and December, the amount of pasture decreases and, consequently, in pasture intake. Additionally, there is a contraction in the growing season for the late spring (October to November) and early summer (December to January). The contraction in the growing season is only seen as evident in the high emission scenario in 2050 and 2080 and there is less growth over summer even in the historical data (Figures 1 and 2).

Other studies produced similar findings. A simulation of the effects of climate change on farms in New Zealand showed that, in the absence of adaptation strategies, the effects of climate change would negatively impact pasture growth, which would then have an effect on farm profits overall (Kalaugher *et al*., 2017). Furthermore, changes in temperature and rainfall patterns will impact pasture quality by altering the concentration of P and Ca2+ (Hidalgo *et al*., 2023).

Future climate change will cause pasture growth rates to increase because warming will overcome the cool temperature barriers that prevent growth during the winter and because atmospheric CO_2 concentrations will rise. Elevated CO_2 concentrations have both advantageous and detrimental effects on plants. As CO_2 builds up and increases photosynthesis efficiency, pasture growth may be aided by the rise in CO_2 concentrations (Cullen *et al*, 2009). Conversely, a decrease in pasture proteins could result from an increase in CO_2 and thus lower the quality of the feed (Howden and Stokes, 2009).

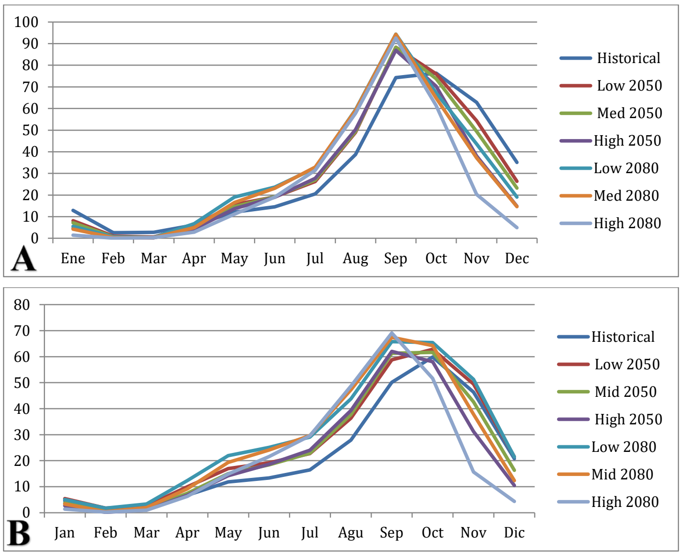

Figure 1: *Monthly average of pasture growth rate expressed in (kg/ha)/day across the emission scenarios in Gippsland (A) and in South Australia (B).*

Future climate change will negatively affect feed consumption, in particular reducing pasture intake (Figure 2). Feed consumption decreases across the scenarios in 2050 and 2080. Pasture intake decreases and forage intake increases in order to fulfil the animals' requirements. The concentrate intake doesn't vary across emission scenarios because the model used fixed permanent concentrate consumption. In the case of Gippsland, by 2050 in the high change scenario total feed consumption will decrease by 9%, the mean annual pasture intake decreases by 19% and the forage intake increase by 8% in relation to the historical base. By 2080 in the high change scenario the total feed consumption decreases by 12%, the mean annual pasture intake decreases by 29% and the forage intake increases by 19% in relation to the historical base. In the case of South Australia, by 2050 in the high change scenario total feed consumption will decrease by 5%, the mean annual pasture intake decreases by 11% and the forage intake increase by 7% in relation to the historical base. By 2080 in the high change scenario the total feed consumption decreases by 10%, the mean annual pasture intake decreases by

7% and the forage intake increases by 19% in relation to the historical base.

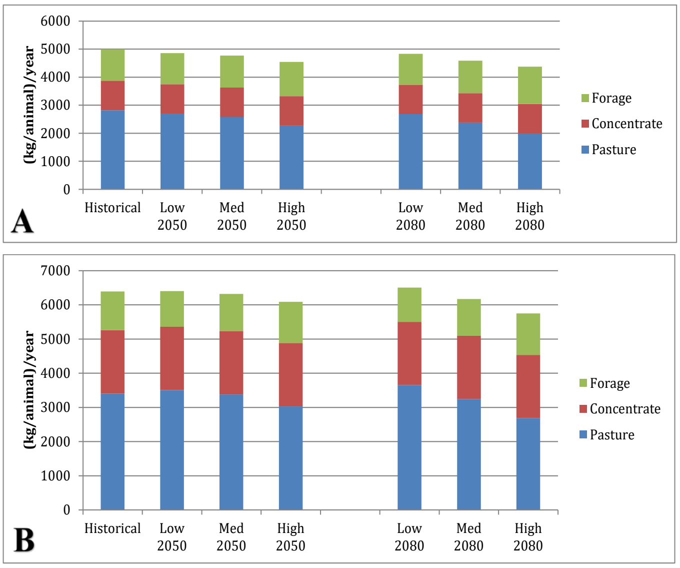

Figure 2: *Impacts of future climate change on average pasture, concentrate and forage consumption expressed in (kg DM/animal)/year in Gippsland (A) and South Australia (B).*

Future climate change will negatively affect annual milk production (Figure 3). In the case of Gippsland, the annual milk production decreases as much as 14% in the high change scenario in 2050 and it decreases 21% in the high change scenario in 2080 in relation to the historical base. In the case of South Australia, the annual milk production decreases as much as 5% in the high change scenario in 2050 and decreases 11% in the high change scenario in 2080 in relation to the historical base.

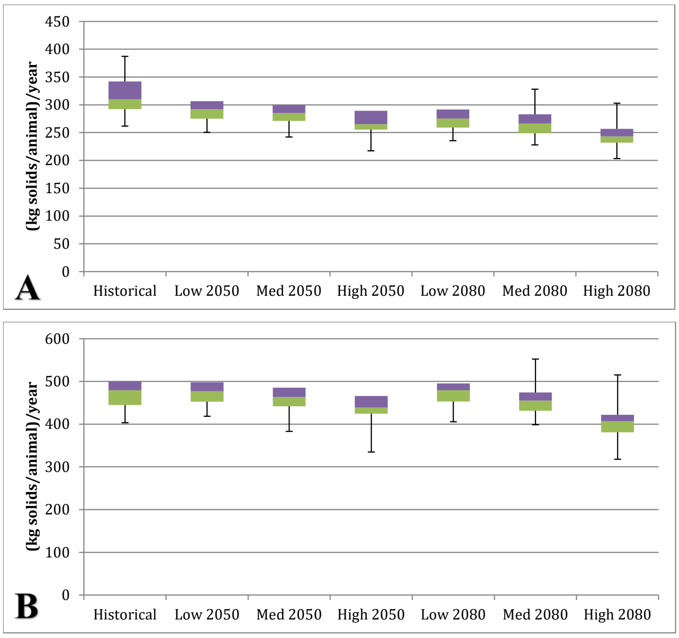

Figure 3: *Impacts of future climate change on annual milk production expressed in (kg solids/animal)/year in Gippsland (A) and South Australia (B).*

In a study performed in order to evaluate heat stress in dairy cows, by applying a generalized additive mixed model, the results showed that while temperature-humidity index increase, the performance of the cow decreased (Gorniak *et al*., 2014). In a study performed in the United States of America it was estimated that the milk production loses per cow due to climate change was up to -6, 2 (Kg/day) in 2050 and –7, 5 (Kg/day) in 2080 (Mauger *et al*., 2015).

Adaptation options

In the case of Gippsland, the implementation of genetically improved ryegrass helps to overcome contraction of the growing season in 2050, but it doesn't in 2080 where the contraction of the growing season is more severe (Figure 4). In the case of South Australia, the implementation of genetically improved ryegrass helps to overcome contraction of the growing season in 2050 and 2080 (Figure 5).

The implementation of each adaptation options helps to overcome the impacts of future climate change on pasture growth patterns. The combination of adapted perennial ryegrass DR+HT was the most successful adaptation strategy to mitigate the effects of future climate change on pasture growth patterns in both case studies (Figures 4 and 5). This result indicates that the combination of the two traits is more effective than the implementation of each individual trait. This is because the combination of genetic traits has additive effects (Singh *et al*., 2012).

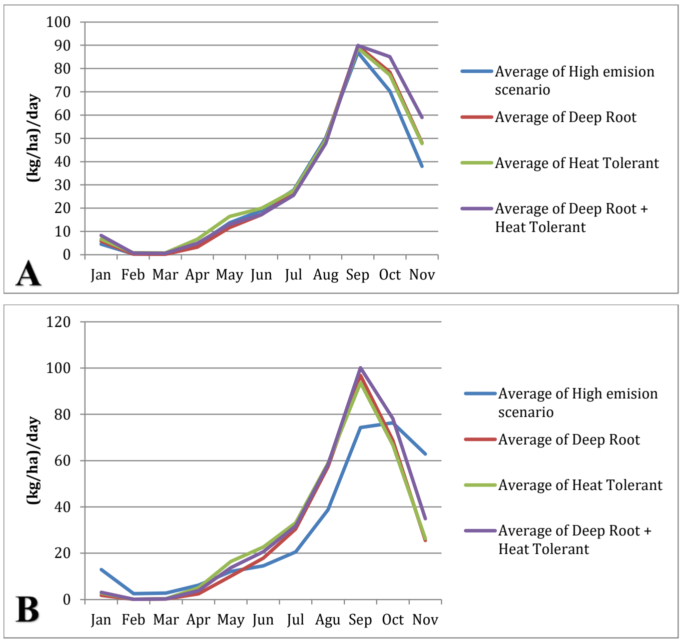

Figure 4: *Effect of pasture adaptation options on monthly average of pasture growth rate expressed in (kg/ha)/day in Gippsland, 2050 (A) and 2080 (B).*

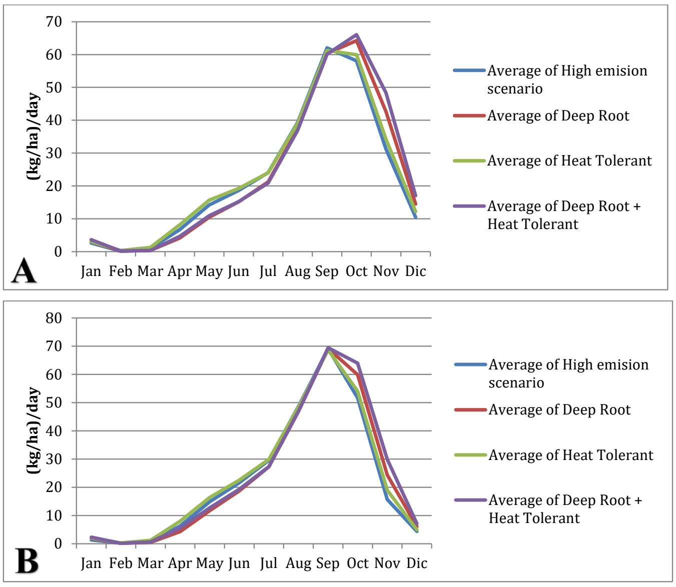

Figure 5: *Effect of pasture adaptations options on monthly average of pasture growth rate expressed in (kg/ha)/day in South Australia, 2050 (A) and 2080 (B).*

The implementation of each adaptation options helps to overcome the impacts of future climate change in the distribution and total feed consumption and milk production in 2050 and 2080, but the results are clearly seen in 2080.

Since their roots have access to deeper soil, plants with deeper roots can withstand a reduction in water stress more readily and produce more (Odone *et al*., 2023). The livestock industry and natural grazing communities are significantly impacted by the negative effects of climate change on pasture productivity, which leads to shortages in cool-season forage availability (Churchil *et al*., 2022).

The combination of perennial ryegrass DR+HT and multiple adaptations FCE+DR+HT proved to be the most successful option for mitigating the effects of future climate change on feed consumption overall and its distribution, with pasture intake rising and forage intake falling (Figure 6). With these adaptation options in the case of Gippsland the annual total intake decreases only 2% in 2050 and 8% in 2080. In the case of South Australia, the annual total intake doesn't vary in comparison to the high chance scenario with no adaptation options, but in 2080 decreases total intake by only 5%.

Multiple adaptations DR+FCE+HT proved to be the most successful strategy for mitigating the effects of climate change on milk production (Figure 7). In the case of Gippsland this adaptation option increased milk production by 5% in 2050 and decreased by 7% in 2080. In the case of South Australia in 2050 the implementation of the adaptation options the annual mean milk production doesn't vary, but in 2080 it decreased mean milk production only by 2% in relation to the historical base. These results indicate that in order to adapt a dairy system it is necessary to implement genetically adapted ryegrass and genetically adapted dairy cattle at the same time. These combinations of traits make the system more resilient.

In the two case studies the heat tolerant ryegrass HT was more effective than the perennial ryegrass with deeper root DR in overcoming the effects of climate change in milk production and feed consumption (Figures 6 and 7). These results are similar to the results found in Cullen *et al.* (2014). In the case of Gippsland, the implementation of the heat tolerant ryegrass HT helps to overcome to a higher extent the effects of future climate change in relation to South Australia this could be mainly because future temperatures in Gippsland are expected to be higher than in South Australia.

The superior FCE dairy cow overcame the decline in milk production, but not the decline in feed consumption. The main reason for this is that the better FCE dairy cow is more effective at turning animal feed into milk, so it doesn't require as much feed to produce as much milk. Feed conversion efficiency (FCE) is the ratio of dry matter intake and milk production (Connor *et al*., 2012). In order to minimize energy loss, particularly through methane CH_4, animals that are more effective feed converters consume more feed that is more digestible (Niemann, 2011).

According to some research, livestock genetic advancements can partially mitigate the effects of climate change on animal production, particularly in drier regions where adaptation is more critical (Moore and Ghahramani, 2013; Lee *et al*., 2012). But there isn't as clear of a link between animal productivity and pasture genetic advancements (Lee *et al*., 2012). Furthermore, there is a relationship between FCE and CH_4 emissions per kilogram of milk produced, suggesting that choosing cows with higher feed efficiency can reduce CH_4 emissions (Basarab *et al*., 2013; Løvendahl *et al*., 2018; Van Middelaar *et al*., 2014). In broilers, a similar correlation has been observed between FCE and the decrease in emissions per unit of weight (Williams and Speller, 2016). It was discovered that genetic enhancement of the feed conversion ratio in catfish lessens environmental impacts by combining life cycle assessment and bioeconomic modelling of genetic response to selection (Besson *et al*., 2016).

To be conservative in this project, it was assumed that the genetically modified dairy cow would be 10% more productive than the historical base dairy cow in each case study. Genetic selection can help achieve this 10% improvement in FCE. Milk yield has increased rapidly in the last few decades, mostly as a result of genetic advancements (Oltenacu and Broom, 2010). Over the past 30 years, Holstein milk yields in Australia and the USA have increased by about 1% annually (Hayes *et al*., 2013). The milk yield per cow has increased by 16% over the past ten years (Oltenacu and Broom, 2010; Connor *et al*., 2012). Furthermore, since the model fixed the forage consumption for both case studies, it was predicted that future climate change would result in a decrease in milk production due to the lack of supplemental feed and other inputs. This implies that even in the event that climate change has an impact on milk production, it could increase by up to 5% until 2050 if all farms have the same resources, there is no increase in supplements, particularly forage, and genetically adapted dairy cattle and ryegrass are used.

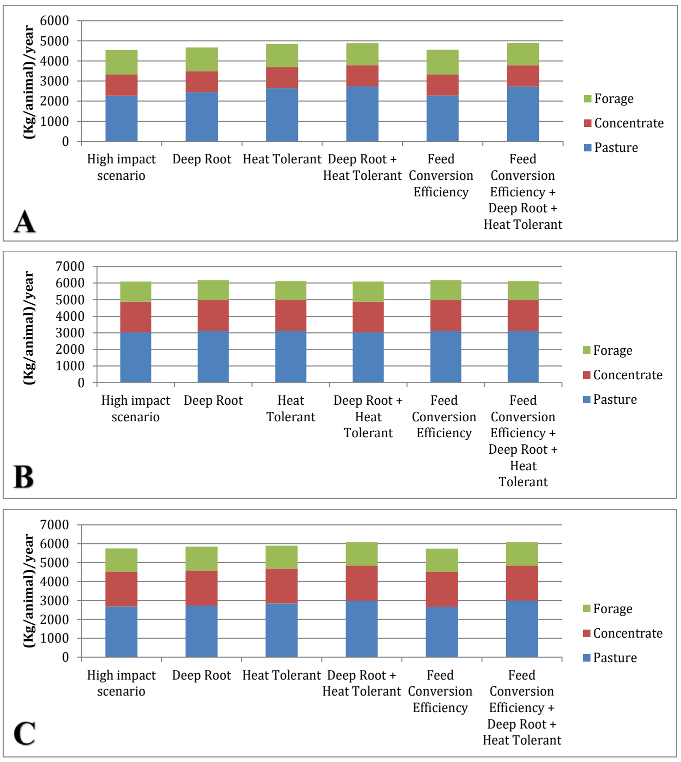

Figure 6: *Effect of adaptation options on pasture, concentrate and forage consumption expressed in (kg/animal)/year in 2050 for Gippsland (A) and South Australia (B) and in 2080 for Gippsland (C) and South Australia (D).*

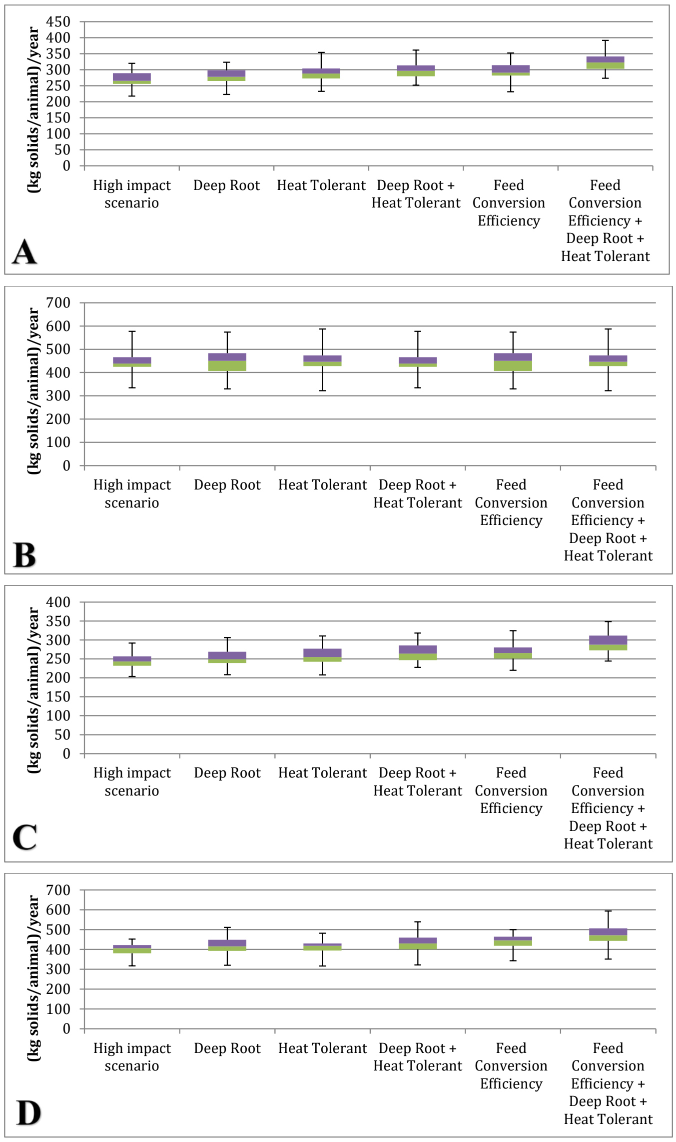

Figure 7: *Effect of adaptation options on annual milk production in 2050 for Gippsland (A) and South Australia (B) and in 2080 for Gippsland (C) and South Australia (D).*

In the two case studies included in this project, it was illustrated how future climate change would impact dairy production. In 2080, it is evident how future climate change will affect dairy production and how much genetic advancements will help to mitigate those effects. Depending on the area in which the farm is located, the effects of potential climate change on dairy production will vary.

Australia is divided into eight dairy regions; however, the research for this project was performed on two farms in separate states: South Australia and Gippsland, Victoria. These two farms were selected because they are situated in distinct locations that are typical of Australia's dairy regions, each with its own unique climate and set of needs (Dairy Australia, 2014). Depending on the climate vulnerability and management strategies of each region, milk production will be impacted by climate change in different ways (Fodor *et al*., 2018).

Future climate change would have a greater impact on the Gippsland farm than on South Australia. The Gippsland farm had spring calving, which occurred from September to November. This mean that the farm was more vulnerable to climate change in the future because the cows' early and mid-lactation, which is the peak of lactation, depends on the growth of the pasture in the spring and early summer, which coincided with a decline in pasture growth. This indicates that when there is a greater need for nutrients, pasture declines. Although it is unlikely to completely mitigate the negative effects of the future climate, an earlier calving time for this farm may have some adaptation benefits by better matching animal feed demand with the altered pattern of pasture growth. In the case of South Australia, the Autumn calving in (March to May) increased the demands during the peak lactation period of the cows, which is late winter to early spring. During this period of the year, pasture increased under all future emission scenarios.

Conclusions and Recommendations

Future climate change will have a negative effect on milk production, feed consumption, and pasture growth rates. The degree of those effects varies depending on the area in which the farm is situated. In the two case studies, the adaptation options are implemented to varying degrees, mitigating the effects of future climate change. Gippsland was more impacted by future climate change than South Australia, so the outcomes of putting the adaptation options into practice there are more obvious in that state. Maintaining production requires the implementation of management adaptation practices alongside genetically adapted livestock and ryegrass. To determine whether the combination of genetic adaptations can be achieved, more research is required.

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Novelty Statement

In order to mitigate the negative effects of a warmer and drier climate, the project's goals are to evaluate how climate change is affecting the dairy industry and look into the possibility of genetic improvement in pasture and animals. Studies have been conducted regarding the effects of climate variability and potential mitigation strategies. The significance of genetic improvement as a means of adaptation is emphasized by this project. There aren't many projects involving genetic improvement, but more study is required to determine whether or not genetic adaptations can be implemented.

Author's Contribution

Brendan Cullen: Conceived the idea and developed the methodology.
Brendan Cullen and Elena Balarezo: Perform the project.
Elena Balarezo and Jose Luis Flores: Wrote the document with the input of BC.

Conflict of interest
The authors have declared no conflict of interest.

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