The importance of genetic improvement as adaptation option for climate change in the dairy industry
(Based on case studies in pasture based production)
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Abstract

The dairy industry is facing many challenges. It has to increase production while at the same time reduce its environmental impact. It also has to overcome the impacts of future climate change. For these reasons the dairy industry has to become more efficient. This project is focused on genetic improvements as an adaptation option to overcome the impacts on the dairy industry of climate change. The objectives of this project are to address gaps in the impacts of climate change on the whole dairy system, and to investigate the potential of genetic improvement in pasture and animals to overcome negative impacts of a warmer and dryer climate. In order to achieve these objectives DairyMod was set up to take into account the different management practices and climate variability of two farms, one in Gippsland and the other in South Australia. Firstly it modelled the impacts of climate change on pasture growth, feed consumption, and lactation, and then modeled pasture growth, feed consumption and lactation in future climate change years with better adapted pastures and livestock. Climate change will affect pasture growth patterns by contracting the spring growing season. Additionally climate change will decrease feed consumption and decrease lactation. The most effective adaptation option in order to overcome the impacts of climate change in pasture growth is the combined adapted perennial ryegrass DR+HT, while the most effective adaptation options to overcome the impacts in total feed consumption are the multiple adaptations FCE+DR+HT and the combined adapted perennial ryegrass DR+HT. The multiple adaptations FCE+DR+HT are also the most effective adaptation option in order to overcome the decrease in lactation. 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. It concludes that future climate change will impact different areas to different extents, with the farm in Gippsland being more affected than South Australia. Similarly, the implementation of adaptation options will overcome the impacts of future climate change to different extents. The genetically adapted ryegrass and livestock also need to be implemented together with management adaptation practices in order to maintain production and farmers profitability. The paper recommends further research should be done in how to manage the uncertainty of future climate change, and in the use of multiple traits in the genetic adaptation.
Introduction

The dairy industry in the future has to become more efficient. On the one hand, as milk is one of the most important sources of nutrients for humans, the production of milk in the future has to increase by more than double in order to fulfill the demands of the growing population. On the other hand, the dairy industry has to become more sustainable, overcome the impacts of future climate change, and reduce its environmental footprint. The sustainability of the dairy industry in the future has been widely debated because dairy cattle require a great amount of land and resources in order to produce and the environmental impacts of the industry are great. The dairy industry is a great contributor to greenhouse gas (GHG) emissions, land clearance and degradation, and water pollution. At the same time dairy production is very sensitive to the impacts of future climate change. In the future, temperature and CO2 will increase, rainfall will decrease, the climate will be more variable, and the incidence of extreme weather events will increase. This will impact dairy production by decreasing pasture yield and quality, decreasing animal performance, increasing the incidence of pests and diseases, and increase soil degradation, which will cause severe losses in dairy production. The dairy industry in Australia is mostly based on pasture and for this reason future climate change will cause a rise in the price of animal feed and inputs affecting farmers’ future profitability.

In order to ensure food security in the future it is necessary to implement adaptation practices, which have to cope with the levels of uncertainty of changes that will occur in each region. Some adaptation practices include a change in management practices and the implementation and improvement of farm infrastructure. The genetic improvement of plants and animals is also an important adaptation option in order to make dairy production more efficient and to adapt it for future climate change. The advantage of genetic adaptation is that it increases in effectiveness over time. In the case of dairy cattle genetic improvement 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. In the case of pastures (perennial ryegrass), genetic improvement has great importance for future pasture profitability because it will be difficult to maintain pasture yield and quality with fertilization and management for future climate change. With the genetic improvement of dairy cattle and pasture, dairy
production will become more efficient for future scenarios, increasing dairy production to fulfill future demands, improving dairy production adaptability for climate change, and decreasing the dairy industry’s environmental footprint.

This project addresses the gaps in the impacts of climate change in the whole dairy system and the importance of genetic improvement in pasture and livestock for dairy adaptation to climate change.

**Future challenges for the dairy industry**

In 2050 the human population is projected to increase by 70% more than it was in 2010 (Food and Agriculture Organization (FAO), 2009 cited in Berry, 2013). The consumption of milk and dairy products is projected to increase due to the growing population and because of the increase in consumption in some developing countries where people are changing their diets to consume more meat, milk and dairy products (Steinfeld, 2006). By 2050 the consumption of milk and dairy products will be more than double than it is now, increasing from 580 to 1043 million tones (Steinfeld, 2006). Furthermore, milk and dairy products are an important part of human nutrition because they provide protein carbohydrates and vitamins and minerals such as calcium, zinc and iodine (Millward and Garnett, 2010). Some studies have been performed in order to find different sources of these nutrients but milk has been demonstrated to be the most important source, especially for children (Millward and Garnett, 2010).

The dairy industry in the future has to face some challenges. Firstly, it has to increase production in order to fulfill the growing demands for milk and dairy products (Berry, 2013). Secondly, because of the impacts of climate change, dairy cattle in the future need to become better adapted to less intensive environments with lower feed quality and limited resources (Boichard, 2012). As well consumers are starting to voice concern about the environmental footprint of dairy products (Connor, 2012) and the impacts of their production on animal welfare (Steinfeld et al, 2006). Finally, the dairy industry has to become more sustainable and reduce its environmental footprint (Dewhurst, 2012). These challenges can be overcome by improving the production efficiency of dairy cattle with more efficient and better-adapted plants and animals (Berry, 2013; Howden and Stokes, 2009).
A sustainable food production in the future will provide enough food to feed the growing population while at the same time minimize greenhouse gas emissions (Steinfeld et al, 2006). In the future, the dairy industry has to become more efficient in order to be more sustainable, fulfill the demands of the growing population for animal protein, and at the same time reduce its environmental impacts (Dewhurst, 2013). The sustainability of the dairy industry in the future is being debated because the conversion of food into milk is low and the dairy industry requires high amounts of land and natural resources in order to produce (Steinfeld, 2006). Dairy cattle can produce high quality protein from pastures and feeds that can’t be directly consumed by humans (Dewhurst, 2013). However, the sustainability of the dairy industry in the future is debatable because the system needs land and resources that can be used for more sustainable production – such as vegetables – and most cattle feed is made from grains and feeds that humans can consume. In an intensive dairy production, 96% of the protein that cattle eat can be consumed by humans (Oltenacu and Broom, 2010).

The dairy industry in the future has to reduce its environmental footprints. The environmental impacts of the dairy industry include land clearance and degradation, GHG emissions and water pollution (Steinfeld et al, 2006). The expansion of the dairy industry causes land clearance and degradation. Animals overgrazing causes erosion and land degradation, and the increase of grazing lands in order to produce pasture forages for dairy cattle causes land clearance and deforestation (Steinfeld, 2006). Additionally, water pollution and utilization are other environmental impacts of livestock, including dairy. More than 8% of the water used for humans is utilized by livestock, for irrigation, cleaning and animal feeding and the pollution is caused by animal waste and the use of pesticides and chemicals for feed crops (Steinfeld et al, 2006). These alterations in the environment cause the loss of biodiversity (Steinfeld et al, 2006).

In 2009, agriculture production contributed around 6% of the total US GHG emissions; approximately one third of these emissions was due to enteric fermentation and around 12% to manure management. Anthropogenic GHG emissions are the main cause for recent climate change (Yadav, 2011). Livestock production is a great contributor to GHG gases; beef and dairy cattle are the main contributors to these emissions due to enteric fermentation and the GHG emissions caused by deforestation.

**Impacts of future climate change on the dairy industry**

In Australia the dairy industry is one of the most important rural industries after beef and wheat. Around 65% of milk production in Australia is produced in Victoria and most of the production is pastured based which makes dairy production more prone to the impacts of climate change (Howden and Stokes, 2009). Future climate change will affect the dairy industry. The grazing industry has been an important factor for economic growth in Australia but at the same time this industry is affected by the variability of climate change, and this sensibility in agriculture has been determined as one of the main factors for the volatility in Australia’s economy (Howden and Stokes, 2009).

In the future, limitations in pasture production due to climate change will cause producer reliance on feed inputs, and producers will have to buy more supplementary feed and rumen modifiers (Howden and Stokes, 2009). In Australia the number of farms that use supplementary feed such as grains and forages is increasing (Howden and Stokes, 2009). This will affect animal production in the future because the prices of some grains making up the animal feed are projected to increase, which is the case for soybean and corn. This will cause an increase in the cost of supplementation and animal feed affecting the sustainability of the system, because the cost of feed in the dairy industry is the main input cost, being more than 50% of the overall cost of production (USDA-NASS, 2011 cited in Connor, 2012). Additionally, the quality and availability of animal feed will decrease because during severe heat episodes the price and quality of grains decrease and high temperatures cause the accelerated deterioration of stored animal feed. This will decrease animal feed availability and quality (Ogunsipe, 2012).

In the future temperatures will increase affecting pasture yield and quality as well as animal welfare and performance. In cold areas the elevated temperature will decrease the damage caused by frost and will increase the duration of the growing season. These changes are beneficial for pasture productivity but can deplete soils in cooler months (Howden and Stokes, 2009). The elevated temperatures affect pasture growth
but the decrease in rainfall will be the main factor that limits pasture growth, as the pastures will take more time to grow because of the water stress. This will decrease the percentage of leaves in pastures, decreasing pasture quality and animal performance (Howden and Stokes, 2009).

The increase in temperature has significant regional and seasonal variations. In cooler areas the increase in temperature will allow an expansion of suitable crop areas, but significant losses are predicted in hot areas due to heat and water stress. In the tropics a temperature increase of less than 2°C will cause yield losses. In temperate regions the crops will be benefit by changes up to 2°C, and further warming will affect crop yield (Yadav, 2011). The increase in temperature causes heat stress, which affects animal welfare decreasing reproduction and affecting performance (Sieuve de Menezes, 2011). Additionally, if temperatures increase, the water requirement of animals increases and feed consumption decreases thus limiting grazing (Howden and Stokes, 2009; Ogunsipe, 2012).

The incidence of pests and diseases also increases in warm conditions. In the case of plants this occurs because warm temperatures are optimal for the spread of pests for fungal spore production (Anwar, 2013). Additionally, the competition between pastures increases allowing the increase of C4 species that are less digestible and have less nutrients than C3 species (Howden and Stokes, 2009). In high temperatures cattle diseases such as bovine respiratory disease, and other chronic respiratory diseases increase, and warm temperatures are optimal for the spread of diseases between regions (Ogunsipe, 2012).

With the growing demand for food and rising temperatures, the requirements for water will increase (Yadav, 2011). Global irrigation requirements could increase around 5% to 8% by 2070, but the water supply will not fulfill these requirements. Additionally, with the growing population the competition for water between agriculture, households and industry will increase (Yadav, 2011).

The decrease and variability of rainfall between seasons causes soil degradation. Severe droughts after intensive rainfalls will cause soil erosion and nutrient leaching (Howden and Stokes, 2009 Yadav, 2011). One percent of a decline in rainfall will produce a 1.5-2% increase in erosion rates (Nearing, 2004 cited in Yadav, 2011). The
nutrient leaching is caused because of the increase in temperature as well, which increases the decomposition of organic matter by stimulating microbial activity (Yadav, 2011).

The incidence of extreme climate events is projected to increase. These extreme climate events such as severe droughts, heatwaves, floods and storms will affect future agriculture causing severe losses. Heavy rainfall events will cause soil erosion and salinization, and increasing floods will cause damage to crops and animal production. In regions nearer to the coastlines, the rise in sea level will cause damage to large areas of fertile land because the salt water affects soil fertility (Yadav, 2011).

**Adaptation options for the dairy industry in future climate change**

In order to ensure food security in the future it is necessary to implement practices that improve the adaptation capacity of the agricultural sector (Yadav, 2011). These practices have to cope with the levels of uncertainty of the changes that will occur in each location because some regions will be more affected by climate change than others (Howden and Stokes, 2009).

In order to maintain soil fertility it is necessary to ensure the adequate use of fertilizers. Used in the proper way, with the right amounts at the right time, the efficiency of fertilizers can be seen immediately because it enhances soil fertility. On the other hand if the fertilizer is not used adequately as in the case of nitrogen fertilizers, the nitrogen can leach into the soil or volatilize in the atmosphere causing nutrient loss (Howden & Stokes, 2009; Ghahramani & Moore, 2013). In order to make the use of nitrogen fertilizers more efficient, controlled release fertilizers could be used, such as urease inhibitors and nitrification inhibitors. Additionally, it is important to test the nutrients in the soil before the application of fertilizers and to split the applications of nitrogen fertilizers (Delgado, 2013). In order to increase soil fertility the addition of phosphorus is also important to adapt crops to climate change. Some alternatives in order to increase the protein levels in pastures are the addition of lucerne or some legumes into the grazing area; lucerne has a better response in summer compared to grazes (Ghahramani & Moore, 2013).

The efficient use of water will be an important adaptation management factor in order to adapt animal production to climate change. The decrease in rainfall will lead to the
use of more water for agricultural production; this is the reason improving water capture and storage and avoiding water waste are important points. A management strategy is to implement the use of irrigation scheduled according to water forecasts, rainfall and evapotranspiration records (Dairy Australia, 2010; DairySAT, 2010).

One of the most important impacts in agriculture is land degradation. In order to mitigate land degradation and soil erosion in the case of pasture based systems, it is necessary to implement infrastructures where the animals can stay in periods where the pasture cover is lower, or when the paddocks are flooded. This management practice will avoid soil damage and compaction that are caused from animals grazing (Ghahramani & Moore, 2013).

The control of weeds and plant diseases has to be improved in the future. Future climate change will increase the incidence of pests and diseases in plants; this is why producers will depend on the use of herbicides and pesticides. On the other hand, the cost of these will rise and the plant diseases and weeds will become more resistant to such chemicals (Howden & Stokes, 2009). It is necessary to implement adequate weed management options in each farm in order to decrease the reliance on herbicides and pesticides (Ash, 2012).

In the case of animals, the increase in the incidence and spread of animal diseases has to be managed by governmental programs (Howden & Stokes, 2009). The management of pests and diseases will be difficult in the future because as in plants, animal pests and diseases will become more aggressive and resistant to the chemicals that nowadays are used. Producers have to be informed about emerging animal pests and use antibiotics and chemicals under veterinary prescription (DairySAT, 2010).

In order to mitigate heat stress in cattle it is important to provide shelter during heatwaves or when the temperature and solar radiation increases. In pasture-based systems the use of trees is important in order to provide shade for cattle; in intensive production the use of feedlots with adequate structures that provide shade during summer and shelter during winter is important (Howden & Stokes, 2009). Additionally the climate variability between seasons could lead to changes in management practices such as in modifying the timing or mating period and matching the periods of specific nutrient requirements of animals with the periods when the
quality and quantity of pasture are better and climate conditions are more adequate. Adjusting the stoking rate is necessary in order to improve the use of resources and at the same time avoid erosion (Howden & Stokes, 2009).

The genetic improvement of pastures and livestock play an important role in order to adapt animal production to climate change. The advantage of genetic adaptation is that it increases in effectiveness over time, which is different for feed-based adaptation, which declines over time (Moore and Ghahramani, 2013). In the case of pasture, the implementation of better-adapted varieties will depend on the location of the farm. In temperate areas it is necessary to implement pasture varieties that have higher levels of non-structural carbohydrates that provide more metabolizable energy. In the case of the tropics it is necessary to implement pasture varieties better adapted to warmer climates and that have higher adaptation to drought (Howden & Stokes, 2009).

**Genetic improvement of dairy cattle**

In order to achieve more efficiency and better dairy production, management options and genetic improvements were previously always focused on increasing milk production (Oltenacu and Broom, 2010). The genetic improvement in feed efficiency has been the main driver for improving production (Berry, 2013). This is mainly because milk production and feed intake are highly genetically correlated (Connor, 2012). In several countries the genetic improvement in dairy cattle has caused milk production per cow to increase by more than double in the last 40 years (Oltenacu and Broom, 2010). This rapid progress in milk yield is mainly due to genetic improvements; before the mid-1980s the improvement in milk yield was caused by improvements made in management and nutrition, but now genetic improvements are the main driver of progress in milk yield and with the use of artificial insemination and other breeding techniques the sires of the most efficient bulls can be spread worldwide (Oltenacu and Broom, 2010).

The use of genomics and reproductive biotechnology and the use of new precision farming technologies will play an important role in the improvement of livestock production in the future (Niemann, 2011). Genomic selection increases the potential genetic gain by 60 to 120% because it reduces the generation interval. The generation
interval can be reduced to two years. The predominant reproductive biotechnology has been artificial insemination, and then embryo transfer technology which significantly increases animal performance and the rate of genetic gain. New reproductive biotechnologies such as in vitro embryo production and transgenesis can accelerate these changes even more. (Niemann, 2011). Additionally precision farming will make genetic improvements more efficient by improving the availability of information about genetic traits (Boichard, 2012; Hayes, 2013).

There are some negative implications of genetic improvement focused only on one trait. For example the improvement in milk production over the years has led to animal health and welfare problems such as metabolic diseases. This is because high productive dairy cows have high requirements for energy and nutrients and if the feed doesn’t meet these requirements the animal mobilizes energy reserves from body tissue causing a negative energy balance affecting cow’s reproduction and performance (Coleman, 2010; Connor, 2012; Spurlock, 2012). Additionally genetic improvement focused only on milk production in Holsteins has resulted in larger cows, and therefore increased the feeding requirements per cow (Coleman, 2010).

In order to describe a more feed efficient dairy cow several definitions have been proposed:

1. Feed Conversion Efficiency (FCE): which is the ratio of milk produced in relation to DMI or energy intake (Connor, 2012).
2. Residual Feed Intake (RFI) or residual energy balance: which is the difference between an animal’s actual feed intake and its expected feed intake (Veerkamp 1995; Williams, 2011; Basarab, 2013).
3. Residual Solids Production (RSP): which is defined as the actual milk solids produced, related to expected solids production (Crowley, 2013).

The appropriate definition of a feed efficient dairy cow is debatable. Animals that mobilize more tissue reserves can be ranked as having high FCE because the calculation of FCE doesn’t discriminate the energy requirements, which can be for maintenance or production, and it doesn’t take into account the mobilization of body reserves (Veerkamp, 1995; Connor, 2012). On the other hand the calculation of RFI discriminates the energy requirements and the mobilization of body reserves.
indicating the metabolic efficiency of the animal (Veerkamp, 1995; Williams, 2011; Basarab, 2013). Some authors have indicated that FCE and RFI might be inappropriate approaches to quantify feed efficiency in dairy cows indicating that selecting cows for RSP improves animal welfare and economic responses (Crowley, 2013; Coleman, 2010).

By improving feed conversion efficiency in cattle, dairy farmers’ profits will increase and at the same time the environmental footprint will be reduced. The efficiency of feed conversion is the main factor that contributes to the variation of the carbon footprint of the dairy industry because of its consequences in the methane discharge by enteric fermentation and manure; improving FCE would reduce GHG emissions (Innovation Centre for US Dairy, 2010 cited in Connor, 2012). More efficient animals produce less GHG per unit product (Dewhurst, 2012). The improvement of feed efficiency in dairy cows will increase milk production, increasing energy efficiency and maintaining farmers’ future profits because small numbers of animals will be needed to produce the same amount of milk – which also reduces land use, the cost of feed inputs, and inputs such as energy and fuel (Connor, 2012).

There are some characteristics that more efficient feed convertor animals could have. Firstly, animals should have a higher feed intake with higher digestibility so they can reduce energy loss, especially via methane CH4. The extent of feed intake in an animal depends on its physiological stage, age and body weight, feed quality and structure and other influences. Increasing feed intake will improve the availability of energy and nutrient inputs per animal. A greater digestion of animal feeds can be achieved with a greater expression of specific digestive enzymes in the gastrointestinal tract of the animal. Secondly, animals should be more metabolically efficient with less energy and nutrient requirements. Energy and nutrient requirements depend on animal species, body composition and other influences. Reducing maintenance requirements would save nutrients and energy, contributing to a better feed convertor animal (Niemann, 2011).
Genetic improvement of perennial ryegrass

It will be difficult to maintain pasture yield and quality with fertilization and management for future climate change (Parsons, 2011). For this reason genetic improvement is an important adaptation option in pastures. The genetic improvement of ryegrass has been focused on improving dry matter yield (Sampoux, 2011). In the case of Australia the main breeding objectives of perennial ryegrass (PRG) are the following: herbage production and seasonal pattern, persistence, drought and heat tolerance, quality, resistance to fungal and viral diseases, resistance to invertebrate pests, and seed production (Cunningham, 1994). The selection for a trait will be influenced by economic value but regardless the selection of multiple traits will be required for taking into account that the cultivar must not have unacceptable performance for any trait (Stewart, 2011).

Some parts of Southern Australia have droughts for 2–4 months, and these conditions are similar to Mediterranean conditions where PRG persists being dormant during summer and actively growing during winter, and in this way the plants avoid drought stress (Arcioni, 1980 cited in Cunningham, 1994). The genetic selection of PRG for drought tolerance is complicated because there are many traits involved in it, such as low maintenance respiration, epicuticular wax content, osmotic adjustment, pigmentation composition, leaf angle and rolling, low leaf water conductance, etc. (Cunningham, 1994; Reynold, 2010). Additionally, the genetic selection of drought tolerant PRG should take into account not only the plant’s survival from abiotic stress but also take into account the rapid recovery and growth ability under poor conditions (Chaves, 2004; Reynold, 2010).

Drought is the main limitation for plant production (Chaves, 2004). It is important to improve management practices and implement genotypes adapted to drought areas in order to maintain pasture productivity; however, in order to achieve these objectives it is necessary to have further understanding about the mechanisms of drought resistance and the efficient use of water by plants (Chaves, 2004; Reynolds, 2010). Studies on the genetic improvement in crops in the last decade has been focused on resistance to biotic stress such as drought, but most of the studies have been restricted to laboratory experiments and the progress in improvement of stress resistance was
minimal. Nowadays, recent advances demonstrate that in the near future rapid genetic progress will be achievable (Chaves, 2004).

There are some strategies that would help plants to overcome future climate change. Such strategies are focused on improving photosynthetic responses, transpiration efficiency, water use efficiency and homeostasis maintenance (Chaves, 2004; Reynolds, 2010). An advantage of PRG is its dormancy in summer, because changing the phonological pattern of a crop so that the critical growth stages don’t coincide with stressful conditions is the most effective strategy in order to overcome drought (Reynolds, 2010). Another strategy is to improve the root system by increasing root depth, and root mass. Drought resistance is linked with deeper root penetration (Bonnos, 2004). With deeper roots the plants have access to water deeper in the soil and during heat stress the plants have transpiration rates that match evaporative demands (Reynolds, 2010). Additionally, deeper roots increase nitrate interception (Crush, 2007).

During severe drought episodes there are some changes in plant physiology and the understanding of these changes can help animal breeders to understand the impacts on plant physiology and how to mitigate these impacts by genetically changing plant physiology. Some studies have indicated that during water stress leaf carbon fixation decreases due to stomata closure; under field conditions water stress caused the decrease in photosynthesis mainly because of stomata closure (Chaves, 2004). Some studies have also suggested that oxidative stress has an important role in severe drought episodes (Chaves, 2004; Flexas, 2006). Other studies have determined that by modifying the respiration in plants, the photosynthetic behavior can also be altered and this increase in respiration rate helps plant photosynthesis recovery after a period of water stress (Flexas, 2006).

Pasture yield and quality can be changed by modifying plant physiology. Some studies demonstrated that breeding for long leaves or for a high leaf elongation rate could improve the DM yield during spring (Sampoux, 2011) and contribute to superior pasture growth (Lee, 2012). Leaf dimension contributes to the plant efficiency as well; photosynthesis rates increase in plants with thicker leaves and this increases water use efficiency (Boote, 1994). It is possible to change pasture quality by changing flowering behavior; the growth rate increases after flowering, because of
an increase in the rate of cell division and this is the reason why the seasonal productivity of PRG is influenced by the timing and spread of the reproductive phase (Cunningham, 1994). Additionally as flowering progresses, the quality of pastures and pasture digestibility declines (Stewart, 2011; Lee, 2012).
Methodology

Case studies simulation

There are eight dairy regions in Australia; however, this project was conducted on two farms located in different regions: in Gippsland (Victoria), and in South Australia. These two farms were chosen as they are located in specific places that are representative of dairy regions in Australia with different climate conditions and requirements (Dairy Australia, 2014). Additionally the evaluation of the impacts of future climate change and the adaptation options is an extensive research endeavor and this limits the number of places where the project can be conducted. In this project a sample of two case studies makes the computational load manageable.

The farm study simulations were validated using DairyMod which is a dairy production system model where daily climate information is set up in order to simulate pasture and animal production for pasture based systems. In this project DairyMod was used as a tool to model dairy production because it simulates daily pasture growth, water availability and animal production under different climate conditions and management options, fertilization and irrigation (Cullen et al, 2008). The model has been applied to simulate dairy pasture growth rates, and dairy farming production with successful results (Johnson, 2008). The model can be used as a research tool because it can meet the needs of the researchers and is continually being improved (Johnson, 2008).

In order to set up the data for the case studies in Gippsland and South Australia, some parameters and management practices for each farm were established in DairyMod. The Gippsland farm was located near Moe, in a region with an average annual rainfall of 940 mm. The farm was stocked at 3.2 cows/ha with a spring calving pattern. Annual concentrate feeding averaged at approximately 1 t/cow. The South Australian farm was located in the Fluerieu Peninsula. It had a similar annual rainfall but a lower stocking rate and an autumn calving pattern. Concentrate feeding levels were higher on this farm, averaging approximately 1.6 t/cow.
Some parameters were fixed in DairyMod for both case studies. In the case of feed management, the maximum consumption of forage was 5 kg per day as indicated in each farm’s policy management. The nitrogen (N) fertilization management was fixed at 50 kg N/ha applied every time the paddock was grazed or cut. All the paddocks established in the program were based on perennial ryegrass. The pasture biophysics was set up with a ryegrass that responds to heat stress. The temperature in which the plant starts to be affected by heat stress was set up at 28 °C and the full pause of the plant photosynthesis was at 35 °C.

Table 1 Case study description.

<table>
<thead>
<tr>
<th>Farm Description</th>
<th>Gippsland</th>
<th>South Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total farm area (ha)</td>
<td>144</td>
<td>347</td>
</tr>
<tr>
<td>Land available for pasture/feed production (ha)</td>
<td>118</td>
<td>252</td>
</tr>
<tr>
<td>Area for milkers grazing (ha)</td>
<td>110</td>
<td>208</td>
</tr>
<tr>
<td>Soil type</td>
<td>Gray dermosol.</td>
<td>Gray dermosol.</td>
</tr>
<tr>
<td>Milking</td>
<td>26-a-side double up.</td>
<td>25-unit swing-over.</td>
</tr>
<tr>
<td>Pastures</td>
<td>Predominantly perennial ryegrass</td>
<td>Predominantly perennial ryegrass</td>
</tr>
<tr>
<td>Milking herd</td>
<td>352 cows</td>
<td>350 cows</td>
</tr>
<tr>
<td>Stoking rate</td>
<td>3.2 cows/ha</td>
<td>1.6 cows/ha</td>
</tr>
<tr>
<td>Calving dates</td>
<td>Spring calving.</td>
<td>Autumn calving.</td>
</tr>
<tr>
<td>Herd live weight</td>
<td>475 kg</td>
<td>600 kg</td>
</tr>
<tr>
<td>Stock Breed</td>
<td>Holstein-Friesian, Jerseys, and more recently Aussie Red cattle.</td>
<td>Holstein-Friesian, but has been crossed with Aussie Red and Montbeliarde cattle in the last 2 years.</td>
</tr>
<tr>
<td>Replacement calves/year</td>
<td>100 range (80-120)</td>
<td>100 range (80-120)</td>
</tr>
<tr>
<td>Total milk production (L)</td>
<td>1598947.667</td>
<td>2601286.667</td>
</tr>
<tr>
<td>Milk fat</td>
<td>4.60%</td>
<td>3.80%</td>
</tr>
<tr>
<td>Milk protein</td>
<td>3.40%</td>
<td>3.20%</td>
</tr>
<tr>
<td>Average milk production per cow (L/cow)</td>
<td>4712</td>
<td>7299</td>
</tr>
<tr>
<td>Average milk fat production per cow (kg/cow)</td>
<td>162</td>
<td>279</td>
</tr>
<tr>
<td>Feed consumption</td>
<td>60-70% grazed pasture</td>
<td>50% grazed pasture</td>
</tr>
</tbody>
</table>
Table 1 presents a description and the management policies of the Gippsland and South Australian case studies. The land areas shown in the table indicate the total area inside the farm and the area available for milking and production; in both case studies the dry cows were not feeding in the milking area. In order to replicate this management practice in the Dairy Mod the feed consumption of the dry cow was not included in the calculation of the total feed consumption of the dairy cow for this study.

**Climate change simulation**

Daily climate information from the SILO meteorology database was used in order to define future climate scenarios. Future climate change was estimated according to emission scenarios that are representations created according to human population growth, socioeconomic development, energy use and technological change. The tendency of these changes are uncertain; in order to describe the changes in the future, the Intergovernmental Panel on Climate Change (IPCC) designed possible future emissions scenarios (Yadav, 2011). This project used the Representative Concentration Pathways (RCP), which is based on the emission scenarios in the IPCC 5th Assessment Report. The RCPs are a set of projections, which take into account the flow of the radiation in the atmosphere caused mainly by changes in atmospheric composition. There are four RCPs based on to their total radiative forcing in 2100. In this project, the predictions were modeled based on the Representative Concentration Pathway 8.5 (World Meteorological Organization, 2014), a high emission scenario which is the most appropriate climate scenario in order to evaluate the impacts of climate change on agriculture (IPCC, 2013) because it has been demonstrated that climate change is occurring worse than expected in all scenarios (Anwar, 2013).

The uncertainty in predictions of Global Climate Models (GCMs) needs to be interpreted in order to assess the uncertainty in the impacts of climate change. There are some sources of errors in GCMs, especially in the daily mean of precipitation. The source of the errors is mainly because many small-scale processes cannot be assessed
in climate models with certainty, and therefore have to be approximated (Semenov and Stratonovitch, 2010).

In order to assess uncertainty in future climate change projections across GCMs, this project used six Global Climate Models for projections of future climate change which have the best performance in order to predict weather in Australia and the availability of the monthly-scale projected weather data required for downscaling (CSIRO, 2007 cited in Moore and Ghahramani, 2013). In order to assess the climate impact in pasture and dairy production, the climate variations to be taken into account were: temperature (°C), rainfall (mm) and CO₂ (ppm) in low, medium and high emission scenarios for the years 2020, 2050 and 2080.

In order to assess the uncertainty in daily means predictions, this project used historical data from 40 years prior to the study, with the daily variation across these 40 years used to create a future climate scenario with the projection of the six GCMs, dividing these projections into low, medium and high, according to the climate variable projection changes across the six GCMs.

![Climate variability in Gippsland in 2020](image)

Figure 1 Climate variability in Gippsland in 2020.
Figures 1 to 3 above show the average of daily rainfall (mm) and the average of the daily minimum and maximum temperature (°C) based on historical data and across the emission scenarios for the years 2020, 2050 and 2080. 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 2020 the average annual rainfall is 965 mm, 925 mm and 881 mm in the low, medium and high scenarios respectively, with a range of temperature
from around 9 to 20 °C (Figure 1). 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 (Figure 2). 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 (Figure 3).

Figure 4 Climate variability in South Australia 2020.

Figure 5 Climate variability in South Australia 2050
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 2020 the average annual rainfall is 957 mm, 917 mm and 878 mm in the low, medium and high scenarios respectively with a range of temperature from around 10 to 18 °C (Figure 4). 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 (Figure 5). 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 (Figure 6).

Note that in this project a monthly change factor was applied in the historical data based on extremes, and the average was not used in order to manage the variability of factors, especially of rainfall and temperature.

In the two case studies, in the case of the atmospheric CO₂ concentration (ppm) in the historical data, a constant base of 380 ppm was used. For future climate impacts the atmospheric CO₂ concentration was changed: in 2020 the CO₂ concentration was
415.78 ppm; in 2050 the CO$_2$ concentration was 540.54 ppm, and in 2080 the CO$_2$ concentration was 758.18 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, in the case of pasture: the growth pattern of the pasture measured as pasture growth rate expressed in (kg/ha)/d and cut yield expressed in (t dwt/ha)/year. While in the case of livestock, the outputs assessed were: 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. No economic analysis was carried out, as this was beyond the scope of the project.

For each farm, historical climate data and climate variables for 2020, 2050 and 2080 for low, medium and high panorama were inserted into the DairyMod software. In order to assess how future climate change will affect pasture and livestock production in two different parts of Australia by the years 2020, 2050 and 2080, box-and-whiskers plots were used to compare the historical dairy production versus future dairy production and in this way determine the impacts of future climate change on dairy production, especially in lactation and cut yield. In the case of feed consumption a stacked column was used and in the case of pasture growth rate a line chart was used.

**Simulation of adaptation options**

To assess the effectiveness of the adaptation options in overcoming the negative impacts of warmer and drier climates, the farm systems were simulated again in DairyMod using different pasture and livestock parameters. In the case of pasture a genetically adapted ryegrass was used and in the case of livestock a genetically adapted dairy cow was used. To determine the genetic improvements for adaptation to climate change that have the greater results in pasture and dairy productivity, the adaptation options were inserted into DairyMod. To assess the adaptation options the
predictions were modeled in the high emission scenario of RCP 8.5 for 2050 and 2080.

In DairyMod the adaptation options inserted were in the case of pastures, root depth and distribution, and heat tolerance, and in the case of livestock improved Feed Conversion Efficiency (FCE). In order to improve root depth in the model, in the biophysics of the perennial ryegrass the root base was changed because drought resistance is linked with deeper root penetration (Bonnos, 2004). It is possible to select plants for root mass because genetic variations and heritability are adequate for breeding for this trait (Crush, 2010). In order to improve heat tolerance in the model, in the biophysics of the perennial ryegrass the temperature in which the perennial rye grass is affected by stress was changed because plants that are more tolerant to heat stress are plants with higher temperatures from the outset and for the full cessation of growth (Cullen, 2014).

In the case of livestock, in the biophysics of the stock the production efficiency was changed in order to improve Feed Conversion Efficiency. In several studies the milk yield in cows increased approximately 1% per year and most of this increase was due to genetic improvement, especially over the last three decades (Oltenacu and Broom, 2010; Hayes, 2013). Milk production and feed intake are highly genetically correlated (Connor, 2012) and for this reason genetic improvement in FCE is the main driver for improving milk production (Berry, 2013). In this study the 10% in improvement in FCE was a conservative improvement. Even if genomic selection and future reproduction biotechnologies could lead to a future increase in genetic improvement, it is important to take into account dairy cattle’s genetic potential (Niemann, 2011). The genetic potential of an animal is the maximum level of a particular trait that it is capable of being achieved (HEIFERMAX, 2014). Several studies have indicated that genetic variations in FCE actually exist and that the characters are moderately hereditable, and so the genetic improvement by selection of FCE and RFI is possible (Crowley, 2013; Hill, 2012; Williams at al, 2011). The higher the genetic variation, the higher the possible genetic gain (Crowley, 2010).
For each case study, five adaptation options due to genetic improvements were applied as follows:

1. Perennial Ryegrass with Deeper Root (DR): The base perennial ryegrass maximum length was 40 cm and 50% of its root distribution was found in the first 15 cm. The maximum length of the adapted root deep perennial ryegrass (DR) was 60 cm and 50% of root distribution was found in the first 25 cm. The change in root parameters was based on a study of perennial ryegrass traits (Crash, 2010 cited in Cullen, 2014).

2. Heat Tolerant Perennial Ryegrass (HT): To improve heat tolerance in the model the initial temperature in which the plant heat stress starts to occur was changed by 2 °C from 28 °C in the base perennial ryegrass 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 in the base perennial ryegrass to 37 °C in the heat tolerant perennial ryegrass (HT).

3. Combined adapted perennial ryegrass (DR+HT): The perennial ryegrass has the two traits combined: Perennial Ryegrass with Deeper Root (DR) + Heat Tolerant Perennial Ryegrass (HT). This combination is a possible genetic improvement because the feasibility and the outcomes for selecting plants of more than one trait are still unknown (Cullen, 2014). Some authors have indicated that the genetic selection for more than one trait could slow down the genetic gain (Boote, 1994).

4. Better-Feed Conversion Efficient Dairy Cattle (FCE): In order to improve the conversion efficiency of livestock in the biophysics of the stock, 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. This change increased Feed Conversion Efficiency by 10%.

5. Multiple adaptations (FCE+DR+HT): In this case the perennial ryegrass 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).

In order to assess the magnitude in which genetic improvements will help to overcome future climate change impacts in the two cases study by the years 2050 and
2080, box-and-whiskers plots were used to compare the future lactation and cut yield affected by climate change without any genetic improvement and the future dairy production affected by climate change with genetic improvement. In the box-and-whiskers plots the variability in the data, the shape of distribution, and the media can be determined (SigmaPlot Statistics, 2014). In the box-and-whiskers plots it is easy to assess the range of uncertainty in the climate change projections (Semenov and Stratonovitch, 2010). In the case of feed consumption, a stacked column was used in order to indicate the distribution and the proportion of pasture, concentrate and forage intake. In the case of net positive growth rate, a line chart was used in order to show the tendency of the data. Because of the mechanistic, non-stochastic nature of the model and correlations between climate scenarios, statistical analyses were not performed on the model outputs (Cullen, 2014).
Results

Impacts of future climate change on pastures and dairy production

Impacts of climate change on pasture growth patterns

Gippsland

Future climate change increase pasture growth patterns rates in winter and early spring, but reduce the length of the spring growing season (Figure 7 and Figure 8). Figure 7 indicates that across the emission scenarios there is a higher peak of net positive growth rate, where the higher 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, but there is a decline in pasture in November and December and thus a decline in pasture intake. Additionally, there is a contraction in the growing season for the last spring and early summer.

The mean annual cut yield under the historical climate scenario was 1.7 (t dwt/ha)/year (with a range of 0.4 to 2.0). By 2020 the annual cut yield is similar to the historical. By 2050 the annual average cut yield increased to 2.2, 2.3 and 2.2 in the low, medium and high scenarios respectively. By 2080 the annual cut yield increases – in the low and medium scenarios the median annual cut yield is similar at 2.5 and 2.2 in the high scenario.
Figure 7 Monthly average of pasture growth rate expressed in (kg/ha)/day across the emission scenarios in Gippsland.

Figure 8 Cut yield expressed in (t dwt/ha)/year across the emission scenarios in Gippsland.
South Australia

Future climate change increase pasture growth patterns rates in winter and early spring, but reduce the length of the spring growing season (Figure 9 and Figure 10). Figure 9 indicates that across the emission scenarios there is a higher peak of net positive growth rate, where the highest peak is in the high emission scenario in 2080. The accumulation of pasture because of the peak in the pasture growth rate is not as big as in Gippsland. 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.

The mean annual cut yield under the historical climate scenario was 1 (t dwt/ha)/year (with a range of 0 to 3.5). By 2020 the mean annual cut yield increases to 1.7 in the low scenario and 1.6 in the medium and high scenario. By 2050 the mean annual cut yield increases to 2.5 in the low scenario and 2.1 in the medium and high scenario. By 2080 the mean annual cut yield increases to 3.5, 3.1 and 2.3 in the low, medium and high scenario respectively.

![Pasture growth rate in South Australia](image)

Figure 9 Monthly average of pasture growth rate expressed in (kg/ha)/day across the emission scenarios in South Australia.
Impacts of future climate change on feed consumption

Gippsland

Future climate change will negatively affect feed consumption (Figure 11). The mean annual feed consumption under the historical climate scenario was 4993 (kg/animal)/year. Where the mean pasture annual intake was 2819 (kg/animal)/year (with a range 2173 to 4006), the mean of the annual concentrate intake was 1049 (kg/animal)/year with a minimum of 1050 (kg/animal)/year, and the forage intake was 1123 (kg/animal)/year (with a range 598 to 1313).

By 2020 the feed consumption declines slightly across the emission scenarios, the mean annual feed consumption was 4904, 4878 and 4837 (kg/animal)/year in the low, medium and high scenarios respectively. The pasture intake decreases slightly across the emission scenarios but the forage intake increases in order to compensate the feed requirements. The concentrate intake doesn’t vary across emission scenarios because the model used a fixed permanent concentrate consumption.

In 2050 and 2080 the decline in feed consumption is more evident because the mean pasture intake evidently declines and the forage intake cannot exceed the maximum that was fixed in the model. By 2050, feed consumption declines – recording 4853,
4767 and 4545 (kg/animal)/year in the low, medium and high scenarios respectively. The mean annual pasture intake declines, especially in the high scenario where the pasture intake was 2272 (kg/animal)/year (with a range of 1748 to 3253) and the forage intake increases in order to fulfil feed requirements – the annual forage intake in the high scenario was 1223 (kg/animal)/year (with a range of 889 to 1576).

The impacts of future climate change on feed consumption are clearly seen in 2080. The mean annual feed consumption decreases across all emission scenarios, at 4831, 4586 and 4375 (kg/animal)/year in the low, medium and high scenarios respectively. In the low scenario the mean annual pasture intake is 2681 (kg/animal)/year (with a range of 1998 to 3249) and 2379 (kg/animal)/year (with a range of 1779 to 3290) and 1992 (kg/animal)/year (with a range of 1399 to 2973) in the medium and high scenarios respectively. The mean of the annual forage intake is 1101 (kg/animal)/year (with a range of 855 to 1510) in the low scenario and 1158 (kg/animal)/year (with a range of 839 to 1586) and 1334 (kg/animal)/year (with a range of 942 to 1640) in the medium and high scenarios respectively.

![Figure 11 Distribution of the feed consumption expressed in (kg/animal)/year in Gippsland.](image-url)
South Australia

Future climate change will negatively affect feed consumption (Figure 12). The mean annual total intake under the historical climate scenario was 6389 (kg/animal)/year. Where the mean pasture annual intake was 3406 (kg/animal)/year (with a range of 2763 to 4001), the mean annual concentrate intake was 1854 (kg/animal)/year and the forage intake was 1129 (kg/animal)/year (with a range of 916 to 1329). By 2020 the feed consumption declines slightly across the emission scenarios; the pasture intake also decreases slightly as the forage intake increases. In the case of South Australia the concentrate intake was fixed in the model in order to stay permanent and a maximum intake was established for forage intake.

In the low emission scenario in 2050 and 2080 future climate change increases slightly because of high pasture growth, especially in the low scenario in 2080 where the total intake is 6503 (kg/animal)/year. In 2080, in the medium and high emission scenarios, future climate change decreases feed consumption – it is 6170 and 5747 (kg/animal)/year in the medium and high scenarios respectively. In the high scenario in 2080 the mean annual pasture intake decreases to 2683 (kg/animal)/year (with a range of 1659 to 3428) and the forage intake increases to 1210 (kg/animal)/year (with a range of 984 to 1442).

Figure 12 Distribution of the feed consumption expressed in (kg/animal)/year in South Australia.
Impacts of future climate change on lactation

Gippsland

Future climate change will negatively affect annual lactation (Figure 13). The mean annual lactation under the historical climate scenario was 309 (kg solids/animal)/year (with a range of 261 to 387). By 2020 the mean annual lactation decreases slightly across the emission scenarios. By 2050 the decrease in annual lactation is more evident, with decreases of 6%, 8% and 14% in the low, medium and high scenarios respectively. By 2080 the impacts of future climate change on annual lactation are clearly seen, especially in the high emission scenario – the annual lactation decreases by 11%, 14% and 21% in the low, medium and high scenarios respectively.

![Lactation in Gippsland](image)

Figure 13 Impacts of future climate change on annual lactation expressed in (kg solids/animal)/year in Gippsland.

South Australia

Future climate change will negatively affect annual lactation (Figure 14). The mean annual lactation under the historical climate scenario was 479 (kg solids/animal)/year (with a range of 403 to 578). By 2020 the mean annual lactation decreases slightly across all emission scenarios. By 2050 and 2080 the annual lactation decreases slightly in the low scenario, while in 2050 it decreases 3% and 5% in the medium and
high scenarios respectively and in 2080 it decreases 5% and 11% in the medium and high scenarios respectively.

Figure 14 Impacts of future climate change on annual lactation expressed in (kg solids/animal)/year in South Australia.

**Adaptation Options**

**Pasture growth patterns**

**Gippsland**

The implementation of genetically improved ryegrass helps to overcome constriction of the growing season in 2050 (Figure 15), but it doesn’t in 2080 where the constriction of the growing season is bigger (Figure 16). The most effective adaptation option is the combined adapted perennial ryegrass DR+HT, which has a higher peak of the net positive growth rate, which means that there is a higher accumulation of pasture growth in September. The perennial ryegrass with deeper root DR and the heat tolerant ryegrass HT have higher peaks of the pasture growth rate in comparison to the base. The heat tolerant ryegrass HT increases the pasture growth rate in autumn (Figure 15 and Figure 16).
Figure 15 Adaptation options and monthly average of pasture growth rate expressed in (kg/ha)/day in Gippsland, 2050.

Figure 16 Adaptation options and monthly average of pasture growth rate expressed in (kg/ha)/day in Gippsland, 2080.

**South Australia**

The implementation of genetically improved ryegrass helps to overcome constriction of the growing season in 2050 and 2080 (Figure 17 and Figure 18). The most effective adaptation options were the combined adapted perennial ryegrass DR+HT
and the perennial ryegrass with deeper root DR, which have a higher peak of the pasture growth rate in October 2050 and September 2080. The heat tolerant ryegrass HT increases the pasture growth rate in autumn (Figure 17 and Figure 18).

![Pasture growth rate in South Australia 2050](image)

Figure 17 Adaptation options and monthly average of pasture growth rate expressed in (kg/ha)/day in South Australia, 2050.

![Pasture growth rate in South Australia 2080](image)

Figure 18 Adaptations options and monthly average of pasture growth rate expressed in (kg/ha)/day in South Australia, 2080.
Feed consumption

Gippsland

With no adaptation options, by 2050 in the high emission scenario total feed consumption will decrease by 9%, the mean annual pasture intake decrease by 19% and the forage intake increase by 8% in relation to the historical base. With no adaptation options, by 2080 in the high 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.

The implementation of genetically improved ryegrass and dairy cattle mitigates the impact of future climate change on feed consumption, helping to overcome the decrease in total feed consumption and pasture intake and decrease the forage intake under the high emission scenario in 2050 and 2080 (Figure 19). The most effective adaptation options are the multiple adaptation FCE+DR+HT and the combined adapted perennial ryegrass DR+HT that have similar results and in the high scenario in 2050 decreases total feed consumption by only 2%, and the mean annual pasture intake by 3%. The multiple adaptation FCE+DR+HT slightly increases forage intake and the combined adapted perennial ryegrass DR+HT increases forage intake by around 3%. By 2080 under the high emission scenario the multiple adaptation FCE+DR+HT and the combined adapted perennial ryegrass DR+HT help to overcome the decrease in feed consumption with similar results of a decrease around 8%, and both have a decrease in pasture intake of around 16% and increase forage intake around 4%.

The next most effective adaptation option is the heat tolerant ryegrass HT which under the high emission scenario in 2050 has a decrease of around 3% in the total feed intake, a 6% decrease of annual pasture intake, and a 2% increase in forage intake. By 2080 under the high emission scenario, heat tolerant ryegrass HT has a decrease in feed consumption of 10%, decreases pasture intake by 21% and increases forage intake by 7%. In 2050 the perennial ryegrass with deeper root DR has a decrease in feed consumption of 6% and 13% in pasture intake, and an increase of 5% in forage intake. In 2080 the perennial ryegrass with deeper root DR has a decrease in
feed consumption of 11% and 27% in pasture intake, and an increase of 17% in forage intake. Finally, the better FCE dairy cow doesn’t help to overcome the decrease in feed consumption.

Figure 19 Adaptation options and the distribution of the feed consumption expressed in (kg/animal)/year in Gippsland, 2080.

### South Australia

With no adaptation options, by 2050 in the high emissions scenario the total feed consumption decreases by 5%, the mean annual pasture intake decreases by 11% and the forage intake increases by 7% in relation to the historical base. With no adaptation options, by 2080 in the high scenario the total feed consumption decreases by 10%, the mean of the annual pasture intake decreases by 7% and the forage intake increases by 19% in relation to the historical base.

By 2050 with the implementation of genetically improved ryegrass and dairy cattle the impacts of climate change on total feed consumption and distribution doesn’t vary in comparison to the high scenario with no adaptation options. By 2080 the implementation of genetically improved ryegrass and dairy cattle mitigate the impacts of future climate change on feed consumption (Figure 20). The most effective adaptation options are the multiple adaptation FCE+DR+HT and the combined
adapted perennial ryegrass DR+HT that decrease total intake by only 5%, pasture intake by around 12%, and increases forage intake by around 9%.

The next most effective adaptation option is the heat tolerant ryegrass HT and the perennial ryegrass with deeper root DR that under the high emission scenario in 2080 decreases total feed intake by around 8%. The heat tolerant ryegrass HT has around a 16% decrease in annual pasture intake and an increase of 7% on forage intake. The perennial ryegrass with deeper root DR has a 19% decrease in annual pasture intake and a 12% increase in forage intake. Finally the better FCE dairy cow didn’t help to overcome the decrease in feed consumption.

Figure 20 Adaptation options and the distribution of the feed consumption expressed in (kg/animal)/year in South Australia, 2080.

**Lactation**

**Gippsland**

The implementation of genetically improved ryegrass and dairy cattle mitigate the impacts of future climate change on dairy production (Figure 21). By 2050 under the high emissions scenario the mean annual lactation decreases 14% in comparison to the historical base. The most effective adaptation option is the multiple adaptation FCE+DR+HT that increases the mean annual lactation by 5% in comparison to the historical base; this means that the adaptation option not only overcomes the impact
of climate change but also increases milk production. The next most effective adaptation option is the combined adapted perennial ryegrass DR+HT that has a decrease of 4%, followed by the better FCE dairy cow that has a decrease of 6%, heat tolerant ryegrass HT that has a decrease of 7%, and the perennial ryegrass with deeper root DR that has a decrease of 10%.

By 2080 under the high emissions scenario, the mean annual lactation decreases by 21% in comparison to the historical base. The most effective adaptation option is the multiple adaptation FCE+DR+HT that decreases annual lactation by 7% in comparison to the historical base, followed by the combined adapted perennial ryegrass DR+HT and the better FCE dairy cow that have a decrease of 14%, heat tolerant ryegrass HT that has a decrease of 17%, and the perennial ryegrass with deeper root DR that has a decrease of 19%.

![Lactation in Gippsland 2080](image)

Figure 21 Adaptation options and annual lactation in 2080 in Gippsland.

**South Australia**

The implementation of genetically improved ryegrass and dairy cattle mitigate the impacts of future climate change on dairy production, especially in 2080 (Figure 22). By 2050 under the high emissions scenario, the mean annual lactation decreases by 8% in comparison to the historical base. With the implementation of the adaptation options the decrease in annual mean lactation doesn’t vary and they decrease the
annual total lactation from 6 to 8% in comparison to the historical base. On the other hand, by 2080 the implementation options help to overcome the impacts of future climate change by increasing milk production. By 2080 under the high emissions scenario the mean annual lactation decreases by 15% in comparison to the historical base. The most effective adaptation option is the multiple adaptation FCE+DR+HT that decreases the mean annual lactation by 2% in comparison to the historical base. The next most effective adaptation option was by the better FCE dairy cow that has a decrease of 7%, followed by the combined adapted perennial ryegrass DR+HT that has a decrease of 10%. Finally the heat tolerant ryegrass HT and the perennial ryegrass with deeper root DR both have a decrease of 13%.

Figure 22 Adaptation options and annual lactation in 2080 in South Australia.
**Discussion**

**Gippsland case study**

Future climate change will increase pasture growth rates in winter and early spring but reduce the length of the spring growing season (Figure 7). Additionally, there is a higher peak of pasture growth rate across all emission scenarios and the highest peak is in the high emission scenario of 2080, increasing the accumulation of pasture in the time that the pasture is cut. As well, there is a contraction of the growing season in the last spring and early summer. The implementation of each of the genetically adapted perennial ryegrass helps to overcome constriction of the growing season in 2050 (Figure 15), but not in 2080 where the constriction of the growing season is bigger (Figure 16). The most effective adaptation option was the combined adapted perennial ryegrass DR+HT. The combined adapted perennial ryegrass has a higher peak of pasture growth rate with a higher accumulation of pasture growth in September. The implementation of the heat tolerant ryegrass HT and the combined adapted perennial ryegrass DR+HT increases pasture growth in autumn and the beginning of winter.

Future climate change will negatively affect total feed consumption in Gippsland. Total feed consumption decreases across the emission scenarios and the impacts of climate change are more evident in 2050 and 2080 where the pasture intake declines and the forage intake increases in order to fulfil the animals’ requirements (Figure 11). The implementation of the genetically adapted perennial ryegrass and dairy cattle helps to overcome the decline of feed intake caused by future climate change (Figure 19). The most effective adaptation options were the multiple adaptations FCE+DR+HT and the combined adapted perennial ryegrass DR+HT which have similar results, increasing pasture intake and decreasing forage intake. The next most effective adaptation options were the heat tolerant ryegrass HT, the perennial ryegrass with deeper root DR and finally the better FCE dairy cow, which didn’t overcome the decrease in feed consumption.

Future climate change decreases the mean annual lactation. By 2020 the mean annual lactation declines slightly across the emission scenarios. The decrease in annual lactation is more evident in 2050 and 2080 where the mean decreases up to 21%. The
implementation of genetically improved ryegrass and dairy cattle mitigate the impacts of future climate change in dairy production (Figure 21). The results were more evident in 2050 and 2080. The most effective adaptation option was the multiple adaptations FCE+DR+HT, which in 2050 not only overcomes the impacts of future climate change but also increases milk production by 5% in relation to the historical base. The next most effective adaptation option was the combined adapted perennial ryegrass DR+HT and the better FCE dairy cow, both having similar results. The next most effective adaptation was the heat tolerant ryegrass HT followed by the perennial ryegrass with deeper root DR.

**South Australia case study**

Future climate change will increase pasture growth rates in winter and early spring but reduce the length of the spring growing season (Figure 9). Additionally there is a higher peak of pasture growth rate across all emission scenarios and the highest peak is in the high emission scenario for 2080, increasing the accumulation of pasture in the time that the pasture is cut. The contraction in the growing season is South Australia is not as big as it is in Gippsland.

The implementation of each of the genetically adapted perennial ryegrass helps to overcome constriction of the growing season. The implementation of the adaptation options help to overcome the constriction of the growing season in 2050 and 2080 (Figure 17 and Figure 18). The most effective adaptation option was the combined adapted perennial ryegrass DR+HT. The combined adapted perennial ryegrass has a higher peak of pasture growth rate in October 2050 and in September 2080. The perennial ryegrass with deeper root DR had similar results as the combined adapted perennial ryegrass DR+HT. Winter pasture growth declines slightly with these adaptation options but increases slightly with the implementation of the heat tolerant ryegrass HT.

Total feed consumption declines slightly across all emission scenarios (Figure 12). By 2050 and 2080 in the low scenario the feed intake increases slightly because in the low high emission scenario the rainfall increases, increasing pasture growth, and the future temperature expected in South Australia is lower than the future temperature.
expected in Gippsland. For this reason heat stress doesn’t affect feed intake in South Australia as much as it affects in Gippsland. The implementation of the genetically adapted perennial ryegrass and dairy cattle helps to overcome the decline of feed intake caused by future climate change (Figure 20). The implementation of the adaptation options are not evident in 2050 but they are evident in 2080. The most effective adaptation options were the multiple adaptations FCE+DR+HT and the combined adapted perennial ryegrass DR+HT that have similar results in increasing pasture intake and decreasing forage intake. The next most effective adaptation options were the heat tolerant ryegrass HT, the perennial ryegrass with deeper root DR and finally the better FCE dairy cow, which didn’t overcome the decrease in feed consumption.

Future climate change decreases the mean annual lactation. By 2020 the mean annual lactation declines slightly across the emission scenarios. The decrease in annual lactation is more evident in 2050 and 2080 where the mean of the annual lactation decreases up to 11%. The implementation of genetically improved ryegrass and dairy cattle mitigate the impacts of future climate change in dairy production (Figure 22). The results are more evident in 2080. The most effective adaptation option was the multiple adaptations FCE+DR+HT, followed by the combined adapted perennial ryegrass DR+HT and the better FCE dairy cow with both having similar results. The next most effective adaptations were the heat tolerant ryegrass HT and the perennial ryegrass with deeper root DR. Both these adaptation options have the same results, mainly because the heat stress doesn’t affect dairy production in South Australia as much as it affects dairy production in Gippsland as the increase in temperature caused by future climate change is higher in Gippsland region.

**Discussion**

In this project it was demonstrated how future climate change would affect dairy production in the two case studies. The impacts of future climate change in dairy production have different extents according to the region where the farm is located. For this reason the implementation of the adaptation options and the performance of these adaptations also differ according to the region. The most effective adaptation option will depend on the local climate change (Cullen, 2014). One of the main
differences related to climate change in these two case studies is that the minimum temperature in Gippsland is lower that in South Australia, as well as the maximum temperature being higher, which means that the extreme temperatures in Gippsland makes the farm more susceptible to future climate change. In the case of rainfall the change across the emission scenarios is similar in both case studies. Both farms have winter dominant rainfall but Gippsland is more winter dominant than South Australia.

Future climate change will increase pasture growth rates in winter and early spring. The increase in pasture growth rate and cut yield because of future climate change could be mainly due to the increase in CO2. The effects caused by increased CO2 concentrations are both beneficial and prejudicial for plants. On the one hand, the rise in CO2 concentrations could increase pasture growth due to the accumulation of CO2 that will increase photosynthesis efficiency (Cullen, 2009). On the other hand, the rise in CO2 could decrease forage quality because the proteins in pastures would decrease (Howden and Stokes, 2009).

In Southern Australia, the low growth rates of PRG in winter is the main factor that influences stoking rates and production in sheep and dairy cattle (Cunningham, 1994). In this project winter growth rates increase, which increases pasture cut yield. In order to have a stable seasonal production of pastures and maximize production around the year some other adaptations options can be taken into account such as the selection of later-maturing summer genotypes (Cunningham, 1994) because the time of heading influences the seasonal and total pasture yield (Stewart, 2011).

The implementation of each of the adaptation options – the perennial ryegrass with deeper root DR, the heat tolerant ryegrass HT, and the combined adapted perennial ryegrass DR+HT – help to overcome the impacts of pasture growth patterns. Also, the implementation of each of the adaptation options – the perennial ryegrass with deeper root DR, the heat tolerant ryegrass HT, the better FCE dairy cow, the combined adapted perennial ryegrass DR+HT, and the multiple adaptations FCE+DR+HT – helps to overcome the impacts of climate change in the distribution and total feed consumption and in dairy production.
The most effective adaptation option to overcome the impacts of future climate change in pasture growth patterns in both case studies was the combined adapted perennial ryegrass DR+HT. This result indicates that the combination of the two traits is more effective than the implementation of each individual trait. In a study performed in order to adapt groundnuts to future climate change, the authors concluded that the combination of genetic traits had additive effects and the yield increased considerably (Singh, 2012).

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 lactation and feed consumption. These results are similar to the results found in Cullen, 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.

Additionally, the Gippsland farm was more affected by future climate change than South Australia. Gippsland spring calving made the farm more sensitive to future climate change because the early and mid lactation of the cows, which is the peak of lactation, rely on spring and early summer pasture growth and this was exactly the time of the year when pasture growth declined. This means that pasture declines when there is a higher demand for nutrients. In the case of South Australia, autumn calving created higher demands of cows in their peak of lactation, being in late winter through early spring, and in this time of the year pasture increased in all future emission scenarios.

Future climate change decreases feed consumption by different extents in the two case studies. The decline in feed consumption is more evident in 2050 and 2080, because a maximum forage intake was fixed in the model, so the lack of pasture intake cannot be totally fulfilled by increasing forage intake while the concentrate intake is permanent across the emission scenarios. The most effective adaptation option in overcoming the impacts of future climate change in total feed consumption and its distribution, increasing pasture intake and decreasing forage intake, was the multiple adaptations FCE+DR+HT. At the same time this adaptation option was the
most effective in overcoming the impacts of climate change in lactation. 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. This combination of traits make the system more resilient.

In both cases the better FCE dairy cow did not overcome the decrease in feed consumption, but it did overcome the decrease in lactation. This is mainly because the better FCE dairy cow doesn’t need more feed in order to produce more milk as the better FCE dairy cow is more efficient in converting animal feed into milk. The genetic improvement in dairy cattle has been always focused on increasing production and feed efficiency has been the main driver for improving production (Berry, 2013). Some studies have indicated that the genetic improvement of livestock is able to overcome, to some extent, the impacts of climate change in animal production especially in drier locations where the need for adaptation is greater (Moore and Ghahramani, 2013; Lee, 2012). However, the relationship between the genetic improvements of pastures and animal production is less direct (Lee, 2012).

In this project in order to be conservative the genetically adapted dairy cow was taken to be 10% more efficient than the dairy cow used in the historical base in each case study. Additionally, as the forage consumption was fixed for both case studies in the model, with future climate change milk yield was projected to decrease because of the lack of supplementary feed and other inputs that farmers use to maintain milk production. This means that with the same resources on each farm, and without any increase of supplements, especially forage, and with the implementation of genetically adapted ryegrass and genetically adapted dairy cattle, there could be an increase of up to 5% in milk yield until 2050 even when it is affected by climate change.

In the last decades there has been a rapid progress in milk yield, mainly due to genetic improvements (Oltenacu and Broom, 2010). The following data indicate the increase in milk yield in recent decades. In Australia and the USA the milk yield in Holsteins has increased by approximately 1% per year over the last 30 years (Hayes, 2013). In Australia, from 1988 to 2007 the mean yield per lactation in Holstein cattle increased from 5,500 kg to 8,200 kg and in Simmentals from 4,500 kg to 6,600 kg (Knaus 2009...
cited in Oltenacu and Broom, 2010). In the UK from 1996 to 2002 the milk yield per cow increased 200 kg per year and 50% of this increase was because of genetic improvements (Pryce and Veerkamp 2001 cited in Oltenacu and Broom, 2010). In the USA from 1957 to 2007 the milk yield per cow increased by 5,997 kg, with 56% of this increase due to genetics, and in the last 10 years the milk yield per cow has increased by 16% (Van Raden 2004 cited in Oltenacu and Broom, 2010; Connor et al, 2012).

In the case of ryegrass several studies have indicated different rates of genetic gain in perennial ryegrass, which means that genetic improvement is driving the increase in pasture yield. In Europe and New Zealand the genetic gains in dry matter yield of perennial ryegrass has been estimated to be 4% to 5% per decade, an annual genetic gain of around 0.4% (Sampoux, 2011). In the case of the USA where there is little improvement in perennial ryegrass the genetic gain is less than 1% (Stewart, 2011). In France and Italy over two decades the genetic improvement was 5%, which means a 0.5% increase in annual dry matter yield (Veronesi, 1991 cited in Sampoux, 2011). In the United Kingdom the genetic gain was estimated to be around 4% to 6% per decade (Wilkins and Humphreys, 2003 cited in Sampoux, 2011). In a study conducted in Australia on Victorian perennial ryegrass the rate of improvement in yield due to genetic improvement was 0.18% per year (Nie, 2004).

**Limitations of the project**

- There are some sources of errors in the Global Climate Models (GCMs) especially in the daily means for precipitation. The source of the errors is mainly because many small-scale processes cannot be assessed in climate models with certainty, and therefore have to be approximated. For these reasons the daily mean predicted by GCMs are not suitable for using directly with process-based models or for the analysis of extreme events (Semenov 2007 cited in Semenov and Stratonovitch, 2010).

- This project is focused on the implementation of genetically improved ryegrass and dairy animals as an adaptation option. However, there are some management options that can be used as adaptation options that are not part of this project. These other adaptations options include the use of controlled
released fertilizers, implementing farm infrastructure and animal shelters, changing feed management etc. All of the adaptation options that can be implemented on a farm have to be performed according to the management practices and resources that each farm possesses. Some studies indicate that genetic adaptation combined with other adaptation options such as the change in feed base will complement each other for overcoming the impacts of future climate change (Moore and Ghahramani, 2013).

- This project addressed how pasture grow patterns are affected by future climate change but pasture quality was not part of the extent of the project. It is known that future climate change will affect pasture yield and quality. The increase in temperature causes a rise in non-structural carbohydrates, increasing the sources of energy for animals. The elevated temperature causes a decrease in protein and the digestibility of the pastures. These changes in pasture patterns will affect animal performance because livestock performance is influenced by the consumption of young and digestible plants (Howden and Stokes, 2009).

- The combined adapted perennial ryegrass DR+HT is a possible genetic improvement because the feasibility and the outcomes of selecting plants for more than one trait are still unknown (Cullen, 2014). Some authors have indicated that the genetic selection for more than one trait could slow down the genetic gain (Boote, 1994).
Conclusions

- Future climate change has negative impacts on pasture growth rates, feed consumption and lactation. Those impacts are to different extents, although Gippsland is more affected than South Australia.

- The implementation of the adaptation options overcome the impacts of future climate change to different extents in the two case studies. In the case of Gippsland the results of implementing the adaptation options are seen more clearly than in South Australia.

- Genetically adapted ryegrass and livestock have to be implemented together with management adaptation practices in order to maintain production and farm profitability.

Further research should also be conducted. Firstly, in how to manage the uncertainty of future climate change projections and how to model extreme events in agriculture. Secondly in the understanding of the feasibility and the outcomes of the selection of multiple traits in pastures and livestock. Finally in the use of genetic adaptation options together with management practices in order to mitigate future climate change.
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