Final report

Whole Farm Systems Analysis of Climate Change Impacts on the Southern Grazing Industries

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Abstract

This investment enabled in regional consultation with producers to present modelling and gather regionally specific feedback from on likely adaptation and mitigation options as part of the Climate Change Adaptation in the Southern Australian Livestock Industries (CCASALI) program 2012-2019. The CCASALI program focused on the mitigation of greenhouse gases and climate change adaptation options for the dairy industry at a farm systems level.

Biophysical modelling simulations addressed the key regional questions of climate change impacts on current dairy grazing systems in a future environment, adaptation options and new farming systems; keeping in mind mitigation options given an emissions constrained environment.

Modelling analysis revealed that the potential Carbon Farming Initiative (CFI) income from adopting currently possible mitigation options in Dairy production was in the vicinity of ~ 1% of total milk production income. Therefore, adoption of CFI offset mitigation options in Dairy production were found to be unlikely unless other non- GHG emissions aspects of the mitigation option, e.g. increases in milk production, could provide significant financial gain.

Executive summary

Background

Climate change will impact on the Australian grazing industries both through policies to mitigate climate change (e.g. the Carbon Farming Initiative), and the physical impact of warmer temperatures, increased atmospheric CO_2 concentrations and changed rainfall patterns on pasture production. For producers, regionally specific information will be required to make informed decisions, as outcomes will be determined by multiple and complex interactions between climatic and edaphic factors.

Biophysical models are the only means that we currently have available to decipher these interactions and provide simulations of likely future outcomes at a regional level. This project is collaborative in its approach to addressing the climate adaptation and GHG mitigation options for the dairy industry and southern grazing industries within the Climate Change Adaptation in the Southern Australian Livestock Industries (CCASALI) program.

Objectives

There were three main objectives of this specific sub-project and all were completed by the end of the project:

- Biophysical modelling simulations that address the key regional questions of climate change impacts on current dairy grazing systems in a future environment, adaptation options and new farming systems; keeping in mind mitigation options given an emissions constrained environment;
- Further development of climate change adaptation and mitigation modelling capability for the dairy industry
- A better informed industry and producer population of the opportunities and risks associated with climate change through the publication and communication of research results

Methodology

The two sub projects have utilised the most recently available and acceptable climate projection data and used a direct scaling approach to examine the sensitivity of agricultural production to scaled changes in key climate variables. These climate scenarios have been utilised in conjunction with a range of biophysical, farm system and GHG accounting models to address specific regional impacts of climate change, various adaptation options, GHG emissions and the interacting dynamics between adaptation and mitigation for a range of farming systems.

Results/key findings

This project worked with other teams within this larger program to participate in regional consultations with farmers and industry to present the modelling and gather regionally specific feedback from farmers and consultants on likely adaptation and mitigation options.

Modelling analysis revealed that the potential Carbon Farming Initiative (CFI) income from adopting currently possible mitigation options in Dairy production was in the vicinity of ~ 1% of total milk production income. Therefore, adoption of CFI offset mitigation options in Dairy production were

found to be unlikely unless other non- GHG emissions aspects of the mitigation option, e.g. increases in milk production, could provide significant financial gain.

Benefits to industry

Regional consultation occurred with producers to present the modelling and gather regionally specific feedback from farmers and consultants on likely adaptation and mitigation options. This enabled a greater understanding among producers of the opportunities and risks associate with climate change ibn their region.

Future research and recommendations

There is need to research the component level physiological/agronomical factors associated with modifying the feedbase.

The ability to effectively and efficiently quantify CFI offset methods is needed across a broad spectrum of farming systems for the livestock industries. The current Carbon Offset Scenarios Tool (COST) calculator has begun this process for the dairy industry.

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1. Background

Climate change will impact on the Australian grazing industries both through policies to mitigate climate change (e.g. the Carbon Farming Initiative), and the physical impact of warmer temperatures, increased atmospheric CO_2 concentrations and changed rainfall patterns on pasture production. For producers, regionally specific information will be required to make informed decisions, as outcomes will be determined by multiple and complex interactions between climatic and edaphic factors.

Biophysical models are the only means that we currently have available to decipher these interactions and provide simulations of likely future outcomes at a regional level. This project is collaborative in its approach to addressing the climate adaptation and GHG mitigation options for the dairy industry and southern grazing industries within the Climate Change Adaptation in the Southern Australian Livestock Industries (CCASALI) program. This sub project (B.SBP.0071) was undertaken by Tasmanian Institute of Agriculture (TIA) modelling scientist Dr. Richard Rawnsley and Ms. Karen Christie in collaborative approach with modelling scientists from the University of Melbourne (Associate Professor Richard Eckard, Dr. Brendan Cullen and Dr. Matthew Bell) as part of sub project (B.SBP.0072).

2. Objectives

There were three main objectives of this specific sub-project and all were completed by the end of the project (Table 1).

- Biophysical modelling simulations that address the key regional questions of climate change impacts on current dairy grazing systems in a future environment, adaptation options and new farming systems; keeping in mind mitigation options given an emissions constrained environment;
- Further development of climate change adaptation and mitigation modelling capability for the dairy industry
- A better informed industry and producer population of the opportunities and risks associate with climate change through the publication and communication of research results

Many of the activities within each objective were undertaken in collaboration with University of Melbourne (UoM) project staff members. Where TIA staff members were the lead author, the activities are reported in this Final Report. However, where University of Melbourne staff members were the lead-author, these activities are reported in their Final Report.

3. Methodology

The two sub projects have utilised the most recently available and acceptable climate projection data (e.g OzClim and Climate Futures for Tasmania,) and used a direct scaling approach to examine the sensitivity of agricultural production to scaled changes in key climate variables. These climate scenarios have been utilised in conjunction with a range of biophysical, farm system and GHG accounting models to address specific regional impacts of climate change, various adaptation options, GHG emissions and the interacting dynamics between adaptation and mitigation for a range of farming systems.

The two sub project teams have participated in regional consultations with the larger CCASALI team, industry and producers to present the modelling outcomes and foster regionally specific feedback. This approach has allowed the sub projects to formulate key questions which have been prioritised by the program steering committee and participating parties. The typical questions posed to the modelling team have focused on both adaptation and mitigation and are listed below:

- What are the likely impacts of climate change in 2030 and 2070 on pasture growth, species composition and water balance, relative to a historical baseline?
- What are the specific adaptation options for extensive/intensive grazing systems?
- What are the climate thresholds for adaptation within and between farming systems?
- Are high temperatures going to have the greatest effect on the length of our growing season and how best to adapt to this? What breeding or species selection is required?
- What are the potential impacts of an emissions constrained policy environment on dairy production systems?
- What is the Whole Farm Systems impact and abatement from currently available GHG mitigation strategies?
- What level of abatement can be achieved through best management practices alone?
- What level of GHG abatement is required for additional abatement activities to be economically viable?
- What is the impact of future climate scenarios on the balance between productivity and total greenhouse gas emissions from pasture based dairy systems in SE Australia?

The modelling team possess the skills and capabilities to combine and develop models/tools to address the complex interactions between adaption and mitigation for temperate grazing systems and the project has focused on establishing improved capacity across a range of industry RD&E providers through training, whilst communicating directly with industry and producers the finding, model developments and project outputs.

Table 1. **Project objectives and activities undertaken within this project**

Objectives	Activities Undertaken
Biophysical modelling simulations that address the key regional questions of climate change impacts on current dairy grazing systems in a future environment, adaptation options and new farming systems; keeping in mind mitigation options given an emissions constrained environment;	❖ Biophysical modelling of 3 dairy regions (SE Victoria (Ellinbank), SW Victoria (Terang) and NW Tasmania(Elliott)) using a direct scaling approach: • Adapting to increases in mean daily temperature by increasing the heat tolerance of perennial ryegrass (Appendix 1) • Effects of deficit rainfall and rooting depth of perennial ryegrass on pasture production in South East Australia (Appendix 2) • Modelling pasture based dairy systems to a changing climate in a carbon constrained world (Appendix 3) • An historical analysis of the changes in pasture production and growing season in three dairy regions of South East Australia (Appendix 4) • Pasture growth to lift under climate change (Appendix 5) ❖ Biophysical modelling of 5 dairy/ extensive agriculture regions of Tasmania (Cressy, Flowerdale, Ouse, Ringarooma and Woolnorth) using the Climate Futures for Tasmania climate scenarios data approach • Frequency of wet and dry soil conditions for Tasmanian dairy regions under future climate scenarios (Appendix 6) • Timing of autumn breaks and length of springs in Tasmanian dairy regions under future climate scenarios (Appendix 7) • Frequency of wet and dry soil conditions for Tasmanian beef and sheep regions under future climate scenarios (Appendix 8) Timing of autumn breaks and length of springs in Tasmanian beef and sheep regions under future climate scenarios (Appendix 9)
Further development of climate change adaptation and mitigation	❖ Estimation of the GHG emissions of 60 Tasmanian dairy farms using the Dairy Greenhouse gas Abatement Strategies (DGAS) calculator (Appendix 10, 11 & 12)

modelling capability for the dairy industry	❖ Estimation of the GHG emissions of 41 Australian dairy farms using the DGAS calculator (Appendix 13, 14 & 15) ❖ Improvements to the DGAS calculator aligning with changes to the national methodology and from user feedback (Appendix 16) Development of the Carbon Offset Scenarios Tool (COST) calculator to assess dairy abatement strategies and their profitability with the Carbon Farming Initiative (Appendix 17)
A better informed industry and producer population of the opportunities and risks associate with climate change through the publication and communication of research results	❖ 2 published scientific papers (one with UoM as 1st author) ❖ 15 conference publications (four with UoM as 1st author) ❖ 2 conference presentations ❖ 1 draft scientific publication ❖ 2 popular press publications ❖ 6 workshops/field days held presenting climate change adaption to in excess of 250 farmers, public and private consultants and advisors and government representatives 5 training workshops/webinars associated with DGAS user training of 50+ Dairying for Tomorrow co-ordinators, public and private consultants and advisors ❖ On-going support to DGAS users (farmers, Dairying for Tomorrow co-ordinators, public and private consultants and advisors)

4. Results

4.1 Project activities and major findings

This project was undertaken by TIA staff Richard Rawnsley and Karen Christie. Throughout the project, the TIA team also worked collaboratively with staff from the University of Melbourne (Richard Eckard, Brendan Cullen and Matthew Bell). This report focuses on the collaborative work led by TIA staff, with reference to collaborative work led by University of Melbourne staff where relevant. The project was segmented into two broad theme areas. These were climate change assessments and analysis for the Southern Australian livestock industries and greenhouse gas emission assessments and mitigation options for the Australian dairy industry. Within each of these, the outputs were broadly grouped into five main areas:

- Conference papers/ publications
- Published and submitted papers
- Presentations, workshops, popular press and field days
- Enhanced modelling software development and training
- Other activities

4.1.1 Climate change adaptation

Conference papers/publications

Four conference papers were published in the Proceedings of the Climate Change Research Strategy for Primary Industry (CCRSPI) Conference; Melbourne, February 2011. In addition, one verbal presentation and two posters were also presented from this work at the CCRSPI conference. In the paper titled Adapting to increases in mean daily temperature by increasing the heat tolerance of perennial ryegrass (Appendix 1), historical climate data (1971-2008) for three dairying regions of South East Australia (Elliott (NW Tasmania), Ellinbank (SE Victoria) and Terang (SW Victoria)) was used in combination with the biophysical model DairyMod to ascertain the impact of increasing daily temperatures and carbon dioxide concentrations on pasture production. Five climate data sets for each region were created by direct scaling the historical baseline climate data (1971 to 2008; actual temperatures with current carbon dioxide (CO2) concentration of 380 ppm) by 1, 2, 3, 4 and 5oC with corresponding atmospheric carbon dioxide concentrations of 435, 535, 640, 750 and 870 ppm, respectively. The highest mean annual pasture production for Elliott, Ellinbank and Terang occurred when temperatures/carbon dioxide concentrations were increased by 3°C/640 ppm, 1°C/435 ppm and 2°C/535 ppm, respectively. Exposure to periods of extreme high temperatures and its impact on pasture production was also reviewed. Increasing the high temperature tolerance of perennial ryegrass was able to alleviate the negative effects on annual pasture up to 5oC of warming at Terang and up to 4oC warming at Ellinbank. This highlights the relative benefit of exploring and introducing more heat tolerant perennial ryegrass cultivars to the regions used in this study.

In the paper titled Effects of deficit rainfall and rooting dept of perennial ryegrass on pasture production in South East Australia (Appendix 2), historical climate data (1971-2008) for three dairying regions of South East Australia (Elliott, Ellinbank and Terang) was used in combination with DairyMod to ascertain the impact that altering the rooting depth of perennial ryegrass would have on annual pasture production. Rooting depths of 30cm (baseline), 40cm, 50cm, 60cm and 70cm were explored using the baseline (1971-2008) rainfall. In addition, the abovementioned rooting depths in combination with rainfall deficits of between 50 and 90% of the baseline rainfall were explored. There was a positive linear relationship between rooting depth and annual pasture production for each rainfall deficit scenario, with the greatest benefit of extended rooting depth observed over the spring, and lesser extent summer, months. However, there was no benefit of additional pasture production through extended rooting depths in autumn and winter. In addition, at Ellinbank, extending rooting depth to 50cm was able to overcome a 20% restriction in rainfall.

However, this was not the case at the other two locations where a 60cm rooting depth was still unable to overcome a 20% reduction in annual rainfall. This indicated that although the adaptation of increasing rooting depth for our temperate pasture species may be considered a very favourable adaptation strategy for adapting to a drier future climate, the ability to alleviate the impacts under significant rainfall decline is limited.

In the paper titled Modelling pasture based dairy systems to a changing climate in a carbon constrained world (Appendix 3), DairyMod was used to model a Tasmanian dairy farm system with either a baseline scenario (climate data for 1979-2009) or a future scenario (2°C increase in daily minimum and maximum temperatures, increase of carbon dioxide concentration to 535 ppm and a 10% reduction in daily rainfall). Various farm system adaptation options were implemented on the future scenario dairy system (e.g. increasing stocking rate or removal of concentrate supplementary feeding). The impact of each scenario was then compared to the baseline farm system in terms of changes in annual pasture production, milk production, farm gross margin and GHG emissions. This modelling analysis has shown that the cool temperate dairy regions of Tasmania are well buffered against predicted climate changes and that within farm system adaptations appear more likely with the producers continuing to focus on milk production per ha and pasture consumption per ha as key determinants of business success. The adaptation of increasing stocking rate and or lower concentrate feeding to capture the high level of pasture production being achieved with a warmer environment, resulted in an a higher GHG emissions intensity of milk production, highlighting that in this environment there is an emerging conflict between how dairy farms may adopt to a changing climate and those strategies for mitigating the GHG emission associated with milk production.

In the paper titled An historical analysis of the changes in pasture production and growing season in three dairy regions of South East Australia (Appendix 4), historical climate data (1960-2009) for three dairying regions of South East Australia (Elliott, Ellinbank and Terang) was used in combination with DairyMod to examine changes to annual and seasonal pasture production, the commencement, duration and reliability of the growing season and the duration of wet and dry periods. There was no evidence that the commencement period for wet and dry periods has altered over the last 50 years at any of the three regions. However, in the most recent years (2000 to 2009), there has been a period of unusually low number of wet days and unusually high number of dry days at all three regions.

In 2012, two papers have been accepted for the 16th ASA Conference to be held in October at Armidale, NSW. The first paper is titled Frequency of wet and dry soil conditions for Tasmanian dairy regions under future climate scenarios (Appendix 6). DairyMod was used in combination with climate data generated from the Climate Futures for Tasmania project (https://dl.tpac.org.au/) out to the year 2100 for two dairy regions of Tasmania (Flowerdale and Ringarooma). The number of wet days per annum (soil moisture content is above field capacity) and dry days per annum (all readily available water is exhausted from the soil profile) for each region, based on six general circulation models (GCMs), was determined for four climate periods (years 1971 to 2000, 2001 to 2030, 2031 to 2060 and 2061 to 2090). By years 2061 to 2090, the mean number of wet days, as an average of the six GCMs, at Flowerdale and Ringarooma is predicted to decline by 8.5 and 4.5 days per annum, respectively, when compared to the baseline period of years. In contrast, the mean number of dry days, as an average of the six GCMs, at Flowerdale and Ringarooma is predicted to increase by 7.5 and 4.8 days per annum, respectively, when compared to the baseline period of years.

The second paper for the 16th ASA Conference is titled Frequency of autumn breaks and length of springs in Tasmanian dairy regions under future climate scenarios (Appendix 7). DairyMod was used in combination with climate data generated from the Climate Futures for Tasmania project out to the year 2100 for two dairy regions of Tasmania (Flowerdale and Ringarooma). The frequency of early and late autumn breaks and frequency of short and long springs were determined for four climate periods (years 1971 to 2000, 2001 to 2030, 2031 to 2060 and 2061 to 2090) based on six GCMs. Comparing the mean change between the baseline period of years 1971 to 2000 and the future climate period of years 2061 to 2090, the frequency of early autumn breaks was predicted to increase from 27% to 33% for Flowerdale and from 26% to 34% for Ringarooma. The frequency of late autumn breaks was predicted to decline from 31% to 16% for Flowerdale and from 34% to 17% for Ringarooma. The frequency of short springs was predicted to decline from 14% and 16% for Flowerdale and Ringarooma, respectively, to < 1% for both regions. The frequency of long springs was predicted to remain relatively stable at ~ 32% for both regions.

In 2012, two papers have been submitted to the Grasslands Society of Southern Australia Inc. 53rd Annual Conference to be held in July at Launceston, Tasmania. These two papers were co-authored with Peter Ball; TIA's Extensive Agriculture Centre Industry Development and Extension Leader. The studies followed a similar format to those discussed previously to be presented at the ASA conference. However, the two extensive agricultural regions of Cressy and Ouse were explored with the implications to beef and sheep farms explored as opposed to dairy. The first paper titled Frequency of wet and dry soil conditions for Tasmanian beef and sheep regions under future climate scenarios (Appendix 8) found that by years 2061 to 2090, the mean number of wet days, as an average of the six GCMs, was predicted to decline by 2.8 days per annum when compared to the baseline period (years 1971 to 2000) at Cressy. In contrast, at Ouse, the mean number of wet days, as an average of the six GCMs, was predicted to increase by 0.1 days per annum when compared to the baseline period. By years 2061 to 2090, the mean number of dry days, as a mean of the six GCMs, was predicted to decline by 0.2 and 4.5 days per annum at Cressy and Ouse, respectively, when compared to the baseline period.

The second paper titled Timing of autumn breaks and length of springs in Tasmanian beef and sheep regions under future climate scenarios (Appendix 9) found that when comparing the mean change between the baseline period (years 1971 to 2000) and the future climate period (years 2061 to 2090), the frequency of early autumn breaks was predicted to increase from 18% to 28% at Cressy and from 19% to 29% at Ouse. The frequency of late autumn breaks was predicted to decline from 39% to 26% at Cressy and from 39% to 23% at Ouse. The frequency of short springs was predicted to decline from 29% to 19% at Cressy and from 22% to 13% at Ouse. The frequency of long springs was predicted to decline from 22% to 20% at Cressy and from 27% to 18% at Ouse.

The TIA team have presented climate change research from this project at various conferences, field days, workshops and in popular press. These include:

- Climate change modelling outcomes on annual pasture production for NE (Ringarooma) and NW (Mawbanna) Tasmania, March 2010. Total attendees were 66 farmers, public and private advisors and consultants.

- Modelling Climate Change for Tasmanian Dairy Regions at the Dairy Climate Forum, December 2010. Total attendees were 20 public and private advisors and consultants
- An historical analysis of the changes in pasture production, growing season and the number of wet and dry days in three dairy regions of South East Australia at the Climate Change Research Strategy for Primary Industries: Melbourne, Victoria, February 2011. Total conference attendees were approximately 300 public and private researchers, advisors, consultants and government representatives.
- Whole farm system analysis of the GHG emissions of Australian dairy farms at the Climate Change Research Strategy for Primary Industries: Melbourne, Victoria, February 2011. Total conference attendees were approximately 300 public and private researchers, advisors, consultants and government representatives.
- Modelling approaches to adapting pasture based dairy systems to a changing climate in a carbon constrained world at the Dairy Science Symposium; Ellinbank, Victoria, March 2011. Total attendees were 55 extension and researcher officers from the Victorian DPI.
- Agriculture, Greenhouse Gas and Carbon Farming: Burnie, November 2011. Total attendees were 60 representing local council, public and private advisors and consultants.
- Pasture growth to lift under climate change. Publication in the Australian Dairyfarmer magazine, November 2011 (Appendix 5). Target audience includes all Australian dairy farmers, public extension and research officers, milk factory field officers, private consultants and advisors.
- Australian dairy farm greenhouse gas emissions. Publication in the Australian Dairyfarmer magazine, November 2011 (Appendix 14). Target audience includes all Australian dairy farmers, public extension and research officers, milk factory field officers, private consultants and advisors.
- Modelling the effects of climate change on Tasmanian dairy production systems to the Fonterra Supplier Forum meeting; Burnie, November 2011. Total attendees were 34 dairy field officers and Fonterra staff
- Climate projections and modelling climate influences on dairy production to a group of 15 Victorian dairy farmers and rural bankers; TIA Dairy Research Facility, March 2012.

4.1.2 Greenhouse gas emission assessments and mitigation options

Published and submitted papers

A major output of this project was two peer reviewed journal papers assessing dairy GHG emissions. The first was a paper titled A whole farm systems analysis of greenhouse gas emissions of 60 Tasmanian dairy farms and was published in the Animal Feed Science and Technology journal in 2011 (Appendix 12). The study found that the GHG emissions intensity of milk production was 1.04 kg CO_2e/ kg fat and protein corrected milk (FPCM; varied between 0.83 and 1.39 kg CO_2e/ kg FPCM). Linear regression analysis showed that 93% of the difference in total farm GHG emissions was explained by annual milk production and that feed conversion efficiency (kg milk/kg dry matter intake) and nitrogen (N) fertiliser application rate (kg N/ha) could explain 60% of the difference in the GHG emissions intensity of milk production. The GHG emissions intensity per cow and per hectare was also examined. Given the strong influence that feed conversion efficiency and/or N based fertiliser application rates had on the GHG emissions intensity of milk production, these factors should be key research target areas for lowering the GHG emissions associated with dairying in Tasmania. Of interest also was that the results from this study were comparative to studies in other countries, thus illustrating that the pasture dominant farming systems in Tasmania were as GHG efficient as other pasture-based farming systems in New Zealand, Ireland and Europe.

The second paper titled Whole farm systems analysis of Australian dairy farms greenhouse gas emissions was submitted for publication in the Animal Production Science journal in early 2012 (see Appendix 15 for the submitted draft paper) and with minor revisions, will be published in 2012. The study assessed the GHG emissions of 41 Australian dairy farms and found that the GHG emissions intensity of milk production was 1.04 kg CO_2e/ kg FPCM (varied between 0.76 and 1.68 kg CO_2e/kg FPCM). Linear regression analysis showed that 95% of the difference in total farm GHG emission was explained by annual milk production and that milk production per cow (kg fat and protein correct milk/cow lactation) could explain 70% of the difference in the GHG emissions intensity of milk production. The GHG emissions intensity per cow and per hectare was also examined as well as the influence of regional and farming system on milk, cow and area GHG emissions intensity. While the results of this study suggest that milk production alone could be a suitable surrogate for estimating GHG emissions for national inventory purposes, the GHG emissions intensity of milk production, on an individual farm basis, was shown to vary by over 100%. It is clear that using a single emissions factor, such as milk production alone, to estimate any given individual farm's GHG emissions, has the potential to either substantially under or over-estimate individual farms' GHG emissions. Enteric methane emissions were found to be responsible for over half the total farm emissions associated with milk production in Australia and milk production per cow was found to be the key driver influencing the GHG emissions intensity of milk production. As such, implementing management practices that reduce enteric methane production whilst also improving milk production per cow, will have a positive impact on reducing the GHG emissions intensity of milk production in Australia.

Conference papers/publications

The findings reported in the above-mentioned two papers were also communicated through several conference papers and as a conference presentation. Two conference papers titled DGAS: software for modelling and managing greenhouse gas emissions for Australian dairy farms and A whole farm systems analysis of the greenhouse gas emissions of 60 Tasmanian dairy farms were published in the

Proceedings of the 4th International Greenhouse Gases and Animal Agriculture Conference; Banff, Canada, October 2010 (Appendix 10 and 11).

A conference paper titled A whole farm systems analysis of the greenhouse gas emissions of Australian dairy farms was published in the Proceedings of the Climate Change Research Strategy for Primary Industry (CCRSPI) Conference; Melbourne, February 2011 (Appendix 13), with a verbal presentation of this research study at the CCRSPI Conference by Karen Christie.

Presentations, workshops, popular press and field days

The results of the GHG emissions assessment of the Australian dairy industry was also published in The Australian Dairyfarmer magazine (November 2011; Appendix 14). In addition, the results were also made public to various advisers/consultants (e.g. Dairying for Tomorrow co-ordinators, Victorian and New South Wales Dairy Extension Officers) to use in their presentations to farmer groups as relevant.

Enhanced Modelling software development and training

Throughout the duration of the project Karen Christie ran webinars and face-to-face training in the use of the Dairy Greenhouse gas Abatement Strategies (DGAS calculator). Participants included Dairying for Tomorrow co-ordinators, private consultants, milk factory and government department field officers in December 2009, September and November 2010, and in June and November 2011. In addition there has been on-going assistance/training of individuals as required (e.g. famers, public and private advisers/consultants). Total training and assistance would be to in excess of 50 people over the duration of the project.

Throughout the duration of this project, there have been several modifications and improvements to DGAS (Appendix 16). These changes were due to changes to interpretation of the national inventory methodology and from user feedback. Some of the most significant changes have included the introduction of the abatement strategy of applying a nitrification inhibitor to reduce direct and indirect nitrous oxide emissions from animal waste, the alteration of pre-existing abatement strategies to align with recent advances in research findings (e.g. reducing the reduction of methane production from 5.6 to 3.5% for each 1% increase in dietary fat in the diet), the alteration of the emission factors for indirect N_2O emissions from leaching/runoff and the development of a series of questions to ascertain the impact of individual farm management practices on the methane and nitrous oxide emissions associated with waste management. These changes were documented in the User Manual for DGAS version 1.4 which is available, with DGAS version 1.4, to the public via the Dairying for Tomorrow website (http://www.dairyingfortomorrow.com.au/index.php?id=47).

Other activities

Throughout this project the priorities for the dairy industry in terms of mitigating their GHG emissions has changed. In 2010, the Australian Federal Government proposed a cap-and-trade emissions trading scheme called the Carbon Pollution Reduction Scheme (CPRS). Due to a lack of bipartisan support, the CPRS was not legislated. However, a new emissions trading scheme, the Clean Energy Future Plan, was legislated in 2011 and will be implemented in 2012. One component of the Clean Energy Future Plan was a shift in the focus from agriculture being a sectoral source of GHG emissions, and thus requiring ‘taxing’ of a proportion of their GHG emissions (as proposed with the CPRS), to agriculture being a sector of the economy that could implement practices that achieve mitigation and gain financial incentive to do so. To facilitate this, the Carbon Farming Initiative (CFI) was the proposed mechanism within the Clean Energy Bill for assisting agricultural farmers and land managers to obtain carbon offset credits by sequestering carbon on-farm or by reducing/avoiding on-farm GHG emissions. These carbon credits could then be tradable, allowing for other high carbon polluting industries (e.g. electricity companies) to offset their GHG emissions.

In 2011 the TIA project team were approached by this projects’ Dairy Australia steering committee member to assist Dairy Australia in developing a list of standard practices for the Department of Agriculture, Fisheries and Forestry (DAFF) in formulating farm practices that could be included as methodologies that qualify for the ‘Additionality’ requirements in the CFI. These farm practices were broadly grouped into the three broad themes of nutrients and effluent, pasture management and herd and dairy shed practices. In addition, the TIA project team developed the MS Office Excel spreadsheet Carbon Offset Scenarios Tool (COST) calculator and expanded the three abovementioned themes and potential mitigation options provided to DAFF into four theme areas. These were herd and breeding management, diet management, feedbase management and waste management. Within each theme area, mitigation strategies were identified and at the time of finalising the final report, seven individual mitigation strategies had been identified and incorporated into the COST calculator (Appendix 17). However, several more have been identified (e.g. improved reproductive performance, manure digesters to reduce the amount of stored animal waste in lagoons) and these will be incorporated into the COST calculator into the future. In addition, as science progresses and/or the CFI encourages the development of new technologies to reduce and/or remove on-farm GHG emissions, these too will be incorporated into the COST calculator.

Other activities in collaboration with member of the University of Melbourne modelling team

In addition to the above-mentioned conference papers/proceedings, the TIA team have also been co-authors on several other papers with members of the University of Melbourne team. These include:

- BR Cullen, RP Rawnsley, RJ Eckard (2010) Adapting pasture-based dairy systems to future climates. In 'National Climate Change Adaptation Research Facility (NCCARF) 2010 Climate Adaptation Future Conference Proceedings' Gold Coast, Queensland.
- Cullen BC, Rawnsley RP, Snow VO (2010) Repositioning the forage base for dairy production in a volatile and risky climate. In 'Proceedings of the 4th Australasian Dairy Science Symposium' Christchurch, New Zealand.
- Bell MJ, Cullen BR, Christie KM, Rawnsley RP, Eckard RJ (2011) Is the variability of seasonal pasture growth patterns changing? In 'Proceedings of the 2011 Annual Grassland Society of Southern Australia Inc Conference' Hamilton, Victoria.
- Cullen BR, Bell MJ, Christie KM, Rawnsley RP, Eckard RJ (2011) Trends in annual pasture production and its variability. In 'Proceedings of the 2011 Annual Grassland Society of Southern Australia Inc Conference' Hamilton, Victoria.
- Cullen BR, Eckard RJ, Rawnsley RP (2012) Resistance of pasture production to projected climate changes in south-eastern Australia. Crop & Pasture Science 63, 77-86.

5. Conclusion

In the cool temperate regions, such as Tasmania, the current feedbase of perennial ryegrass pastures are well suited to the current environment. Biophysical modelling using future climate projections has indicated that pasture production will most likely increase in most regions. This is primarily due to the current pastures species being limited by relatively low temperatures and so the future climate projections for increased warming, increased atmospheric CO_2 concentrations and minimal changes in precipitation will provide a more favourable environment for pasture growth.

5.1 Key findings

Increased pasture production in early spring and mid to late autumn should provide livestock managers with greater confidence. To adapt to these changes, within systems adaptations may need to be implemented to capture the benefits of this change in seasonal pasture growth patterns. These adaptations include changes to calving dates, stocking rates, and winter nitrogen fertiliser management etc. for the dairy industry or increased capacity for autumn lambing/calving or earlier weaning strategies for the extensive agriculture industry. Modelling has indicated that these adaptations will result in improved profits above 'business as usual' (BAU). However, modelling has also indicated that summer feed deficits will remain into the future so reliance on irrigation and/or summer forage crops and the potential for greater forward purchasing of supplementary feeds will continue into the future. The severity and frequency of extended wet periods is projected to slightly decline over time for most regions of Tasmania thus indicating that no new adaptation options will be required beyond current practices that are already in place. However, there appears to be some projected increase in the number of dry days into the future for most Tasmanian regions examined. Therefore within farming system adaptation options such as deeper rooted pasture species or the implementation of irrigation may be required into the future.

In the temperate regions of southern Australia, modelling has shown that the current feedbase of perennial ryegrass will become limited by temperature increases and/or the availability of soil moisture into the future. Modelling has shown that modifying the feedbase with pasture species that possess greater high temperature tolerance and/or have deeper root systems to capture soil moisture will be able to alleviate some of the impact of increased temperatures and/or reduced precipitation out to 2050. Therefore, modifying the feedbase will be more critical in these regions, given that changes within the current feedbase will not be sufficient to overcome increases in mean daily temperatures of more than 2°C or declines in annual rainfall by more than 20% compared to the current baseline climate.

One hundred Australian dairy farms were assessed for their GHG emissions with the GHG emission intensity of milk production averaging 1.04 kg CO_2e/kg FPCM. Total annual milk production was shown to be a good surrogate for predicting total farm GHG emissions. However, there was substantial variation between farms with the GHG emission intensity of milk production varying between 0.76 and 1.68 kg CO_2e/kg FPCM.

5.2 Benefits to industry

Enteric methane emissions were > 50% of total farm GHG emissions and so the key driver of the GHG emissions intensity of milk production being milk production per cow is not surprising. Key mitigation areas include improved feed conversion efficiency in livestock and improvements in the efficiency of N fertiliser usage.

Modelling analysis has shown that the potential CFI income from adopting currently possible dairy mitigation options is in the vicinity of ~ 1% of total milk production income. Therefore on farm adoption of CFI offset mitigation options are unlikely unless other non- GHG emissions aspects of the mitigation option, e.g. increases in milk production, can provide significant financial gain.

6. Future research and recommendations

One of the major outcomes of this project is a clear need to demonstrate/extend adaptations options, whether they are changes within the current feedbase system, a modification of the current feedbase system or a change in farming system. Whole of farm systems evaluation will strongly assist in providing a greater level of validation to the whole of system models currently available and highlight the potential adaptation opportunities within or across farming systems. The extension/demonstration of adaptation options should be regionally specific. For example whole of farm system evaluation of modifying the current feedbase to adapt to future climates should be undertaken in regions in which this project have clearly shown that a modified feedbase will strongly alleviate projected climate change and therefore result in improved resilience and farm profitability.

There is also a corresponding need to research the component level physiological/agronomical factors associated with modifying the feedbase. There is general reluctance to shift to a modified feedbase as the knowledge underpinning a changing feedbase is not as great as the knowledge for the current feedbase, and therefore there is uncertainty about how best to move to a modified feedbase amongst producers. In regions that have been clearly shown that a modified feedbase is required then developing the “local know how” is viewed with high importance.

Another area highlighted is the need to have the ability to effectively and efficiently quantify CFI offset methods across a broad spectrum of farming systems for the livestock industries. The current COST calculator has begun this process for the dairy industry. Seven individual mitigation strategies had been identified and incorporated into the COST calculator which efficiently and effectively evaluates the adoption of these strategies on the farm GHG emission profile and potential farm profit under the proposed CFI. However, it is envisaged that several other strategies need to be added to the calculator. For example, improved reproductive performance through extended lactations could result in reduced total farm GHG emissions as less stock are required for a similar level of milk production. In addition, the current COST calculator focuses on the impact of various diet management strategies as they influence enteric methane production only. However, many of the current mitigation strategies could also alter the crude protein concentration of the diet and therefore influence animal waste nitrous oxide emissions. Therefore, incorporating the COST calculator into DGAS is seen as a critical next step to not only strengthen the mitigation strategies already included in DGAS but also allow for a full farm systems approach to explore the impact of mitigation strategies on total farm GHG emissions and any associated change to business profit under the proposed CFI. In addition, developing a similar calculator to examine the implications of mitigation options for both beef and sheep industries is viewed as an important need for agricultural managers to have confidence in implementing CFI-adopted mitigation options on farm.

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Dairying for Tomorrow website URL *(http://www.dairyingfortomorrow.com.au/index.php?id=47)*

Parliament of Australia Senate Committee, Carbon Pollution Reduction Scheme, The CPRS: Economic cost without environmental benefit (Interim Report) (2009) website URL
https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Former_Committees/fuelenergy/interim_report/c03

8. Appendix

8.1 Adapting to increases in mean daily temperature by increasing the heat tolerance of perennial ryegrass

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Abstract

Climate projections for Australia suggest that there will be a general increase in daily temperatures of 0.4 to 1.8°C by 2030 and 2.2 to 5°C by 2070 (CSIRO and BoM, 2007). Climate change impact modelling based on future climate scenarios, created by direct scaling of historical climate data, can be used to examine the effect of increased temperature on pasture production and potential adaptation approaches, while maintaining the inherent climate variability. The biophysical model DairyMod (Johnson et al. 2008) was used to simulate mean annual pasture yields for the three Australian dairying regions of Elliott (North West Tasmania), Ellinbank (South East Victoria) and Terang (South West Victoria), which heavily rely on perennial ryegrass (Lolium perenne L.) to support dairy production. Five climate files for each region were created by direct scaling the historical baseline climate file (1971 to 2008) by 0, 1, 2, 3, 4 and 5°C with corresponding atmospheric CO_2 concentrations of 380, 435, 535, 640, 750 and 870 ppm, respectively. The highest mean annual yield for Elliott, Ellinbank and Terang resulted from scaling to 3°C/640 ppm (a 27.2% increase above the baseline climate data), 1°C/435 ppm (1.7% increase) and 2°C/535 ppm (10.1% increase), respectively. At Elliott, increases in temperature with corresponding increases atmospheric CO_2 concentration increased annual pasture yields. At Ellinbank and Terang, increasing temperature and CO_2 concentrations to and above 2°C/535 ppm and 4°C/750 ppm respectively, resulted in lower annual yields than those produced using the baseline climate data. The effect of exposure to periods of extreme high temperatures on the growth of perennial ryegrass was then explored using nine variations of high temperature tolerance, in conjunction with the scaled increases in temperature and atmospheric CO_2 concentrations described above. Three onset and full temperature combinations (28/35°C, 29/36°C and 30/37°C) were examined across three critical T-sums (20, 35 and 50°C). The onset temperature represents the temperature at which a reduction in plant function commences due to heat stress, the full temperature represents the upper temperature at which plant function ceases, and the critical T-sum represents the recovery period required following exposure to heat stress. Increasing the high temperature tolerance of perennial ryegrass was able to alleviate the negative effects on annual pasture up to 5°C of warming at Terang and up to 4°C warming at Ellinbank. This highlights the relative benefit of exploring and introducing more heat tolerant perennial ryegrass cultivars to the regions used in this study.

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8.2 Effect of deficit rainfall and rooting depth of perennial ryegrass on pasture production in South East Asia

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Abstract

The biophysical model DairyMod (Johnson *et al*. 2008) was used to simulate the annual and seasonal production of perennial ryegrass (*Lolium perenne* L.) pastures for the three dairying regions of Elliott (North West Tasmania), Ellinbank (South East Victoria) and Terang (South West Victoria). Five rooting depth treatments were assessed; a baseline rooting depth of 30 cm, and then increments of 10 cm to a maximum of 70 cm. Six differing rainfall scenarios were implemented; a baseline rainfall scenario (current rainfall pattern for the period 1971 to 2008) and five deficit increments between 0.5 and 0.9 of the baseline rainfall. Mean annual and seasonal pasture production (kg DM/ha) figures for each rooting depth/rainfall treatment was calculated for the period 1971 to 2008.

There was a positive linear relationship between rooting depth (cm) and annual pasture production (kg DM/ha.year) for each rainfall scenario. The greatest benefit of increasing rooting depth was observed over the spring period, and to a lesser extent summer, in all regions. There was very little benefit of increased rooting depth in autumn and winter when the winter-dominant rainfall patterns of these regions was sufficient for maintaining growth, especially if rainfall deficits were minimal. Increasing the rooting depth from 30cm to 50cm was able to alleviate the impact of a 20% decline in rainfall on mean annual pasture production at Ellinbank.

However, this increase in rooting depth was not able to overcome a 20% rainfall deficit at the other two regions, with an 8.8 and 0.9% decline in mean annual pasture production for Terang and Elliott, respectively. At all three regions, when the rainfall deficit exceeded 20%, a doubling of the rooting depth to 60cm was not able to alleviate the effects on mean annual pasture production. This indicates that although the adaptation of increasing rooting depth may be considered a very favourable adaptation strategy for adapting to a drier future climate, the ability to alleviate the impacts under significant rainfall decline is limited. Shallow rooted perennial temperate pastures, such as perennial ryegrass, are currently considered the main forage source for dairy cattle in temperate regions of SE Australia. However, a changing and variable climate may lead to alterations to the current the forage base. Further work is required to analyse the adoption of these forage combinations at whole of farm system level and under agreed climate projection scenarios for the differing regions.

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8.3 Modelling approaches to adapting pasture based dairy systems to a changing climate in a carbon constrained world

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Abstract

The temperate regions of Australia support over 80% of the nation's milk production, (Dairy Australia, 2009). Perennial ryegrass (*Lolium perenne* L.) is commonly sown in a mixed sward with white clover (*Trifolium repens* L.) and is the dominant pasture specie in many of these regions (Mason, 1993; Fulkerson and Doyle, 2001). In such pasture-based systems, consumption of home- grown herbage is a key determinant to business success (Beca, 2005; Chapman *et al*., 2008).

Increasing pasture productivity, through improved production and consumption, has been highlighted as an important objective for the dairy industry into the future (Dairy Australia, 2010). Modelling the pasture production under future climate scenarios for the cool temperate dairy regions of Tasmanian has shown that pasture production is likely to increase between 15 and 30% (Cullen *et al*. 2009, Holz *et al*. 2010). The average per cow production of Tasmanian dairy farms is 5,000 L /cow (Dairy Australia, 2009), with on average less than 20% of the cows diet coming from purchased grain concentrates or by products (Barlow, 2008) and average annual nitrogen fertiliser applications exceeding 200kg N/ha (TIAR, 2010). These dairy farm systems are classified as farm system 1 (FS1) and are characterised by being predominantly pasture based with less than 30% purchased supplementary feeding. Climate change projections for Tasmania's dairy regions has highlighted that the current forage base is quite resilient to future climate scenarios and that adaptations are likely to be within system adaptations with the industry continuing to focus on milk production per ha and pasture consumption per ha as key determinants of business success. Cullen *et al*. (2010) showed that increasing stocking rate and changes in calving date are profitable adaptive response to a warming climate in these regions, however, there is an emerging conflict between the most profitable approaches to adapting to changing climate and that of mitigation of greenhouse gases (GHG) in a carbon-constrained world. The GHG emissions intensity of milk production of FS1 farms have been shown to be higher than those of dairy farm systems with higher levels of concentrate feeding and higher per cow production (Christie *et al*. 2009). For these predominantly pasture based systems there is an urgent need to develop agreed approaches to examining adaptation strategies and their influences on total farm GHG emissions, the emission intensity of milk production and farm profitability.

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8.4 An historical analysis in pasture production, growing season and the number of wet and dry days in three dairy regions of South East Australia

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Abstract

The production of high quality perennial ryegrass (*Lolium perenne* L.) is a strong determinant of business success for pasture-based dairy systems in Australia (Beca, 2005; Chapman *et al*., 2008). There is concern regarding the influence of a changing and variable climate on these systems, with evidence that the global climate has changed over the past century and that the risk of extreme events and abrupt changes in climatic patterns is increasing (NRMMC 2006). It is important to quantify these changes and their effects in order to identify and explore potential system adaptations. For pasture-based dairy systems in South East Australia, seasonal and annual pasture production, the commencement, length and reliability of the growing season and the duration of wet and dry periods are all significant factors that influence management decisions and profitability. Using the biophysical pasture simulation model DairyMod (Johnson *et al*. 2008), the current study quantified the changes and variability of these factors, by undertaking a historical analysis (1960 - 2009) across three dairy regions in South East Australia: Terang (South West Victoria, Mediterranean climate); Ellinbank (Gippsland, Victoria, temperate climate); and Elliott (North West Tasmania, cool- temperate climate).

A significant linear relationship between year and commencement date of the growing period at Elliott (P = 0.04) and Terang (P = 0.01) indicated that for every 10 year period, between 1960 and 2009, the commencement date of the growing period for these regions was 1.5 days earlier. There was no evidence that the commencement date of the wet and dry periods has changed over the last 50 years. However, during the last four to five years, all three sites have experienced an unusually low number of days in the year when soil moisture content has exceeded field capacity, and an unusually high number of days when the readily available water in the root profile has been exhausted.

Although unpredictable to date (i.e. there was no significant (P > 0.05) linear relationship between year and the number of days for the wet and dry periods at any of the sites over the last 50 years), the observation that the length of wet periods may be decreasing and length of dry periods may be increasing, has important implications for farm management decision-making.

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8.5 Pasture growth to lift under climate change

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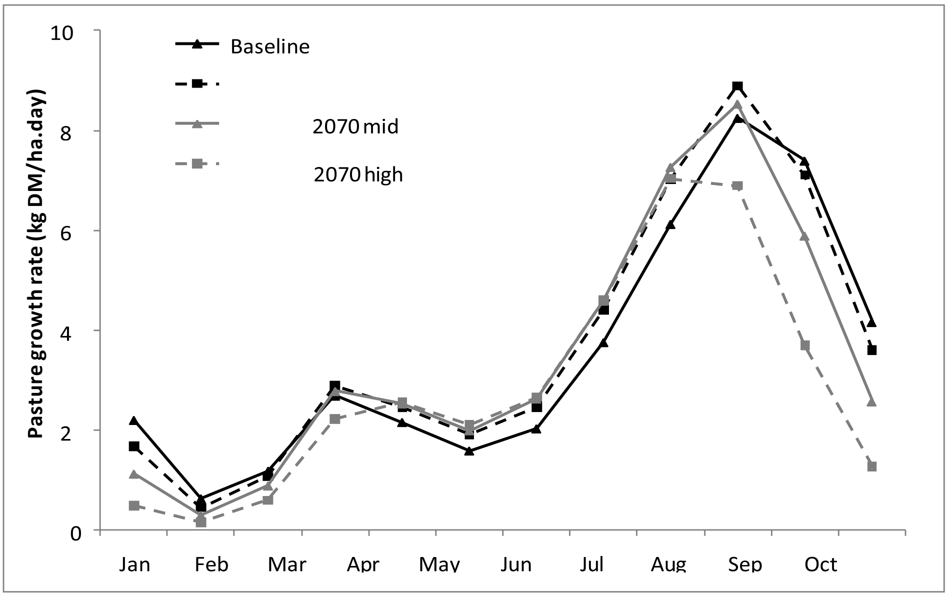
Dairy systems in south eastern Australia may be facing a warmer and drier future, but a recent modelling research has shown that dairy producers in some areas could maintain or even increase pasture production under a changing climate. It is well established that pasture consumption is a key index of dairy farm business success. Climate change is a feature of the 21st century and pasture production is heavily reliant on the climate. Projected climatic changes will alter the pattern of pasture growth requiring dairy farmer to adapt their grazing systems. Using biophysical models, researchers from the Tasmanian Institute of Agricultural Research and the University of Melbourne have been studying what dairy systems might look like at a regional level under a future climate. The research has focused on the production of perennial ryegrass and white clover under future climate scenarios and examined adaptation options at both a biophysical and farm system level. Annual and seasonal pasture growth was predicted by inputting projections of future rainfall and temperature – based on three future climate change scenarios – into the grazing systems models DairyMod and SGS Pasture Model. The future climate scenarios were developed for each site by adjusting baseline climate data (from the period 1971–2000) with climate change projections based on a high greenhouse gas emission scenario in 2030, and mid- and high-emission scenarios in 2070.

Researchers found that although higher temperatures and reduced rainfall are likely to result in a contraction of the spring growing season by a few weeks, warmer temperatures in winter and early spring, and higher levels of atmospheric carbon dioxide concentrations will elevate pasture growth rates enough to offset most, and in some cases all, of the decline later in the season (Fig 1)

Figure 1. Mean monthly pasture growth rates under a baseline (1971-2000) and three future climate scenarios at Ellinbank.



The research also highlighted that the use of deeper rooted perennials and higher temperature tolerant plants were able to alleviate the impact of a warmer and drier on pasture production. Incorporating deep rooted and heat tolerance traits into pasture species may involve breeding new cultivars of perennial ryegrass or changing to species such as tall fescue that already have these traits.

At a farm system level, the capacity to adapt stocking rate and calving time to future climates was explored. The impact of climate change on pasture production and farm gross margin at three sites; Terang (south-west Victoria, Mediterranean climate); Ellinbank (Gippsland, Victoria, temperate climate); and Elliott (north-west Tasmania, cool-temperate climate) were modelled under a range of climate by stocking rate by calving date scenarios. In the cool temperate region where pasture production was expected to increase in most climate scenarios adapting calving pattern and stocking rate resulted in significant increases in gross margins. No benefit or a decrease in gross margin were simulated in the Mediterranean and temperate regions suggesting that further changes to the farm system are required to maintain profitability in these regions.

While maintaining or improving pasture consumption is considered critical to the underlying competitive advantage of the dairy industry it is also important that these climate change adaptation strategies do not conflict with climate change mitigation. For example, the logical response of producers to warmer winter conditions will be to increase nitrogen fertiliser application, resulting in greater nitrous oxide emissions. The greenhouse gas emissions intensity of milk production of predominately pastured based dairy farms have been shown to be generally higher than those of dairy farm systems with higher levels of concentrate feeding and higher per cow production. For these predominantly pasture based systems the research teams are exploring climate change adaptation strategies that are not only resilient to a changing climate but also reduce emission intensity of milk production and improve farm profitability.

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8.6 Frequency of wet and dry soil conditions in Tasmanian dairy regions

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Abstract

Durations of wet and dry periods are significant factors that influence pasture management on dairy farms. Historical and future simulated daily climate data for two dairy regions of Tasmania (Flowerdale and Ringarooma) was accessed from the 'Climate Futures for Tasmania' project and used to simulate a perennial ryegrass sward growing on a clay loam soil. The simulated soil moisture content to depth of 400mm was used as the criteria for determining number of wet (soil moisture > 160mm) and dry (soil moisture <120mm) days per annum. The mean number of dry and wet days for each region for six general circulation models (GCMs; CSIRO-Mk3.5, ECHAM5, GFDL 2.0, GFDL 2.1, MIROC3.2 and UKHad), was computed for the baseline period (years 1971 to 2000) and three future climate periods (years of 2001 to 2030, 2031 to 2060 and 2061 to 2090). By years 2061 to 2090, the mean number of wet days at Flowerdale and Ringarooma is predicted to decline by 8.5 and 4.5 days per annum, respectively. In contrast, the mean number of dry days for Flowerdale and Ringarooma is predicted to increase by 7.5 and 4.8 days, respectively. While there was little change in the mean number of wet and dry days when averaged over each GCM, there was substantial variation between GCMs for any particular period and region. This paper discusses the implication of these results and also highlights the influence of inter-annual climate variability on dairy farming systems.

Key Words

Climate Futures for Tasmania, climate change, field capacity, readily available water, Flowerdale, Ringarooma

Introduction

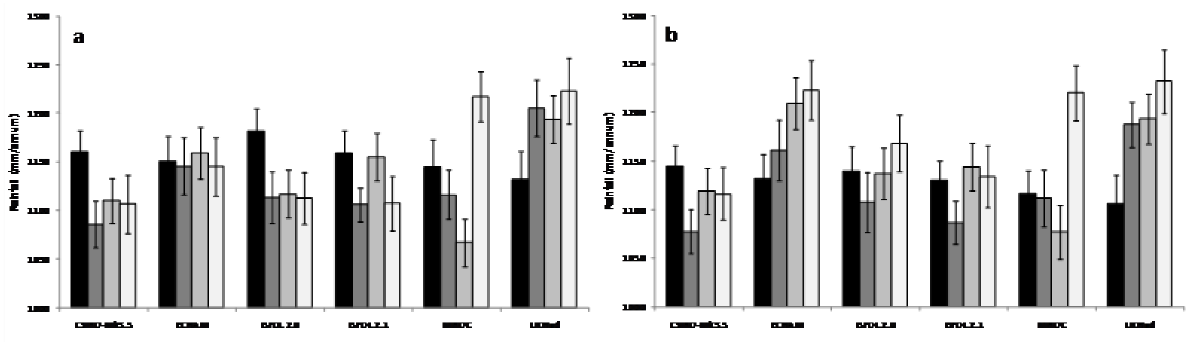
Climate is an important driver of pasture production and the intra-annual variability in climate results in different patterns of pasture production needs to be managed to meet feed demands on dairy farms. In recent decades, South Eastern Australia has experienced a decline in total annual rainfall (Australian Bureau of Meteorology 2008), with the most substantial reduction occurring in autumn (Gallant *et al.* 2007). General Circulation Models (GCMs) provide the best estimates for assessing potential changes to the climate on a global scale however projections of climate change are not evenly distributed over the globe. This necessitates that local or regional climate projections are required to quantify local or regional climate impacts (Corney *et al* 2010). The Climate Futures for Tasmania (CFT) project generated climate projections specific to Tasmania through a dynamical downscaling approach (Grose *et al.* 2010). This downscaling approach increased the spatial resolution from 2° to 3° grid cells (~200 to 300km) in the GCMs down to a 0.1° grid (~10km) for Tasmania, thus capturing regional and sub-regional differences allowing the projected climate change impacts to be quantified on a local scale (Corney *et al* 2010).

Extended periods of both wet and dry soil conditions can strongly influence the managerial operations of a pasture based dairy system. For example, extended periods of wet soil moisture conditions can result in pugging of pasture, increased lameness and an increase incidence of mastitis, whilst extended dry soil conditions often results in lower pasture production, reduced pasture persistence and an increased reliance on purchased feed. This study examined the changes in the frequency of wet and dry days per annum for two dairy regions of Tasmania out to 2090 using climate projection data from the CFT project.

Methods

Daily climate data developed from the CFT project (https://dl.tpac.org.au/) was accessed for Flowerdale (41.0°S, 145.6°E) and Ringarooma (41.3°S, 147.7°E). For both regions, six down-scaled A2 emissions scenario GCM files (CSIRO-Mk3.5, UKHad, ECHAM5, GFDL 2.0, GFDL 2.1 and MIROC3.2) were used, in combination with the biophysical model DairyMod (Johnson *et al.* 2008), to simulate a rain-fed perennial ryegrass pasture sward using a generic clay loam soil. Each GCM predicts varying increases or decreases in mean annual rainfall for future climate periods for Flowerdale (Figure 1a) and Ringarooma (Figure 1b) compared to its corresponding baseline period. The simulated soil moisture content to depth of 400mm was used as the criteria for determining number of wet (soil moisture > 160mm) and dry (soil moisture <120mm) days per annum. The number of wet days represents when the soil is above field capacity and the number of dry days represents the point where water in the soil profile is no longer readily available to the pasture sward, and evapotranspiration falls below its potential rate. The mean number of dry and wet days for each region, averaged across the six GCMs, was computed for the baseline period (years 1971 to 2000) and three future climate periods (years 2001 to 2030, 2031 to 2060 and 2061 to 2090). In addition, a ten-year moving mean number of wet and dry days and the associated coefficient of variation (CV%) for each region and GCM were calculated (mean of years 1971 to 1980 = 1980 value).

Figure 1. Mean annual rainfall for Flowerdale (a) and Ringarooma (b) for the climatic periods of years 1971 to 2000 ■ , 2001 to 2030 ■ , 2031 to 2060 ■ and 2061 to 2090□ according to six general circulation models (vertical bars indicate the standard error of the mean).



Results

Wet days

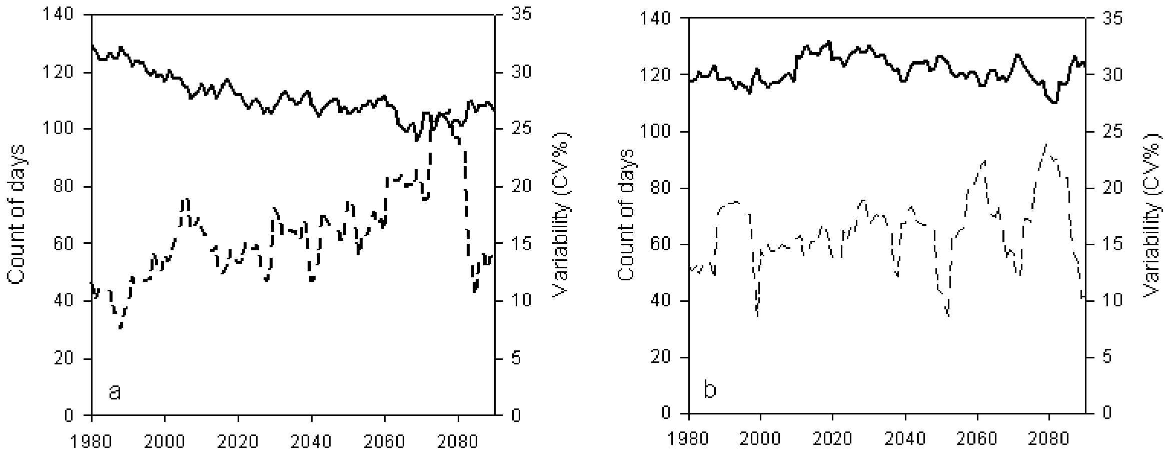
The mean number of wet days, averaged over the six GCMs, was predicted to decline by 8.5 days per annum at Flowerdale and 4.5 day per annum at Ringarooma (Table 1). While there was little variation in the mean number of wet days between GCMs during the baseline period, each GCM predicted varying changes in the number of wet days per annum for three future climate periods. At Flowerdale, five of the six models predicted a reduction in the mean number of wet days per annum by years 2061 to 2090 when compared to the baseline period of years (Table 1). The only exception was the UKHad model with a predicted increase in the mean number of wet days per annum by years 2061 to 2090 when compared the baseline period of years (Table 1). At Ringarooma, all models predicted either no change (i.e. ECHAM model) or a decline in the mean number of wet days per annum by years 2061 to 2090 when compared to the baseline period of years (Table 1).

Table 1. Mean annual number of wet days (soil moisture > 160mm) per annum for Flowerdale and Ringarooma using six general circulation models for a baseline period (year 1971 to 2000) and change in the number of wet days for three future climate periods (years 2001 to 2030, 2031 to 2060 and 2061 to 2090) compared to the baseline period.

Region	General Circulation Model	1971 to 2000	2001 to 2030	2031 to 2060	2061 to 2090
Flowerdale	CSIRO-Mk3.5	123.9	-11.8	-15.3	-20.6
	ECHAM5	121.6	+0.5	-3.0	-7.3
	GFDL 2.0	122.4	-4.5	-8.7	-13.4
	GFDL 2.1	119.9	-6.5	+1.3	-5.4
	MIROC3.2	122.3	-6.7	-18.1	-5.4
	UKHad	118.2	+9.2	+3.0	+1.3
	Overall mean	121.4	-3.3	-6.8	-8.5
Ringarooma	CSIRO-Mk3.5	115.7	-10.1	-10.4	-16.6
	ECHAM5	116.1	-2.6	-1.4	0.0
	GFDL 2.0	114.6	-5.3	-5.2	-6.3
	GFDL 2.1	111.9	-3.3	+1.2	-0.8
	MIROC3.2	115.3	-9.6	-16.1	-1.4
	UKHad	113.6	+5.2	+1.3	-2.1
	Overall mean	114.5	-4.3	-5.1	-4.5

There was substantial inter-annual variability in the number of wet days both within GCMs over time and between GCMs during the same timeframe (only limited data shown). The CSIRO-Mk3.5 model predicted a decline in the moving ten-year mean number of wet days per annum over time for Flowerdale (2.0 days per decade decline; Fig. 2a). In contrast, the UKHad model predicted only a very small reduction in the moving ten-year mean number of wet days per annum over time (< 0.01 days per decade decline; Fig. 2b). However, for both regions, it appears that there will be trend towards increasing year-to-year variability in the number of wet days, as evidenced by the increase in coefficient variation of the ten year moving mean.

Figure 2. Moving ten-year average number of wet days (solid line), defined as soil moisture > 160mm in the top 400mm of soil profile, and its associated variability (CV%, dashed line), from years 1980 to 2090 for Flowerdale using the CSIRO-Mk3.5 (a) and UKHad (b) general circulation models



Dry days

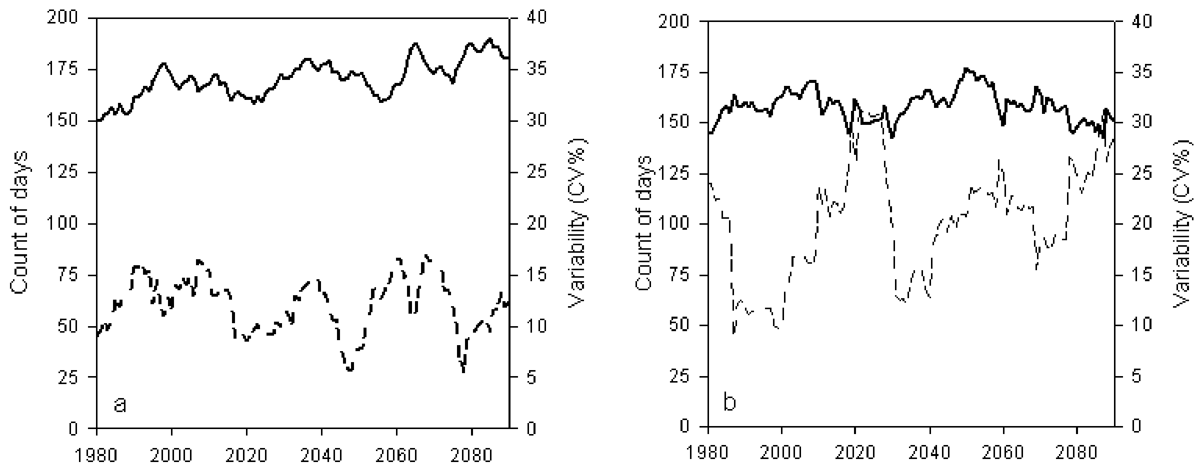
The mean number of dry days, averaged over the six GCMs, was predicted to increase by 8.0 days per annum for Flowerdale and 7.2 days per annum for Ringarooma in the period of years 2031 to 2060 (Table 2). There was little variation in the number of dry days between GCMs during the baseline period. However, post the baseline period, there was substantially more variation between the climate models. For example, the CSIRO-Mk3.5 model resulted in Ringarooma having, on average, an additional 19.5 dry days per annum in the period of years 2061 to 2090 compared to the baseline period of years while the ECHAM model predicted a decline of 1.4 dry days per annum in the period of years 2061 to 2090 compared to the baseline period of years (Table 2).

Table 2. Mean annual number of dry days (soil moisture < 120mm) per annum for Flowerdale and Ringarooma using six general circulation models for a baseline period (years 1971 to 2000) and change in the number of dry days for three future climate periods (years 2001 to 2030, 2031 to 2060 and 2061 to 2090) compared to the baseline period.

Region	General Circulation Model	1971 to 2000	2001 to 2030	2031 to 2060	2061 to 2090
Flowerdale	CSIRO-Mk3.5	157.9	+7.6	+12.5	+13.0
	ECHAM5	156.8	-3.4	+2.8	+5.7
	GFDL 2.0	155.5	+7.6	+13.5	+19.7
	GFDL 2.1	160.2	+1.6	+5.4	+6.4
	MIROC3.2	160.7	+0.4	+11.9	+2.6
	UKHad	157.9	-4.9	+2.0	-2.7
	Overall mean	158.1	+1.5	+8.0	+7.5
Ringarooma	CSIRO-Mk3.5	161.0	+5.4	+11.9	+19.5
	ECHAM5	155.7	-0.3	+8.5	-1.4
	GFDL 2.0	161.1	+6.6	+8.5	+5.2
	GFDL 2.1	163.8	+2.2	+4.4	+0.6
	MIROC3.2	162.5	+1.6	+9.1	+5.6
	UKHad	161.9	+0.4	+0.8	-1.0
	Overall mean	161.0	+2.7	+7.2	+4.8

There was also substantial inter-annual variability in the number of dry days both within GCMs over time and between GCMs during the same timeframe (only limited data shown). For example, Fig. 3 shows the moving ten-year mean number of dry days per annum for Ringarooma using the CSIRO-Mk3.5 and ECHAM models. The CSIRO model showed a trend towards an increase in the moving ten-year mean number of dry days per annum (2.0 days per decade increase; Fig. 3a). In contrast, the ECHAM model showed a trend towards a decline in the moving ten-year mean number of dry days per annum (0.1 days per decade decline; Fig. 3b). The variability in the moving ten-year mean number of dry days per annum was also predicted to decline for the CSIRO-Mk3.5 model but increase for the ECHAM model over time.

Figure 3. Moving ten-year average number of dry days (solid line), defined as soil moisture < 120mm in the top 400mm of soil profile, and its associated variability (CV%, dashed line), from years 1980 to 2090 for Ringarooma using the CSIRO-Mk3.5 (a) and ECHAM (b) general circulation models.



Conclusion

This study concluded that while there was substantial variation between GCMs, over time there will be an increase in the number of dry days per annum when available water in the soil profile will limit pasture production for the two Tasmanian dairy regions examined in this study. In addition, inter- annual variability in the number of wet and dry days will continue to occur and may increase in the future. There is currently no conclusive evidence to suggest that for the two dairy regions of Tasmania examined in this study that adaptation strategies for managing extended dry or wet periods are going to be any more imperative into the future beyond how imperative they are today. Managing extended dry periods could include the adoption of deeper rooted pasture species into the feedbase or the implementation of irrigation, whilst managing extended wet periods could include improvements to on-farm drainage or the provision of infrastructure to support a standoff area for herd. There will also be a need to quantify the whole of farm biophysical and business performance when adopting such potential adaptation strategies.

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8.7 Timing of autumn breaks and lengths of springs in Tasmanian dairy regions under future climate scenarios

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Abstract

The timing of autumn breaks and the length of the spring growing season are considered two times of the year when pasture growth can be most variable. Daily climate data for two dairy regions of Tasmania (Flowerdale and Ringarooma) was accessed from the 'Climate Futures for Tasmania' project and used to simulate a perennial ryegrass sward using the biophysical pasture model DairyMod. The mean frequency of early and late autumn breaks and frequency of short and long spring seasons for a baseline period (years 1971 to 2000) and three climate periods (years 2001 to 2030, 2031 to 2060 and 2061 to 2090) was predicted for each region using climate projections from six general circulation models. Comparing the mean change between the baseline period and the future climate period, years 2061 to 2090, the frequency of early autumn breaks was predicted to increase from 27% to 33% for Flowerdale and from 26% to 34% for Ringarooma. The frequency of late autumn breaks was predicted to decline from 31% to 16% for Flowerdale and from 34% to 17% for Ringarooma. The frequency of short springs was predicted to decline from 14% and 16% for Flowerdale and Ringarooma, respectively, to < 1% for both regions. The frequency of long springs was predicted to remain relatively stable at ~ 32% for both regions. The results of this study indicate that for both regions of Tasmanian, earlier autumn breaks and a reduction in the frequency of short springs will result in a more reliable growing season. This paper discusses the implications of these results and possible adaptation options.

Key Words

Climate Futures for Tasmania, Flowerdale, Ringarooma, autumn breaks, spring seasons

Introduction

Climate is an important driver of pasture production and the intra-annual variability in climate results in differing patterns of pasture production which needs to be managed to meet feed demands on dairy farms. In recent decades, south eastern Australia has experienced a decline in total annual rainfall (Australian Bureau of Meteorology 2008), with the largest decline occurring in autumn (Gallant *et al.* 2007). General Circulation Models (GCMs) provide the best means of estimating the potential changes to the climate on a global scale. However, projections of climate change are not evenly distributed over the globe. To assess the impact of changes in climate within Tasmania, the Climate Futures for Tasmania (CFT) project generated climate projections specific to Tasmania through a dynamical downscaling approach (Grose *et al.* 2010). This downscaling approach increased the spatial resolution from 2° to 3° grid cells (~200 to 300km) in the GCMs down to a 0.1° grid (~10km) for Tasmania, allowing the projected climate change impacts to be quantified on a local scale (Corney *et al* 2010).

The timing of the autumn break is most strongly influenced by precipitation, and its occurrence strongly influences feed availability for autumn calving herds or the accumulation of a feed wedge for late winter/ early spring calving herds. The timing and duration of springs may be short or long, depending on soil moisture availability and the onset of warmer temperatures.

The length of the spring season influences both the quality and quantity of surplus pasture, which in turn influences the need to purchase feed. This study examined the changes in frequency of late and early autumn breaks and frequency of long and short spring seasons for two dairy regions of Tasmania out to 2090 using climate projection data from the CFT project.

Methods

Daily climate data developed from the CFT project (https://dl.tpac.org.au/) was accessed for Flowerdale (41.0°S, 145.6°E) and Ringarooma (41.3°S, 147.7°E). For both regions, six down- scaled A2 emissions scenario GCM files (CSIRO-Mk3.5, ECHAM5, GFDL 2.0, GFDL 2.1 and MIROC3.2 and UKHad) were used, in combination with the biophysical model DairyMod (Johnson *et al.* 2008), to simulate a monthly cut study to a residual of 1.4 t DM/ha for a rain-fed perennial ryegrass pasture sward using a generic clay loam soil. Monthly pasture growth rates (PGR; kg DM/ha.day) were simulated using climate data from a baseline period (years 1971 to 2000) and three future climate periods (years 2001 to 2030, 2031 to 2060 and 2061 to 2090).

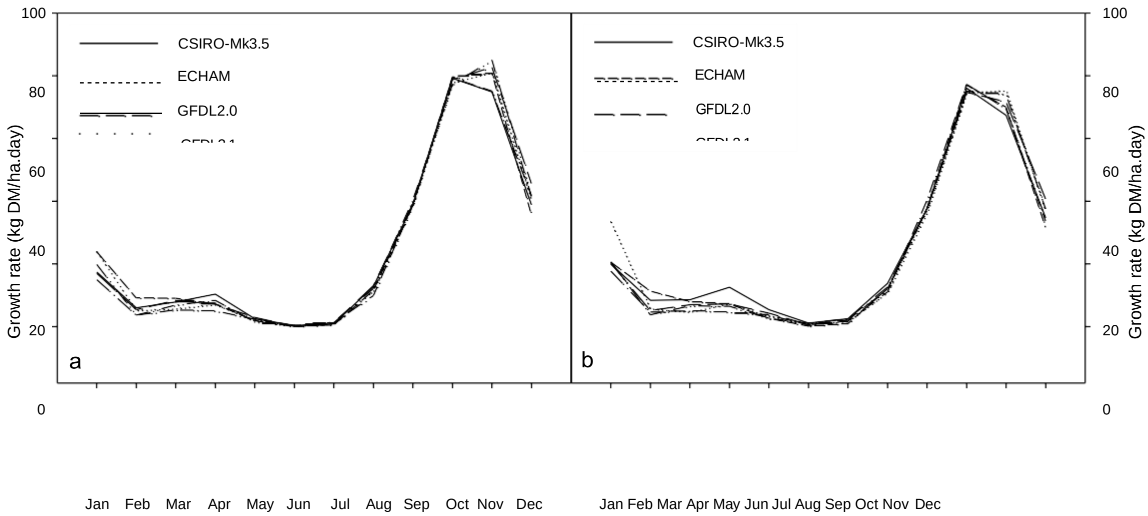
The frequency of late and early autumn breaks and frequency of long and short spring seasons were defined in terms of monthly PGRs following a similar method as described by Chapman *et al.* (2008):

- Early autumn break: PGR in both March and April > baseline period average for March and April
- Late autumn break: PGR in both April and May < baseline period average for April and May
- Short spring season: PRG in both October and November < baseline period average for October and November
- Long spring season: PRG in both November and December > baseline period average for November and December

Results

There was generally good agreement (less than 10kg DM/ha.day difference) between the six GCMs for simulating mean monthly PRGs for the baseline period (Fig. 1). Across the six GCMs the mean daily temperature increase, relative to the baseline temperature, for Flowerdale and Ringarooma were 0.5, 1.2 and 2.2°C and 0.5, 1.3 and 2.3°C in the 2001-2030, 2031-2060 and 2061-2090 periods, respectively. Annual rainfall changes, relative to the baseline rainfall, for Flowerdale and Ringarooma were -2.3, -1.8 and -0.2% and -0.5, +1.6 and +4.8% in the years 2001 to 2030, 2031 to 2060 and 2061 to 2090 periods, respectively.

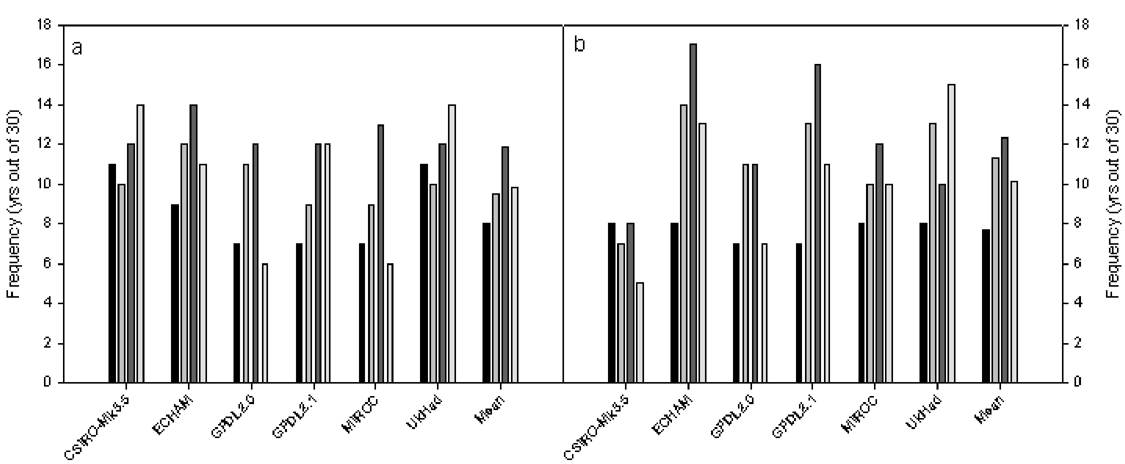
Figure 1. Mean monthly pasture growth rate (kg DM/ha.day) for Flowerdale (a) and Ringarooma (b) for the baseline (years 1971 to 2000) climatic period according to six general circulation models.



Autumn breaks

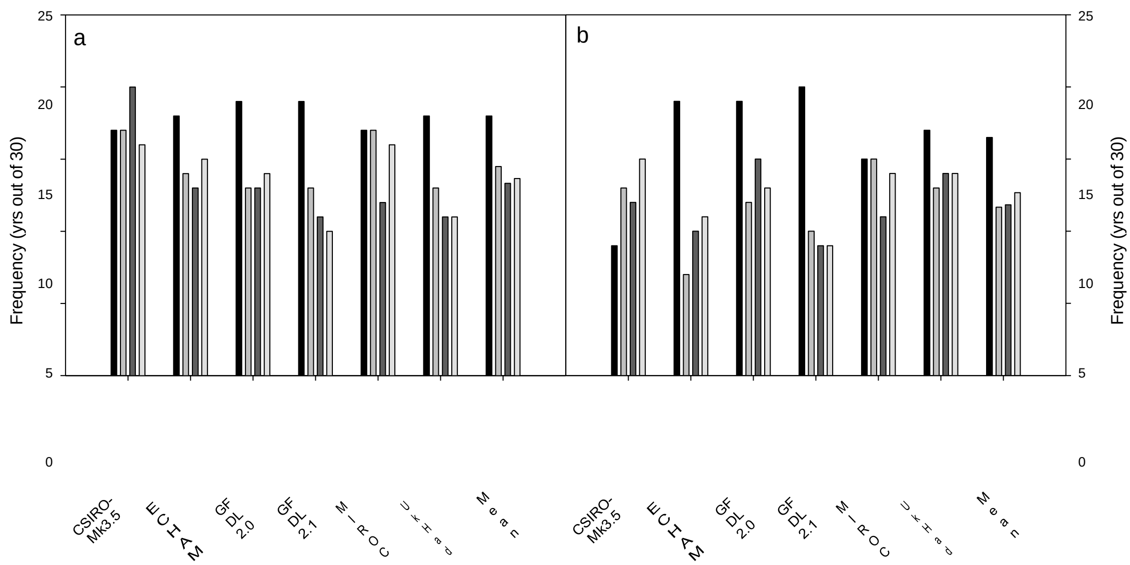
For Flowerdale and Ringarooma, the frequency of early autumn breaks (Fig. 2), as a mean of the six GCMs, was lower than the frequency of late autumn breaks (Fig. 3), as a mean of the six GCMs, during the baseline period of years. At Flowerdale, the frequency of early autumn breaks, as a mean of the six GCMs, was predicted to increase from 27% (i.e. 8.0 years out of 30) in the baseline period to 33% by years 2061 to 2090 (Fig. 2a). At Ringarooma, the frequency of early autumn breaks, as a mean of the six GCMs, was predicted to increase from 26% (i.e. 7.7 years out of 30) in the baseline period to 34% by years 2061 to 2090 (Fig. 2b).

Figure 2. Frequency (number of years out of 30) of early autumn breaks at Flowerdale (a) and Ringarooma (b) for six general circulation models for the periods of years 1971 to 2000 ■ 2001 to 2030 ▢, 2031 to 2060 ■ and 2061 to 2090 ▢.



At Flowerdale, the frequency of late autumn breaks, as a mean of the six GCMs, was predicted to decline from 31% (i.e. 9.3 years out of 30) in the baseline period to 16% by years 2061 to 2090 (Fig. 3a). At Ringarooma, the frequency of late autumn breaks, as a mean of the six GCMs, was predicted to decline from 34% (i.e. 10.2 years out of 30) in the baseline period to 17% by years 2061 to 2090 (Fig. 3b).

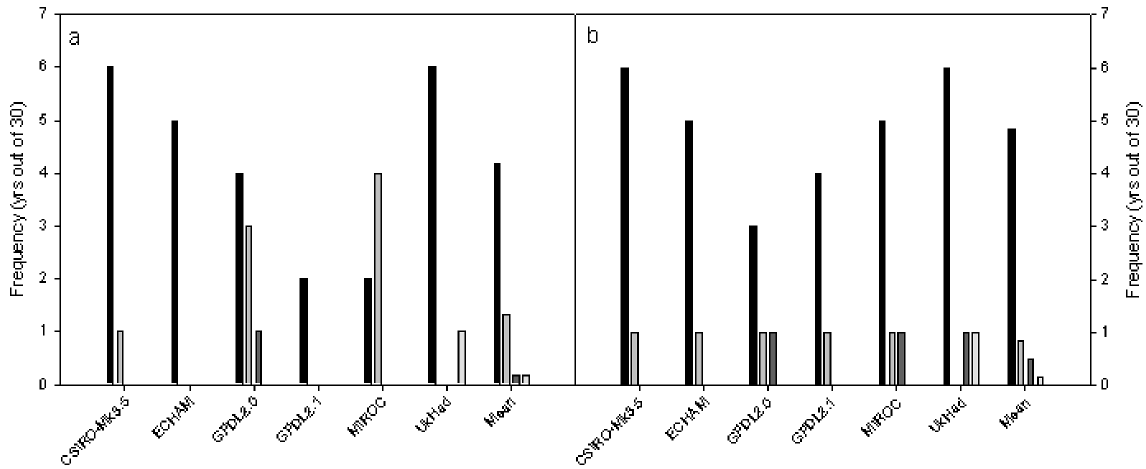
Figure 3. Frequency (number of years out of 30) of late autumn breaks at Flowerdale (a) and Ringarooma (b) for six general circulation models for the periods of years 1971 to 2000 ■, 2001 to 2030 ▢ 2031 to 2060 ■ and 2061 to 2090 ▢ .



Spring seasons

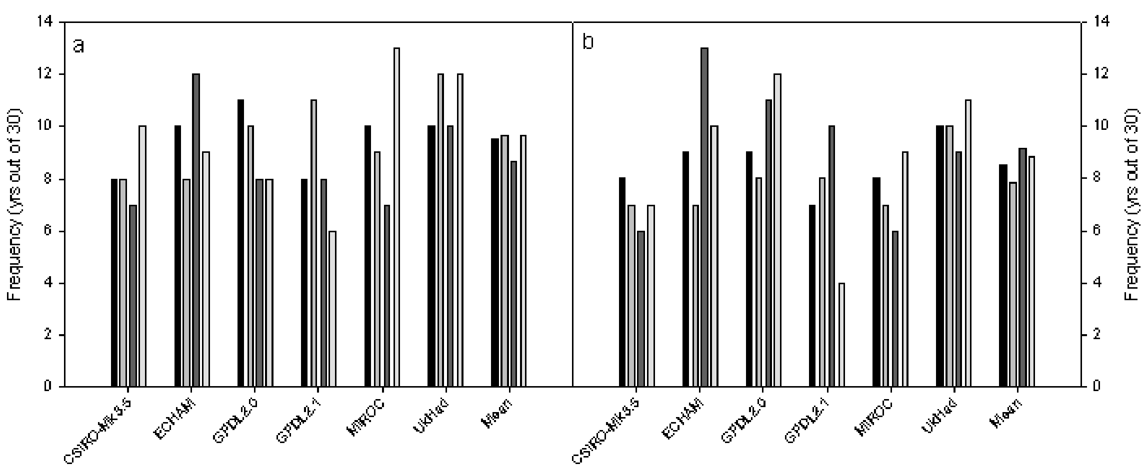
For Flowerdale and Ringarooma, the frequency of short springs (Fig. 4), as a mean of the six GCMs, was lower than the frequency of long springs (Fig. 5), as a mean of the six GCMs, during the baseline period of years. At Flowerdale, the frequency of short springs, as a mean of the six GCMs, was predicted to decline from 14% (i.e. 4.2 years out of 30) in the baseline period to < 1% by years 2061 to 2090 (Fig. 4a). At Ringarooma, the frequency of short springs, as a mean of the six GCM's, was predicted to decline from 16% (i.e. 4.8 years out of 30) in the baseline period to < 1% by years 2061 to 2090 (Fig. 4b). There was general consensus between GCM's that the frequency of short springs would decline dramatically in all three future climate periods when compared to their corresponding baseline period (with the exception of the MIRCO model for years 2001 to 2030 at Flowerdale; Fig. 4a).

Figure 4. Frequency (number of years out of 30) of short spring seasons at Flowerdale (a) and Ringarooma (b) for six general circulation models for the periods of years 1971 to 2000 ■, 2001 to 2030 ■, 2031 to 2060 ■ and 2061 to 2090 □ .



At Flowerdale and Ringarooma, the frequency of long springs, as a mean of the six GCMs, was predicted to remain relatively stable across all climate periods at between 29% and 32% (i.e. between 8.7 and 9.7 years out of 30) for Flowerdale (Fig. 5a) and between 26% and 31% (i.e. between 7.8 and 8.5 years out of 30) for Ringarooma (Fig. 5b).

Figure 5. Frequency (number of years out of 30) of long spring seasons at Flowerdale (a) and Ringarooma (b) for six general circulation models for the periods of years 1971 to 2000 ■, 2001 to 2030 ■, 2031 to 2060 ■ and 2061 to 2090 □ .



Conclusion

This study has indicated that it is likely that the mean frequency of early autumn breaks, as defined within this study, for both regions of Flowerdale and Ringarooma would increase into the future. There is also a corresponding likelihood that the mean frequency of late autumn breaks will decline in the future for the two regions. Increases in PGR above the historical average PGR for the months of March and April could lead to farmers considering autumn only or split calving (i.e. autumn and spring) in these environments. This study also concluded that while the mean frequency of long springs, as defined in this study, was unlikely to change dramatically in the future, the mean frequency of short springs was predicted to decline substantially in the future. This predicted increase in early spring season growth was mostly likely a result of warmer temperatures, higher levels of atmospheric CO_2 and minimal changes in precipitation, leading to more consistent PGR for the spring period. An increased frequency of an early autumn break and a more consistent spring pasture growth may promote management changes, such as earlier calving times or increased stocking rates, to take advantage of any increase in the length of the pasture growing season.

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This study was supported by funding from Dairy Australia, Tasmanian Institute of Agriculture and the Australian Government Department of Agriculture, Fisheries and Forestry under its Australia's Farming Future Climate Change Research Program.

8.8 Frequency of wet and dry soil conditions in Tasmanian beef and sheep regions under future climate scenarios

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Introduction

Climate is an important driver of pasture production and the intra-annual variability in climate results in different patterns of pasture production which needs to be managed to meet feed demands on extensive livestock farm systems (beef and sheep farms). In recent decades, south eastern Australia has experienced a decline in total annual rainfall (Australian Bureau of Meteorology 2008), with the most substantial reduction occurring in autumn (Gallant *et al.* 2007). General Circulation Models (GCMs) provide the best estimates for assessing potential changes to the climate on a global scale however projections of climate change are not evenly distributed over the globe. This necessitates that local or regional climate projections are required to quantify local or regional climate impacts (Corney *et al* 2010). The Climate Futures for Tasmania (CFT) project generated climate projections specific to Tasmania through a dynamical downscaling approach (Grose *et al.* 2010). This downscaling approach increased the spatial resolution from 2° to 3° grid cells (~200 to 300km) in the GCMs down to a 0.1° grid (~10km) for Tasmania, thus capturing regional and sub-regional differences allowing the projected climate change impacts to be quantified on a local scale (Corney *et al* 2010).

Extended periods of both wet and dry soil conditions can strongly influence the managerial operations and productivity of a pasture based farming system. For example, extended periods of wet soil moisture conditions can result in significant pugging damage to pasture, erode the benefits of rotational grazing, reduce pasture growth, increase lameness and the incidence of footrot and foot abscess and other health challenges, add feed costs and incur remedial pasture management costs. Extended dry soil conditions can lower pasture production, live weight gain and wool quality, reduce pasture persistence, ground cover and increase erosion and weed ingress risk and require either reduced herd or flock size or increased reliance on purchased feed to meet animal dietary requirements. This study examined the changes in the frequency of wet and dry days per annum for two extensive agricultural regions of Tasmania out to the year 2090 using climate projection data from the CFT project.

Methods

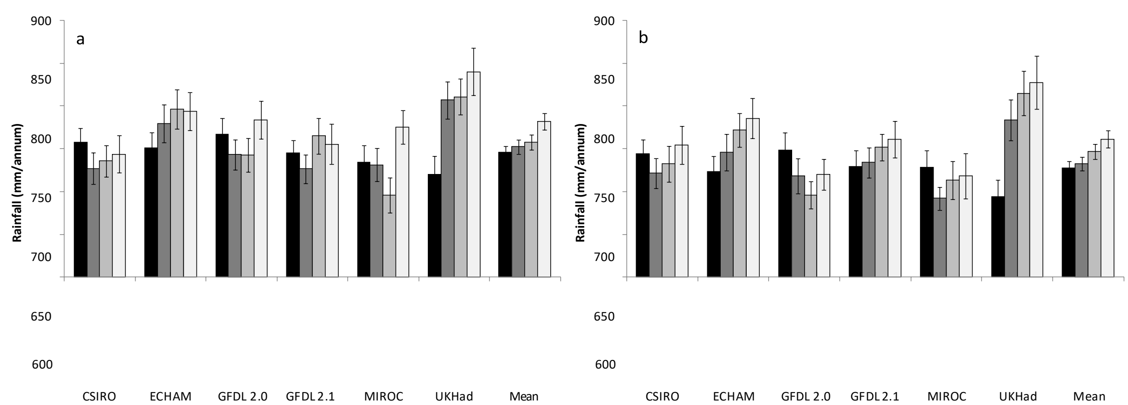
Daily climate data developed from the CFT project (https://dl.tpac.org.au/) was accessed for Cressy (41.7°S, 147.1°E) and Ouse (42.5°S, 146.7°E). For both regions, six down-scaled A2 emissions scenario GCM files (CSIRO-Mk3.5, UKHad, ECHAM5, GFDL 2.0, GFDL 2.1 and MIROC3.2) were used, in combination with the Sustainable Grazing Systems (SGS) biophysical simulation tool (Johnson *et al.* 2003), to simulate a rain-fed perennial ryegrass pasture sward using a generic clay loam soil. The simulated soil moisture content to depth of 400mm was used as the criteria for determining number of wet (soil moisture > 160mm) and dry (soil moisture <120mm) days per annum. The number of wet days represents when the soil is above field capacity and the number of dry days represents the point where water in the soil profile is no longer readily available to the pasture sward, and evapotranspiration falls below its potential rate. The mean number of dry and wet days for each region, averaged across the six GCMs, was computed for the baseline period of years 1971 to 2000 and three future climate periods of years 2001 to 2030, 2031 to 2060 and 2061 to 2090.

Results

Annual rainfall

At Cressy, the mean annual rainfall, as an average of the six GCMs, was predicted to be 726 mm/annum during the baseline period and increase by 3.6, 4.3 and 7.7% during the periods of years 2001 to 2030, 2031 to 2060 and 2061 to 2090, respectively, when compared to the baseline period of years (Fig. 1a). At Ouse, the mean annual rainfall, as an average of the six GCMs, was predicted to be 728 mm/annum during the baseline period and increase by 0.5, 2.6 and 4.5% during the periods of years 2001 to 2030, 2031 to 2060 and 2061 to 2090, respectively, when compared to the baseline period (Fig. 1b). Most of the increase in annual rainfall occurred during summer and to a lesser extent in autumn, for both regions (data not shown).

Figure 1. Mean annual rainfall for Cressy (a) and Ouse (b) for the climatic periods of years 1971 to 2000 ■, 2001 to 2030 □, 2031 to 2060 ■ and 2061 to 2090 □ according to six general circulation models (vertical bars indicate the standard error of the mean).



Wet days

The mean number of wet days per annum at Cressy, averaged over the six GCMs, was predicted to decline by 3.0, 3.7 and 2.8 days for the period of years 2001 to 2030, 2031 to 2060 and 2061 to 2090, respectively, when compared to the baseline period (Table 1). At Ouse, the mean number of wet days per annum, averaged over the six GCMs, was predicted to decline by 4.4 and 1.5 days for the period of years 2001 to 2030 and 2031 to 2060, respectively, when compared to the baseline period, before increasing by 0.1 days for the period of years 2061 to 2090 (Table 1). Each GCM predicted varying changes in the number of wet days per annum for three future climate periods. During the period of years 2001 to 2030, four of the six GCMs predicted a reduction in the number of wet days per annum compared to the baseline period for both locations (Table 1). The only exceptions were a predicted increase in the number of wet days per annum with the ECHAM5 and UKHad models at Cressy and with the GFDL2.1 and UKHad models at Ouse (Table 1).

Table 1. Mean number of wet days (soil moisture > 160mm) per annum for Cressy and Ouse using six general circulation models for a baseline period (years 1971 to 2000) and change in the mean number of wet days per annum for three future climate periods (years 2001 to 2030, 2031 to 2060 and 2061 to 2090) compared to the baseline period.

Region	General circulation model	1971 to 2000	2001 to 2030	2031 to 2060	2061 to 2090
Cressy	CSIRO-Mk3.5	64.3	-11.3	-11.0	-15.9
	ECHAM5	60.9	+3.3	+3.6	+2.3
	GFDL 2.0	66.1	-5.9	-6.1	-3.4
	GFDL 2.1	63.7	-8.9	+1.9	-9.1
	MIROC3.2	63.1	-5.9	-12.1	+5.0
	UKHad	62.5	+10.5	+1.4	+4.0
	Mean	63.4	-3.0	-3.7	-2.8
Ouse	CSIRO-Mk3.5	53.1	-12.0	-4.1	-8.9
	ECHAM5	49.8	-0.8	+2.1	+5.6
	GFDL 2.0	57.1	-11.4	-13.9	-15.3
	GFDL 2.1	46.1	+2.1	+5.2	+5.8
	MIROC3.2	51.4	-14.8	-11.9	-6.2
	UKHad	45.2	+10.7	+13.7	+19.5
	Mean	50.5	-4.4	-1.5	+0.1

Dry days

At Cressy, the mean number of dry days per annum, averaged over the six GCMs, was predicted to increase by 0.4 and 3.9 days for the period of years 2001 to 2030 and 2031 to 2060, respectively, before declining by 0.2 days for the period of years 2061 to 2090 when compared to the baseline period (Table 2). At Ouse, the mean number of dry days per annum, averaged over the six GCMs, was predicted to increase by 1.2 days during the period of years 2001 to 2030 before declining by 3.4 and 4.5 days during the period of years 2031 to 2060 and 2061 to 2090, respectively, when compared to the baseline period (Table 2). This decline in the mean number of dry days per annum at Ouse was mainly as a consequence of the GFDL2.1 and UKHad models predicting that the number of dry days would decline by between 14 and 27 days during the latter two periods when compared to the baseline period (Table 2).

Table 2. Mean annual number of dry days (soil moisture < 120mm) per annum for Cressy and Ouse using six general circulation models for a baseline period (years 1971 to 2000) and change in the number of dry days per annum for three future climate periods (years 2001 to 2030, 2031 to 2060 and 2061 to 2090) compared to the baseline period.

Region	General circulation model	1971 to 2000	2001 to 2030	2031 to 2060	2061 to 2090
Cressy	CSIRO-Mk3.5	204.3	+5.0	+18.9	+21.8
	ECHAM5	207.1	-10.5	-1.3	-9.7
	GFDL 2.0	204.5	+5.8	+6.3	+6.8
	GFDL 2.1	210.6	+9.2	-6.9	-3.4
	MIROC3.2	208.3	+6.3	+11.3	-9.2
	UKHad	214.6	-13.1	-4.6	-7.9
	Mean	208.2	+0.4	+3.9	-0.2
Ouse	CSIRO-Mk3.5	198.5	+8.6	+9.3	+10.8
	ECHAM5	201.0	+2.9	+0.2	-5.1
	GFDL 2.0	204.7	+2.3	+3.5	+4.8
	GFDL 2.1	208.6	-0.9	-13.5	-14.8
	MIROC3.2	204.2	+15.5	+7.2	+2.8
	UKHad	219.2	-21.3	-27.4	-25.3
	Mean	206.0	+1.2	-3.4	-4.5

Discussion and conclusions

This study concluded that while there was substantial variation between GCMs, there is an indication that the mean number of wet days per annum at Cressy for all three future climate periods will decline. In contrast, the mean number of wet days was predicted to remain relatively similar at Ouse for the two latter periods of years (years 2031 to 2060 and 2061 to 2090) when compared to the baseline period. Managing extended wet periods could increase the need for improvements to on-farm drainage, the provision of feed pads, for sacrifice areas, for more consideration of topography and livestock class in the grazing/feed plan, flexible approaches to managing stock density aligned to triggers for action, and possibly consideration of pasture species more tolerant to water logging.

There was also substantial variation between GCMs in terms of the number of dry days per annum for both regions under the future climate scenarios. The mean number of dry days was predicted to increase at Cressy during the period of years 2031 to 2060. Interestingly the increase in rainfall during summer and autumn did not necessarily result in a reduction in the mean number of dry days per annum at Cressy, highlighting the importance of undertaking a biological assessment of future climate impacts through biophysical modelling and not relying exclusively on meteorological data. In contrast, the mean number of dry days was predicted to decline at Ouse, predominantly as a consequence of two of the six GCMs predicting a substantial decline in the number of dry days per annum and thus diluting the influence of the four other GCMs that predicted an increase in the mean number of dry days per annum. Managing extended dry periods could include the adoption of better adapted and deeper rooted pasture species into the feedbase, making provision for confinement feeding or the implementation of irrigation, especially given the relatively low mean annual rainfall for both regions.

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8.9 Timing of autumn breaks and lengths of springs in Tasmanian beef and sheep regions under future climate scenarios

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Introduction

Climate is an important driver of pasture production and the intra-annual variability in climate results in different patterns of pasture production which needs to be managed to meet feed demands on beef and sheep farms. In recent decades, south eastern Australia has experienced a decline in total annual rainfall (Australian Bureau of Meteorology 2008), with the most substantial reduction occurring in autumn (Gallant *et al.* 2007). General Circulation Models (GCMs) provide the best estimates for assessing potential changes to the climate on a global scale however projections of climate change are not evenly distributed over the globe. This necessitates that local or regional climate projections are required to quantify local or regional climate impacts (Corney *et al* 2010). The Climate Futures for Tasmania (CFT) project generated climate projections specific to Tasmania through a dynamical downscaling approach (Grose *et al.* 2010). This downscaling approach increased the spatial resolution from 2° to 3° grid cells (~200 to 300km) in the GCMs down to a 0.1° grid (~10km) for Tasmania, thus capturing regional and sub-regional differences allowing the projected climate change impacts to be quantified on a local scale (Corney *et al* 2010).

The timing of the autumn break is most strongly influenced by precipitation, and its occurrence strongly influences feed availability for autumn calving/lambing or the accumulation of a feed wedge for late winter/ early spring calving/lambing. The ability to meet increased nutritional demands associated with an autumn joining is also strongly influenced by feed availably during the autumn period. The duration of springs may be short or long, depending on soil moisture availability and the onset of warmer temperatures. The length of the spring season influences both the quality and quantity of available feed, livestock production potential, and the demand for either conservation or purchase feeds. This study examined the changes in frequency of late and early autumn breaks and frequency of long and short spring seasons for two extensive agricultural regions of Tasmania out to the year 2090 using climate projection data from the CFT project.

Methods

Daily climate data developed from the CFT project (https://dl.tpac.org.au/) was accessed for Cressy (41.7°S, 147.1°E) and Ouse (42.5°S, 146.7°E). For both regions, six down-scaled A2 emissions scenario GCM files (CSIRO-Mk3.5, UKHad, ECHAM5, GFDL 2.0, GFDL 2.1 and MIROC3.2) were used, in combination with the Sustainable Grazing Systems (SGS) biophysical simulation tool (Johnson *et al.* 2003), to simulate a monthly cut study for a rain-fed perennial ryegrass pasture sward using a generic clay loam soil. Monthly pasture growth rates (PGR; kg dry matter/ha.day) were simulated using climate data from a baseline period (years 1971 to 2000) and three future climate periods (years 2001 to 2030, 2031 to 2060 and 2061 to 2090). The frequency of late and early autumn breaks and frequency of long and short spring seasons were defined in terms of monthly PGRs following a similar method as described by Chapman *et al.* (2008):

- Early autumn break: PGR in both March and April > baseline period average for March and April
- Late autumn break: PGR in both April and May < baseline period average for April and May
- Short spring season: PRG in both October and November < baseline period average for October and November
- Long spring season: PRG in both November and December > baseline period average for November and December

Results

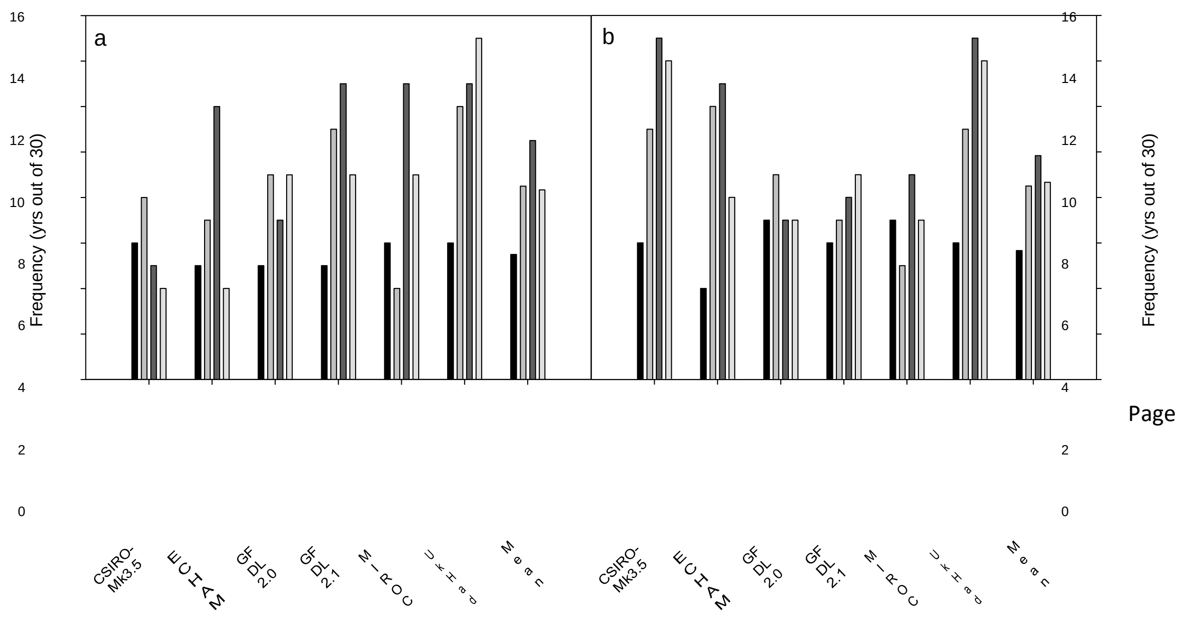
There was generally good agreement (less than 10kg DM/ha.day difference except in November at Cressy and in November and December at Ouse) between the six GCMs for simulating mean monthly PRGs for the baseline period (data not shown). The mean daily temperature, as a average of the six GCMs, was predicted to increase by 0.5, 1.3 and 2.3°C at Cressy and by 0.5, 1.2 and 2.2°C at Ouse in the period of years 2001 to 2030, 2031 to 2060 and 2061 to 2090, respectively, when compared to the baseline period of years. Annual rainfall changes, relative to the baseline rainfall, for Cressy and Ouse were +3.6, +4.3 and +7.7% and +0.5, +2.6 and +4.5% in the period of years 2001 to 2030, 2031 to 2060 and 2061 to 2090 periods, respectively.

Autumn breaks

The frequency of early autumn breaks, as a mean of the six GCMs, was predicted to increase from 18% (i.e. 5.5 years out of 30) in the baseline period of years to 28% by years 2061 to 2090 (Fig. 1a) at Cressy. The frequency of early autumn breaks, as a mean of the six GCM, was predicted to increase from 19% (i.e. 5.7 years out of 30) in the baseline period of years to 29% by years 2061 to 2090 (Fig. 1b) at Ouse.

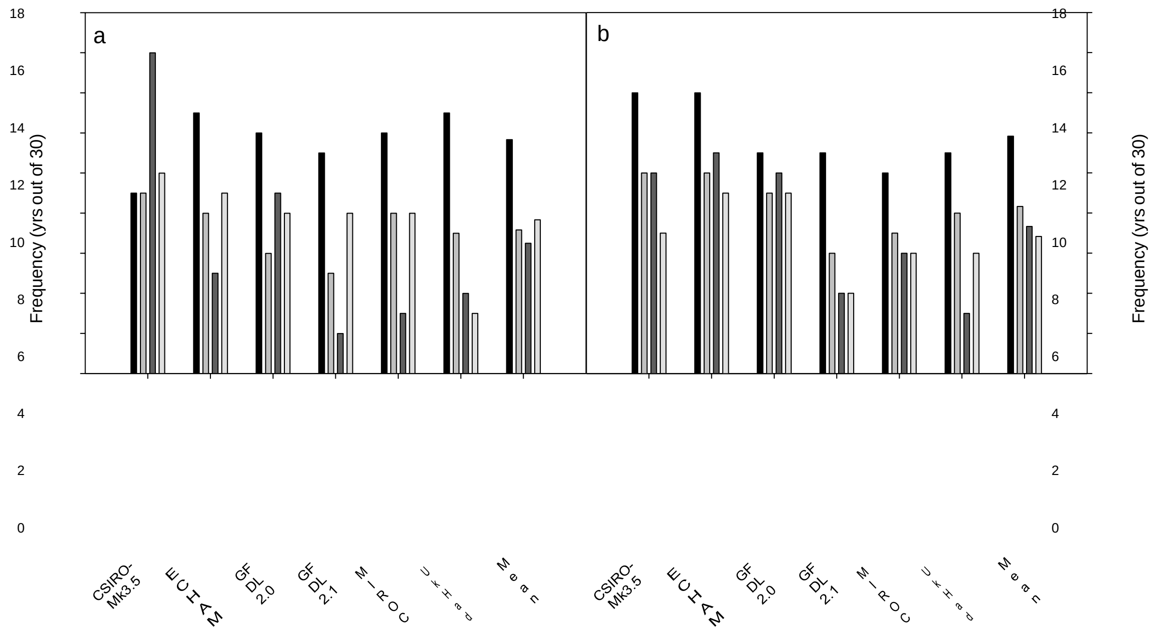
Figure 1. Frequency (number of years out of 30) of early autumn breaks at Cressy (a) and Ouse (b) six general circulation models for the periods of years 1971 to 2000 ■, 2001 to 2030 □ 2031 to 2060 ■ and 2061 to 2090 □.

for six general circulation models for the periods of years 1971 to 2000 ( ), 2001 to 2030 ( ), 2031 to 2060 ( ) and 2061 to 2090 ( ).



The frequency of late autumn breaks, as a mean of the six GCMs, was predicted to decline from 39% (i.e. 11.7 years out of 30) in the baseline period of years to 26% by years 2061 to 2090 (Fig. 2a) at Cressy. The frequency of late autumn breaks, as a mean of the six GCMs, was predicted to decline from 39% (i.e. 11.8 years out of 30) in the baseline period of years to 23% by years 2061 to 2090 (Fig. 2b) at Ouse.

Figure 2. Frequency (number of years out of 30) of late autumn breaks at Cressy (a) and Ouse (b) for six general circulation models for the periods of years 1971 to 2000 ■, 2001 to 2030 ▢ 2031 to 2060 ■ and 2061 to 2090 ▢.

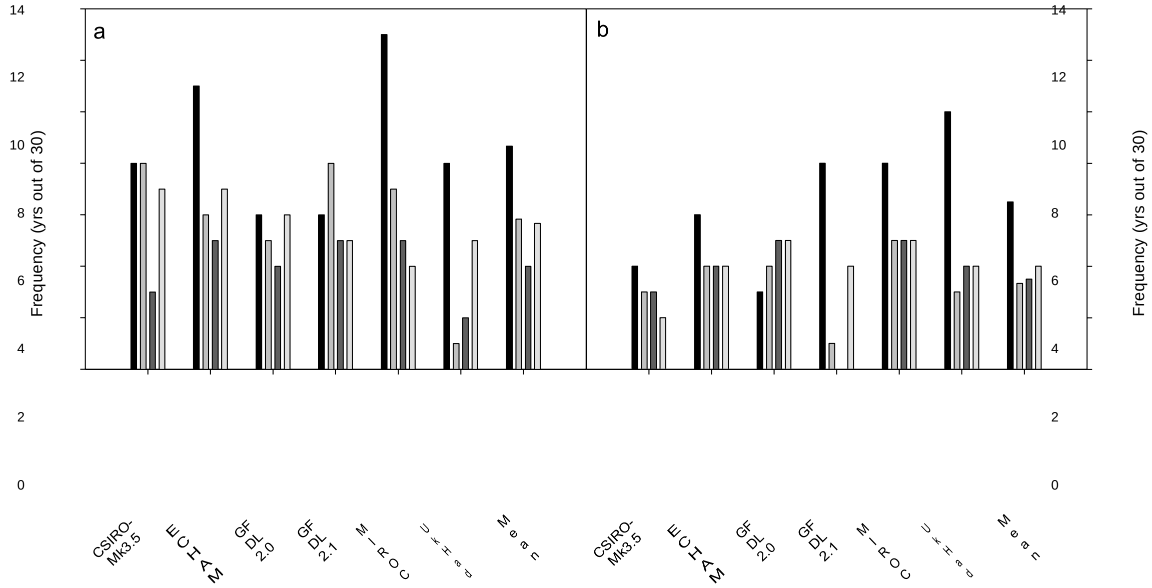


Spring seasons

The frequency of short springs, as a mean of the GCMs, was predicted to decline from 29% (i.e. 8.7 years out of 30) in the baseline period of years to 19% by years 2061 to 2090 (Fig. 3a) at Cressy. The frequency of short springs, as a mean of the six GCMs, was predicted to decline from 22% (i.e. 6.5 years out of 30) during the baseline period of years to 13% by years 2061 to 2090 (Fig. 3b) at Ouse.

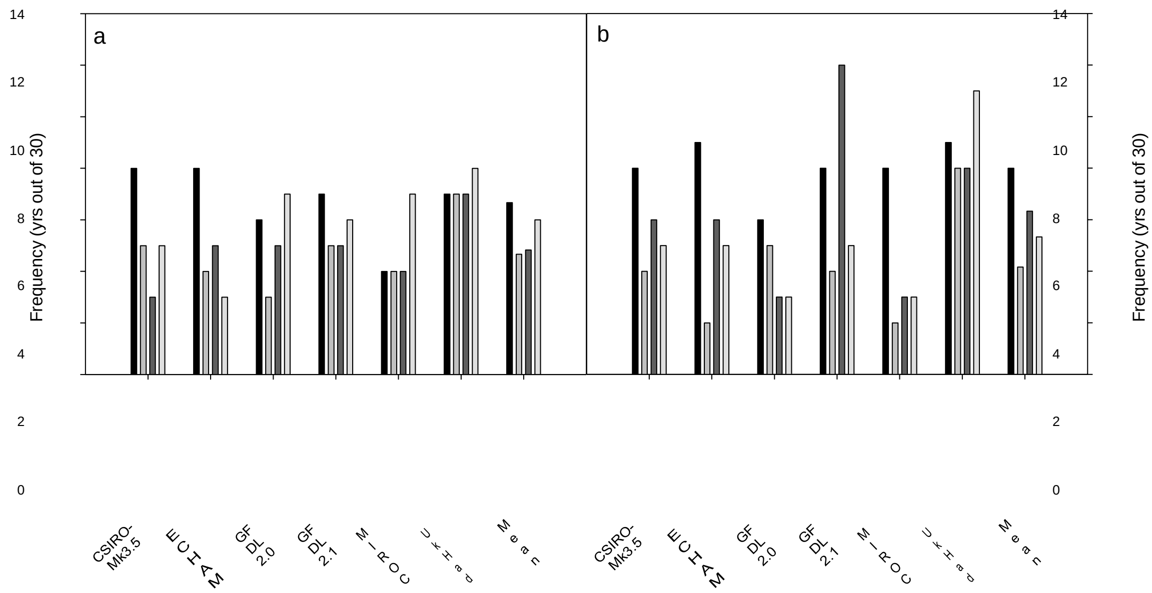
Figure 3. Frequency (number of years out of 30) of short springs at Cressy (a) and Ouse (b) for six general circulation models for the periods of years - 1971 to 2000 ■, 2001 to 2030 ▢, 2031 to 2060; ▢ and 2061 to 2090 ▢

The frequency of long springs, as



a mean of the six GCMs, was predicted to decline from 22% (i.e.6.7 years out of 30) during the baseline period of years to 20% during years 2061 to 2090 (Fig.4a) at Cressy. The frequency of long springs, as a mean of the six GCMs, was predicted to decline from 27% (i.e. 8.0 years out of 30) during the baseline period of years to 18% during years 2061 to 2090 (Fig. 4b) at Ouse.

Figure 4. Frequency (number of years out of 30) of long springs at Cressy (a) and Ouse (b) for six general circulation models for the periods of years 1971 to 2000 ■, 2001 to 2030 ▢, 2031 to 2060 ▢ 2061-2090 ▢



Discussion and conclusions

This study has indicated that the likelihood of the mean frequency of early autumn breaks increased and the mean frequency of late autumn breaks declined, as defined within this study, into the future for both Cressy and Ouse. Increases in PGR above the historical average PGR for the autumn months and reduced autumn variability (early autumn's increase, late autumn's declined) could lead to increased winter feed supply, winter carrying capacity and management confidence. This may increase the capacity for autumn lambing/calving, winter finishing, or leverage increased winter stocking rates and consequent spring pasture harvests in spring calving/lambing enterprises.

This study also concluded that while the frequency of short springs, as defined in this study, was predicted to decline into the future, the frequency of long springs was also predicted to decline into the future. The decline in frequency of short springs was mostly likely a result of warmer temperatures, higher levels of atmospheric carbon dioxide concentrations and minimal changes in precipitation, leading to more consistent PGR for the spring period. However, the decline in the frequency of long spring periods could be as consequence of reduced soil moisture content in late spring/early summer restricting pasture growth. This decline in long springs in these two regions could be offset with deeper rooted pasture species with longer season growth potential, the introduction of irrigation to maximise productivity on beef and sheep enterprises, and the use of management like early weaning strategies or changes in sale target weights to adapt feed demand to changing feed supply. Increased consistency of spring may also assist planning by improving management confidence.

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This study was supported by funding from Dairy Australia, Meat and Livestock Australia, Tasmanian Institute of Agriculture and the Australian Government Department of Agriculture, Fisheries and Forestry under its Australia's Farming Future Climate Change Research Program.

8.10 DGAS: software for modelling and managing greenhouse gas emissions for Australian dairy farms

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The Dairy Greenhouse gas Abatement Strategy (DGAS) software was developed to model the carbon dioxide, methane and nitrous oxide emissions associated with dairying in Australia, using standard national inventory methods, algorithms and emission factors (DCC, 2008). The user interface of the software includes two data entry pages; the farm and the herd. The farm data includes farm size, proportion of area rain-fed and irrigated, location, rainfall, tree plantings, manure management system, electricity, diesel, fertiliser and purchased feed inputs. The herd data includes herd milk production, five livestock classes including animal numbers, live weight and weight gain, and the dietary composition for each livestock class. The diet for the milking herd allows for seasonal variation, whereas the diets of other livestock classes are entered on an annual basis. The results are available as a comparative bar chart showing the 10 contributing sources of GHG emissions in addition to the potential storage of GHG emissions in tree plantings, expressed as t CO_2e/t milksolids. Total farm, broken down into four sub-totals (pre-farm embedded, carbon dioxide, methane and nitrous oxide) is also displayed.

Once the data has been entered for the farm, it can be copied to a hypothetical scenario. The software allows users to compare the hypothesised farm or ‘strategy’, against the existing farm allowing for a range of potential abatement strategies to be explored. Comparative analysis between the existing farm and the hypothesised farm are presented on the results page. Farm economic data can be entered for both the baseline and hypothesised farm. Should dairy GHG emissions be included as a liability or offset as part of a future emission trading scheme, two economics pages are included (existing and hypothetical farms) to assess the effects of an emissions trading scheme on farm income. The software requires very little data storage and as such has been developed using MS Excel. User forms provide a friendly interface while the data storage and modelling activities are stored on worksheets.

DGAS analysis of 60 Tasmanian dairy farms found that on average 56 and 21 percent of total farm GHG emissions came from methane and nitrous oxide, respectively. Pre-farm embedded emissions and fuel and electricity emissions both accounted for 11 percent of total farm emissions. This paper explores potential current GHG abatement options for Tasmanian dairy farm using the functionalities of DGAS.

8.11 A whole farm system analysis of the greenhouse gas emissions of 60 Tasmanian dairy farms

Published in the Proceedings of the 4th Greenhouse Gases and Animal Agriculture Conference, Banff, Canada, October 2010.

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The Australian dairy industry contribute approximately two percent of the nation's greenhouse gas (GHG) emissions with 8.9 million tonnes of carbon dioxide equivalents per annum (t CO_2e; DCC 2008). This study examined the GHG emissions of 60 Tasmanian dairy farms using the Dairy Greenhouse gas Abatement Strategies calculator (DGAS; Christie *et al.* 2010), which incorporates the IPCC and national inventory methodologies, algorithms and emission factors.

Sources of GHG emissions including the pre-farm embedded emissions associated with key farm inputs, such as fertiliser and purchased forages and the on-farm emissions from carbon dioxide, methane and nitrous oxide were determined. The mean total farm GHG emissions was 2,785 t CO_2e, ranging between 704 and 5,339 t CO_2e/farm. Dividing total farm emissions by annual milk production, milking herd size and farm area, the mean GHG emission intensities was 14.5 t CO_2e/t milk solids, 6.9 t CO_2e/cow or 12.6 t CO_2e/ha.

Linear regression analysis showed that 0.93 of the variation in total farm emissions could be explained by milk production (equation 1) while milking herd size (equation 2) and farm area (equation 3) were less indicative.

(1) Total emissions = Milksolids production * 13.54 + 151.83; R^2 = 0.93
(2) Total emissions = Milking herd size * 5.94 + 373.75; R^2 = 0.75
(3) Total emissions = Total farm area * 7.68 + 993.95; R^2 = 0.41

A stepwise multiple linear analysis showed that individual farm GHG emissions intensity could be explained using key farm indicators, expressed either on a per milksolids basis, per cow basis or per hectare basis:

(1) Milksolids intensity (t CO_2e /t milksolids) = 29.156 + (-14.235 * feed conversion efficiency) + (0.005 * kg nitrogen fertiliser/ha); R^2 = 0.60
(2) Cow intensity (t CO_2e /cow) = -0.599 + (1.228 * total dry matter intake) + (0.002 * kg nitrogen fertiliser/ha); R^2 = 0.87
(3) Farm area intensity (t CO_2e /ha) = 1.891 + (0.011 * kg milksolids/ha) + (0.008 * kg nitrogen fertiliser/ha); R^2 = 0.94

This study has shown that total GHG emissions of Tasmanian dairy farms can be accurately and most easily estimated by the farms total milk production. Feed conversion efficiency and nitrogen fertiliser inputs were able to explain 0.6 of the variation in the GHG emissions intensity of milk production for these pasture based dairy systems. This highlights these two factors as target areas for lowering the intensity of emissions associated with dairying in this environment.

8.12 A whole farm system analysis of the greenhouse gas emissions of 60 Tasmanian dairy farms

K.M. Christie, R.P. Rawnsley, R.J. Eckard, A whole farm systems analysis of greenhouse gas emissions of 60 Tasmanian dairy farms, Animal Feed Science and Technology, Volumes 166–167, 2011, pp. 653-662.
https://doi.org/10.1016/j.anifeedsci.2011.04.046

8.13 Whole farm systems analysis of the greenhouse gas emissions of Australian dairy farms

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The Australian dairy industry contributes approximately 1.6% of the nation's greenhouse gas (GHG) emissions, emitting an estimated 8.9 million tonnes of carbon dioxide equivalents (t CO_2e) per annum (DCC, 2008). This study examined GHG emissions of 41 dairy farms from throughout eight dairying regions of Australia, using the Dairy Greenhouse gas Abatement Strategies calculator, which incorporates International Panel on Climate Change and Australian inventory methodologies, algorithms and emission factors. The sources of GHG emissions were the CO_2 emissions associated with the pre-farm embedded emissions of key farm inputs and on-farm emissions from CO_2, methane and nitrous oxide. The mean total farm GHG emission was 2,214 t CO_2e/annum. The estimated milk GHG emission intensity was 1.07 ± 0.21 kg CO_2e/litre of milk (mean ± standard deviation), with a range of between 0.79 and 2.01 kg CO_2e/litre of milk. The estimated mean area GHG emission intensity was 7.6 ± 3.7 t CO_2e/ha, with a range of between 1.4 and 17.7 t CO_2e/ha. Farms were grouped according to the farm system (FS) classification as defined by Dairy Australia. This resulted in 19 FS1, 13 FS2 farms and 9 FS3 farms being assessed. Farm system 1 farms are characterised by being predominantly pasture based with less than 30% purchased supplementary feed, FS2 farms are characterised by being pasture based with high levels (>30%) of purchased supplementary feed and FS3 farms are characterised by being a hybrid between a pasture based system with supplementary feeds (FS1 or FS2) and a total mixed ration feeding system (FS4). The mean emission intensity of milk production was found to be significantly ($P<0.05$) higher for FS1 farms than FS2 and FS3 farms which were not significantly ($P>0.05$) different to each other. There was no significant ($P>0.05$) differences in mean milk GHG emissions intensity between the regions, with the exception of Tasmania, which was significantly ($P<0.05$) higher, at 1.42 kg CO_2e/litre of milk, compared to between 0.98 and 1.07 kg CO_2e/litre of milk. One reason for Tasmania being significantly higher was partially due to one farm having an estimated milk GHG emission intensity that was approximately 50% greater than the next highest farm. While these results indicate that adopting a more intensive farming system resulted in reducing milk GHG emissions intensity, this could potentially diminish our international competitive advantage of producing milk at a lost cost in addition to reducing the resilience of the farming system in a changing climate.

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8.14 Australian dairy farm greenhouse gas emissions

Published in The Australian Dairyfarmer Magazine, November 2011

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Livestock account for around 11 per cent of Australia's greenhouse gas emissions and researchers are working hard to develop practical on-farm options to reduce emissions without compromising farm productivity. Karen Christie, Project Officer from the Tasmanian Institute of Agricultural Research, was tasked with estimating the greenhouse gas (GHG) emissions of the 44 dairy farms to value-add to the Accounting for Nutrients (A4N) on Australian Dairy Farms project.

The A4N project involved collecting detailed data on nutrient imports, exports and within-farm nutrient flows from 44 dairy farms, on a quarterly basis. The study took place between February 2008 and February 2009 and the farms were located in the eight dairying regions of Australia (Fig. 1). These farms represented the diversity of the industry in terms of herd size, farm size, level of milk production per cow, grain and forage feeding, fertiliser usage and reliance on irrigation.

While the A4N project was never intended to be used as a source of farm data for estimating on farm GHG emissions, it was clear that the dataset was an invaluable source of farm data that could be used to examine this. Of the 44 farms, 41 farms had sufficient data to estimate each farms' GHG emissions, using the Dairy Greenhouse gas Abatement Strategies (DGAS) calculator (version 1.3).

DGAS estimates four sources of GHG emissions; carbon dioxide from the consumption of electricity and fuel, methane from enteric fermentation and management of animal waste, nitrous oxide from management of animal waste and nitrogen fertilisers and a pre-farm embedded emission incorporating the carbon dioxide emitted with the production of grains/concentrates, hay, silage and fertilisers that are brought onto the farm.

The average total farm GHG emissions across the 41 farms was estimated to be 2,255 tonnes of carbon dioxide equivalents (t CO_2e), but varied between 411 and 9,416 t CO_2e. To compare farms within and across dairying regions, total farm GHG emissions were divided by annual milk production (milk solids), milking herd size and total farm area (including runoff/outblock areas in addition to milking platform), to calculate a milk GHG emissions intensity (t CO_2e/ t MS), cow GHG emissions intensity (t CO_2e/cow) and area GHG emissions intensity (t CO_2e/ha). Karen found that there was a strong linear relationship between total farm GHG emissions and either milk production (Fig. 2a) or milking herd size (Fig. 2b), but not between total farm GHG emissions and farm size (Fig. 2c).

Overall, the average milk GHG emissions intensity was 14.7 kg CO_2e/kg MS across all regions (Table 1). The average milk GHG emission for Tasmania was significantly ($P<0.05$) higher than all other regions, with the exception of Queensland, at 18.1 kg CO_2e/kg MS. The four Tasmanian dairy farms were predominantly pasture based with zero or very low levels of grain/concentrate feeding per cow and low milk production per cow at an average of 340 kg MS/cow. Previous research has shown that milk production per cow has a strong influence on the GHG emission intensity of milk production and these abovementioned points contributed to the higher mean GHG emissions intensity of milk production for Tasmania compared to all other regions.

The estimated average GHG emissions per cow was 6.3 t CO_2e/cow, with little variation between regions (Table 1), indicating that regional mean GHG emissions per cow were relatively consistent, irrespective of farm location. However, there was still quite some variation between farms within and across regions. The average GHG emissions per hectare was 7.7 t CO_2e/ha (Table 1), with noticeable variation between regions. Tasmania and to a lesser extent, south eastern Victoria, on average, had a higher GHG emissions per hectare than the other regions as a result of these two regions generally possessing a higher stocking rate (cows/ha). Given the consistent GHG emissions per cow, this increased stocking rate resulted in greater GHG emissions per unit of land. The reverse was the case for regions with lower stocking rates (e.g. New South Wales, Queensland and Western Australia).

A stepwise linear regression analysis of key farm variables identified milk production per cow as a key farm variable driver influencing the GHG emissions intensity of milk production. Increasing in milk production per cow resulted in reductions in the GHG emission intensity of milk production (kg CO_2e/kg MS) and GHG emissions per hectare (t CO_2e/ha). Increasing milk production per hectare and increasing the application rate of nitrogen fertilisers (kg N/ha) were key farm variables that increased the GHG emissions per hectare. Identifying and adopting approaches that improve milk production per cow and/or improve nitrogen fertiliser efficiency are key areas to consider for GHG emissions mitigation, although it is very important that these strategies do not result in lowering farm profitability.

It is also important to note that the estimates of GHG emissions are derived by following the International Panel on Climate Change and Australian GHG inventory methodologies. It is currently not practically possible to directly measure the GHG emissions on all farms due to the significant amount of cost and technology required. Although the methodology used to estimate GHG emissions incorporates the most recent of scientific knowledge, there is still a significant amount of research being undertaken to provide a greater level of accuracy to GHG accounting on-farm.

This project was funded by Tasmanian Institute of Agricultural Research (TIAR, Dairy Australia and the Australian Government Department of Agriculture, Fisheries and Forestry through its Australia's Farming Future Climate Change Research Program.

Contact: For more information on the A4N project, contact Dr Cameron Gourley on (03) 5624 2222 or Cameron.Gourley@dpi.vic.gov.au. For more information on this study, contact Karen Christie on (03) 6430 4921 or Karen.Christie@utas.edu.au or to view the DGAS calculator, visit the Dairying for Tomorrow website http://www.dairyingfortomorrow.com.au/index.php?id=47

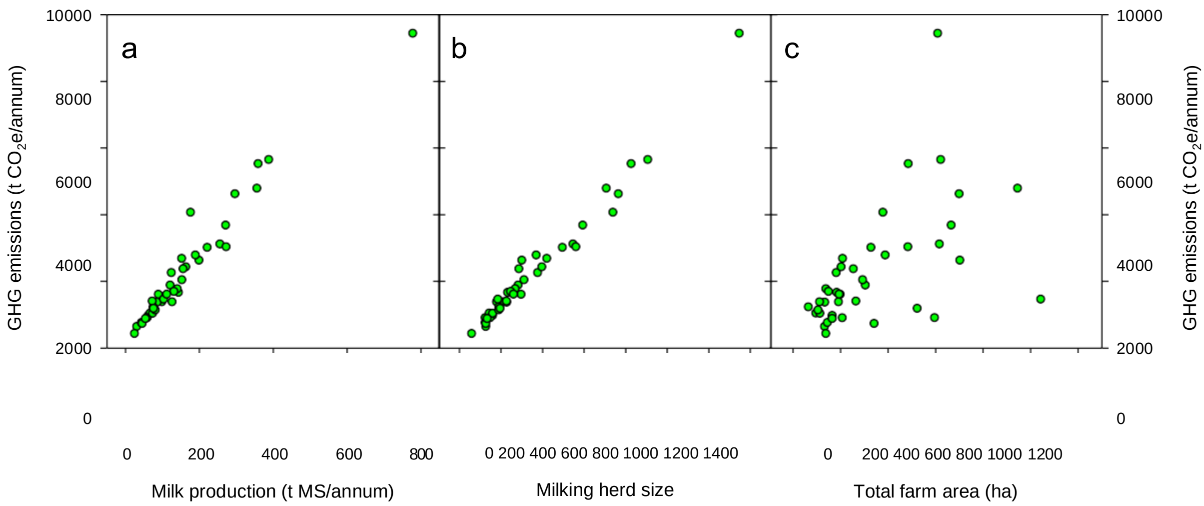
Table 1. Regional means and ranges of milk greenhouse gas emissions intensity (t CO_2e/t MS), cow greenhouse gas emissions intensity (t CO_2e/cow) and farm area greenhouse gas emissions intensity (t CO_2e/ha).

	Milk GHG emissions intensity (t CO_2e/t MS)		Cow GHG emissions intensity (t CO_2e/cow)		Area GHG emissions intensity (t CO_2e/ha)	
	Mean	Range	Mean	Range	Mean	Range
NSW	14.9^{b}	12.0 – 18.7	6.8^{a}	5.3 – 8.6	6.0^{c}	1.4 – 16.2
QLD	15.7^{ab}	13.6 – 19.2	6.2^{a}	4.8 – 7.0	4.8^{c}	1.5 – 7.0
SA	13.8^{b}	12.1 – 15.0	6.8^{a}	5.9 – 7.4	8.2^{abc}	2.2 – 15.4
TAS	18.1^{a}	14.4 – 22.7	6.0^{a}	5.5 – 6.3	11.1^{a}	9.0 – 12.6
Nth VIC	13.2^{b}	12.6 – 13.6	6.4^{a}	5.8 – 6.7	8.8^{abc}	5.0 – 11.0
SE VIC	14.0^{b}	10.6 – 16.4	6.3^{a}	5.8 – 7.5	10.4^{ab}	5.0 – 18.0
SW VIC	13.0^{b}	11.0 – 14.6	5.8^{a}	5.3 – 6.3	6.4^{abc}	4.2 – 8.8
WA	14.5^{b}	13.1 – 15.4	6.1^{a}	5.5 – 6.4	5.2^{c}	2.1 – 6.8
Overall	14.7	10.6 – 22.7	6.3	4.8 – 8.6	7.9	1.4 – 18.0

Superscript letters which differ indicate a significant ($P<0.05$) difference in greenhouse gas emissions intensity

Figure 1. Location of the 44 farms involved in the Accounting for Nutrients project.

Figure 2. Linear relationship between total farm greenhouse gas emissions (t CO_2e/annum) and milk production (a; t MS/annum), milking herd size (b) and farm area (c; ha).



8.15 Whole farm systems analysis of Australian dairy farms greenhouse gas emissions

Christie K. M., Gourley C. J. P., Rawnsley R. P., Eckard R. J., Awty I. M. (2012) Whole-farm systems analysis of Australian dairy farm greenhouse gas emissions. *Animal Production Science* **52**, 998-1011. https://doi.org/10.1071/AN12061

8.16 Improvements/ alterations to the Dairy Greenhouse gas Abatement Strategies (DGAS) calculator

There have been many improvements and changes made to the DGAS calculator since the release of version 1.2 in 2009. These changes/improvements have been undertaken during the duration of this project and are listed below (in no particular order):

1. Inclusion of the current version and date of release in the top right corner of the introduction page.
2. Changes to manure CH_4 emissions due to changes to the manure methane conversion factor (MCF) for milking and non-milking dairy cattle. These changes will affect all farms and locations and therefore the overall results for all farm systems. Users can either define the actual farm management practices for the farm being assessed (preferred method) or use the previous MMS1- Pasture-based system factors (less preferred method). We introduced this option of User estimated as it more accurately reflects how manure is handled on individual farms, as opposed to the previous default state-based averages. The User can now define the amount of time spent in the dairy and on feedpad and/or loafing areas where manure is deposited and then handled. This data is used to estimate the MCF for the milking herd and for all other stock classes in addition to estimating the amount of waste handled by up to five different manure management systems (i.e daily spread, lagoon, dry lot, solids storage and voided onto pastures during grazing). We suggest users refer to the section titled manure management in this manual (page 18) when familiarising themselves with this updated version as they need to access two new data entry pages for the milking herd and other stock classes and implement the copying of the baseline data to the strategy farm via a different mechanism than for copying all other data from the baseline farm to the strategy farm.
3. Changes to indirect N_2O emissions for fertilisers and animal wastes. After discussions with Dr Richard Eckard (methodology expert), it was clear that the risk of leaching/runoff of N fertilisers applied to dryland pastures/crops and animal waste was too low for some regions, especially NSW, QLD, SA and WA. Increases will also occur for VIC and TAS but to a lesser extent as these states already had high emission factors for this source of indirect N_2O emissions. Therefore for all farms and all locations, the indirect N_2O emission will increase due to the changes in DGAS version 1.3. Therefore we suggest when reporting any results, that it is made clear that the version of DGAS used to estimate GHG emissions is version 1.3.
4. Change in the equation to calculate enteric CH_4 for non- milking herd stock classes, resulting in a slight reduction in enteric CH_4 for non-milking stock.
5. Incorrect emission factor for phosphorus-based fertilisers fixed. This will increase the pre-farm fertiliser GHG emissions for farms with phosphorus fertiliser applications.
6. Fixed the radio button option for fertiliser application rates so that the user can use kg/ha for the baseline farm and tonnes/annum for the strategy farm. Previously you needed to use one or the other for baseline and strategy farm.

7. In the Fats and Oils strategy help message- reduced the percentage of reduction in CH_4 from 5.6 to 3.5% for every 1% increase in dietary fat fed in the diet. Fats and oils can now only be fed during summer and autumn as the fat content of pastures are generally high in winter and spring, thus restricting the potential of this as an option during winter and spring.
8. Altered when condensed tannins is a viable abatement strategy to now only be winter and/or spring as opposed to year-round as in previous versions of DGAS. This has due to this strategy only being suitable when diets contain excess crude protein. Implementing the condensed tannin strategy in winter and/or spring will reduce CH_4 emissions by 10% in the activated seasons. Activating this strategy will also reduce the CP content of the diet to 18%, thus replicating the process by which tannins bind excess protein in the diet from being excreted as urine N. If however, the diet is already < 18%, there will be no change to the diet and therefore N2O emissions as in reality, feeding a diet with < 18% CP in addition to feeding a source of condensed tannin could result in a CP deficit.
9. Added a new nitrification inhibitor strategy for spraying the inhibitor onto pastures directly after grazing, with a default 40% seasonal reduction in urine, dung and manure N for direct and indirect leached N_2O emissions. Differences in the % reduction in N2O emissions between the direct and indirect animal waste are due to different emission factors applied to these two sources.
10. Users define the percentage of annual fertiliser that is coated with a nitrification inhibitor and effective in reducing N_2O emissions.
11. Separated indirect N_2O emissions from N fertilisers and indirect N_2O emissions from animal waste. Also added this to the Ad-hoc calculator so can assess the impact of a reduction on these two sources independently.
12. Included the sheets and cells linked to the abatement strategies at the base of the backdrop sheet for any future reference.
13. Greater information in this manual and in the help messages in DGAS regarding abatement strategies and the things to be considered when adopting the strategies. For example, when feeding dietary fats, has the user considered any changes to diet quality and/or milk production and made manual changes to DGAS to reflect these impacts?
14. As each form is opened by progressing through DGAS, the forms remain maximised to the size of the user's monitor.
15. Additional help messages for farm area and electricity and fuel consumption, with unleaded petrol to be included with diesel consumption.
16. Coding to check that the daily diet intake is within an expected range of the estimated intake required to achieve the annual milk production and/or the live weight and live weight gain for the replacements. Users have the option to either accept that their data entry is correct or can re-check and change data entry if an error has been made.
17. Coding to check that diet intakes are filled out for all four seasons for the milking herd. Also if stock numbers for replacements and/or bulls are entered, that the diet intakes are also filled out, otherwise incorrect estimations can occur if no annual digestibility and crude

protein figures are determined. A message will appear when progressing to the results page indicating which areas need filling in.

18. Altered the layout of the results page by moving the bar chart to the bottom of the page, altering the chart to be a column graph, colour coded the column and pie charts so that all sub-sources are the same colour (i.e. all four N_2O emissions are blue, CH_4 are yellow), the baseline farm results is a solid column and the strategy results is a faded/ hashed column, re- worded some of the source headings to be more reflective of the source.
19. Removed the Save Results button from the results page – removed due to complications with saving formulas and formatting between workbooks. We recommend that the User can either print the results and/or save a new copy of DGAS using the 'SAVE DGAS AS' option.
20. Altered the ETS liability to now read CH_4 & N_2O only figure to the table of results for the Baseline and Strategy farm. This is due to the changes to the government policy in regards to the Australian emissions trading scheme since the last DGAS release.
21. Added a button to hide/unhide the Ad-hoc calculator when not in use.
22. Altered the economics page to reflect the more recent policy changes regarding agriculture, emissions trading and carbon credits. Farmers may now have the opportunity to gain carbon credits for management practices that meet the rigorous requirements under the Carbon Farming Initiative (CFI). It is not clear if the abatement strategies currently available in DGAS will meet the requirements of the CFI in terms of additionality, permanence, avoidance of leakage, measureable and verifiable, scientifically sound and meets international consistency. The economics calculations also do not take into consideration the additional costs in terms of time required to meet the requirements needed on-farm to meet methodology requirements. Therefore the economics page should still be used with a high degree of caution when reporting to farmers the economic benefits of adopting abatement strategies, especially in light of carbon policies.
23. General tidying up of headings, data entry, greater explanation for some of the help messages etc.
24. Data entry sheet included as an appendix in manual to use when collecting data from farmers.