Final report

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

Project code: B.SFP.0072

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Abstract

Modelling activities were undertaken to investigate a range of key questions on climate change impacts, mitigation, and adaptation measures for the southern Australian grazing industries as part of the Southern Livestock Adaptation 2030 (SLA 2030) program. Numerous simulations were conducted, resulting in over 15 peer reviewed papers, one book chapter and 15 conference papers.

The Carbon Offset Scenarios Tool (COST) was developed to explore the viability of a range of mitigation options that could be included as Carbon Farming Initiative (CFI) offsets. A comparison of whole farm greenhouse gas emissions from different farm types in south eastern Australia showed dairy farms producing the highest emissions per hectare, followed by beef, sheep and grains. Whole system mitigation modelling showed that the emissions intensity per unit product can be minimised simply by maintaining a productive pasture base.

Executive summary

Background

This project (sub-project B.SBP.0072 under B.SBP.0080) of the Southern Livestock Adaptation 2030 (SLA 2030) program conducted and coordinated modelling activities to address a range of key industry questions on climate change impacts, adaptation and mitigation for the southern Australian grazing industries, as approved by the SLA 2030 Steering Committee.

Objectives

- To develop biophysical modelling simulations that address the key regional questions of climate change impacts (short and long-term) on current grazing systems in a future environment, adaptation options and new farming systems.
- Further development of a distributed climate impacts and mitigation modelling capability in the Australian grazing industries.
- 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 project used dedicated modellers to conduct, coordinate and publish a series of modelling studies on climate change impacts, adaptation and mitigation strategies for the southern Australian grazing industries. The project used dedicated modellers to conduct, coordinate and publish a series of modelling studies on climate change impacts, adaptation and mitigation strategies for the southern Australian grazing industries.

Results/key findings

All objectives were achieved in this project. Numerous simulations were conducted, resulting in over 15 peer reviewed papers, one book chapter and 15 conference papers from the team. The project team also developed the Carbon Offset Scenarios Tool (COST) to explore the viability of a range of mitigation options that could be included as Carbon Farming Initiative (CFI) offsets. A comparison of whole farm GHG emissions from different farm types in south eastern Australia showed dairy farms producing the highest emissions/ha, followed by beef, sheep and grains. Whole system mitigation modelling showed that the emissions intensity per unit product can be minimised simply by maintaining a productive pasture base.

Benefits to industry

Significant additional modelling capability and capacity was developed. The DairyMod and SGS models were expanded with a more sophisticated animal model, improved soil organic carbon modules, and the explicit treatment of urine patch dynamics. These have all enhanced the models capacity to predict methane, nitrous oxide, soil carbon and the interactions between these. The project team provided training to over 50 scientists, consultants and extension officers, and six postgraduate students, representing a significant capability boost for industry.

Future research and recommendations

While methane emissions will mainly change with livestock numbers, nitrous oxide emissions may increase with warmer climatic conditions in the medium-high rainfall zone of southern Australia, particularly in less free draining soils. This emphasises that mitigation modelling must include consideration of adaptation and vice versa.

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1. Background

Climate change will impact on the Australian grazing industries both through policies to mitigate greenhouse gas emissions, and the physical impact of warmer temperatures, increased atmospheric carbon dioxide equivalents (CO_2e) concentrations and changed rainfall patterns on pasture and animal production. For producers to make informed decisions about mitigation and adaptation options, industry and region specific information is required, as the outcomes will be determined by multiple and complex interactions between climatic change and farm systems management. Biophysical models are the only means that we currently have available to predict and understand these interactions and provide simulations of likely future outcomes at a regional scale. Using a modelling approach can also take into account uncertainties and risk in the climate change projections.

This project was carried out in collaboration with other teams from the Southern Livestock Adaptation 2030 program, addressing key questions as prioritised by the program steering committee.

2. Objectives

2.1 Project Objectives (as per Contract)

Objective	Status at Project End
To develop biophysical modelling simulations that address the key regional questions of climate change impacts (short and long-term) on current grazing systems in a future environment, adaptation options and new farming systems.	Numerous simulations were conducted and are detailed in 15 peer reviewed papers, one book chapter and 15 conference papers. The SGS and DairyMod tools have been developed to consider all GHG emission sources and sinks and interactions in grazing systems.
Further development of a distributed climate impacts and mitigation modelling capability in the Australian grazing industries.	The project team has developed the capability to model the balance between productivity and greenhouse gas (GHG) emissions from dairy, beef and sheep grazing systems, including the impacts of climate change and variability. The project team have also provided training to over 50 scientists, consultants and extension officers, plus six postgraduate students.
A better informed industry and producer population of the opportunities and risks associated with climate change through the publication and communication of research results.	The team published nine refereed papers, five conference papers and ten conference abstracts during the project. There are a further six journal papers in the peer review process and one book chapter. Results from the project have been published in Australian Dairy Farmer and communicated at field days, seminars, industry conferences and science conference (see Communication activities).

2.2 Project Activities

Activity	Contracted requirement	Status at Project End
1. Regions modelled	**NA**	
2. Locations modelled	**NA**	**Victoria**: Hamilton, Ellinbank, Terang, Dookie, Vasey, Kyabram **Tasmania**: Elliott, Bothwell, Cressy **New South Wales**: Wagga Wagga, Moree, Camden, Bega, Taree **Queensland**: Mutdapilly **Western Australia**: Albany **South Australia**: Roesworthy, Morchard, Milaton, Angaston
3. Enterprises modelled	**NA**	Beef, Sheep, Dairy
4. Producer workshops held	**NA**	
5. Other awareness events held (e.g. seminars)	**NA**	See Communication activities below
6. Producers directly engaged	**NA**	See Communication activities below
7. Communication products produced	Popular articles Prograzier, Feedback or Frontier, Australian Dairy Industry Farmer, Grassland Society Conference, newsletters or similar.	15 peer reviewed papers, 1 book chapter and 15 conference papers from the team. Project web site plus fact sheets. See Communication activities below
8. Producers aware of the key project findings?	**NA**	See Communication activities below
9. **Adaptations modelled**	**NA**	

2.3 Communication activities

The University of Melbourne staff have been involved in presenting project results to farmer audiences. The seminars and number of attendees are detailed below

Field days seminars, conferences

- Climate Change Research Program Demonstration field day, Hamilton, 11th November 2010. Richard Eckard and Brendan Cullen presented. **65 producers attended**.
- Climate Change Research Program Demonstration field day, Terang, 12th May 2011. Richard Eckard and Brendan Cullen presented. ***50 producers attended.***
- Dairy Directions farmer steering group at Ellinbank. Brendan Cullen presented. ***10 attendees made up of researchers and farmers.***
- Grasslands Society of Southern Australia - two posters (and short presentations) were presented in June 2011. ***Attendance over 150 mainly advisers and some farmers.***
- Oral presentations were made by Richard Eckard, Brendan Cullen to science audiences at the CCRSPI conference in February 2011. ***Attendance 326 delegates from State Government (29.8%), Universities (20.1%), RDCs (15.3%), non-university research institutions (12.3%), farmers (5.5%).***

Popular Press Articles

- Pasture growth to lift under climate change. Publication by Brendan Cullen in the Australian Dairy Farmer magazine, November 2011.
- Prograzier article summarising key findings submitted by Brendan Cullen in October 2011.
- Carbon conundrum. Article in the Warrnambool Standard, 19th May 2011.
- Papers and presentation at the Grasslands Society of Southern Australia annual conference, by Brendan Cullen and Matt Bell, June 2011.
- Forecasting pasture growth rates. Article published Brendan Cullen in The Grassland Society of Southern Australia newsletter No. 273, May 2008. Page 14-15.
- A project web site was established at www.piccc.org.au/research/projects/southern-livestock providing access to project details, publications and a project fact sheet.

3. Methodology

The project used dedicated modellers to conduct, coordinate and publish a series of modelling studies on climate change impacts, adaptation and mitigation strategies for the southern Australian grazing industries. A/Prof Richard Eckard, Dr Brendan Cullen, Dr Matt Bell worked collaboratively with Ms. Karen Christie and Dr. Richard Rawnsley, TIAR, and Dr Andrew Moore, CSIRO to coordinate the modelling activities. The team used a range of biophysical (DairyMod, SGS Pasture model, GrassGro and APSIM), farm systems and GHG (inventory calculators) modelling tools in a number of simulation studies. The project utilised a network of credible 'base' simulations for over 20 sites across southern Australia. The sites spanned a range of climates in southern Australia from high rainfall, cool temperate in Tasmania to lower rainfall, temperate environments of southern New South Wales, through to Mediterranean climates in Western Australia and sub-tropical climates in south eastern Queensland.

3.1 Climate change impacts and adaptation

The latest downscaled climate change projections from Ozclim were used to develop future climate scenarios (www.csiro.au/ozclim/home.do). The biophysical models were used to predict the impact of changed climate conditions on plant and animal productivity plus emissions of CH_4 and N_2O and soil C balance. Adaptation to climate change and mitigation of greenhouse gas emissions were assessed based on regional differences in:

- Climate (rainfall and temperature changes);
- Soil types (site specific characteristics);
- Pasture species (legumes, temperate and sub-tropical grasses); and
- Grazing system (beef, sheep and dairy).

4. Results

4.1 Biophysical modelling simulations that address climate change impacts

4.1.1 Pasture Production

Historical variability

Climate variation in the last decade, in particular low rainfall, has resulted in lower annual production and increasing variability in south eastern Australia. However, variability in pasture production is not outside the range observed using the 110 year climate records. The lack of a clear trend in variability is encouraging, even though annual production has declined. See Cullen BR, Bell MJ, Christie KM, Rawnsley RP and Eckard RJ (2011).

Historical seasonal changes

Analysis of historical climate indicates that within and between sites examined in south-eastern Australia there is considerable variation in the decadal frequency of early and late autumn breaks and short and long springs. There also appears be a trend towards an increase in frequency of shorter springs at all sites and late autumn breaks at Hamilton. These trends can be linked to declining autumn and spring rainfall. These changes in seasonal distribution of growth will require changes to grazing management strategies to maintain efficient utilisation of annual pasture growth. See Bell MJ, Cullen BR, Christie KM, Rawnsley RP and Eckard RJ (2011).

Future climates and resilience

In a range of pasture systems in eastern Australia, little change or higher annual pasture production was simulated at all sites studied with 1°C warming, but varying responses were observed with further warming. In a pasture containing a deeper rooted and heat tolerant C4 grass, annual pasture production increased with further warming, while production was stable or declined in pasture types based on C3 species in temperate environments. In a cool temperate region pasture production increased with up to 2°C warming. Compared with the historical baseline climate, warmer and drier climate scenarios led to lower pasture production, with summer and autumn growth being most affected, although there was some variation between sites. At all sites winter production was increased under all warming scenarios. Inter-annual variation in pasture production, expressed as the coefficient of variation, increased in the lower rainfall scenarios where production was simulated to decline, suggesting that changing rainfall patterns are likely to affect the variability in pasture production more than increasing temperatures. Together the results indicate that annual pasture production is resistant to climatic changes of up to 2oC warming. See Cullen BR, Eckard RJ and Rawnsley RP (2012).

Future climates and productivity

Using metabolisable energy yield as a measure of quality and quantity of pasture production, modelling suggested that temperature increases of 3, 1, 2 and 3°C at Dookie, Ellinbank, Elliott and Hamilton would be required before a more heat tolerant and deeper rooted pasture species like kikuyu grass was more beneficial compared to the average ME yield provided by perennial ryegrass. However, across sites, kikuyu grass could provide a useful source of ME during the warmer months of December to February compared to perennial ryegrass. See Bell MJ, Cullen BR and Eckard RJ (2011).

4.1.2 Production system greenhouse gas emissions

Carbon Offsets Scenarios Tool

The team developed the Carbon Offset Scenarios Tool (COST) to explore the viability of a range of mitigation options that could be included as Carbon Farming Initiative (CFI) offsets. This spreadsheet tool allows for the exploration of key questions such as the price of carbon required to make a strategy profitable and costs of implementing these strategies. The University of Melbourne and Tasmanian Institute of Agriculture teams developed tool in collaboration. The tool is detailed in the final report submitted by the Tasmanian Institute of Agriculture (Project code: B.SBP.0071) and will therefore not be repeated here.

Emissions intensity of different livestock systems in Southern Australia

Using actual farm data from the Farm Monitor Reports, together with biophysical modelling, whole farm GHG emissions were calculated for merino fine wool, prime lamb, beef cattle, milk, wheat and canola. Dairy farms produced the highest emissions/ha (8.4-10.5 t CO_2e/ha), followed by beef (3.9-5.1 t CO_2e/ha), sheep (2.8-4.3 t CO_2e/ha) and grains (0.1-0.2 t CO_2e/ha). When compared on an emissions intensity basis (t CO_2e/t product), cow/calf farms emitted the most (22.4-22.8 t CO_2e./t carcass weight) followed by wool (18.1-18.7 t CO2e/t clean fleece), prime lamb (11.4- 12.0 t CO_2e/t carcass weight), dairy (8.5–9.4 t CO_2e/t milk fat + protein), steers (6.3-6.7 t CO_2e/t carcass weight) and finally grains (0.04–0.15 t CO_2e/t grain). Emissions intensities of top farms surveyed in the Farm Monitor Reports were not always less than average farms. If a C price were imposed on agriculture, emissions intensity provides insight about relative cost impacts of the C price on production of different agricultural products under different production systems. See Browne N, Eckard RJ, Behrendt R and Kingwell R (2010).

Productivity and dairy system emissions

Annual emissions per unit area for sites in south- eastern Australia ranged from 2.6 to 13.1 t CO_2e/ha among sites and climate scenarios, and generally reflected stocking rates. However, in the future scenarios, there were changes in N_2O emissions at dryland sites due to increased direct N_2O losses and lower indirect N_2O through volatilisation and leaching. Annual emission intensities ranged from 7.5 to 10.9 t CO_2e/t milk fat+ protein among sites and climate scenarios. The lowest emissions intensity was at Elliott, which also had little change in future climates. At Terang and Ellinbank, the emission intensity was 8.8 t CO_2e/t fat + protein in the baseline climate, but this increased by more than 20% in the 2070 high warming scenario. Pasture based production systems will continue as the basis of the dairy industry in north-western Tasmania, but lower production and higher emission intensity at Terang and Ellinbank suggest that systems adaptations may be required to meet future GHG emissions reduction and production goals. See Cullen BR and Eckard RJ (2010).

Productivity and sheep system emissions

Sites across southern Australia with the highest predicted decline in rainfall, together with C3 temperate pasture species, showed lower pasture intakes and lamb live weights at weaning in future warmer and drier climates. At sites where future predicted rainfall declines were lower, pasture intakes and the live weight of lamb produced at weaning were maintained. The CO_2e emissions/ ha (ranging from 4.1 to 5.6 t CO_2e/ ha) and per unit product (ranging from 11.0 to 21.7 kg CO_2e/ kg lamb live weight) varied across the sites and across climate scenarios studied. Results indicated that emissions per unit product can be minimised by maintaining a productive pasture base and lamb production. With warming, a site with a C4-based pasture system became significantly more productive and with a lower GHG emissions intensity, whereas some grazing systems may need to adapt their pasture-base to maintain productivity and minimise emissions intensity in the future. Within grazing systems, the N_2O emissions by denitrification may become more significant as a result of warming. See Bell MJ, Eckard RJ and Cullen BR (2012).

Productivity and beef suckler cow system emissions

The C_4 pasture at Albany had the highest rate of pasture intake per cow and a low reliance on supplementary feed compared to other sites. However, poorer feed quality limited the annual carrying capacity of the grazing system and the total live weight of calves weaned/ha, resulting in a greater CO_2e emissions/ kg calf live weight at weaning (14.7 kg/ kg compared to between 11.0 to11.2 kg/ kg at the other sites in south eastern Australia). Compared to a C_4 grazing system, the temperate C_3 systems were associated with a potentially higher metabolisable energy content (ranging from 9.4 to 9.9 MJ/kg DM and 9.3 to 11.4 MJ/kg DM respectively) and dry matter digestibility (65 to 68 % and 64 to 78% respectively). Across sites, the average annual CO_2e emissions/ ha ranged by approximately 17% (1.11 to 1.34 kg CO_2e/ ha) and 11% for CO_2e/ kg DM intake (0.58 to 0.65 kg CO_2e/ kg DM intake). The major source of CO2e emissions from the low input systems simulated was from enteric CH_4 (between 0.87 and 0.94 of whole system emissions). See Bell MJ, Cullen BR and Eckard RJ (2012).

Grazing system annual N2O emissions

Nitrous oxide emissions were predicted to increase in the future projected climates at all sites in south eastern Australia except Elliott, where N_2O emissions remained low due to well drained soil. At the remaining sites, the model showed an increase in number of days with soil water filed pore space (WFPS) in the range of 0.6–0.8 during the wetter colder months and fewer days with WFPS 0.6–0.8 during the drier, warmer months. Warmer soil temperatures, coupled with wet but less saturated soils, resulted in an increased opportunity for N_2O production during cooler months, while the potential for N_2O production during warmer months remained low. Emission factors (i.e., proportion of N inputs lost as N_2O) changed in the future climate scenarios, emphasising the need for a more dynamic and mechanistic modelling approach in development of national greenhouse gas inventories. See Eckard RJ and Cullen BR (2010).

Breeding dairy cows for reduced emissions

Selective breeding was evaluated for its use in reducing greenhouse gas (GHG) emissions from dairy cows. One approach that would be cost- effective and reduce the emissions intensity (per ha and per unit product) of milk production would be to select animals that better utilise their feed intake to meet their genetic potential for milk production. Work is being carried out with the Biosciences Research Division at Bundoora to incorporate feed intake as a breeding goal in the national Profit Ranking Index. Reductions in GHG emissions by genetic selection of dairy cows in the past has been achieved largely by increased productivity and gross efficiency, whereby the maintenance cost of animals in the system has been reduced and less animals are required to produce the same amount of product. Based on current breeding goals, a similar rate of reduction in emissions intensity can be expected in the near future. Selecting dairy cows on feed efficiency, and possibly CH4 and nitrogen losses, will have a large impact on the environmental footprint of milk production, once implemented in breeding schemes. Further research and development of novel technologies to better understand the physiological and genetic differences between animals that lead to differences in energy and nitrogen efficiencies (or overall feed use efficiency) are still required. See Bell MJ, Eckard RJ, Pryce J (2012).

4.2 Further development of a distributed climate modelling capability

4.2.1 The animal module in SGS/Dairy Mod

A generic daily time-step model of animal growth and metabolism for cattle and sheep has been developed. It includes total body weight as well as protein, water and fat components, and also the energy components associated with the growth of protein and fat, and activity costs. Protein decay is also incorporated along with the energy costs of resynthesising degraded protein. Protein composition is taken to be the primary indicator of metabolic state, while fat is regarded as a potential source of metabolic energy for physiological processes such as the resynthesis of degraded protein. Normal weight is defined as maximum protein and the associated fat component so that if the animal's weight exceeds the normal value, all excess weight is in the form of fat. It is assumed that the normal fat fraction increases from birth to maturity. There are relatively few parameters, all of which have a reasonable physiological interpretation which helps simplify choosing parameters for different animal types and breeds. Simulations for growing and mature cattle and sheep in response to varying available metabolisable energy are presented and comparisons with empirical curves reported in the literature for body composition are in excellent agreement. See Johnson IR, France J, Thornley JHM, Bell MJ and Eckard RJ (2012).

4.2.2 GHG Dynamics

The work on the soil organic matter module has allowed detailed analyses of the complete GHG dynamics in grazed pastures. The SOM dynamics are described in terms of three SOM pools: fast and slow turnover and an inert component. The decay rates of the fast and slow pools depend on soil water content and temperature. In addition, the decay rate for the fast pool is influenced by the quality of the dead organic matter inputs to this pool. A central focus of our analysis is to give a balanced treatment of all aspects of the carbon dynamics – that is, inputs from dead plant material, plant growth in relation to soil nutrient status as affected by SOM dynamics, animal processes including pasture intake and dung and urine returns, and the impact of nitrogen inputs from fertilizer and fixation by legumes. The model is performing well and is providing insight into GHG dynamics in response to climate variation and pasture management. We are in the final stages of completing a paper for submission on this topic. See Johnson IR, Eckard RJ (2012).

4.2.3 Dung and urine distribution

Modelling showed that the non-uniform distribution of excreta significantly influences the annual nitrogen losses through leaching and denitrification from a grazing system. These issues have been addressed in a newly updated version of the SGS and DairyMod models, now able to simulate dung and urine patch distribution. See Bell MJ, Cullen BR and Eckard RJ (2011).

4.2.4 Model development

The SGS Pasture Model and DairyMod, which have the same underlying biophysical core and are referred to as the 'model', are continually being updated and adapted to meet the needs of the project. During this phase, the model has been re-structured to improve reporting of simulation results and to allow more flexible handling of model parameter sets. The main focus of model improvement has been to the animal, soil organic matter modules, and the treatment of urine patch dynamics. In addition, aspects of model testing and evaluation have been addressed.

4.2.5 Model validation

With the increase in biophysical modelling applications, we have also given consideration to the notions of testing and evaluating large-scale models. The challenges facing such testing are well established in the literature. Often, model testing is restricted to whole- system behaviour. If the model and data agree, then some level of 'validation' is said to have been achieved but if they disagree, then the usual conclusion is that the model is at fault and either the structure requires revision or parameters need adjusting. One difficulty with this process, particularly with complex biophysical models with a large number of parameters, is that similar results can be obtained for different combinations of parameter values, raising the question as to which parameter combinations are appropriate. Indeed, with validation defined this way, models will inevitably be proven to be invalid. Validation as generally applied is more appropriately termed 'verification' and it is well established, that no scientific hypothesis, or model, can ever be verified. It is suggested that we focus on the notion of testing and evaluating models, recognising that they are always, at best, an approximation of the real world, just as the factors influencing observational data cannot be completely known. This opens the way to work closely with models and data together to gain greater understanding of the underlying system. These ideas are expanded in Johnson (2011).

4.2.6 Model training

- Brendan Cullen conducted two DairyMod/ Sustainable Grazing Systems model training courses for NSW Industry and Investment staff. The first was held in Tamworth 23rd and 24th June, 2010, and the second was at Orange on 22nd and 23rd September 2010. In total, 20 scientists and extension officers were trained.
- Training and support provided by Brendan Cullen to Victorian DPI extension teams in the project and Tasmanian modelling teams.
- A model training and support workshop was hosted the 7th and 8th December 2010, at the Amora Hotel, Bridge Rd, Melbourne, to focus on modelling greenhouse gas mitigation strategies for grazing industries.
- A modelling workshop was conducted on the 12th and 13th May 2010 to discuss and plan appropriate methods for modelling extreme events under future climate change scenarios.
- DairyMod training was conducted for the Intelact consultancy group in Melbourne in May 2011. Six consultants attended.
- An introduction to DairyMod was conducted by Brendan Cullen at Ellinbank Dairy Research Centre in September 2011 and attended by 10 researchers.
- Postgraduate students currently use the SGS/DairyMod models as part of their research and receive ongoing support.

5. Conclusion

5.1 Key findings

Summary of adaptations examined and potential impact / benefit

- Total annual pasture production in southern Australia is generally resilient to climate changes of +1° with 10% less rainfall, but further changes may reduce annual pasture growth.
- Deep rooted and heat tolerant traits will be important adaptations for pasture species in future warmer and drier climates.
- Pasture systems that currently utilise C_4 pasture species are more resilient to warmer climates, but in regions where C_4 grasses are not currently grown substantial warming is required before they will be more productive than the current C_3 species.
- Analysis of historical climate indicates that at five sites across Victoria and Tasmania there is a trend for a greater frequency of short spring growing seasons across sites, but a lack of a clear trend in terms of pasture production variability.
- Warmer and drier future climates projected for southern Australia will change the seasonal pattern of pasture growth, with higher pasture growth rates in winter and early spring but a contraction of the spring growing season.
- Changes in the seasonal pattern of pasture growth impacts on animal production and ground cover, even if the production over the whole year is maintained.

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5.2 Benefits to industry

Significant additional modelling capability and capacity was developed during this project. The DairyMod and SGS models were expanded with a more sophisticated animal model, improved soil organic carbon modules, and the explicit treatment of urine patch dynamics. These have all enhanced the models capacity to predict methane, nitrous oxide, soil carbon and the interactions between these. The project team provided training to over 50 scientists, consultants and extension officers, plus six postgraduate students.

6. Future research and recommendations

- **Mitigation modelling:** During the term of this project, the CFI was legislated by the Australian government. Mitigation modelling conducted during this project, through the development of the COST tool, indicated that many of the offset options available to graziers are simply not cost- effective and therefore engagement by graziers in the CFI is likely to be limited initially. More comprehensive biophysical and economic modelling is therefore required to understand the conditions under which these strategies may be adopted and where research and extension needs to focus to further develop cost-effective strategies for engagement under the CFI.

- **Extreme events:** Modelling of the impact of, plus strategies to recover from extreme events like flooding, heat waves and drought. Future model developments should aim to include this capability in our existing biophysical models where possible. However, not all extreme events lend themselves to biophysical modelling and these should be identified, with an alternative response pathway identified.

- **Adaptation modelling:** Future adaptation modelling needs to move from impacts analysis to adaptation and a range of scales. Modelling also needs to consider the appropriate counterfactual, when modelling the benefits of a specific adaptation e.g. using a prediction of what pastures may have been like in 2050 in the absence of climate change as the baseline and modelling specific adaptations against these.
- Future modelling should consider the balance between adaptation, sequestration and mitigation impacts of proposed farming systems changes.

7. References

Not applicable

8. Appendix

8.1 Published papers and extension products

Refereed journal

Bell MJ, Cullen BR, Eckard RJ (2012). The influence of climate, soil and pasture type on productivity and greenhouse gas emissions intensity of beef suckler cow grazing systems in southern Australia. Animal Production Science (In review).

Bell MJ, Eckard RJ, Cullen BR (2012). The effect of future climate scenarios on the balance between productivity and greenhouse gas emissions from sheep grazing systems. Livestock Science (in press).

Browne N, Eckard RJ, Behrendt R, Kingwell R (2011). A comparative analysis of greenhouse gas emissions from agricultural enterprises in SE Australia. Animal Feed Science and Technology, 166-167:641-652. doi:10.1016/j.anifeedsci.2011.04.045

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Johnson IR, Eckard RJ (2012). Modelling greenhouse gas dynamics in Australian pastures. Animal Production (in prep).

Refereed conference papers

Bell MJ, Cullen BR, Eckard RJ (2011). Effect on nitrogen losses from a sheep grazing system by the randomised distribution of excreta. 2011 International Congress on Modelling and Simulation (MODSIM 2011), Perth, Western Australia, 12 to 16 December 2011. http://www.mssanz.org.au/modsim2011/B1/bell.pdf

Bell MJ, Cullen BR, Eckard RJ (2011). The production of perennial ryegrass and kikuyu pastures in south-eastern Australia under warmer and drier future climate scenarios. 2011 International Congress on Modelling and Simulation (MODSIM 2011), Perth, Western Australia, 12 to 16 December 2011. http://www.mssanz.org.au/modsim2011/B1/bell2.pdf

Johnson IR (2011). Testing and evaluating large-scale agricultural simulation models. Keynote address, 19th International Congress on Modelling and Simulation, Perth, Australia, 12–16 December 2011. http://www.mssanz.org.au/modsim2011/Keynote/johnson.pdf

Book chapters

Bell MJ, Eckard RJ, Pryce J (2012). Breeding dairy cows to reduce greenhouse gas emissions. Book chapter in Livestock Production (in press).

Conference papers

Bell MJ, Cullen BR, Christie KM, Rawnsley RP, Eckard RJ (2011). Is the variability of seasonal pasture growth patterns changing? Proceedings of the 2011 Annual Grassland Society of Southern Australia Inc conference, June 2011, Hamilton.

Browne NA, Behrendt R, Kingwell RS, Eckard RJ (2012) Comparing Greenhouse Gas Emissions and Farm Profit on Sheep, Beef, Dairy and Grain Farms in Southwest Victoria. Proceedings of the 2nd Joint Conference of the New Zealand & Australian Societies of Animal Production. Lincoln University, Lincoln, New Zealand, 2nd to 5th July 2012.

Browne NA, Kingwell RS, Behrendt R, Eckard RJ (2012) Comparing the profitability of sheep, beef, dairy and grain farms in southwest Victoria under different rainfall scenarios. Proceedings of the 56th Australian Agricultural and Resource Economics Society annual conference, Fremantle, Western Australia, February 7-10.

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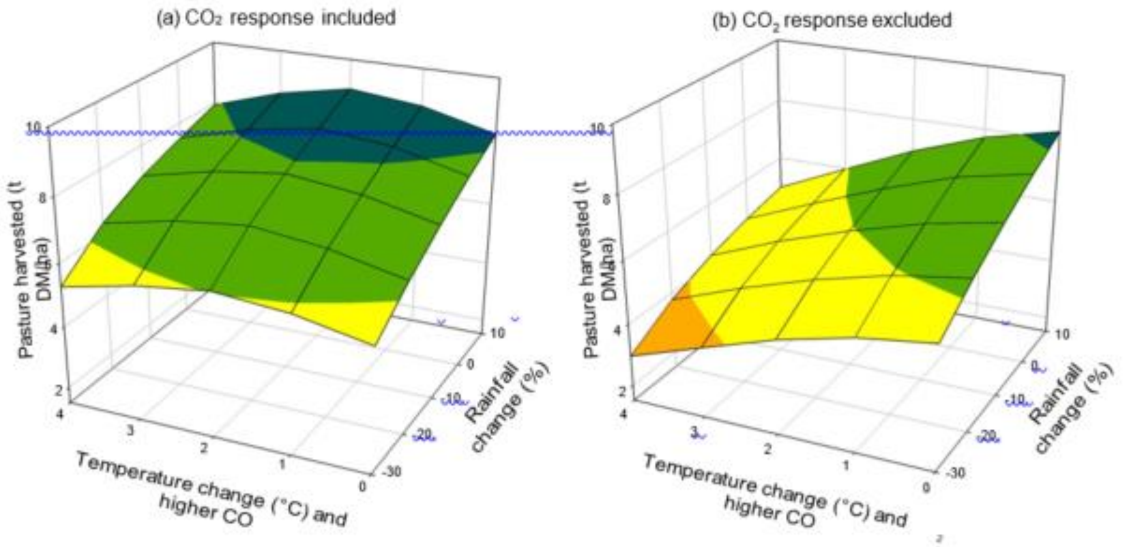
8.2 Future Filling the Research Gap Project

8.2.1 Capitalising on the production benefits from higher atmospheric CO2 concentrations

Three general plant responses to higher atmospheric CO2 concentrations are evident from research on the CO2 fertilisation effect on temperate (C3 photosynthetic pathway) plant species. These are that under elevated levels of CO2 plants will have: (i) increased photosynthetic efficiency, (ii) reduced nitrogen content, and (iii) increased water use efficiency (Ainsworth and Long 2005). Together these physiological responses will act to buffer the impact of projected warmer drier climate scenarios on plant production. This is demonstrated by modelling the pasture production response of a perennial ryegrass and subterranean clover pasture at Hamilton under projected future climates with and without the plant responses to CO2 included (Figure 1). Clearly, maximising the dry matter production responses to elevate CO2 will be important for maintaining productive pasture-based livestock systems in future.

Figure 1. Annual pasture harvested (t DM/ha) for a perennial ryegrass and subterranean clover sward at Hamilton in south west Victoria (a) with and (b) without the plant responses to elevated CO2. Climate scenarios are based on historical data from 1971-2010 scaled by 0, +1, +2, +3 and +4°C (with CO2 concentrations of 380, 435, 535, 640 and 750 ppm) with +10, 0, -10, -20 and -30% rainfall changes.



Recent research from the AgFACE experiment at Horsham has demonstrated significant variation in the production responses of wheat cultivars to elevated CO2 concentration, with work currently underway to establish the physiological basis of these differences (S. Seneweera pers. comm.). This research will identify the important plant traits, which can then be incorporated into plant breeding programs. No similar work is under way for pasture species. It is likely that there will be differences in responses to elevated CO2 between pasture species and potentially cultivars of the same species. Understanding the effects of elevated CO2 on dry matter production, forage quality and persistence, and then harnessing plant traits to improve productivity will be important to buffer the impact of projected climate change.

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