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Whole Farm Systems Abatement Modelling

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Executive summary

The project conducted ~25 biophysically and economically evaluated options for reducing net emissions (NE), emissions intensity (EI) and improving farm profitability. These studies were published in 27 peer reviewed papers (plus another 6 in prep and 4 in review), 4 book chapters and 29 conference papers, focused on exploring mitigation options for the grazing industries. In some cases the modelling (e.g. feeding dietary oils to dairy cattle, the herd method, nitrate supplementation) was used to inform the development of CFI/ERF methods.

The WFSAM project further developed modelling capability and capacity, specifically in greenhouse gas abatement options for the livestock industries. Model improvements were made in the DairyMod and SGS models to enhance their capacity to model methane and nitrous oxide emissions at a whole farm systems scale. The project developed a number of decision support tools including improving the Sheep and Beef Greenhouse Accounting Frameworks, the DGAS model and the Sheep COST. The team also developed a steady state framework to analyse the profit, cash and wealth of a farm business.

The case studies modelled provided some examples where both NE reductions and productivity gains could be achieved (e.g. extended lactation in dairy and introducing legumes to beef and sheep systems). In most of the studies conducted, however, reducing NE to maximise offset income was not the most profitable strategy for the farm, when compared with maximising productivity or profitability while reducing EI. There will always be exceptions to this where economies of scale can make the numerical benefit worthwhile, even if the benefits as a proportion of total income are still extremely low.

The two carbon neutral grazing systems modelled also served to demonstrate that a livestock farm can be productive, profitable and carbon neutral through planting trees, while increasing production on the balance of the land. Another case study showed that, while environmental plantings were not profitable if productive land was set aside, if these plantings could provide shade and shelter that reduced heat stress and lamb mortality, this would more than cover the cost of establishment.

While research on options to profitably reduce NE should still be a key priority, given the distinct lack of clear options to profitably reduce NE this raises the question if EI is a better metric to underpin future offset methods for the livestock industries, as the WFSAM modelling provides numerous examples where EI was reduced profitably, while meeting productivity targets. Examples are provided on how this could underpin offset methods and how this may work at a farm or industry scale.

Future mitigation research needs to include consideration of profitability impacts of the mitigation interventions, as it is clear that at current carbon prices the offset income alone is insufficient to incentivise the majority of graziers.

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1. Background

Climate change is already impacting on agriculture, through what we have termed the 3Ps: through the direct Physical effects on plants, soils and animals, the policy impacts (e.g. Carbon Pricing Mechanism; Direct Action, the CFI and now the ERF) and the Peripheral impacts (e.g. carbon footprint labelling, consumer preferences). The Carbon Farming Initiative, now merged into the Emissions Reduction Fund, is a potentially positive policy impact aimed at incentivising farmers to reduce emissions and/or store carbon. Participation in the ERF is voluntary and it provides potential for earning additional farm income. However, to claim credits under the ERF a method needs to be developed from peer reviewed science, with the aim of achieving a net reduction in emissions relative to business as usual.

With global population growth projected to exceed 9B people by 2050, and potentially 14B by 2100, there is increasing recognition of the need to improve agricultural production (and efficiency) to meet this growing demand (FAO 2009). Australian agriculture needs to be part of this equation mainly to capitalise on the demand for higher value production from the rising world middle class. However, there is also growing recognition that this increase in food production will need to produce less emissions per unit product than before and markets are already sending signals requiring reduced carbon footprints of agricultural products – this signal therefore requires a reduction in emissions intensity of the production, rather than a net reduction in emissions. Numerous examples can be provided where the grazing industries have been steadily reducing their emissions intensity (Henry and Eckard 2009), through improvements in production efficiency.

Whole farm systems analysis, using a range of modelling and decision support tools, is the only way to understand and fully account for the complex interactions at a farm system level of any emissions management technology or management intervention. This research project therefore aimed to analyse a range of options that can further improve production efficiency, while further reducing either net emissions and/or emissions intensity, to address the signals coming from the ERF policy and those from the supply chain, respectively.

The hypothesis of this project was that there are cost-effective options for livestock producers in southern Australia to profitably reduce their net greenhouse gas emissions, and/or emissions intensity, while further improving production efficiency.

2. Objectives

The objectives of the project were to:

- Model (biophysical and economic) likely Carbon Farming Initiative offset options, applicable to the southern Australian livestock industries;
- Model (biophysical and economic) non- Carbon Farming Initiative emissions intensity and adaptation options, applicable to the southern Australian livestock industries;
- Enhance modelling capability and capacity;
- Develop simple decision support tools for industry to evaluate emissions intensity and Carbon Farming Initiative abatement options.

3. Outcomes

The outcomes from the project are a series of biophysically and economically evaluated options for reducing emissions intensity, improving farm profitability and/or further development into ERF offset methods.

4. Methodology

The project was conducted through 4 key activities:

Activity 1: Biophysical and economic modelling of likely Carbon Farming Initiative offset options

An Investor Steering Group was formed with the terms of reference to decide and prioritise the modelling tasks for the project team. This provided the flexibility required by the project to respond to emerging new technologies in a timely manner and ensures that investor's priorities can be addressed, particularly as the policy environment developed and new research emerged from the Filling the Research Gap program. The structure for the management of the project is provided in Figure 1.

Drawing on data and outputs from the previous Climate Change Research Program (RELRP, NORP, SCaRP) and future Carbon Farming Futures national programs, the team conducted whole farm systems biophysical and economic modelling of a wide range of likely ERF offset options for the livestock industries. This modelling built on previous investments in modelling and capability from the WFSAT, Southern Livestock Adaptation and Dairy Directions projects. Whilst these modelling projects quantified the impacts of climate change scenarios, explored adaptation options, quantified the sources of greenhouse gas emissions and enhanced modelling capabilities, the CFI and ERF was not in place at this time. There was therefore a need to explore both individual and multiple CFI/ERF offset options across a range of agro-climatic regions and farming systems.

Activity 2: Biophysical and economic modelling of non- Carbon Farming Initiative emissions intensity and adaptation options

Using the same team, approach, tools, studies and modelling described in Activity 1, the project modelled a range of farming systems that were of strategic interest to the grazing industries in positioning them in a carbon constrained future, through reduced emissions intensity. This aimed to align with the strategic directions of the grazing industries, where some processors are setting targets to reduce emissions intensity by up to 30% by 2020, to address issues of international reputation, corporate social responsibility and marketing.

This Investor Steering Committee again directed Activity 2, allowing the project flexibility to respond to an emerging domestic and international policy and marketing environment.

Activity 3: Enhanced modelling capability

In previous projects, the team had built significant national capability in modelling grazing systems, through user workshops, training and direct model support. This capacity development was primarily focused on climate change adaptation. The WFSAM project further developed this capacity in modelling (biophysically and economically) greenhouse gas abatement options for the dairy, sheep and southern beef industries. Six monthly model user workshops were organised and hosted to continue developing more distributed modelling capability, in collaboration with other national modelling projects, in ensuring that the appropriate assumptions were being made in both the model parameters and assumptions on abatement options. These workshops also aimed to provide internal peer review and updates on modeling progress.

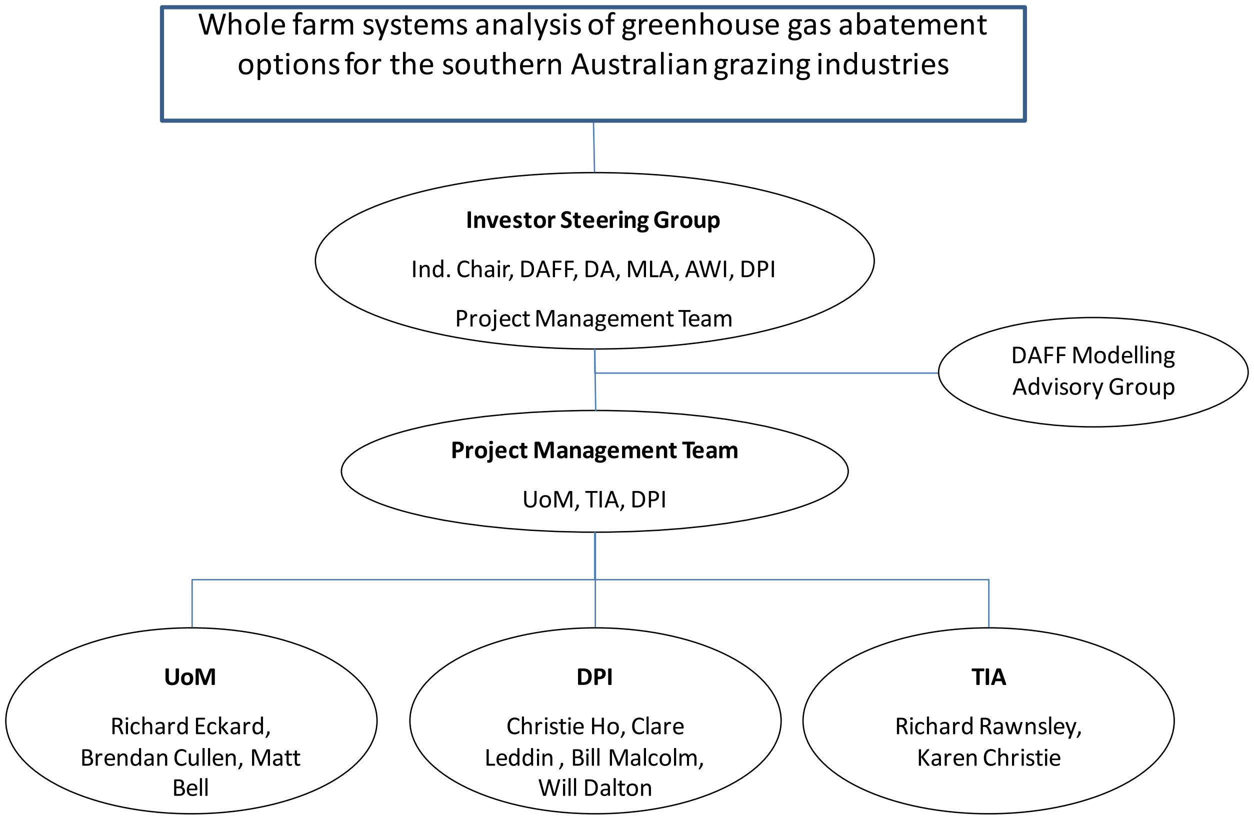

Figure 1. Management structure used in the WFSAM project.

While the team had strong and proven modelling tools for the biophysical/ economic analyses required, some model development was required to specifically answer all abatement questions raised. The team worked with the 'Facilitation of improvement in systems modelling capacity for Carbon Farming Futures' project and associated Filling the Research Gap modelling projects, to coordinate model improvements, and to avoid duplication. Model improvements will were made in the DairyMod, SGS models, and the Sheep and Dairy COST tools, plus an economic analysis spreadsheet were developed.

Activity 4: Development of simple decision support tools for industry to evaluate emissions intensity and Carbon Farming Initiative abatement options

This project developed and improved a number of decision support tools including improving the Sheep and Beef Greenhouse Accounting Frameworks, the DGAS model and the Sheep COST. The team also developed a steady state framework to analyse the profit, cash and wealth of a farm business.

5. Results

1. Activity 1 and 2: Biophysical and economic modelling of likely offset options and emissions intensity and adaptation options

To date the project has conducted ~25 modelling studies and published 27 peer reviewed papers (plus another 6 in prep and 4 in review), 4 book chapters and 29 conference papers, focused on exploring mitigation options for the grazing industries.

The specific results from each of these are either detailed in the published papers listed in Appendix I. Where these studies are not complete, not yet published, or not previously reported in detail, they are provided as individual reports in Section D.

The modeling studies were as follows:

- Earlier mating and improving fertility in beef production in a northern Australian herd.
- Environmental plantings on sheep and dairy properties.
- Dietary oils for dairy cattle.
- Nitrification inhibitor use on dairy, beef and sheep enterprises,
- Nitrogen use efficiency for dairy farms.
- Increasing longevity on beef and wool farms,
- Increasing ewe genetic fecundity.
- Modelling novel forages.
- Feeding nitrates to beef cattle,
- Modelling the Wambiana long term grazing site.
- Controlled feeding versus voluntary feed intake effects on herd methane,
- Animal genetics and flock management in wool production systems,
- 3 in 2 milking frequency,
- Genetic and pasture-base adaptations to prime lamb enterprises,
- Potential for soil carbon to offset animal emissions,
- Beef systems using Leucaena,
- Greenseeker technology for applying nitrogen fertiliser in dairy systems,
- Earlier mating of dairy heifers in the sub-tropics,
- Whole farm responses to rising costs from greenhouse emissions and changes in climate,
- Herd structures and climate variability,
- A comparative analysis of on-farm and pre-farm greenhouse gas emissions from three beef cattle herds in Northern Australia.
- What is the best use of oil from cotton and canola for reducing net greenhouse gas emissions?
- A carbon neutral wool case study at Yass, NSW
- A carbon neutral case study of Jigsaw farms near Hamilton, Victoria
- A case study of finishing steers on an existing and new irrigated Leucaena development (including land clearing)

2. Activity 3: Enhanced modelling capability

The WFSAM project organised a number of workshops as detailed below.

2.1 Workshop 1 - Informing approaches to mitigation modelling: 1 - 2 May 2013, Best Western Airport Motel & Convention Centre, Melbourne.

This workshop was hosted jointly by the 'Facilitation of Improvement in Systems Modelling Capacity for Carbon Farming Futures' and 'Whole Farm Systems Analysis of greenhouse gas abatement options for the Australian grazing industries (WFSAM)' projects. The workshop was attended by 32 representing the majority of scientists involved in mitigation modelling and grazing systems, both in Australia and New Zealand. Delegates attended from the University of Melbourne, Tasmanian Institute of Agriculture, DEPI-Victoria, DPI-NSW, DAFF-QLD, SARDI, CSIRO, Dairy Australia, MLA, AWI, University of Southern Queensland, University of New England and AgResearch, New Zealand.

Purpose:

- To develop improved modelling capacity for the DAFF Filling the Research Gap program, through developing an agreed pro-forma, ensuring that modellers are planning and designing modelling experiments with similar level of thought and planning as field experiments.

- To ensure that modellers under the Filling the Research Gap program are making correct and appropriate use of data from the various measurement programs in challenging and validating their models, leading to further model improvement and improved confidence in the modelling outputs.

- To develop an agreed modelling pre-experimental protocol pro-forma.

Day 1 of this workshop involved presentations from researchers conducting mitigation modelling, with a view to informing the workshop of the scope of modelling being conducted and the various approaches used. Day 2 was a facilitated workshop session that aimed to developed a FtRG mitigation modelling planning protocol

The outcome of the workshop was an agreed pro-forma to use as a pre-schedule in the planning of future mitigation modelling studies; the focus of the second day.

The workshop report is attached as Appendix IIA.

2.2 Workshop 2 - Mitigation modelling training workshop: 19-20 November 2013, Best Western Airport Motel and Convention Centre in Melbourne.

This workshop was jointly hosted by Facilitation of Improvement in Systems Modelling Capacity for Carbon Farming Futures and Whole Farm Systems Analysis of Greenhouse Gas Abatement Options for the Australian Grazing Industries (WFSAM).

(a) Purpose:

- To build on the modelling skills develop in earlier workshops, through presenting case studies and provide opportunity for peer review of these.

- To develop greater understanding of the theoretical and technical aspects of mitigation modelling.

The workshop was attended by 17 agricultural sector researchers actively engaged in developing models and using mitigation modelling in their research. 42 invitations were distributed, 18 accepted to attend (43%) and 17 attended (38%, with 2 cancellations received on day 1 of the workshop).

Day 1 of the workshop included presentations from researchers conducting mitigation modelling, focusing on how these studies were conducted in terms of models and tools. Day 2 of the workshop comprised hands-on training sessions, access to modelling experts, plus discussion and feedback on future developments required.

(b) Outcomes and recommendations

- The participants strongly affirmed the value of holding workshops to improve skills in mitigation modelling, mainly through continued development of knowledge about various models and approaches and increasing in skills and confidence in modelling.
- Participants also valued networking and engagement opportunities arising from the workshops.
- The key outcome will be improved quality of mitigation modelling, plus a more informed and consistent approach to mitigation studies.

The workshop report is attached as Appendix IIB.

2.3 WFSAM Workshop 3: Modelling - livestock production systems of northern Australia

A workshop was held on 25th and 26th June 2014 at the Watermark Hotel, Brisbane, focused on grazing systems modelling in northern Australia. The workshop was attended by 24 delegates mainly from CSIRO, DAFF-QLD and PI-NT.

(a) Purpose

To recommend to MLA and partners how a modelling project can be designed so that it answers immediate industry questions (around production, profit, sustainability in differing regions) and satisfies the longer term objective of providing the livestock industry and stakeholders in northern Australia with the capacity to do pre and post-experimental modelling, use models more prospectively, and identify research or capacity gaps in northern Australia.

The workshop report is attached as Appendix IIC.

2.4 Model development

While the team had strong and proven modelling tools for the biophysical/ economic analyses required, some model development was required to specifically answer all abatement questions raised.

Model improvements in the DairyMod, SGS models were contracted to Dr Ian Johnson, IMJ Consultants. The details of these improvements are provided in Appendix III with a report provided in section D.

3. Activity 4: Development of simple decision support tools for industry to evaluate emissions intensity and Carbon Farming Initiative abatement options

This project developed and improved a number of decision support tools including improving the Sheep and Beef Greenhouse Accounting Frameworks, the DGAS model and the Sheep COST. The team also developed a steady state framework to analyse the profit, cash and wealth of a farm business.

The details of these decision support tools are provided in Section D.

6. Discussion

The research conducted under WFSAM explored a number of greenhouse gas (GHG) mitigation strategies, the impact of implementing these strategies and their financial effect on the farm. The modelling included a focus on productivity, net emissions (NE) and emissions intensity (EI) in all cases. In some cases the modelling (e.g. feeding dietary oils to dairy cattle, the herd method, nitrate supplementation) was used to inform the development of CFI/ERF methods.

There were a limited number of examples where NE could be reduced while also improving profitability and productivity. These included extended lactation in dairy and introducing legumes to beef and sheep systems, where the action reduced emissions (NE) but also increased the productivity of the farm system. However, while this is promising, the likely income from the sale of offsets in these examples was consistently an order of magnitude less than the added income from productivity gains.

In most of the studies conducted, however, reducing NE to maximise offset income was not the most profitable strategy for the farm, when compared with maximising productivity or profitability (note that not all studies included an economic analysis) while reducing EI. Some examples from the modelling are summarised in Table 1.

Table 1. A comparison the change (Δ) in estimate profit/ha, from modelled scenarios where EI was minimised, to maximise profitability, versus scenarios where NE was minimised to maximise offset income.

	Δ Net emissions (NE)			**Δ Emissions intensity (EI)***	
Strategy	**NE abatement (t CO_2e/ha)**	**Δ gross CFI/ERF income ($/ha)**	**NE Profit ($/ha)**	**EI abatement (t CO_2e/t product)**	**EI Profit ($/ha)**
Beef - Leucaena	0.66	$15.04	$27.39	2.3	$110.56 [1]
Beef - Longreach	0.04	$0.99	$4.79	4.2	$7.94 [1]
Beef - Boulia	0.01	$0.23	$0.58	3.4	$1.14 [1]
Wool - Lotus	0.02–0.38	$0.49 to $9.22	$15.28 to $38.60	0 to 3.3 t CO_2e/t CFW	$15.28 to $38.60 [3]
Prime lamb – Lotus	0.05–0.48	$1.10 to $11.71	$31.36 to $81.88	0.1 to 2.8 t CO_2e/t CW	$31.36 to $81.88 [3]
Ewe - fecundity	1.0	$13.95	$110.21	2.1 t CO_2e/t LWT+CFW	$250.35 [2]
Sheep – Longevity	0.01-0.03	$0.23 to $0.69	-$2.50 to -$7.78	0	-$2.50 to -$7.78 [3]
Dairy - Longevity	0.33 - 0.37	$7.67 to $8.50	51.85 - 114.82	0.6 - 1.6 t CO_2e/t MFP	51.85 to 114.82[3]
Wool - Management and genetics	0.50	$11.50	$25.00	6.5 (t CO_2e/t CFW)	$25.00 [1]

* - where EI was maximised there was no ERF income.

[1] GM = Gross margin; [2] FP = Farm profit; [3] OP = Operating profit

In the scenarios where NE were minimised, to target maximum offset income, the gross offset income was typically $0 to $15/ha. This compares with an increase in profitability in the scenarios that targeted EI of up to $39/ha, $250/ha, $111, and $115/ha on wool, prime lamb, beef and dairy enterprises, respectively. The gross carbon offset income equates to between 7 and 24% of the likely income from focusing in on profitability, a figure that farmers would be understandably reluctant to pursue, unless these actions were aligned (which in most cases studies they were not), or there were economies of scale, third party aggregation, or the risks were low and transactions costs negligible. Additionally, the NE scenarios do not include transaction costs of claiming carbon offsets, such as recording, monitoring and auditing, as these were unknown and thus not included in the analysis.

While research on options to profitably reduce NE should still be a key priority, given the distinct lack of clear options to profitably reduce NE this raises the question if EI is a better metric to underpin future offset methods for the livestock industries, as the WFSAM modelling provides numerous options where EI was reduced profitably, while meeting productivity targets.

Using EI as a metric opens up many more mitigation options for graziers than reducing NE and could be used to reconcile global food production targets with emissions targets. This was the conclusion of a major review of the livestock industries, commissioned by the FAO (Hristov *et al.* 2013). Improving

EI reduces total emissions when the same amount of product is produced at a lower EI, or where the rate of EI reductions exceeds the rate of overall productivity growth in the sector.

Figure 1 below uses data from the Longreach case study (Table 2) to illustrate how this may be used in recognising the offset achieved from the above two options. The blue solid (NE Historic) and dashed (EI Historic) lines in Figure 1 show both the NE and EI of the farm before any management improvements, respectively. This assumes no change to management and could be considered as a projected baseline for the project; the EI remains at 14.9 t CO_2e/t LWT through this baseline. The BAU lines assume that the business is developing and growing, but without the key improvements required to improve emissions intensity (e.g. simply increasing stock numbers). This could be seen as an industry baseline, where the focus is on increasing production but not productivity (e.g. recovery from the drought by simply increasing stocking rates). Thus the red solid line (NE BAU) shows increasing NE as more steers are produced from more cows, but the EI remains constant at 14.9 t CO_2e/t LWT (red dashed line – EI BAU). The green solid line (NE Project) then shows the total emissions over time, as the business develops but reduces its EI through early mating and selection for higher fertility. Here the EI of the Project (green dashed line) is steadily reducing as the farm reduces EI from 14.9 to 12.6 t CO_2e/t LWT over the life of the project.

There is then a cumulative emission reduction of 2,015 t CO_2e from this farm, relative to what the atmosphere would have seen under the BAU (red lines). While this is not as large as the 2,824 t CO_2e cumulative NE reduction between the NE project and NE Historic scenarios, at $13.95/t CO_2e this would still be worth $28,109 for this particular case study farm. However, this is still small compared to the value of the additional profit close to $200K, with the ERF projected income.

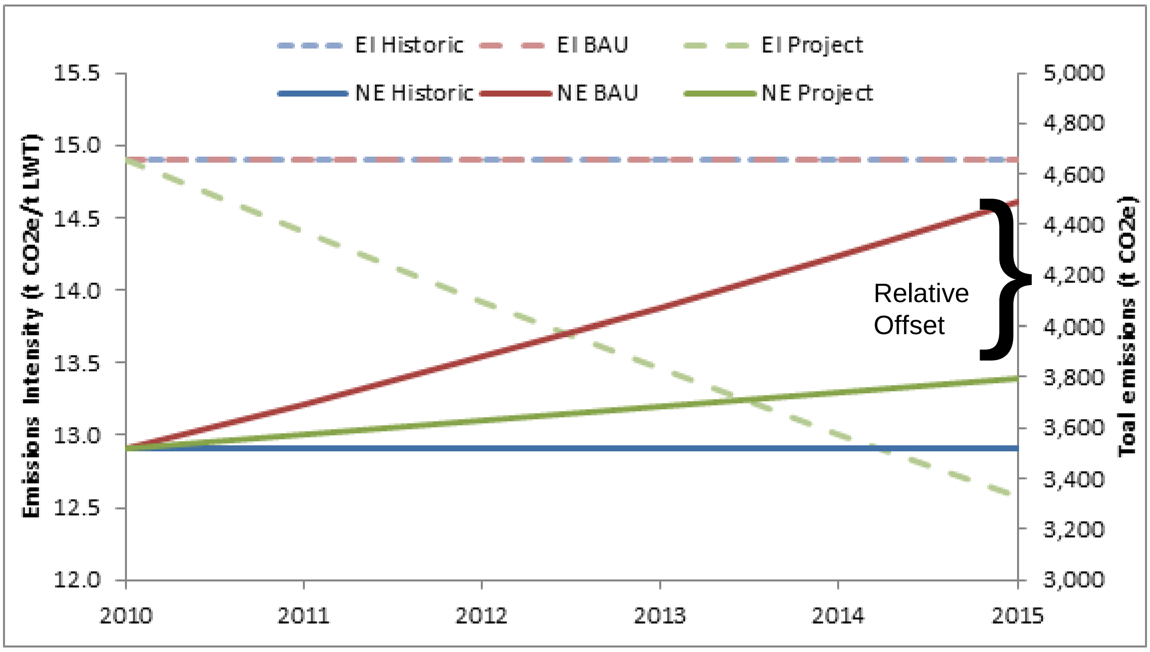

Figure 1. The net emissions (NE) and emissions intensity (EI) from a beef production system at Longreach, under constant historic management (Historic), a business development scenario with no change in emissions intensity (BAU) and a business development scenario with a focus on reducing emissions intensity (Project).

An example of how the logic in Figure 1 may be used at an industry level could be: In 2000, the national dairy industry produced 10,847 million litres of milk with an average emission intensity of 1.11 kg CO_2e/kg FPCM, equating to 11.31 Mt CO_2e. During the millennium drought milk production dropped to 9,023 million litres. If the dairy industry recovered from the millennium drought at an EI of 1.11 kg CO_2e/kg FPCM than this would simply return total emissions to 2000 levels.

However WFSAM research has shown that EI in the dairy industry can range between 0.8 and 1.7 kg CO_2e/kg FPCM. If a modest reduction of 0.21 kg CO_2e/kg FPCM was achieved across the whole industry (i.e. 0.9 kg CO_2e/kg FPCM) through an ERF method, and we assumed the industry recovered production to 2000 levels, the new total emissions from the industry would be 9.21 Mt CO_2e, an abatement of 2.1 Mt CO_2e Mt across the industry. At the last auction price of $13.95 per t CO_2e this would be worth $ $29.33 million, or an average price per farm of around $ 4,645 per year.

7. Future research

Future mitigation research needs to include consideration of profitability impacts of the mitigation interventions, as it is clear that at current carbon prices the offset income alone is insufficient to incentivise the majority of graziers. There will always be exceptions to this where economies of scale can make the numerical benefit worthwhile, even if the benefits as a proportion of total income are still extremely low – examples of this would be the ERF savannah burning method and perhaps aggregation within the larger pastoral companies of the herd management and nitrates methods.

If we assume the grazing industries aim to further increase production, then there is a clear potential to include EI as a basis for future ERF methods. Further research would be beneficial on how emissions intensity could effectively be used as a key metric in future offset method developments. this report provides suggestions on how this can be achieved.

The majority of studies under WFSAM were conducted under historic or static climate conditions. Future research on mitigation options should be assessed under future climate scenarios, including extreme events, as recent studies by Eckard and Cullen (2011) and Cullen and Eckard (2011) showed increase emissions from livestock systems under future climates in Victoria. Additionally some of the case studies should be examined over a range of variable years to understand the vulnerability of these offset options to climate variability. In particular, this research should compare the resilience of systems that optimise for NE versus EI, as there is a risk that a focus on profitability may not increase resilience and that, perhaps, optimising for NE may be more sustainable in the longer term.

More research is required on novel ways (and business models) that might exist for farmers to insulate themselves from the risk of increasing climate variability. One such option is the development of business models for expanding into multiple areas with different environments that can provide additional feed for livestock, such as using farmland in areas with both summer-dominant and winter-dominant rainfall (i.e. the Kidman principle). Farmers may be able to lower the risk of reduced rainfall in the future by expanding their ability to produce feed or move stock between different climate regions. To some extent this is already happening with larger corporates, but options could be developed for smaller farm businesses to participate.

Emissions research in the wool industry would benefit from further research into allocation methods. Allocation issues are of particular importance for sheep systems where wool and meat and are included as co-products. In particular, further work is required to form a consensus on allocation methods for the sheep industry. Of particular interest is whether there is an easier way of using the recommended biophysical allocation method. An energy-based allocation method that was simplified for easier use would be more readily applied.

8. Significance of findings

The project has identified a number of potential mitigation options for the livestock industries including those that reduce NE and EI. There were some examples where both NE reductions and productivity gains could be achieved, but in the majority of cases NE reductions required animal numbers to be held constant or reduced (i.e. producing more steers from less cows) where this was not the most profitable option.

A number of potential win-win options were also identified, including pasture improvement through legumes (lotus and Leucaena) and improved lamb survival and reduced heat stress from tree planting. The two carbon neutral grazing systems modelled also served to demonstrate that a livestock farm can be productive, profitable and carbon neutral through planting trees, while increasing production on the balance of the land. Further modelling could look at appropriate mitigation strategies for livestock systems by calculating the rolling 12-year offset required to permanently offset the methane produced, based on the actual lifetime of methane in the atmosphere. In theory, if this 12-year rolling offset was in place, and stock numbers did not increase, the farm could be carbon neutral in perpetuity.

The research demonstrated the most effective way to reduce greenhouse gas emissions from farm enterprises was through the use of mitigation strategies that focused on EI and profitability as key metrics. Farmers would be more likely to implement mitigation strategies that allow continued increases in productivity, because the additional income generated is more likely to cover the implementation costs than carbon offset income alone.

However, the down side of this is that it may still result in a net increase in emissions from agricultural production, but it seems this is inevitable if Australian agriculture is to be part of meeting the food demands of a rising world middle-class. The question then becomes how can we feed a growing world population with less emissions than would otherwise be produced? An EI metric is the only realistic option to achieve this goal. The above discussion really reflects the current situation where cost-effective and profitable options to reduce NE are not yet widely available. This research remains a high priority.

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D1. Project title

Participation in the AgMIP and C3MP programs

Organisations Tasmanian Institute of Agriculture and University of Melbourne

Primary contact Matthew Harrison

a. AgMIP benchmarking (coordinated by Matthew Harrison)

Karen Christie, Matthew Harrison, Brendan Cullen, Natalie Doran-Browne, Rachelle Meyer, Richard Rawnsley and Richard Eckard continued their collaborative research in The Agricultural Model Inter-comparison and Improvement Project (AgMIP). AgMIP is an international program involving more than 10 different international models and 40 research institutes, and aims to compare results from several agricultural biophysical models in simulating grassland, livestock and crop production. AgMIP has dedicated projects in major themes of livestock, pasture grasslands, and crops. The program links the climate, livestock, crop and economic modelling communities with cutting-edge information technology to produce improved crop and economic models and the next generation of climate impact projections for the agricultural sector. The goals of AgMIP are to substantially improve the characterisation of world food security due to climate change and to enhance adaptation capacity in both developing and developed countries. Analyses of the agricultural impacts of climate variability and change require a transdisciplinary effort to consistently link state-of-the-art climate scenarios to livestock, crop and economic models. Model outputs are aggregated as inputs to regional and global economic models to determine regional vulnerabilities, changes in comparative advantage, price effects, and potential adaptation strategies in the agricultural sector. Climate, livestock- and cropping models, economics, and information technology protocols are presented to guide coordinated AgMIP research activities around the world, along with cross-cutting themes that address aggregation, uncertainty, and the development of Representative Agricultural Pathways (RAPs) to enable testing of climate change adaptations in the context of other global trends. The organization of research activities by geographic region and specific crops is described, along with project milestones. AgMIP aims to utilize inter-comparisons of these various types of methods to improve livestock, crop, grassland and economic models and ensemble projections and to produce enhanced assessments by the crop and economic modeling communities researching climate change agricultural impacts and adaptation (see http://www.agmip.org/about-us/ for further information).

Pasture and animal production, emissions of carbon dioxide, enteric methane and nitrous oxides, as well as other outputs, were simulated using inputs from five diverse sites using either DairyMod or SGS. The simulations were a challenge to both the model and modellers, since in many circumstances the model could not replicate the experimental details exactly, therefore requiring adaptation of the scenario modelled and the modeller’s best judgement. For example, many sites did not have consistent and complete climate information (although Stage 2 inputs have advanced significantly on Stage 1 inputs). In many cases, both grazing and cutting were conducted simultaneously, but such management cannot yet be simulated using version 5 of DairyMod or SGS and so all modellers converted their model systems and repeated simulations using version 4 of the model. AgMIP requires outputs in defined dimensions, so this often necessitated conversion of DairyMod outputs into the correct format (e.g. DairyMod outputs nitrous oxide emissions in kg N/ha, whereas AgMIP required this output in ug NO3-N/m2).

AgMIP benchmarking will be conducted in five successive stages, with the first and second having been completed on 3 October 2014 and 20 March 2015 respectively. The next step will be updating of current simulations with further site data (e.g. plant and soil parameters) for pre-experimental years and re-running of the model at each site. It is expected that AgMIP organisers will provide feedback on the reliability and accuracy of DairyMod/SGS simulations, as well as a comparison against other grassland-livestock models who have been entered as participants in the inter-comparison exercise. This activity will result in model improvement and further international awareness of livestock farm systems research undertaken by the WFSAM team.

b. Benefits for WFSAM and the Australian red meat, dairy and wool industries

Outputs simulated and entered in AgMIP have already resulted in international feedback and peer-review on the reliability of DairyMod/SGS in simulating climate change impacts, as well as biophysical variables such as dry matter production, animal liveweight gain, emissions of nitrous oxides and enteric methane emissions, which are central to simulations conducted in WFSAM. It is hoped that such feedback will be incorporated into future model development and improvement in model predictions.

These results will help foster international awareness of whole farm livestock production, profitability and greenhouse gas emissions research being conducted and supported by the federal government and the Australian red meat, dairy and wool industries. Results will also raise international attention to current and future Carbon Farming policies in force and being mooted by the Australian Departments of Environment and Agriculture. Further, AgMIP organisers are currently preparing research reports using results from Stages 1 and 2 for submission to peer-reviewed scientific journals, which will further communicate the ability of DairyMod/SGS to reproduce actual dynamic changes in livestock weight gain, grasslands, soil carbon and nitrogen, as well as associated whole farm emissions.

D2. Project title

Influence of climate variability on total greenhouse gas (GHG) emissions and GHG emissions intensity in the northern Australian beef industry.

This study is not complete. Results shown here are preliminary.

Organisation University of Melbourne, CSIRO Sustainable Ecosystems

Primary contact Brendan Cullen

Executive summary

Previous studies of GHG emissions from northern beef production systems have modelled ‘steady state’ herd structures, however the highly variable climate leads to considerable inter-annual variation in mortality and branding percentages, and in rates of liveweight gain. This study aimed to quantify the variation in total GHG emissions and emissions intensity when effects of climate variation were incorporated on a breeding property near Charters Towers in Queensland. Both fixed and flexible stocking policies were investigated. A modelling approach using the GRASP and ENTERPRISE models was used. Preliminary results indicate that substantial year-to-year variation in breeder herd size and beef liveweight sold exists, particularly when the flexible stocking policy was imposed. This is likely to result in substantial inter-annual variation in both total GHG emissions and emissions intensity. The next step in this work is to calculate the annual GHG emissions using the Australian inventory approach.

Background

Previous studies of GHG emissions from northern beef production systems have modelled ‘steady state’ herd structures with fixed assumptions about mortality and branding percentages, and rates of liveweight gain (eg Cullen *et al.* 2015). However the highly variable climate which is characteristic of northern Australia leads to considerable inter-annual variation in mortality and branding percentages (eg Bortolussi *et al.* 2005a; Fordyce *et al.* 2013), and in rates of liveweight gain (Bortolussi *et al.* 2005b). Thus any ‘steady state’ analysis cannot capture the range of outcomes expected across seasons.

In addition, flexible stocking policies in response to climatic variation (eg by varying stock numbers in response to total standing dry matter at the end of the growing season) have been recommended as a means of capitalising on the benefits of good seasonal conditions while protecting species composition and land condition in poor years (O’Reagain and Scanlan 2013). With flexible stocking there will be fluctuations in breeder herd size and numbers of livestock sold in the de- and re-stocking phases which will have implication for GHG emissions. The aim of this study was to quantify the variation in total and GHG emissions intensity for the northern beef industry when variation in mortality and branding percentages, rates of liveweight gain and stocking policies are taken into account. A case study breeding herd in northern Queensland was modelled to quantify the variation.

Method

A breeding herd was modelled near Charters Towers in northern Queensland, based on the Wambiana property. To capture seasonal variation in mortality and branding percentages, rates of liveweight gain and stocking policies, a combined GRASP-ENTERPRISE modelling platform was used (Scanlan *et al.* 2013). GRASP was used to determine the liveweight gain for individual years and the flexible stocking policy based on total standing dry matter at the end of the growing season, while ENTERPRISE allowed breeder herd structures to be imposed and incorporated seasonal effects on mortality and branding percentages. Two stocking policies were tested: fixed, where the breeder herd number was kept constant across years, and flexible, where breeder herd size can vary by up to 40% each year up to a maximum increase in breeder herd size of 90% and minimum of 40% decrease.

Calculation of GHG emissions from the systems will be based on the Australian inventory approach using the numbers of animals in each livestock class and their weight from the GRASP-ENTERPRISE models. GHG emissions and emissions intensity will be calculated annually for the 30 years simulated (1980-2011) to quantify the range across seasonal conditions and grazing management practices.

Preliminary results

The number of animal in the breeding herd and the beef liveweight sold from the farms under the fixed and flexible stocking polices are shown in Figure 1. With fixed stocking policies, variation in beef liveweight sold (217-285 t liveweight) was due to variation in mortality rates (3.7-5.0% for breeders and 2.2-2.7% for dry stock), branding rates (67-88%) and annual steer liveweight gain (92-130 kg liveweight/head).

With flexible stocking policy, beef liveweight sold ranged from 45-591 t liveweight. Much of the additional variation in beef production was due to changes in breeder herd size (Figure 1). It is notable that beef turnoff varies with breeder herd size but the impact is lagged. For example, minimum beef sold occurs when breeder herd size is increasing after poor seasonal conditions, while maximum beef turnoff occurs with the onset of poor seasonal conditions when cows are culled to reduce breeder herd size.

Discussion

The variation in breeder herd size and beef sold for the fixed, and in particular the flexible, stocking strategies indicates that seasonal variation in total GHG emissions and emissions intensity is likely to be significant for the northern beef industry. Total GHG emissions are likely to be closely related to total animal numbers so will be more variable with the flexible strategy. However, the GHG emissions need to be calculated using the Australian inventory method before conclusion can be drawn.

Next steps

The calculation of GHG emissions and emissions intensity will be next step. The work will be written up for a paper in the ‘Greenhouse Gas and Animal Agriculture’ conference in 2016.

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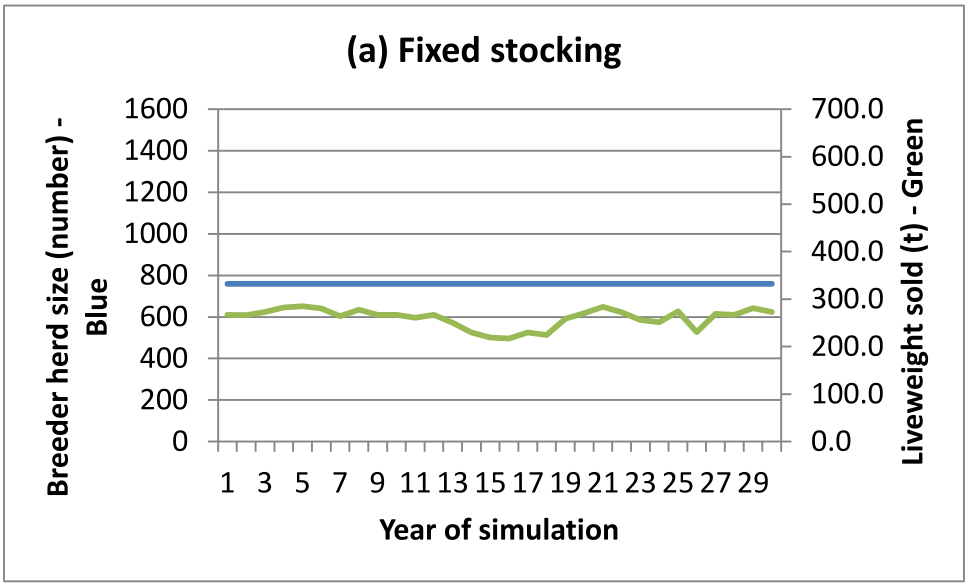

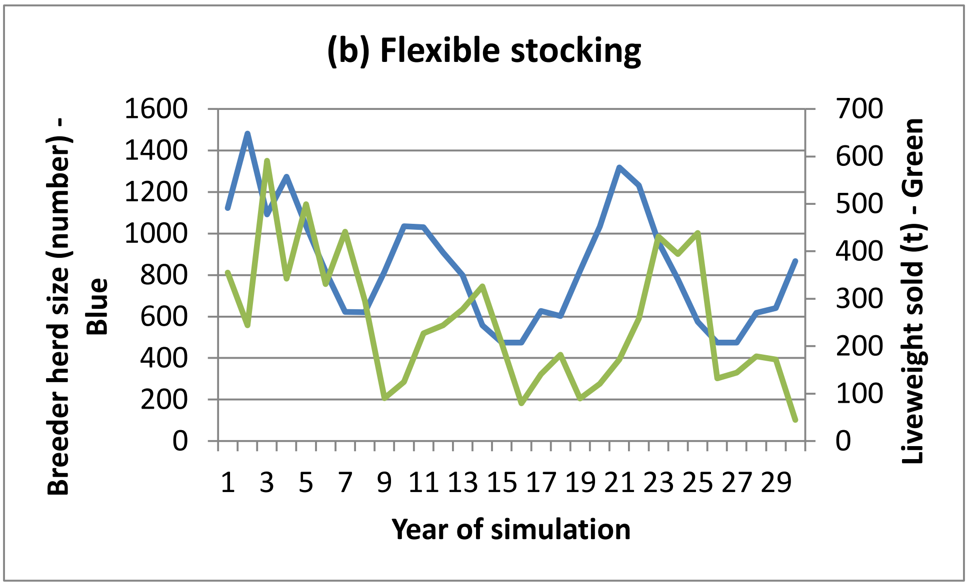

Figure 1. Breeder herd size (blue lines) and liveweight sold (green line) under the (a) fixed and (b) flexible stocking policies on the Wambiana property.

D3. Project title

Modelling the abatement of enteric methane from earlier mating for dairy heifers by offering a high quality diet in sub-tropical Australia

Organisations Tasmanian Institute of Agriculture and University of Melbourne

Primary contact Karen Christie

This paper is in draft and may change before publication. This paper will be submitted to the 6th Greenhouse Gas and Animal Agriculture Conference (GGAA2016) to be held in Melbourne, 14th to 18th February 2016 and subsequently published in Animal Production Science.

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Keywords: greenhouse gas emissions, liveweight gain, SGS pasture model, subtropical pastures

Abstract

Greenhouse gas (GHG) emissions from agriculture contribute around 14% of global emissions and improvements in farm system management can help abate such emissions. While the milking cow is the single largest source of on-farm dairy GHG emissions, replacement young heifers also contribute and more importantly emit GHG emissions without producing milk, thus increasing the GHG emissions intensity of milk production. This modelling study examined the relative time it takes for dairy heifers to meet the target liveweight (LW) for first mating by feeding a diet of contrasting nutritive values, estimating the greenhouse gas (GHG) emissions associated with reducing the target LW for mating. Based on a static steady-state herd where climatic conditions do not influence intakes and LW gain, for a target mating LW of 360 kg, growing heifers should be able reach their target LW at approximately 19 months of age while consuming C_4 grasses with an average metabolisable energy (ME) content of 9.5 MJ/kg DM. This can be reduced to approximately 12 months of age if the daily intake is achieved by consuming a diet of 11.0 MJ ME/kg dry matter (DM). Enteric methane (CH_4) emissions were reduced from 1.3 to 0.8 t CO_2e/heifer over the 19 and 12 month periods, respectively, to achieve the same target LW for mating.

One issue of examining the time to reach target LW using a static steady-state approach is that seasonal pasture availability and nutritive value are not taken into consideration; the heifers are assumed to maintain constant dietary intake irrespective of time of year and seasonal variation in pasture quality and quantity. To explore the extent with which static approaches influence results, we used the Sustainable Grazing Systems (SGS) whole-farm biophysical model comparing the outermost two static ME concentration diets over a period of 44 years. A predominantly pasture based diet with minimal concentrates (1.5 kg DM/head.day of a supplement with an ME of 12.0 MJ/kg DM) and with an overall diet mean (± standard deviation; SD) ME of 9.5 ± 0.1 MJ/ kg DM, resulted in heifers taking 22.2 ± 4.0 months post-weaning to reach mating LW. Increasing the level of supplementation to 3.3 kg DM/head.day, to achieve a diet with an overall mean of 10.9 ± 0.1 MJ/ kg DM, reduced the time between weaning and mating to 16.8 ± 1.1 months, representing a reduction of 5.6 months relative to the lower quality diet. There was little difference in estimated enteric CH_4 emission estimations between the static and dynamic approaches for the high quality (~ 11ME) diet, at 0.8 and 0.7 t

CO_2e/heifer, respectively, during the period from weaning to mating. Similarly for low quality (9.5 ME) diets, the estimated enteric CH_4 emissions were similar at 1.3 and 1.2 t CO_2e/heifer for the static and dynamic approaches, respectively, during the period from weaning to mating. While estimated enteric CH_4 emissions were similar between the two approaches, the timeframe to reach target liveweight was around 50% longer for the dynamic approach when diet quality was low, increasing to around 100% longer when diet quality was high. This difference is largely attributed to adverse climatic conditions reducing feed intake when kikuyu growth rates were minimal over the cooler months. This study underscores the importance of increasing growth rates of heifers, with the most important being feeding animals with energy-dense feedstuffs, to reduce overall feed requirements and cumulative emissions of enteric CH_4 prior to mating to reduce the emissions intensity of milk production over the lifetime of the animal.

Introduction

The average age of first calving on Australian dairy farms varies considerably and generally reflects whether the region supplies liquid milk or manufactured products destined for export. Traditionally, there has been a trend towards a flatter annual milk production curve in northern Australia to supply the liquid milk market, resulting in an all-year round calving system (e.g. Kempton and Waterman, 2014). This is best illustrated by an average calving age of around 33 months for the northern Australian dairy industry, reflecting a first mating age of 24 months (Hough, 1992). In contrast, in southern Australia, there are generally two dominant peak periods of milk supply, in spring and to a lesser extent autumn, to reflect seasonal climatic conditions and associated pasture growth and where milk is predominantly converted into product for export (e.g. Gilmour *et al.,* 2012). Heifers are traditionally mated to coincide calving with these more opportunistic seasonal periods as shown with a first calving average age of 27 months in Tasmania and Victoria, reflecting a mating age of 18 months (Hough, 1992).

A preliminary survey of herd recording data collected between 1992 and today for the northern dairy industry suggests that the average to first calving has risen slightly to 34 months in recent times (Trevaskis, unpub. data). The relatively slow growth of heifers in the northern dairying regions of Australia is generally associated with the use of tropical C_4 pasture species, which are typically higher in fibre and lower in dry matter digestibility and crude protein than temperate C_3 pasture species, especially if sub-optimally managed (Moss, 1993). Due to the low energy density of these tropical pastures and without supplementation, typical heifer growth rates during periods of low energy intake are approximately 0.25 kg/day (Moss, 1993).

Dobos *et al.* (2001) found that, assuming heifers calved at a similar liveweight (LW), those calving at 2 years of age produced 88% of the milk production in their first lactation of those heifers calving for the first time at 3 years of age. However, by the end of their third lactation, differences in milk production per lactation have been shown to be minimal between the two calving age groups (Cowan *et al.,* 1974; Dobos *et al.,* 2004), implying that early mating will increase lifetime milk production. Reducing the mating age has other benefits, such as reducing the number of replacement heifers required, and acceleration in genetic improvement of the herd (Hoffman and Funk, 1992; Moss, 1993).

The Australian dairy industry has set a target of reducing the industry's GHG emissions intensity by 30% by the year 2020 relative to the early 2010's emissions intensity (Australian Dairy Industry Council, 2013). This will only be achieved if a myriad of mitigation options are explored across the whole farm system. Mating heifers at a later age increases greenhouse gas (GHG) emissions per unit product produced over the animal's lifetime, since these animals are emitting methane (CH_4) and associated nitrous oxide emissions (N_2O) from dung and urine deposition without generating any product (milk) for a longer period of their lifetime.

In the current study we hypothesise that the latitudinal range in age at first mating spanning the north-south dairy regions of Australia, reflects differences in diet, especially the quality of grazed pasture.

The most obvious difference, in this regard, is the higher proportion of tropical C_4 grasses that make up the diet of heifers in northern Australia (northern NSW and QLD). To explore this hypothesis, we estimated the relative time to reach a typical mating LW of 360 kg and the associated enteric CH_4 emissions when maiden heifers were fed a range of diets with varying nutritive value reflective of local conditions. We examined animal growth rates and GHG emissions using an approach that assumed daily energetic supply and animal growth rates were constant (static approach) and compared this with a dynamic approach conducted using the SGS biophysical simulation model that accounted for seasonal variation in pasture nutritional quality and heifer LWG.

Methods

Two forms of desktop analysis were undertaken in the current study. The first was a static assessment, where feed nutritional characteristics were invariant over the course of the year. The second was a dynamic assessment where feed nutritional characteristics varied throughout the year dependant on seasonal climatic conditions and the effect of this on LW gain (LWG). Both analyses were based on data obtained from case study farms (see supplementary information), based on kikuyu (*Pennisetum clandestinum*) pastures.

Static analysis to assess time to reach target liveweight and subsequent enteric methane emissions

The first stage of this study was conducted to determine the average daily LWG and associated time between weaning of dairy heifers, at 100 kg LW and 100 d old, and mating at 360 kg. This static approach was computed using the Feeding Standards for Australian Livestock- Ruminants (CSIRO, 2007). Dry matter intake (kg DM/day.head) was calculated as a function of body LW, mature body size and relative size with adjustments for nutritive value. Total metabolisable energy intake (MEI) was calculated as the product of intake and metabolisable energy (ME) density of the feed (MJ ME/kg DM). The modelling assumed a stocking rate of 3.5 head/ha, a pasture allowance of 1.5 t DM/ha and that the heifers walked 1.0 km/day with a 1.2 gradient (1 to 2 scale) to reflect a gradient from flat to steep. Heifers were offered a diet containing 100% C_4 grasses with varying nutritive values; 9.5, 10.0, 10.5 or 11.0 MJ ME/kg DM reflecting values typical or at the upper range for the study region (Fulkerson *et al*., 1998, 2007; Garcia *et al.*, 2008, 2014).

Enteric CH_4 emissions from the growing dairy heifers (weaning to first mating) were estimated using the Australian National Greenhouse Gas Inventory (NGGI) methodology (DCCEE, 2012). Since the NGGI method requires additional nutritive data other than that used in the Feeding Standards for Australian Livestock, dry matter digestibility (DMD) was calculated based on the equation:

DMD (as a fraction) = (ME +1.037) / 0.1604 (DCCEE, 2012).

The global warming potential of 21 was used to convert CH_4 emissions into carbon dioxide equivalents (CO_2e; DCCEE, 2012). Enteric CH_4 emissions of the heifer calves prior to weaning were not included in the static or dynamic analyses as emissions are considered minimal while the rumen is developing (IPCC, 2006). Nitrous oxide emissions were not computed due to the protein concentration of kikuyu pastures being manipulated by the use of N fertiliser and generally not considered a limitation to LWG (Reeves *et al.*, 1996; Marais, 2001). Therefore this source of emissions was also not explored in the dynamic analysis.

Dynamic analysis to assess time to reach target liveweight and subsequent enteric methane emissions

The Sustainable Grazing Systems (SGS) whole-farm biophysical model (Johnson *et al.,* 20030, herein referred to as the SGS model (version 5.3), was used to simulate a 100 ha dairy farm, with animals grazing rain-fed kikuyu pastures all year and with some supplementary feeding to ensure that average annual dietary ME was similar to that used in the static analysis (see below). The SGS model is a whole farm systems-level model that includes modules for soil water and nutrient balance, pasture production and utilisation, and animal intake and growth (Johnson *et al.*, 2003). The model has been used extensively in Australia to model grazing enterprises for temperate and, to a lesser-extent, sub-tropical farm systems (Lodge and Johnson, 2007; Powell *et al.*, 2011; Christie *et al.*, 2014; Doran-Browne *et al.*¸ 2014). Validation has shown that the model accurately estimates pasture consumption and seasonal dry matter accumulation (Cullen *et al.*, 2008; Rawnsley *et al.*, 2009; Doran-Browne *et al.*¸ 2014).

The default kikuyu parameters in the SGS model (Bell *et al.*, 2013) were used in combination with daily weather data for Gympie (26.2°S, 152.7°E) which was accessed as a Patched Point Dataset from the Bureau of Meteorology SILO dataset (Jeffrey *et al.,* 2001). The climate data inputs were between 1 Jan 1970 and 31 Dec 2013 and included daily minimum and maximum temperature (°C), rainfall (mm), solar radiation (MJ/m^2), vapour pressure (kPa) and evapotranspiration (mm). Over the 44 year simulation period, the mean minimum and maximum temperatures were 14.1 and 26.9°C, respectively. Rainfall was summer dominant and averaged 1,099mm/annum over the simulation period, varying between 600 and 1,766 mm/annum. The soil type was classified as a uniform medium textured loam soil with a bulk density of 1.5 g/cm^3 and a saturated hydraulic conductivity of 30mm/hr in the top 400mm of soil profile. The saturation point, field capacity and wilting point were 43%, 29% and 17% by volume, respectively.

At the commencement of the simulation period, a herd of 350 heifers were brought onto the dairy farm as weaners with a LW of 100kg. The herd rotationally grazed paddocks down to a residual biomass of 1.2 t DM/ha once the pastures reached the 4.5-leaf regrowth stage or if the pasture biomass had reached 3.0 t DM/ha. Once the heifers reached the target LW of 360kg, the herd was removed from the farm as they were considered ready for mating. The following 1 Jan another herd of 350 weaned heifers entered the dairy farm system, beginning the management cycle anew.

Nitrogen (N) fertiliser, in the form of urea, was applied during the growth phase of kikuyu on 1 Feb, 1 Oct and 1 Dec every year at a rate of 20 kg N/ha per application. Kikuyu has an excellent response to fertility (Garcia *et al.*, 2014). However, we chose to limit fertiliser inputs to represent a pasture which is not managed to its optimum.

For simplicity, we chose to simulate two levels of average annual ME intake (rather than the four levels as used in the static analysis), since the aim was to gauge the difference in time taken and associated GHG emissions in reaching mating LW when diet nutritive values varied over time. We conducted simulations iteratively and incrementally adjusted supplementary feeding over the 44 year simulation period such that average annual diet ME over the simulation period was as close as possible to the extremes of 9.5 and 11.0 MJ/kg DMI as per the static approach. The lower level required minimal concentrate feeding and mainly consisted of kikuyu pasture (hereafter this system is termed *Minimal concentrates*) whereas the higher energy level required addition of both grain and forage to the pasture diet (termed the *Partial mixed ration* system). Details of feedstuffs of the Minimal concentrates and Partial mixed ration systems are shown in Table 1. Surplus pasture was removed from the grazing rotation via cutting once the biomass reached 3.5 t DM/ha. Surplus conserved pasture was not used as a feed source in the current study.

Table 1 near here

Enteric CH_4 emissions were estimated based on the fraction of digestible energy lost through CH_4 fermentation, which was 6.1% and 4.2% from high fibre and low fibre feed sources, respectively (Johnson, 2013). For the current study, pastures represented a high fibre feed source whereas concentrates and partial mixed ration represented low fibre feed sources. Enteric CH_4 emissions were then multiplied by 21 to convert into carbon dioxide equivalents (CO_2e; DCCEE, 2012).

Data analysis

For each SGS model simulated farm system, the number of days required to reach target LW was computed for each herd of heifers. In addition, for each herd of heifers to reach target LW, the mean ME concentration of the diet (MJ ME/kg DM) was estimated by dividing the mean daily ME intake (MJ ME/head) by the daily DM intake (kg DM/day) and averaging this over the period that the heifers were present on the farm. For each simulated farm system, the daily enteric CH_4 emission was summed to estimate each herd's CH_4 emissions between weaning and reaching the target mating LW. Overall farm systems mean days to target LW, ME intake, ME concentration and enteric CH_4 emissions were then computed over the 44-year simulation period.

Results

Static analysis

Time to reach mating liveweight and enteric methane emissions

The four diets strongly influenced the time required to reach the targeted mating LW. The highest energy diet of 11.0 MJ ME/kg DM resulted in a daily LWG of 1.0 kg per day, with the number of months between weaning and target mating LW being 8.3 (Table 2). This reflects a heifer being able to be mated at approximately 12 months of age. When fed the lower energy diet (9.5 MJ ME/kg DM), the estimated LWG was 0.6 kg per day and the number of months between weaning and target mating LW was 15.3 (Table 2). This reflects a heifer being able to be mated at approximately 19 months of age.

As diet quality improved, cumulative DM intakes between weaning and target LW declined, such that enteric CH_4 was reduced from approximately 1.3 to 0.8 t CO_2e/heifer when diet quality improved from 9.5 to 11.0 MJ ME/kg DM (Table 2). Irrespective of diet quality, heifers emitted 2.3 kg CO_2e/day between weaning and mating. Alternatively, when reviewing the emissions intensity of LWG, improving diet quality from 9.5 to 11.0 MJ ME/kg DM resulted in this being reduced from 5.0 to 3.1 kg CO_2e/kg LW (Table 2) as a result of the heifers reaching target LW for mating approximately 7 months sooner with the ME 11.0 MJ/kg DM diet compared to the ME 9.5 MJ/kg DM diet (Table 2).

Table 2 near here

Dynamic analysis

Feeding animals on a pasture-based diet with minimal concentrates

Over the 44-year simulation period, 18 herds of heifers were grown out to a LW of 360 kg on the minimal concentrates diet. Eleven herds took between one and two years post-weaning to reach target LW and the remaining seven herds took between two and three years' post-weaning. The mean (± SD) number of months post-weaning required to reach mating LW over the simulation period was 22.2 ± 4.0 months (Table 3), with individual herds ranging between 16.5 and 27.7 months (Figure 1a). Mean ME intake was 48.2 MJ ME/head.day based on a mean daily intake of 5.1 kg DMI/heifer and a mean (± SD) diet ME of 9.5 ± 0.1 MJ/ kg DM. Mean enteric CH_4 emissions over the simulation period were 1.2 t CO_2e/head (Table 3), with individual herds ranging between 1.0 and 1.5 t CO_2e/head (Figure 1a). Mean LWG was 0.4 kg/ day, with each kg of LWG resulting in an enteric CH_4 emission of 4.7 CO_2e per heifer (Table 3). For each day delay in reaching the desired LW for first mating, there was an associated increase in enteric CH_4 emissions. This equated to a 1.8 kg CO_2e increase per day of delay per heifer during the period from weaning to mating (Table 3).

Figure 2a illustrates the effect that seasonal climatic conditions had on heifers reaching target LW compared to the static approach. The solid line illustrates the static approach where heifers took 13.5 months post-weaning to reach target LW. In comparison the dashed and dotted lines illustrates two extremes, where it took 16.5 and 27.7 months post-weaning to reach target LW, respectively (Figure 2a). As LW increased up to approximately 200kg there was little difference in enteric CH_4 emissions between the two dynamic examples. However, for a herd that then incurred a plateauing and later decline in LWG, this had a marked effect on enteric CH_4 emissions by the time the heifers reached target LW for mating (Figure 2a).

Table 3 near here

Figure 1 near here

Figure 2 near here

Feeding animals on a partial mixed ration

Over the 44-year simulation period, 22 herds of heifers were grown out to a LW of 360 kg on the partial mixed ration diet, with all herds taking between one and two years post-weaning to reach target LW. The mean (± SD) number of months post-weaning required to reach mating LW over the simulation period was 16.8 ± 1.1 months post-weaning (Table 3), with individual herds ranging between 15.0 and 18.9 months (Figure 1b). Over the simulation period mean ME intake was 50.1 MJ ME/head.day, mean daily intake was 4.6 kg DM and mean (± SD) ME was 10.9 ± 0.1 MJ/ kg DM. Mean enteric CH_4 emissions over the simulation period for the partial mixed ration diet was 0.7 t CO_2e/head (Table 3) with individual herds ranging between 0.6 and 0.8 t CO_2e/head (Figure 1b). Mean LWG was 0.5 kg/day, with each kg of LWG resulting in an enteric CH_4 emission of 2.8 kg CO_2e per heifer (Table 3). For each day delay in reaching the desired LW for first mating, there was an associated increase in enteric CH_4 emissions. This equated to a 1.4 kg CO_2e increase per day of delay per heifer during the period from weaning to mating (Table 3).

Figure 2b illustrates the effect that seasonal climatic conditions had on reaching target LW compared to the static approach. The solid line illustrates the static approach where heifers took 8.3 months post-weaning to reach target LW. In comparison the dashed and dotted lines illustrates two extremes, where it took 15.0 and 18.9 months post-weaning to reach target LW, respectively (Figure 1b). Both dynamic approach examples incurred lower enteric CH_4 emissions relative to the static approach. Similarly to the *Minimal concentrates* dynamic assessment, there was a divergent of LWG once the herds attained approximately 225kg LW, there was a divergent between the best and worst case scenarios, illustrating little variation in feed quality for these two herds up to this stage before variations in climatic conditions between the two herds influenced LWG.

Discussion

In the current study we explored the effects of dietary ME content and computation method on the time for weaned heifers to reach target LW for mating and their resultant enteric CH_4 emissions. The first computation method was a static approach that assumed feed supply was non-limiting and constant every day. Liveweight gain was a function of total energy intake due to variation in the four feed qualities simulated. Increasing the diet quality from 9.5 to 10.0 MJ ME/kg DM reduced mating age by 98 days. This was reduced to 49 days when diet quality increased from 10.5 to 11.0 MJ ME/kg DM. For every 0.1 MJ ME/kg DM increase, enteric CH_4 emissions were reduced by approximately 64 kg CO_2e/heifer over the period between weaning and mating. For a herd of 100 heifers, this would equate to 6.4 t CO_2e and get them in calf and milking sooner, resulting in a ‘dilution of maintenance’ of their lifetime GHG emissions (Bauman *et al.*, 1985). A similar result occurred with the dynamic approach, where enteric CH_4 emissions were reduced by 72 kg CO_2e/heifer over the period between weaning and mating. This is the key to carbon abatement. How can we produce food and fibre with fewer GHG emissions per unit product (Steinfeld *et al.*, 2006)?

A limitation of the static approach was it assumed heifers received consistent feed supply throughout the year, resulting in consistent LWG over the period between weaning and mating. Clearly, this is not realistic so we also undertook a mechanistic approach to estimate the time and GHG emissions between weaning and mating. This approach accounted for climate variation, both within and across years, changes in pasture quantity and nutritional quality, and their compounding influence on animal growth rates. At various times of the year feed demand exceeded pasture supply and even with inclusion of supplementary feeding, there were periods of the year when DM intakes fell below that required for LW maintenance, resulting in a either a plateauing or reduction in LWG. This was particularly evident with the dotted line in Figure 2a for the heifers receiving a small amount of supplementary feed. Their LGW plateaued at approximately 200kg and followed with a reduction in LW occurring when the heifers reached 300kg. These two periods of LWG decline occurred in late winter/ early spring period when kikuyu growth rates and quality was low due to cooler temperatures (Bell *et al*., 2013; Garcia *et al*., 2014) and heifer daily intakes declined below maintenance level. In reality, this would be a key period for management intervention with higher quality alternative pastures and/or additional supplementary feeding to reduce the risk of LW loss. While it should be clear to farmers when heifers are losing LW, a plateauing of LWG could be less clear and highlights the importance of measuring and monitoring LWG on a regular basis so that LW targets at various ages are met (Jagoe and Beggs, 2013).

There was also a trend for lower feed quality during late spring through to mid- autumn, due to the case study site being rain-fed and a relatively low input of N fertiliser (Fulkerson *et al.*, 1998, 2007). Improved feed quality and quantity, especially over the summer period could be achieved with increased N fertilisation and/or the introduction of irrigation (Garcia *et al.,* 2014; Kemp, 1975; Marais 2001). Over-sowing with other pastures species could also be implemented to increase production throughout the autumn to spring period when kikuyu growth declines, thus maintaining heifers on higher quality pastures year round to minimise the loss of LW over this period. In a more temperate environment and under irrigation, Botha *et al.* (2008) found that over-sowing an existing sward of kikuyu with either white (*Trifolium repens*) and red (*Trofolium pratense*) clover or with annual ryegrass (*Lolium multiflorum* var. *westerwoldicum*) was able to increased annual DM production by 5 and 14%, respectively, with most of this increased production occurring in spring. Where the companion species were beneficial was an increase in summer ME values of 2.5 and 1.3 MJ/kg DM for the kikuyu/ clover and kikuyu/ annual ryegrass swards, respectively, relative to the kikuyu-only sward. This increase in ME continued into autumn for both over-sown kikuyu swards. Would similar responses to clovers and annual ryegrass occur within the subtropics?

Using the SGS model to simulate the *Minimal concentrates* feeding system, while cumulative estimated enteric CH_4 emissions were similar between the static and dynamic approach, the estimated age to first mating was 22.2 ± 4.0 months with the dynamic approach. This is considerably longer than the 15.3 months estimated with the static modelling approach for a diet with the same energetic content but assumed *ad libitum* daily intake. When climatic conditions were more optimal for kikuyu production, the period to mating could be reduced to as low as 16.5 months; a result that was similar to the static approach and also what can be achieved in the southern states of Australia for heifers grazing temperate pastures. This highlights the benefits of the dynamic approach which can capture the inter- and intra-annual variation in seasonal pasture supply.

Similarly, the cumulative estimated enteric CH_4 emissions were similar between the static and dynamic approaches when the diet was increased to an ME of around 11 MJ/kg DM as shown with the *Partial mixed ration* feeding system. However, the time to reach target LW was double with the dynamic approach compared to the static approach. In addition, when comparing the timeframes when climatic conditions were more optimum, the period to mating was at best reduced to approximately 15 months which was substantially greater than the 8.3 months estimated with the static approach. This division between the two approaches as feed quality improved highlights the importance of dynamic modelling to estimate the range of potential outcomes (Baldwin, 1995) as opposed to a static approach which can only give one outcome as per large scale reporting of emissions such as national inventories.

One aspect of the environment not included in the dynamic modelling was the effect of stress on LWG. Any set-back in growth due to stress, such as adverse seasonal conditions (e.g. high summer heat), parasites or disease will delay reaching daily LWG targets (Moss, 1993; Le Cozler *et al.*, 2008). For tropical farm systems like those explored in the current study, heat stress as a result of increased temperatures and humidity can have a substantial effect on feed intake (Marcilliac-Embertson *et al.*, 2009; Gaughan *et al.* 2014). This study did not simulate heat stress effect on DMI and subsequent LWG and this may have further delayed heifers reaching target LW for mating beyond what was estimated in this study.

If a farmer chose to mate the heifers based on age alone so as to calve at around 24 to 27 months of age and therefore disregard optimum LW, while enteric CH_4 emissions would be reduced substantially, there are productivity implications. Cowan *et al.* (1974) found that for heifers calving at around 25 months of age, each additional kilogram of LW at first calving resulted in an increase in milk production of 23 litres over the first three lactations. More recent research has confirmed these results, however at a lower magnitude (e.g. Freeman, 1993; Dobos *et al.*, 2004). Therefore any practices put in place to minimise the time required for heifers to reach mating LW, should maximise milk production and reduce the emissions intensity of milk production over the lifetime of the animal.

Conclusion

The current study has illustrated that any impediment to heifer LWG has implications, both from a management and GHG emissions perspective. When optimal LWG is not achieved, mating is delayed and the animal spends a greater proportion of their life not producing milk. The primary reason for these delays can be attributed to lower than optimum energy quality and/or quantity intake. The static modelling approach in the current study showed that for heifers in subtropical environments, a diet with a minimum ME of 10.0 MJ ME/kg DM is required for heifers to reach target LW for mating so as to calve at two years of age. However, this assumes that the heifers are fed to *ad libitum* intake on a daily basis, which is generally not the case in reality. What is clear from the current study is that inputs of high quality supplementary feed during periods of low quality and/or quantity of subtropical pastures are required to reduce mating age for heifers calve to near 24 months. This clearly has financial implications and has to be weighed up against the GHG emissions incurred with delaying mating, which would be a future iteration of this research. With increasing pressure for the Australian dairy industry to reduce its carbon footprint, this may be a strategy that has a win-win for both the industry and environment for tropical regions of Australia where heifers are struggling to calve for the first time at two years of age.

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D3 - Supplementary information

Case studies of three dairy farms

Age at first mating and calving data were obtained from three farms within the sub-tropical dairying region of northern New South Wales and southern Queensland, Australia. This region was selected because it has traditionally had the highest age at first calving across the eastern seaboard of Australia (Hough, 1992). We selected three farms as representative of one of three alternative heifer-raising systems.

- *Case study farm 1- Dryland tropical pastures and minimal concentrates (Gympie, QLD; 26.2°S, 152.7°E)*

The ME concentration of the diet was estimated at 9 MJ/kg DM over the duration between weaning and mating (Trevaskis, unpub. data. 2014). Between weaning at 3 months of age and 12 months of age, heifers grazed rainfed C_4 pastures (predominantly Setaria (*Setaria anceps*) with some Bisset Bluegrass (*Bothriochloa insculpta*) and Kikuyu (*Pennisetum clandestinum*); *c*. 8-9 MJ ME/kg DM). Heifers were fed concentrates (*c*. 12.0 MJ ME/kg DM) at a rate of 1 kg DM/head.day. Heifers also grazed annual ryegrass (*Lolium rigidum*) (*c* 11.5 MJ ME/kg DM) over winter when the dairy farm had surplus annual ryegrass pastures to milker requirements. Between 12 months of age and mating at 23 months of age, heifers grazed the same pasture species as mentioned above with concentrate feeding of 1.7 kg DM/head.day.

- *Case study farm 2- Supplements and grazing (Casino, NSW; 28.8°S, 153.0°E)*

The ME concentration of the diet was estimated at 11 MJ/kg DM over the duration between weaning and mating (Trevaskis, unpub. data. 2014). Between weaning at 3 months of age and 9 months of age, the heifers were fed perennial ryegrass (*Lolium perenne*) silage (9.5 MJ ME/kg DM) and *ad libitum* concentrates containing 90% triticale and 10% canola meal (*c* 13.2 MJ ME/kg DM). Between 9 and 14 months of age, heifers grazed annual ryegrass (*c* 10-12 MJ ME/kg DM) or setaria (*c* 10 MJ ME/kg DM) and received 2.2 kg DM concentrate/ head.day. Between 14 months of age and mating at 17.5 months of age, heifers grazed either annual ryegrass or setaria and received no concentrates.

- *Case study farm 3- Grazed pastures and supplementary feeding (Gympie, QLD; 26.2°S, 152.7°E)*

The ME concentration of the diet was estimated at 11 MJ/kg DM over the duration between weaning and mating (Trevaskis, unpub. data. 2014). Between weaning at 3 months of age and 6 months of age, heifers grazed rain-fed kikuyu (*c* 10 MJ ME/kg DM) and were fed *ad libitum* hay (*c* 8 MJ ME/kg DM) and calf-pellet mix at a rate of 2 kg DM/head.day (*c* 12.5 MJ ME). Between 6 months of age and mating at 17 months of age, heifers grazed rain-fed kikuyu and had *ad libitum* access to a heifer mix which was predominantly palm kernel extract (*c* 11 MJ ME/kg DM).

Table 1. Feeding preference and diet composition for two dairy heifer raising systems examined in the dynamic analysis using the SGS model. See text for details.

Feeding preference	Minimal concentrates	Partial mixed ration
1st	Kikuyu pasture Quality and quantity estimated by SGS model	Concentrates Max. 1.5 kg DM/head.day ME 12.0 MJ/kg DM
2nd	Concentrates Max. 1.5 kg DM/head.day ME 12.0 MJ/kg DM	Partial mixed ration (high quality supplement) Max. 1.8 kg DM/head.day ME 12.0 MJ/kg DM
3rd	N/A	Kikuyu pasture Quality and quantity estimated by SGS model, subject to climate and seasonal variation

ME = Metabolisable energy

Table 2. Estimated months to reach a target mating liveweight of 360 kg, average liveweight gain, total dry matter intake, energy intake and enteric emissions of a dairy heifer offered an *ad libitum* diet containing 100% C_4 grasses and with nutritive values of 9.5, 10.0, 10.5 or 11.0 MJ ME/kg DM.

Diet energy (MJ ME/kg DM)	**9.5**	**10.0**	**10.5**	**11.0**
Months post-weaning to mating	15.3	12.1	9.9	8.3
Average liveweight gain (kg/day)	0.56	0.71	0.86	1.03
Cumulative dry matter intake (t DM/ heifer)	3.5	2.7	2.2	1.8
Cumulative energy intake (GJ/ heifer)	32.9	27.2	23.2	20.3
Cumulative enteric emissions (t CO_2e/ heifer)	1.3	1.1	0.9	0.8
Emissions per day between weaning and mating (kg CO_2e/day)	2.3	2.3	2.3	2.3
Emissions intensity between weaning and mating (kg CO_2e/kg LW)	5.0	4.1	3.5	3.1

Table 3. Estimated months to reach a target mating liveweight of 360 kg, average liveweight gain, total dry matter intake, energy intake and enteric emissions of a dairy heifer offered a diet with either a mean metabolisable energy of 9.5 or 10.9 MJ/kg DMI.

Diet energy (MJ ME/kg DM)	**9.5 ± 0.1**	**10.9 ± 0.1**
Months post-weaning to mating	22.2 ± 4.0	16.8 ± 1.1
Average liveweight gain (kg LW/day)	0.40 ± 0.07	0.51 ± 0.03
Cumulative dry matter intake (t DM/ heifer)	3.4 ± 0.6	2.3 ± 0.1
Cumulative energy intake (GJ/ heifer)	32.5 ± 5.4	25.6 ± 1.4
Cumulative enteric emissions (t CO_2e/ heifer)	1.22 ± 0.20	0.72 ± 0.04
Emissions intensity between weaning and mating (kg CO_2e/day)	1.82 ± 0.08	1.41 ± 0.02
Emissions intensity between weaning and mating (kg CO_2e/kg LW)	4.71 ± 0.75	2.77 ± 0.14

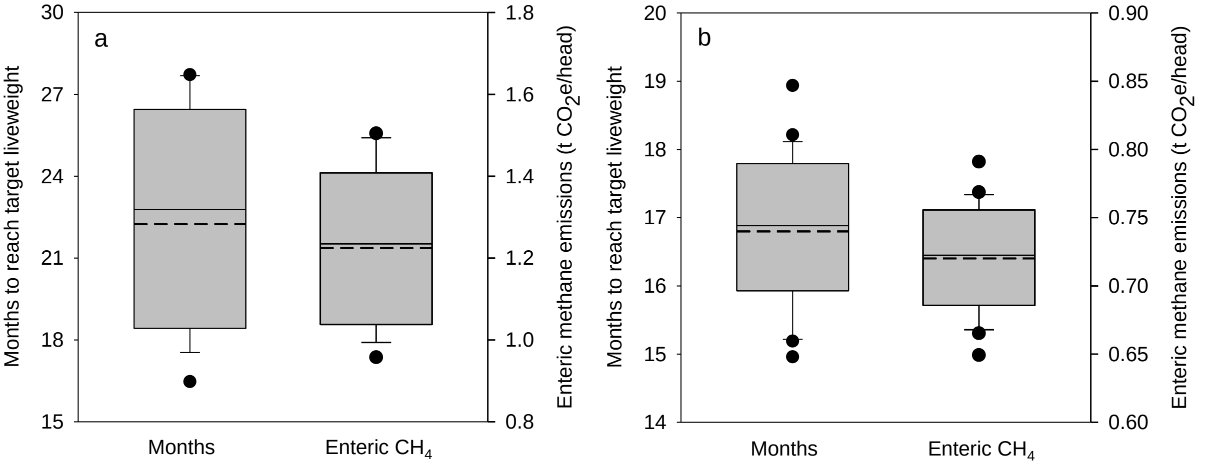

Figure 1. Estimated number of months from weaning to target liveweight for mating (LHS axis) and associated enteric methane emissions (RHS axis) for heifers fed a diet with a mean ME of 9.5 MJ /kg dry matter intake (a) and 10.9 MJ/kg dry matter intake (b). Boxes represent 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, dots represent outliers, solid lines represent medians and dashed lines represent means.

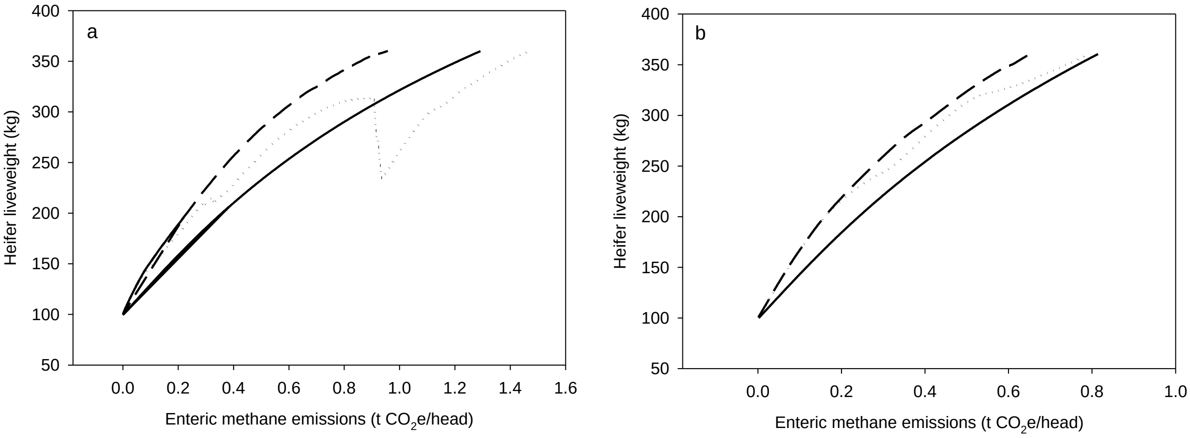

Figure 2. Estimated cumulative enteric methane emissions (t CO_2e/head) for heifers when fed a diet with a mean (± standard deviation) ME of approximately 9.5 MJ/kg DMI (a) and 10.9 MJ/kg DMI (b). The solid lines (———) represents the static approach. The dashed lines (— — —) represents an example of the quickest period to reach target liveweight. The dotted lines (........) represents an example of the slowest period to reach target liveweight.

D4. Project title

Feeding nitrates to extensively-managed beef cattle: impacts on whole farm greenhouse gas emissions, production and profitability

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This paper is in draft with the likely completion post-WFSAM and the submission journal undecided at this stage.

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Abstract

Enteric fermentation is a major source of methane (CH_4) emissions for the livestock sector contributing up to 85% of total carbon dioxide equivalents (CO_2-e) emissions for the agriculture sector. The Australian beef cattle herd, largely dependent on the extensive rangelands of northern regions, has a significant role to play in reducing CH_4 emissions for the agriculture sector. A desktop analysis examined the effect of feeding nitrates (NO_3) to a typical beef production system and a high fertility cross-bred herd for the Longreach district. For a typical beef production system, if there was no previous source of N supplementation (e.g. urea-based licks), feeding NO_3 to the typical beef production system reduced greenhouse gas (GHG) emissions by 4.1 and 6.0% when fed at a rate of 1.0 and 1.5 g NO_3/kg $LWT^{0.75}$, respectively. At a price of \$24.15/t CO_2-e, this equates to a carbon offset income of \$3,054 and \$4,447, respectively. However, some farms already feed N in the form of urea supplementation, resulting in no changes to nitrous oxide (N_2O) emissions from dung and urine. Replacing urea with NO_3-based supplementation increased GHG emissions reductions to 4.9 and 7.1% when fed at a rate of 1.0 and 1.5 g NO_3/kg $LWT^{0.75}$, respectively. At a price of \$24.15/t CO_2-e, this equates to a carbon offset income of \$3,451 and \$5,043, respectively. For a high fertility cross-bred herd, replacing urea with a NO_3-based supplementation reduced GHG emissions by 7.2% when fed at a rate of 1.0 NO_3/kg $LWT^{0.75}$. A gross margin analysis showed that profit for the typical and a high fertility beef production systems could improve by \$4,241 and \$5,758/annum by replacing urea with NO_3-based supplementation when fed at a rate of 1.0 g NO_3/kg $LWT^{0.75}$ based on a carbon price of \$24.15/t CO_2-e and assuming no difference in application cost between a urea and NO_3 supplement. However, if the NO_3 did not replace a urea supplement, the cost of the supplement is 10 times more expensive than the most optimistic CFI gross income scenario and thus would make it very unlikely to be implemented.

Introduction

Enteric fermentation is a major source of methane (CH_4) emissions for the livestock sector contributing up to 85% of total CO_2-e emissions for the agriculture sector (ABS 2010). The Australian beef cattle herd, largely dependent on the extensive rangelands of northern regions, has a significant role to play in reducing CH_4 emissions for the agriculture sector. These rangelands are dominated by C_4 grasses, which are characterised by a rapid pattern of maturity, high levels of fibre, reduced digestibility and lower concentrations of nitrogen and energy compared to temperate pastures

(Minson 1990). Low pasture digestibility is associated with low animal productivity and high CH_4 output/unit intake (Johnson and Johnson 1995). During the dry season, liveweight gain of cattle is low or negative (Dixon and Coates 2010) and supplementation is routine (Bortolussi *et al*. 2005). These supplements are generally based on urea and designed to provide additional rumen degradable protein, stimulate intake of the low energy forage and promote a small liveweight response in the order of 0.1-0.25 kg/day (McLennan *et al*. 1981; Dixon and Coates 2010). The use of dietary additives that could be incorporated into these supplements may be attractive to graziers because there is an existing path to adoption in northern cattle production systems.

Beef cattle on low protein diets, typical of the drier tropical rangeland systems of Australia, increase their efficiency of utilisation of the poor quality forage with urea supplementation, usually in the form of a salt or molasses lick (Dixon 2013). These licks commonly contain around 7 to 11% urea (Dixon 2013). While there is some argument about the amount of urea that should be fed, around 50 g/head.day for breeder cows and 30 g/head.day for dry and growing cattle will result in improved rumen function of cattle, grazing mature grass pastures in northern Australia. Other reports suggest 4 to 10 g/kg liveweight (Dixon 2013). Where the level of protein in pastures is very low (5% and lower) slightly higher amounts may be required (e.g. 70 g/head.day), especially for lactating breeders.

The demand for protein is seasonal, with pasture protein being lowest during the dry months June and December in northern Australia, then rising with the summer rains. This means that urea supplementation should be explored for 6 months of the year or during drought periods, in order to sustain growing or lactating animals.

A recent review of research (Leng 2008) suggests that the urea in a lick can be replaced with nitrate (NO_3) as an alternative source of nitrogen for the rumen microbiota, as long as total NO_3 intakes do not exceed 10 to 25 g NO_3 /kg DMI (0.23 to 0.57% NO_3-N DM basis or 1 to 2.5 g/kg LWT^0.75), although some reports show this can be as high as 2.7 to 4% of the diet (Leng 2008). For a 450 kg steer consuming 10 kg DM per day, this means an intake of between 100 and 244 g NO_3/day with the lower limit equating to ~50 g urea/day.

Nitrate in ruminant diets has a high affinity for H_2 in the rumen, thus reducing the hydrogen available for the formation of CH_4 in the rumen. In addition, the end-product of NO_3 reduction in the rumen is ammonia (NH_3) – a major source of the N for microbial protein synthesis in the rumen, thus providing the same benefit as the urea supplement.

Extensive reviews on dietary mitigation strategies suggest that the introduction of high NO_3 compounds into the rumen have the effect of reducing enteric methanogenesis (Leng 2008). Furthermore NO_3 supplementation has proven to result in successful CH_4 mitigation in diets that require a non-protein source (Nolan *et al*. 2010; van Zijderveld *et al.* 2010; van Zijderveld *et al.* 2011; Hulshof *et al*. 2012). Nitrate supplementation generates an electron sink through the use of hydrogen in the reduction of NO_3 to NH_3 (Leng 2008) and is energetically favourable over the reduction of CO_2 to CH_4. In addition, NO_3 also reduces the number of ruminal protozoa (Sar *et al*. 2005). Since protozoa produce hydrogen that can be used by methanogens, this reduction in protozoa numbers may also contribute to the reduction of enteric CH_4.

There a limited number of *in vivo* studies on the effect of NO_3 on enteric CH_4 from ruminants. Merino crossbred sheep given chopped hay in respiration chambers reduced enteric CH_4 by 23% in response to the addition of 4% K NO_3 (0.6% NO_3-N or 2.7% NO_3) to the diet (Nolan *et al.* 2010) with no detectable changes in DM digestibility or microbial cell outflow from the rumen. The sheep used were acclimated to dietary NO_3 and there was no indication of NO_3 toxicity. Dairy cattle showed a 16% reduction in enteric CH_4, both in g CH_4/day and g/kg DMI, when supplemented with 21 g of NO_3/kg DMI (van Zijderveld *et al.* 2011). Callaghan MS report Nov 13-Mar 14 showed 0% reduction in CH_4.

While NO_3 can be toxic to ruminants, (Leng 2008) suggested that NO_3 accumulation may be avoided if the rumen microbial population has been acclimated to NO_3. The literature in NO_3 e toxicity appears varied with (Eckard 1990) suggesting toxicity in perennial ryegrass to occur above 0.57 to 0.60% NO_3 -N (25 to 27 g NO_3/kg DMI). In a review of literature (Leng 2008) reported likely toxicity in ruminants at levels above 10 to 25g NO_3 /kg DMI (approximately 0.23 to 0.57 % NO_3-N) or above 1 to 1.5 g/kg $LWT^{0.75}$. It would be important to ensure that NO_3 supplements in extensively managed beef cattle do not approach these levels, as the actual intake per animal cannot be closely monitored. Callaghan MS report Nov 13-Mar 14 showed that 50 g NO_3 dosage to steers once daily for seven days (12.5 g NO_3/kg DMI) had a mean blood methaemoglobin concentration measured between two and six hours post dose of 33%, which was significantly greater than other treatments. Cattle dosed with 50 g NO_3 had an elevated heart rate compared to other treatments post-exercise. A significant challenge to respiratory function was evident in the cattle treated with 50 grams of NO_3 a day for seven days then walked for 3 kilometres.

Although NO_3 offers potential to serve as a NPN replacement for urea whilst also reducing CH_4 emissions, there are a number of knowledge gaps to the application. In northern Australian, there is limited labour and capital infrastructure to enable intensive feeding of grazing beef cattle. It is logistically impossible to feed large numbers on a daily basis due to the scale of the grazing operations. Supplements are therefore generally fed free choice as either solidified lick blocks or loose mixes, with a smaller number of graziers utilising molasses or water medication as a carrier for NPN. While it appears the effects of feeding NO_3 on CH_4 production are unequivocal, research to date has focussed upon feedlot and moderate to high digestibility forage diets. A limited number of experiments have utilised low quality forages however these studies largely supplement with moderate to high levels of fermentable energy from grain, protein meal or molasses. These circumstances are markedly different to the diets and supplementary regimes of the northern Australian beef industry as described above. There is no productivity incentive for graziers to oversupply NPN and therefore this sets a natural ceiling for NO_3 inclusion in the total diet even before CH_4 production and safety considerations. Such levels (expressed as a proportion of total intake) appear to be lower than those doses associated with CH_4 reduction in the published literature. The lack of fermentable carbohydrates on these diets may also exacerbate the risk of NO_3 toxicity, especially given the inherent lack of control over supplement intakes. Should NO_3 ingestion elevate blood methaemoglobin concentrations, the oxygen carrying capacity of the blood is impaired (Parkinson *et al*. 2010). In the extensive rangelands, paddock sizes are often very large and cattle must walk to seek both pasture and water. Should NO_3 supplementation reduce exercise tolerance, then both animal productivity and pasture condition may be reduced due to overgrazing.

Method

Data were drawn from a previous case study farm 65 km south of Longreach (23.44°S, 142.25°E), in central Queensland, Australia, being 23,000 ha and located in the Mitchell Grass Downs bioregion. This case study compared a typical beef production system for the Longreach district, with a high fertility cross-bred herd (a complete description of the sites is provided by Cullen *et al.* 2013). The Beef Greenhouse Accounting Framework (B-GAF) was modified to incorporate the effects of NO_3 feeding.

The NO_3 content of the pastures in the simulation was set at 0.2 g/kg DM in spring, 0.6 g/kg DM in summer, 0.4 g/kg DM in autumn and 0.01 g/kg DM in winter, being low and typical of unimproved tropical pasture (Johnson *et al.* 2001). The NO_3 was supplemented at two rates, being 1 and 1.5 g NO_3/kg $LWT^{0.75}$/day based on the data from Leng (2008) and fed between June and December only. These rates were multiplied by the Australian National Inventory (DIICCSRTE 2011) methods estimate of DMI, to provide a total NO_3 intake animal per day. Literature suggests that toxicity in ruminants >10 to 25g NO_3/kg DMI, with sub-clinical toxicity - 5 and 10 g NO_3/kg DMI (Leng 2008). In this simulation the higher rate of 1.5 g NO_3/kg $LWT^{0.75}$ / day meant that the largest animals would be likely to eat up to 24.1 g NO_3/kg DMI.

High levels of NO_3 in the diet may lead to a reduction in voluntary intake in ruminants (Hulshof *et al.* 2012; van Zijderveld *et al.* 2010; van Zijderveld *et al.* 2011). If the total intake of NO_3 is greater than 8.5 g NO_3/ kg DMI then voluntary intake will be reduced by 7.25% (cf. Julian Hill). The modified B-GAF included a check for this effect and adjusted individual intakes accordingly.

The stoichiometry of the reduction of NO_3 to NH_3 is that 1 mol of NO_3 should produce 1 mol of NH_3 and reduce CH_4production by 1 mol or 16 g or 22.4L of CH_4 (1 mol of NO_3) has a molecular mass of 62.00494 g) (Leng 2008). The total NO_3 in the diet was then divided by 62.00494 to calculate the number of mol of NO_3 fed, which was then multiplied by 16 as the molecular mass of CH_4, to estimate the potential CH_4 reduction. To correct for a dose response effect, final abatement potential was calculated by multiplying by -0.17 x g NO_3/ kg $LW^{0.75}$ + 1.13 (van Zijderveld *et al.* 2011). This final figure was then deducted from the total enteric CH_4 as estimated using the national inventory method for beef cattle, then corrected for dose efficiency as above.

To estimate the additional N intake effects in nitrous oxide (N_2O), total NO_3-N intake was converted to CP equivalent by multiplying by 6.25. In the scenarios where the NO_3 supplement did not replace a urea supplement, the calculated CP from NO_3 was then added to the CP in the diet to calculate total daily CP intake. This resulted in a higher N_2O loss from dung and urine as well as indirect N_2O.

Results

The data in Table 1 show the estimated whole farm emissions of CH_4 and N_2O for the case study herd, comparing a baseline (no added NO_3) against NO_3 supplemented at 1 and 1.5 g NO_3/kg $LWT^{0.75}$/day. When supplemented at 1 g NO_3/kg $LWT^{0.75}$/day, enteric CH_4 emissions were reduced by 4.9% (163 t CO_2e/farm) from this herd representing a likely value of $3,451, if costed at $24.15 per tonne CO_2e, or $1,110, if this is costed at the current EU price of $6.80/t CO_2e. At the higher NO_3 supplement rate (1.5 g NO_3/kg $LWT^{0.75}$/day), enteric CH_4 was reduced by 7.1% (238 t CO_2e/farm) from this herd representing a likely value of $5,043, if costed at $24.15 per tonne CO_2e, or $1,621, if this is costed at $6.80/t CO_2e. This would also be the whole herd abatement if the NO_3 supplement displaced a urea supplement, as there would be no difference in N_2O emissions from urine and dung.

In the case where the NO_3 supplement was added to the diet (i.e. either the urea supplement was retained in both the baseline and project, or there was no urea supplement fed prior to the project), then there would be N_2O implications as shown in Table 1. In this case the whole farm abatement would be the last row in Table 1, reducing whole farm emissions by 4.1 or 6.0 % for the two rates, respectively. In this case there would also be a new implementation cost for the abatement action.

In this second case, CH_4 emissions would still be reduced by 4.9% (356 t CO_2e/farm) from this herd, but there was also a 19 and 28 t CO_2e increase in N_2O emissions from the extra N added to the diet, for the two rates, respectively. The net value of this offset would be $3,054 or $4,447, if costed at $24.15 per tonne CO_2e, or $982 or $1,430, if costed at the current EU price of $6.80/t CO_2e for the two rates, respectively.

These strategies were then applied to both the typical baseline herd and high-fertility cross-bred herd at the Longreach case study farm. The gross margins were drawn from the previous case study of this property (cf. Cullen *et al.* 2013), with the likely gross offset income added to the gross margin where NO_3 was fed. The offset income added 2.7% and 1.7% to the gross farm income for the typical and high fertility herds, respectively (Table 2). This was minor compared to the more than doubling of gross margin between the typical and high fertility herds. In theory, both strategies are achievable and could be implemented together improving on the typical herd by $188,370 (Table 2).

The above analysis assumes that a urea-molasses lick can be replaced for the same price as a NO_3 - molasses lick, and does account for a potential reduced voluntary intake.

The typical cost of a lick is around 10 to 12c/head/day, thus for this case study at 1750 AU for the farm this would have cost an additional $31,959 to $38,351 for the lick, excluding additional labour for distribution and monitoring. Therefore the cost of supplementing with NO_3 primarily to secure the CFI offset income would mean paying ~10 times more for the implementation than the gross offset income would generate, under the most optimistic scenario. It would certainly not be an economic proposition unless the primary driver of adoption was to redress a protein deficiency, with the offset income being a secondary consideration.

Conclusions

Nitrate supplementation of beef herds low protein diets, typical of the drier tropical rangeland systems of Australia may be marginally financially viable at a higher carbon price, but only where NO_3 directly replaces a currently used urea supplement at no or little change in implementation costs.

However, if the NO_3 did not replace a urea supplement, the cost of the supplement is 10 times more expensive than the most optimistic CFI gross income scenario.

This analysis also assumes no accidental death from NO_3 toxicity. In the higher rates of NO_3 feeding (1.5 g NO_3/kg $LWT^{0.75}$/day) some animals would be ingesting NO_3 close to toxic levels. In order to manage these risks it would therefore be more realistic to aim at lower levels of NO_3 supplementation in practice.

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Table 1. Whole farm greenhouse gas emissions and likely offset at two prices, for a cross-bred, high fertility herd near Longreach (1750 AU), fed a with a nitrate lick fed at 1 and 1.5 g NO_3/kg $LWT^{0.75}$ / day. If urea was replaced by the nitrate lick, there would be no change in N2O emissions and thus the nitrate lick would result in only a reduction in enteric methane emissions.

	Baseline	1.0 g/kg DMI		1.5g/kg DMI		Offset income 1.0 g/kg DMI		Offset income 1.5 g/kg DMI	
GHG source	t CO_2e	t CO_2e	%	t CO_2e	%	\$24.15/t CO_2e	\$6.80/t CO_2e	\$24.15/t CO_2e	\$6.80/t CO_2e
CH_4-Enteric	3,342	3,178	-4.9	3,103	-7.1	\$3,451	\$1,110	\$5,043	\$1,621
CH_4-Manure	3	3	0	3	0	\$0	\$0	\$0	\$0
N_2O-N fertiliser	0	0	0	0	0	\$0	\$0	\$0	\$0
N_2O-Indirect	49	55	12.6	58	19.0	-\$130	-\$42	-\$195	-\$63
N_2O- Dung & Urine	109	122	11.6	128	17.4	-\$267	-\$86	-\$400	-\$129
Net farm emissions	3,502	3,357	-4.1	3,292	-6.0	\$3,054	\$982	\$4,447	\$1,430

Table 2. Whole farm greenhouse gas emissions and gross margin (assuming an offset income paid at \$24.15 /t CO_2e), for a typical versus cross-bred, high fertility herd near Longreach (both 1750 AU), fed a nitrate lick at 1.0 g NO_3/kg $LWT^{0.75}$ / day.

Herd	GHG emissions (t CO_2-e)	Gross margin after interest (\$)	Difference from typical
Typical ^{A}	3,341	\$157,153	
Typical + Nitrates ^{B}	3,165	\$161,394	\$4,241 $^{(B-A)}$
Early joining and high fertility ^{C}	3,342	\$339,765	\$182,612 $^{(C-A)}$
Early joining and high fertility + Nitrates ^{D}	3,103	\$345,523	\$188,370 $^{(D-A)}$

D5. Project title

Using a modelling approach to estimating the greenhouse gas emissions of dairy cows grazing pasture mixtures and spatially adjacent monocultures containing perennial ryegrass (*Lolium perenne*), plantain (*Plantago lanceolata*) and white clover (*Trifolium repens*)

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This paper is in preparation so the final paper may be different to that presented here. The paper is being prepared for a dairy conference proceeding such as the Australasian Dairy Science Symposium

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Abstract

The reliance of perennial ryegrass (*Lolium perenne* L.) as a monoculture for grazing dairy cattle has some limitations, including bimodal growth with dominance in spring production during the transition from vegetative to reproductive development. Diversification of the forage base with alternative pasture and/crop species can potentially even out the seasonal distribution of pasture supply and improve feed quality. White clover (*Trifolium repens* L.) and plantain (*Plantago lanceolata* L.) were established as a mixed sward with (RCPM) or without (CPM) perennial ryegrass and as a spatially adjacent sward with perennial ryegrass (SAM) and grazed by dairy cattle during three experimental periods in north-western Tasmania. The greenhouse gas emissions intensity (EI) of milk production was estimated for each herd across the three experimental periods using the Dairy Greenhouse gas Abatement Strategies calculator. When comparing the three alternative swards to the perennial ryegrass only sward (PRG), the only significant ($P<0.05$) difference in EI occurred in the September experimental period with the SAM sward herd estimated to have a significantly higher EI, at 0.61 kg carbon dioxide equivalents (kg CO_2e) per kg of fat and protein corrected milk (FPCM), compared to the PRG sward at 0.49 kg CO_2e/kg FPCM with the RCPM and SAM swards intermediate, at 0.52 and 0.54 kg CO_2e/kg FPCM, respectively. There was no significant ($P>0.05$) differences in EI between the four forage swards during the January and May experimental periods. While there were significant ($P<0.05$) differences between swards within experimental periods with respect to the estimated proportion of total GHG emissions emitted as either enteric methane, methane from manure management or nitrous oxide from manure management, the absence of overall differences in EI suggests that including other forage species to a perennial ryegrass sward may not assist in reducing the EI of milk production when only focusing on the emissions of the cow in isolation of other sources of on-farm emission such as from nitrogen fertiliser.

Introduction

Perennial ryegrass (*Lolium perenne* L.) dominated pastures are the principle feed source of dairy cattle in temperate regions of southern Australia (Doyle *et al.* 2000; Chapman *et al.*, 2008). Perennial ryegrass pastures are generally considered to be fast and reliably established, relatively easy to manage and having a strong response to irrigation (Rawnsley *et al.* 2007) and nitrogen (N) fertiliser applications (Holmes *et al.*, 2002; Tharmaraj *et al.*, 2008). All these attributes result in perennial ryegrass being considered a cost-effective feed option for southern Australian dairy systems

(Chapman *et al.*, 2009; Clark *et al.,* 2013). However, perennial ryegrass can have some limitations including low productivity during the summer months, especially under rainfed or sub-optimal irrigated conditions (Neal *et al.*, 2009; Waller and Sale, 2001) and the bimodal distribution of pasture growth with a dominance of spring growth which is associated with the transition from vegetative to reproductive development, leading to reduced nutritive value (Jacobs and Woodward, 2010; Rawnsley *et al.* 2007). The use of forage species to complement perennial ryegrass with respect to quantity, nutritive value or seasonality of production is not a novel idea (Chapman *et al.*, 2014; Farina *et al.,* 2011; Rawnsley *et al.*, 2013). Diversification of the forage base with companion pasture species can potentially even out the seasonal distribution of pasture supply. This may assist in reducing the amount of excess spring pastures being conserved and then transferred to other times of the year and/or the need to purchase expensive supplementary feed to fill these feed gaps (Chapman *et al.,* 2014, Tharmaraj *et al.*, 2014). The current study examined whether the inclusion of white clover (*Trifolium repens* L.) and plantain (*Plantago lanceolata* L.), as complementary forage species to perennial ryegrass, could reduce the greenhouse gas (GHG) emissions intensity of milk production.

Methods and materials

Grazing experiment

The experiments were undertaken at the Tasmanian Dairy Research Facility at Elliott, Tasmania, Australia (41.08°S, 145.77°E). Three experiments were undertaken, covering mid lactation (January 2013), late lactation (May 2013) and early lactation (September/October 2013). In each experiment four replicate herds of four lactating spring calving cross bred dairy cows were grazed continuously on four forage treatments (a total of 64 cows). Each herd was balanced for age, milk production, days in milk, live weight and breed. The forage treatments were a monoculture of perennial ryegrass (PRG), a mixture of perennial ryegrass, white clover and plantain (RCPM), a mixture of white clover and plantain (CPM) and spatially adjacent monocultures of perennial ryegrass, white clover and plantain (SAM) where cows were offered an equal area of each species monoculture. See Pembleton *et al.* (2015) for details on herd milk production (litres/cow.day, milk fat % and milk protein %), liveweight (kg) and liveweight gain (kg/day) and diet intakes (kg DM/cow.day), average dry matter digestibility (DMD %) and average crude protein (CP %)

Greenhouse gas emissions estimations

The Dairy Greenhouse gas Abatement Strategies (DGAS) calculator (Christie *et al.*, 2012) was adapted to estimate the GHG emissions on a daily basis (kg carbon dioxide equivalents (CO_2e)/cow.day) for the four herd replicates grazing the four forage treatments across the three experimental periods. The emissions intensity (EI) of milk production (kg CO_2e/kg of fat and protein corrected milk (FPCM)) was estimated by dividing total GHG emissions by milk production. In the absence of consistent significant differences in EI across experimental periods, while the proportion of total emissions as enteric methane (CH_4), CH_4 from animal manure management and nitrous oxide (N_2O) from animal manure are presented, they are not discussed in the results or discussion sections.

Statistical analysis

Mean EI of milk production, and proportion of total GHG emissions as enteric CH_4, as CH_4 from animal manure management and as N_2O from animal manure management (sum of N_2O lost to the environment from manure deposited directly onto pastures during grazing, from manure stored at the dairy and subsequently spread onto pastures and indirect N_2O emission) for each forage sward by experimental period were analysed using the ANOVA procedure of R (R Core Development Team, 2013). Differences were considered significant when $P<0.05$. All results with respect to the EI of milk production were discussed.

Results

The only experimental period where there was a difference in the EI was during the September experimental period, with the herd grazing the CPM pasture sward emitting 0.61 kg CO_2e/kg FPCM which was significantly higher than the herds grazing the PRG and RCMP swards, at 0.49 and 0.52

kg CO_2e/kg FPCM, respectively. The EI of the herd grazing the SAM sward was not significantly different to any other herd, at 0.54 kg CO_2e/kg FPCM. The EI was greatest in the May experimental period, varying between 0.66 and 0.75 CO_2e/kg FPCM while the EI was lowest in the January experimental period, varying between 0.45 and 0.55 CO_2e/kg FPCM.

Table 1 near here

Discussion

Overall, there was only one significant difference in the EI of milk production across the three experimental periods, during the early lactation experimental period, with the CPM herd emitting an addition 0.12 kg CO_2e/kg FPCM above the control PRG herd. The EI of the herd grazing the CPM sward was significantly higher as a consequence of the CPM herd exhibiting a greater liveweight gain over the 5-day experimental period. Due to the methodology equations in DGAS, increased liveweight gain increases daily intake and therefore increased enteric CH_4 emissions. With no substantial increase in milk production, relative to the other three herds, the increased GHG emissions could not be diluted and thus resulting in the highest EI of milk production.

This study didn't examine the whole-of-farm systems GHG emissions, taking into consideration other sources of GHG emissions that might vary between pasture swards. The most obvious one is that white clover provides a source of N to the pasture sward and therefore the reduction and/or removal of N fertiliser requirements. The inclusion of white clover in the RCPM and CPM swards may reduce the reliance of synthetic fertilisers for N supply. Likewise, one-third of the SAM sward contained white clover as a monoculture so reducing the N requirements of the pasture sward by two-thirds. For a typical farm applying 200 kg N/ha.annum, the GHG emissions associated with this amount of N is approximately 1.24 t CO_2e/ha.annum (Christie *et al.,* 2012). There is the potential that this additional GHG source may have resulted in significant differences in EI for the January experimental period, as the GHG emissions from herd grazing the PRG sward was 0.1 kg CO_2e/kg FPCM higher in EI than the RCPM sward, with the former requiring N fertiliser input and the latter requiring a reduction in N inputs during periods of the year when clover growth was minimal.

Conclusion

This study has shown that there was little benefit in changing the feedbase from a perennial ryegrass only sward to one inclusive of white clover and plantain with respect to reducing the GHG emissions intensity of milk production when only considering the cow's emissions. Assessment of a whole-of-farm GHG emissions intensity may provide a different outcome when the consideration of N fertiliser inputs, and their associated N_2O emissions and manufacturing GHG emissions, is taken into consideration for the forage swards containing white clover.

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Table 1. Mean emissions intensity and proportion of total greenhouse gas emissions from enteric methane, manure methane and manure nitrous oxide for four pasture swards across three experimental periods.

Experimental period	Pasture sward	Emissions intensity (kg CO_2-e/kg FPCM	Enteric CH_4 (%)	Manure CH_4 (%)	Manure N_2O (%)
Early lactation-September	PRG	0.49 b	70.6 a	8.2 b	21.2 b
	RCPM	0.52 b	69.2 ab	8.8 b	22.0 b
	CPM	0.61 a	61.3 c	10.9 a	27.8 a
	SAM	0.54 ab	65.6 b	9.3 b	25.1 a
	P value	<0.05	<0.01	<0.01	<0.01
	SED	0.04	1.8	0.5	1.3
Mid lactation-January	PRG	0.55	71.1 b	9.3 b	19.4 a
	RCPM	0.45	74.4 a	8.4 c	17.2 b
	CPM	0.54	71.1 b	10.0 a	19.1 a
	SAM	0.53	71.1 b	9.3 b	19.7 a
	P value	ns	<0.05	<0.01	<0.05
	SED	0.06	1.4	0.4	0.7
Late lactation-May	PRG	0.68	69.0 a	6.3 c	24.7 bc
	RCPM	0.71	67.4 bc	6.9 b	25.7 ab
	CPM	0.66	68.6 ab	7.3 a	24.1 c
	SAM	0.75	67.1 c	6.7 b	26.2 a
	P value	ns	<0.05	<0.001	<0.01
	SED	0.04	0.5	0.1	0.4

CH_4= methane, N_2O = nitrous oxide, PRG = Perennial ryegrass only sward, RCPM = Perennial ryegrass, white clover and plantain sward, CPM = White clover and plantain sward, SAM = spatially adjacent monocultures of perennial ryegrass, white clover and plantain.

Letters which differ within an emission source and experimental period denote a significant difference in the proportion of total emissions attributed to that source.

D6. Project title

Broad-scale adaptation of extensive sheep enterprises to climate change

Organisations Tasmanian Institute of Agriculture, CSIRO

Primary contact Matthew Harrison

This paper is in preparation so the final paper may be different to that presented here. The research builds upon previous work on pasture and livestock interventions to climate change that have been published in this series ('Climate change and broadacre livestock production across southern Australia') conducted at CSIRO.

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Abstract

Greenhouse gas emissions (GHG) from broadacre livestock production constitute a substantial proportion of total Australian agricultural emissions. The highly diverse nature of broadacre livestock farming across southern Australia obviates accurate estimation of livestock GHG emissions at the regional level by scaling up results from a common farm or from a set enterprise. To realistically capture this diversity we used a farm system modelling approach and equations from the Australian National Greenhouse Gas Inventory to determine whole farm emissions of three representative sheep enterprises in 25 regions across southern Australia using climatic data from 1979-2000, with regions classified according to their average annual rainfall and dominant land use. Each farm/location used the average statistics for that location (land area, rainfall etc.) to set the optimal sustainable stocking rate for that region The study area covered some 3.3×10^5 m^2, representing 84% of the Merino ewe, crossbred ewe/lamb and Merino wether enterprises predominating the region. We used a least squares, linear model of the main effects (adaptation, location, enterprise, year) to examine the influence of 13 interventions to pasture management or to animal genotype on net farm emissions, emissions profiles and emissions per unit land area, dry sheep equivalents (DSE) or product (hereafter, emissions intensity or EI).

Most adaptations that increased production also increased net emissions, resulting in little change in EI. As a corollary, adaptations capable of decoupling the tight linkage between production and emissions were most effective at reducing EI, even though such adaptations may have small effect on total productivity. The adaptations that resulted in lower GHG from livestock related activity, across locations, enterprises and years, were consistently the removing annual legumes, confinement feeding, increasing the area of lucerne and higher fleece weight options, no matter how the GHG or EI were calculated. The best locations that resulted in lower GHG from livestock related activity, across adaptations, enterprises and years were consistently Minnipa, Waikere, Swan Hill, Cunderin, Southern Cross and Mullewa. The worst locations were consistently Ellinbank, Armidale, Launceston, Coolac and Mansfield. These results also highlight differences in GHG emissions intensities metrics, and the need for standardised EI metrics across studies.

Introduction

Greenhouse gas (GHG) emissions from livestock dominate current Australian agricultural emissions and are projected to account for 72% of total agricultural emissions by 2020 (DCCEE 2013). Past research examining strategies for GHG mitigation from the livestock sector has primarily been reductionist, focussing on either a single intervention strategy (e.g. rumen microbial manipulation), a given GHG (typically CH_4), or on measurements of GHG fluxes at the individual animal level (SF_6 tracer techniques) (Harrison *et al.* 2014i).Further whole of farm analyses of intervention strategies to livestock enterprise management and animal genotype are required to generate a holistic view of biophysical feedbacks occurring within these systems, since such analyses can reveal important interactions between key and sensitive variables (Alcock *et al.* 2014; Harrison *et al.* 2014a). For instance, improving animal diet quality can increase liveweight gain with little change in production of enteric CH_4 and can lead to lower GHG emissions per unit animal product (hereafter, emissions intensity or EI). However, improved diet quality may also result in greater dry matter intake (DMI) per animal, such that no net change or even a net increase in GHG emissions can be observed at the whole farm level (Eckard *et al.* 2010). Whole farm level assessments of GHG emissions are also necessary in any regional scale analysis to appropriately account for the diversity of plant and animal genotypes, environments and management systems typically encountered at larger scales (Moore and Ghahramani 2013a).

Previous work has assessed the relative production efficacy and profitability of a range of interventions to pasture management and animal genotype to southern Australian livestock production, both under current and future climates (Ghahramani and Moore 2013; Moore and Ghahramani 2013b). This work demonstrated that a foremost current limitation to livestock production in southern Australia is the constraining effect of a minimum ground cover requirement on stocking rates, and thus proposed several adaptation options to address the risk of soil erosion. Ghahramani and Moore (2013) showed that important pasture adaptation options in ameliorating the negative impact of lower rainfall and higher temperatures expected with future climate change include increasing soil fertility by addition of phosphorus, adding lucerne to a proportion of the feed-base and confinement feeding of livestock during summer, in that order. Moore and Ghahramani (2013b) later reported that breeding animals for greater fleece weight (at constant body size) was likely to invoke the greatest improvements in forage conversion efficiency, and, to a lesser extent, breeding ewes for higher conception rates was also a viable option for crossbred ewe enterprises to increase pasture utilisation, similar to results documented in a detailed ewe fecundity study (Harrison *et al.* 2014i). Together, these studies highlighted the fact that combinations of feedbase and livestock genetic adaptations could be complementary or counter-productive, with the former governing forage availability and forage consumption and the latter influencing the efficiency with which forage was converted to animal product (Moore and Ghahramani 2013b).

Adaptations to sheep enterprises do not always affect profitability, production and net GHG emissions in a mutually aligned direction (Alcock *et al.* 2014; Harrison *et al.* 2014a; Ho *et al.* 2014). Alcock *et al.* (2014) showed that average annual profitability of self-replacing Merino flocks increased by 18% by reducing the joining age of maiden ewes, even though total wool production did not change and net GHG emissions increased. The corollary is that such adaptations tend to have a wide range of effects on EI, and that adaptations increasing productivity do not necessarily reduce EI. Indeed, Harrison *et al.* (2014e) demonstrated that interventions increasing soil fertility raised both production and emissions; consequently this strategy had little effect on EI. They concluded that the best strategies for both sustainably increasing production and reducing EI were those that decoupled the linkage between production and emissions, a relationship that was most often very strong. Taken collectively, these findings suggest that adaptations to sheep enterprises designed to maximise profitability or production at the regional scale may not be coincident with enterprise adaptations designed to either mitigate emissions or to reduce EI.

Here we build upon previous work (Ghahramani and Moore 2013; Moore and Ghahramani 2013a, 2013b) in determining the effects of pasture management adaptation and variation in animal genotypic traits on net farm GHG emissions and EI. Because these studies were carried out within a larger program of research, development and extension (Pattinson 2011), they were able to collate detailed data from farmers and extension agents regarding the management, type and distribution of sheep enterprises across southern Australia; heretofore a gathering of such geographically diverse but detailed information has not been undertaken. We apply systems models to scale the results of X pasture and Y animal genotype interventions from the farm level to the landscape level with the aim of identifying strategies that not only increase productivity and profitability but also maintain or reduce GHG emissions at sustainable stocking rates.

Materials and methods

Study location attributes and enterprises examined

To capture the highly diverse nature of broadacre livestock farming enterprises across southern Australia we used the GRAZPLAN simulation models (Moore and Ghahramani 2013a) and equations from the Australian National Greenhouse Gas Inventory (Browne *et al.* 2011) to determine whole farm emissions of three representative sheep enterprises across southern Australia, where regions were classified according to their rainfall and land use. Enterprises specialised in either (1) Merino ewe production for both fine wool and lambs for meat, (2) Merino × Border Leicester cross ewes with an emphasis on lamb production, or (3) Merino wethers for fine wool production and Merino ewes, following previous work on the impacts of climate change in these production systems (Moore and Ghahramani 2013a). In attempt to encompass the diversity in soil types, climates and typical forage species found in the 1 x 10^6 m^2 study area across southern Australia, 25 separate regions were classified according to their average annual rainfall and dominant land use, representing some 84% of total Australian sheep production (Table 1). A single Australian Bureau of Meteorology weather station was selected to represent each region on the basis of weather and management data availability; all simulations were conducted using historical climates measured between 1979 and 2000. Climates and soil types across the study region varied widely, with ranges in annual rainfall and temperature at the locations modelled of 299-1091 mm and 11.6-19.1°C, respectively, and with soil types ranging from deep sands to red-brown earths to sandy-clay loams. Pasture composition also varied substantially across the study area but in general consisted of an annual or perennial grass combined with a perennial legume, such as perennial ryegrass with white clover. Average annual above-ground productivity (ANPP) for each enterprise × location combination was weighted according to region size and varied from 3137 to 14,334 kg/ha (Table 1). To simplify the analysis further, and to enable insight into how farm productivity and emissions were related to prevailing climate, we sub-classified each site in Table 1 into similar climatic zones, following a modified Koeppen classification system and long-term average climatology records (BoM 2015). Further information on site characteristics, climate, pasture and soil data is given in Table 1 of Moore and Ghahramani (2013a) and Table 3 of Ghahramani and Moore (2013).

To facilitate comparisons between regions, identical livestock genotypes were modelled within each enterprise in all climate zones (Table 2). Management policies (livestock replacement, the timing of the reproductive cycle, the sale of young stock and thresholds for supplementary feeding) were described separately for each of the 25 x 8 location x 3 enterprise combinations following Moore and Ghahramani (2013a). Information on typical management systems elicited by State agency officers in producer workshops was used where possible; otherwise expert opinion, literature accounts and preliminary simulations were used to derive sensible values. The date of age at purchase and age at sale of crossbred ewes and wethers at each location were set to be compatible with the reproductive cycle of the Merino ewe enterprise. At locations in the cereal-livestock zone stubble availability was modelled by removing livestock from the paddocks when there was less than 800 kg/ha of available green herbage in any paddock; these animals were provided with an *ad libitum* diet approximating that which can be expected for sheep on stubble paddocks (Moore and Ghahramani 2013a).

Table 1 Historical pasture and livestock production and farm profitability: optimal sustainable stocking rates (OSSR), long-term average livestock and wool sales and operating profit for three livestock enterprises (ME, Merino ewes; CE, crossbred ewes; W, wethers/ewes) at each of 29 locations under historical climate (1979–99). OSSR values are given immediately after entry of replacement animals. Further details are provided in Ghahramani and Moore (2013). Abbreviations: ANPP = above-ground net primary productivity, CFW = clean fleece weight, DM = dry matter, LWT = liveweight.

Location	ANPP (kg DM/ha)	Fertility scalar (0-1)	OSSR (animals/ha)			Livestock sales (kg LWT/ha.year)			Wool production (kg CFW/ha.year)			Operating profit ($AUD/ha.year)		
			ME	**CE**	**W**	**ME**	**CE**	**W**	**ME**	**CE**	**W**	**ME**	**CE**	**W**
Armidale	6641	0.8	4.5	4	7.8	162	241	81	34	25	34	274	248	137
Bakers Hill	10339	0.8	13.2	8.5	13.9	450	601	162	64	35	57	405	477	214
Birchip	5081	0.7	4.4	3	3.1	108	162	34	20	13	10	109	100	–2
Colac	12472	0.85	16.4	11.1	17.6	427	749	223	64	57	74	449	756	352
Condobolin	4100	0.7	1.4	1.2	3.2	36	61	37	7	5	14	25	23	58
Cootamundra	8801	0.8	7.8	5.4	9.9	211	377	93	27	20	39	229	318	155
Cummins	5263	0.7	2.4	1.9	3.3	73	125	39	12	10	14	64	96	43
Dalwallinu	4147	0.8	1.8	1.4	2.5	55	92	22	9	6	10	51	56	31
Ellinbank	14334	0.8	20.6	13	22.6	560	943	295	85	70	94	855	1132	488
Esperance	6834	0.8	2.4	2	3.7	92	141	32	12	7	14	94	104	35
Goulburn	6974	0.75	5.8	5.3	7.4	159	277	86	33	25	29	249	202	102
Hamilton	11029	0.85	11.9	7.4	12	296	539	261	45	40	50	367	499	233
Katanning	6275	0.8	2.2	1.2	3.1	82	110	31	11	7	14	90	105	44
Kyancutta	3322	0.8	0.9	0.8	1.2	25	40	13	4	3	5	16	19	13
Lake Grace	3137	0.8	0.8	0.4	1	26	29	9	4	2	4	19	16	9
Lameroo	4034	0.7	2.1	1.2	1.5	53	69	15	10	6	6	48	41	5
Launceston	8296	0.75	8.3	5.6	13.6	298	374	157	38	32	55	378	424	277
Lucindale	7958	0.75	6.8	4.9	8.1	216	310	102	36	24	36	302	297	150
Mansfield	7855	0.8	8.1	5.3	9.1	232	334	111	37	26	38	299	311	170
Mt Barker	10776	0.9	10.4	8	12.5	319	518	130	48	33	56	407	544	221
Narrandera	6977	0.8	5.8	4.1	7.5	201	279	65	22	22	31	193	230	125
Stawell	8004	0.8	7.5	5.5	8.7	202	343	105	32	29	37	256	321	162
Swan Hill	4014	0.8	3	2.4	3.1	70	118	32	13	10	11	64	64	41
Tatura	6780	0.8	6.3	4.9	7.3	164	276	87	26	23	30	226	264	153
Wellington	5939	0.8	4	3.9	5.4	118	223	64	21	20	23	163	203	100

Table 2 *Attributes of livestock enterprises modelled at each of the 25 regions (see text for further details). Ranges indicate the minimum and maximum values across all regions.*

	Merino ewes	**Crossbred ewes**	**Wethers**
Genotype of main flock	Merino	Border Leicester × Merino	Merino
Standard reference weight (kg)	50	60	50
Reference fleece weight (kg greasy wool)	5.0	5.0	5.0
Reference wool fibre diameter (µm)	19.0	23.0	19.0
Ram genotype	Merino	Border Leicester	NA
Standard reference weight of rams (kg)	70	84	NA
Adult mortality rate (% per year)	4	4	4
Source of replacement livestock	Self-replacing	Purchase	Purchase
Age at entry (months)	4-15	13-20	5-18
Age at sale (months)	63-78	73-82	54-77
Birth date of lambs	9 Apr-1 Oct	29 May-6 Sep	23 Feb-1 Sep
Age at sale of lambs (months)	4-17	4-19	8-18

Stocking rates, supplementary feeding and ground cover

Stocking rates were determined for each of the 75 enterprise × region combinations according to annual weather conditions, environmental and economic risk constraints following an approach similar to that outlined by Harrison *et al.* (2014a). Stocking rates varied across both years and enterprises, as well as with flock age structure and ewe nutritional requirements (pregnant, lactating etc.), with a minimum of 0.4 DSE/ha at Lake Grace and a maximum of 22.6 DSE/ha at Ellinbank (Table 1). Optimally sustainable stocking rate (OSSR; after Warn *et al.* 2006) were identified in each enterprise × region combination as the stocking rate which maximized long-term operating profit (see below), subject to the constraint that average farm ground cover should be less than 0.7 on no more than a threshold proportion of days, since soil erosion rates below 0.7 increase rapidly. The minimum ground cover frequency was allowed to vary with growing-season rainfall, for consistency with the stocking rates elicited for each grazing system, and are shown in Table 1. A range of 9-15 stocking rates for each enterprise × region combination were initially simulated to allow selection of each OSSR. To compute greenhouse gas emissions on a daily time-step (see below), pasture and livestock variables and ground cover values were recorded on a daily basis in each simulation then aggregated as appropriate. The OSSR for each location × enterprise combination was identified by interpolating relevant simulation results, and all other statistics were interpolated from the simulation outputs at that stocking rate following Moore and Ghahramani (2013a). All results shown here are reported at the OSSR for each location x enterprise combination.

Long-term average production and operating profit

Long-term average annual livestock sales, wool production and profitability are shown in Table 1. In general livestock sales and operating profit were greatest for cross-bred ewe enterprises, and wool production was greatest for wether/ewe enterprises, although there was considerable variation across sites and between enterprises within sites. In all enterprises operating profit was more closely related to livestock sales than to wool production, and livestock numbers in turn were closely associated with

ANPP (Table 1). These data underscore the strong positive relationship between average annual rainfall on operating profit typically observed in Australian extensive livestock grazing systems.

Operating profit ($/ha) was used to compare enterprises and adaptation strategies since this metric is likely to be a major determinant of choices made by Australian producers given the relatively unregulated and low-subsidy environment in which livestock production occurs. The definition of operating profit used here follows that of Moore and Ghahramani (2013a) and is comparable to profit at full equity. Operating profit was calculated as gross income (the sum of product price × quantity of product from sales of each of young stock, culled livestock and wool) less operating costs (animal husbandry, supplementary feed, shearing, livestock trading, wool sales, fertilizer and operator allowance). Costs and prices were computed as 5-year (2006–2010) average values and were assumed to remain constant from year to year and across enterprises where possible. Fertiliser costs associated with maintaining soil fertility were estimated after Ghahramani and Moore (2013) as a function of the grazing pressure and maintenance soil phosphorus requirement. Adaptation strategies were also compared using a 'relative effectiveness' financial metric (*RE*; Eqn 1):

$$RE = (P_A - P_H) / P_H \qquad \textbf{(1)}$$

with P_A equal to the operating profit when an adaptation has been implemented and P_H as the operating profit observed historically.

Pasture adaptation strategies

Pasture adaptation options were identified from literature reviews and livestock producer experience gathered in workshops (these data were collated within a larger program of research, development, and extension; see Pattinson 2011 for further information) and are documented fully in Ghahramani and Moore (2013). Briefly, these included:

(1) Higher soil fertility: Increasing soil nutrients via phosphorus availability (in the GRAZPLAN models soil fertility is modelled using a fertility scalar that ranges from 0 to 1). Baseline soil fertility varied across locations and was based on local practise and soil condition; where possible they were decided in project workshops in consultation with producers and local advisors. Higher soil fertility was examined by raising the fertility scalar in each paddock by 0.1. At locations where the fertility scalar in at least one paddock was less than 0.7, a second level of fertility was also considered, where the fertility scalar in each paddock was raised by 0.2 or to a maximum of 0.9.;

(2) Confinement feeding: placing all animals in a feedlot between 1 December and 31 July each year when total pasture shoot mass fell below 2000, 1500 or 1000 kg/ha to prevent soil erosion; animals were returned when total green mass exceeded 500 kg/ha;

(3) Increased proportion of farm area sown to lucerne: increasing the proportion of farm sown to pure lucerne pasture to either 20% or 40%; we posited that this intervention would increase pasture biomass and ground cover during summer, thereby reducing soil erosion risk;

(4) Removing annual legumes: Removing annual legume species was postulated to reduce competition with and permit greater growth of grass species, thereby reducing potential for low ground cover and soil erosion risk over summer. We hypothesized that this would allow higher average annual stocking rates and increase long-term profitability.

All results shown here represent the level of each factor generating the highest operating profit for each location × enterprise combination.

Livestock genotype intervention strategies

Adaptations to animal genotype were selected based on consultation with livestock producers (Pattinson 2011) and are described fully by Moore and Ghahramani (2013b). Briefly, greater body size was examined under the rationale that maintenance energy requirements relative to body size decreases as body size increases, leaving more energy for growth, wool production or reproduction. Animals with higher fleece weight were assessed since animals expressing this trait would be expected to divert a greater proportion of their energy intake into wool growth, assuming the energy diversion did not compromise survival or reproduction. Greater ewe fecundity was included in the analyses since the trait has been shown to increase whole farm production without concurrently increasing net farm GHG emissions or stocking rate (Harrison *et al.* 2014e). For the crossbred ewe enterprise, sires with higher body weight were examined under the presumption that larger rams would yield larger offspring, and such offspring should have greater growth rates allowing earlier sale. The final adaptation to animal genotype tested was improved heat tolerance, since exposure to high temperature tends to reduce food intake and fertility. All livestock interventions were contrasted on the basis of forage conversion efficiency (FCE, $/kg), defined as the ratio of gross income from meat and wool to mass of pasture dry matter consumed. FCE was computed as the sum of conversion efficiency multiplied by product price for meat and wool following Moore and Ghahramani (2013a).

Whole farm greenhouse gas emissions

Greenhouse gas emissions were determined using equations for broadacre sheep grazing specified by the Australian Government Department of Climate Change and Energy Efficiency (DCCEE 2012) and converted into subroutines of VBA code for use in an Excel spreadsheet containing GrassGro output (livestock data, such as numbers of sheep, DMI, CP, LWG, wool etc. were summarised on a monthly basis for each location/enterprise/adaptation combination, resulting in 253,512 rows of monthly data). In contrast to previous work determining whole farm emissions of prime lamb enterprises on a seasonal basis (Alcock *et al.* 2014; Harrison *et al.* 2014a; Harrison *et al.* 2014e), the present study computed emissions on a daily time-step, which was considered more accurate given temporal variation in pasture quality and quantity, livestock number and liveweight. GHG emissions were calculated on a CO_2-e basis for methane from enteric fermentation and manure deposition and nitrous oxide from leaching and run-off and livestock urine and faeces. All emissions and end products were aggregated into annual totals across all livestock classes (using VBA subroutines) where appropriate. Dry sheep equivalents (DSE) for breeding ewes and other stock classes were calculated based on the season of lambing for the location/enterprise and relative mature size and metabolisable energy intake (Morley 1993, NSW DPI 2015). Autumn, winter and spring lambing breeding Merino ewes were given DSE values of 2.2, 2.0 and 1.7 respectively, while crossbred ewes had these values multiplied by 1.2 due to their larger size.

Statistical analysis

Linear models of all significant effects were fit to the yearly data using JMP (2014) as follows:

Independent variable (GHG emissions) = adaptation + location + enterprise + year + residual.

Including interactions in the statistical model resulted in less degrees of freedom and rendered several least square means (LSMs) undefined, so interactions were not fit in this analysis.

Stacked histograms of adaptation and location results were made to collate the various sources of livestock related GHG into the one graph and the standard error bars were shown for the LSM of total GHGs. The LSM of total GHG equals the sum of the LSMs of the GHG components.

Results

This study is still in progress and the results are not yet finalised. Below are the preliminary results to date.

Goodness of fit of statistical models fitted to greenhouse gas emissions metrics

The main effects of adaptation explained over 90% of the variance of all independent variables (GHG per farm, per ha, per ha/100mm rain, per t wool, per t meat and per 1000 dse).

Greenhouse gas emissions per farm

The annual emissions uncorrected for the size of farm and rainfall are shown in Figure 1a for the adaptations and Figure 1b for the locations.

The interventions that improved emissions relative to the baseline included confinement feeding and zero annual legumes, because total productivity of these adaptations was reduced relative to baseline levels. The best locations (lowest annual GHG) were Mullewa, Waikerie, Minnipa and Swan Hill. The worst locations were Armidale and Launceston.

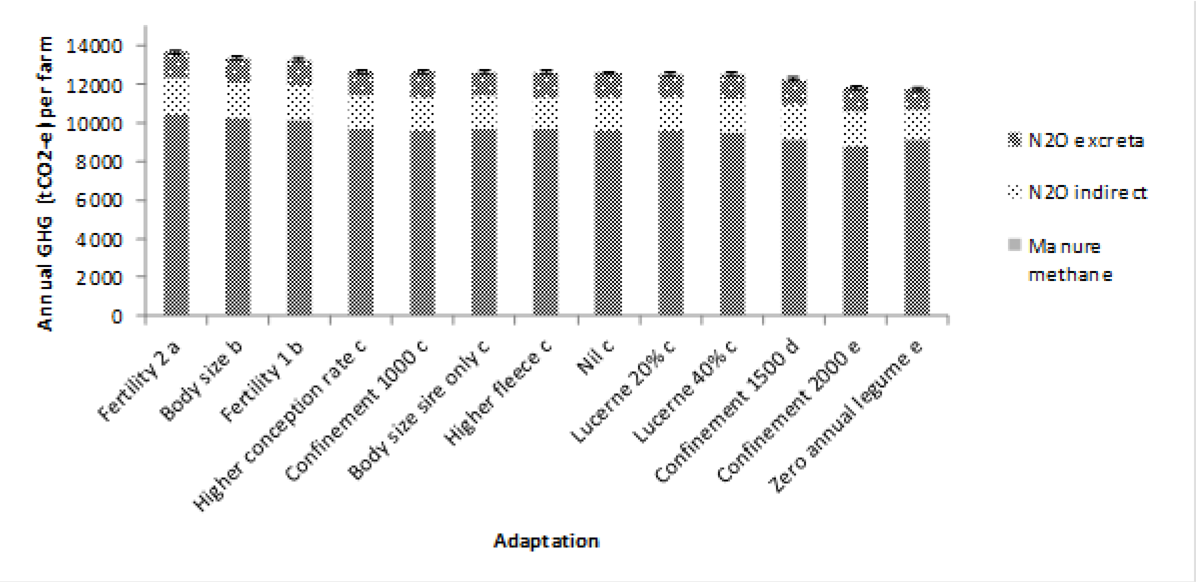

Figure 1a. The annual emissions per farm for each strategy.

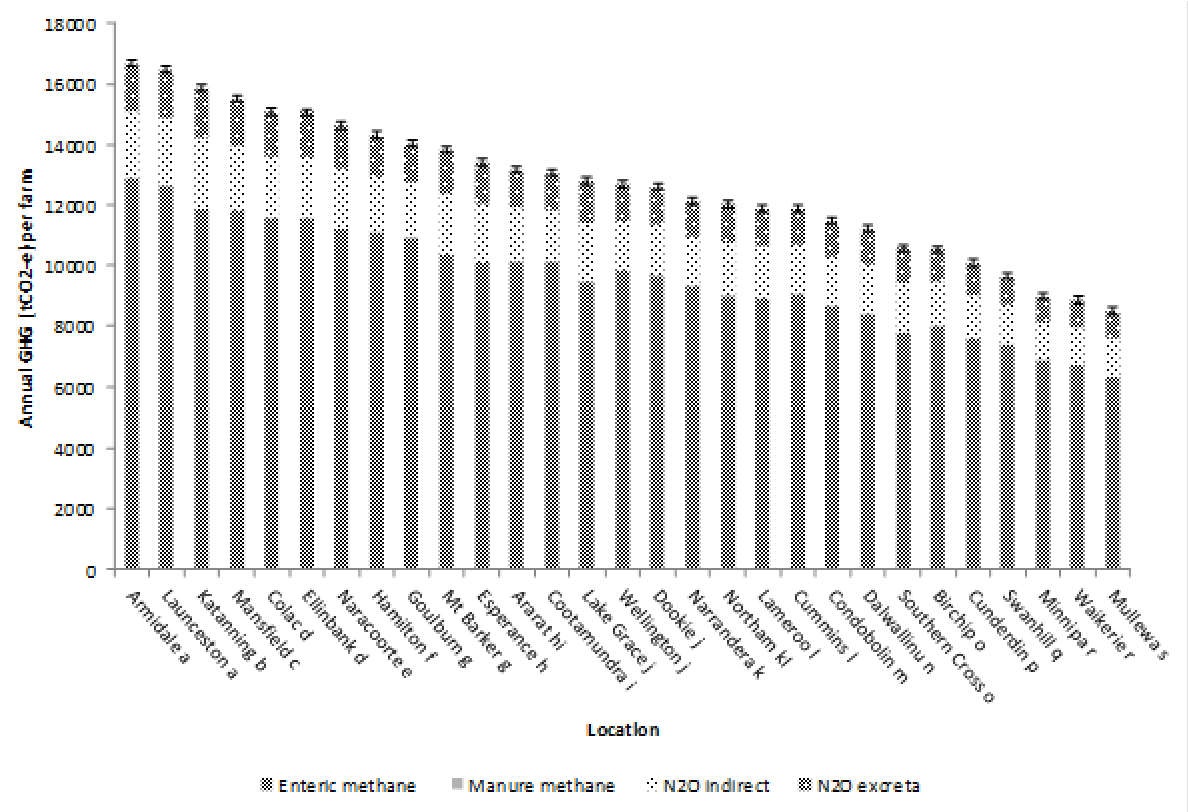

Figure 1b. The annual emissions per farm at the various the locations modelled.

Per hectare results

The annual emissions corrected for the size of farm are shown in Figure 2a for the adaptations and Figure 2b for the locations. The interventions that were better than non-intervention were: zero annual legume, confinement and body size sire only options. The best locations (lowest annual GHG) were Mullewa, Waikerie, Cunderin and Lake Grace. The worst locations were Coolac and Ellinbank. There was a large difference between the best and worst location.

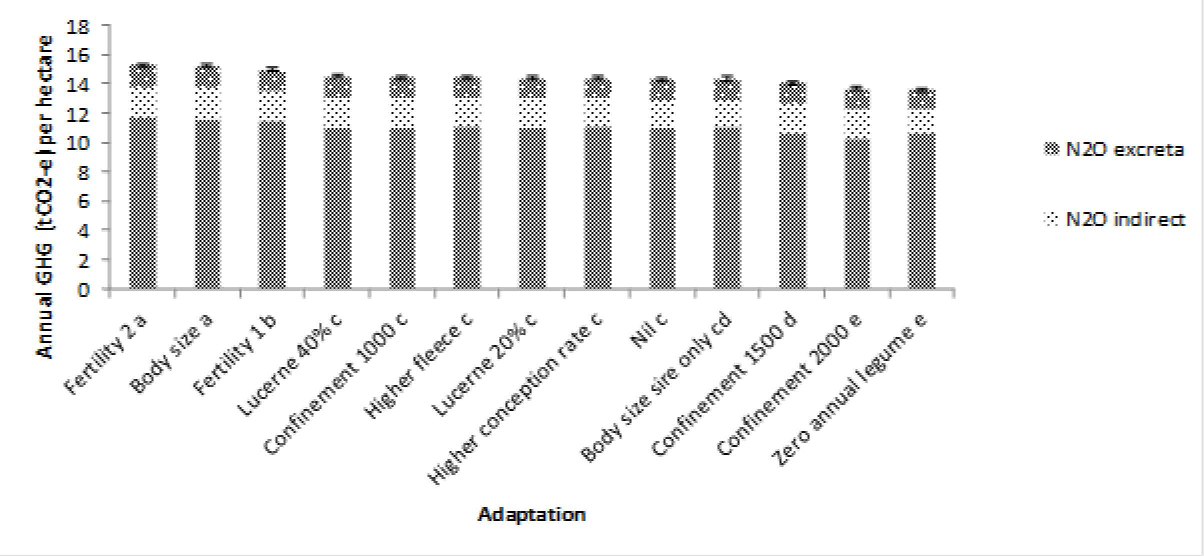

Figure 2a. The annual emissions per hectare for each strategy.

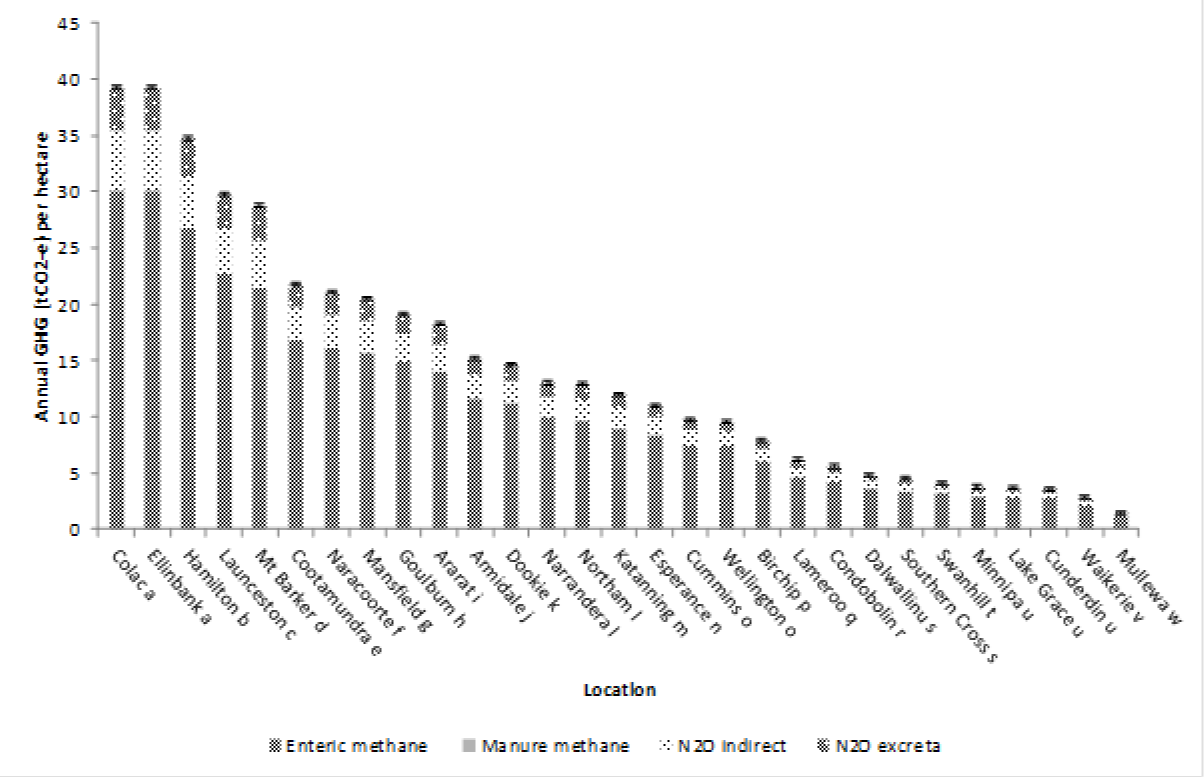

Figure 2b. The annual emissions per hectare at the various the locations modelled.

Per ha per 100mm rain

The annual emissions corrected for the size of farm and rainfall are shown in Figure 3a for the adaptations and Figure 3c for the locations. The interventions that were better than non-intervention were: zero annual legume and confinement. The best locations (lowest annual GHG) were Swan Hill Cunderin and Mullewa . The worst locations were Colac, Hamilton and Launceston.

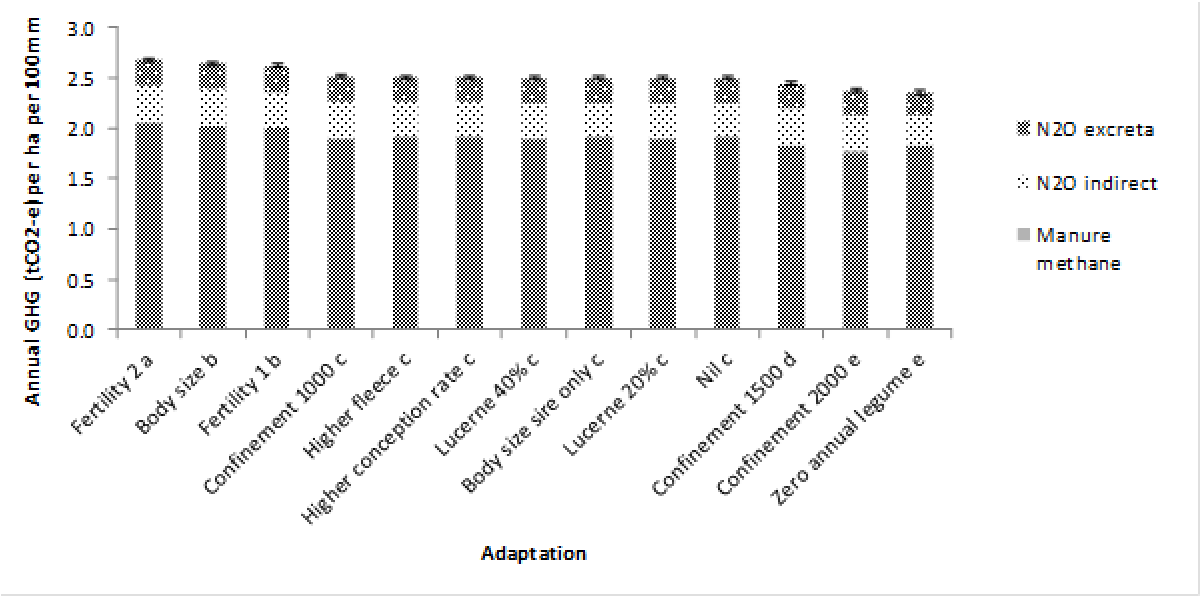

Figure 3a. The annual emissions per 100m rainfall for each strategy.

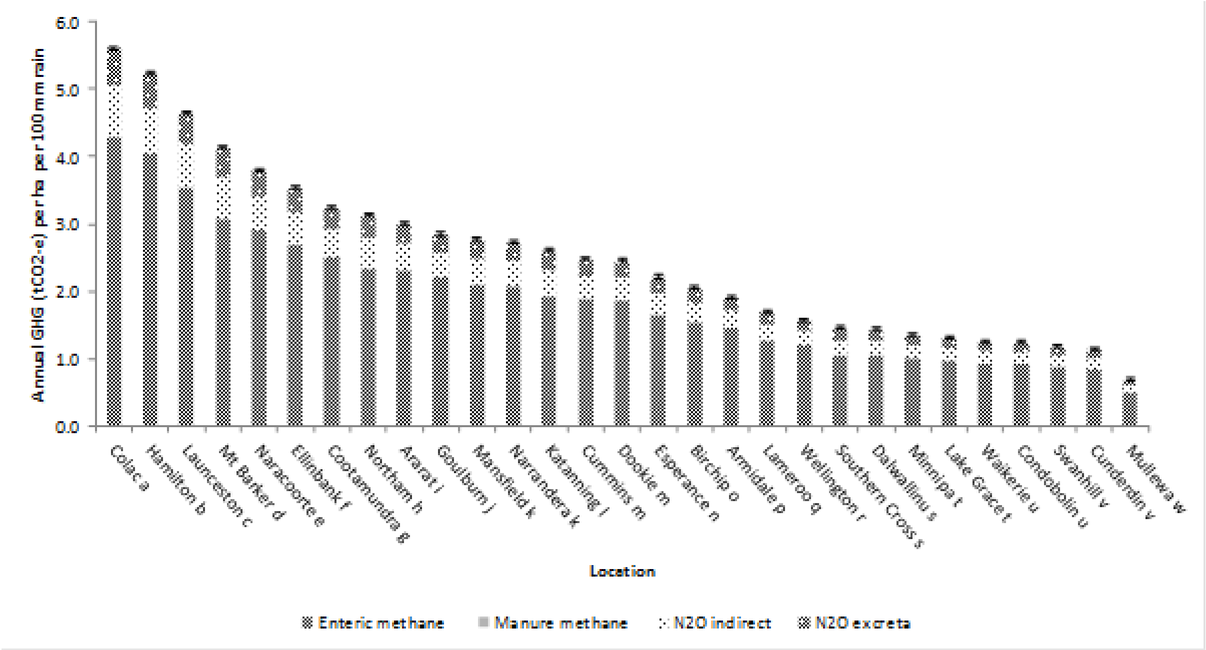

Figure 3b. The annual emissions per 100 mm rainfall at the various the locations modelled.

Per tonne of wool

The annual emissions per tonne wool grown (which corrects for farm effects) are shown in Figure 4a for the adaptations and Figure 4b for the locations. The interventions that were better than non-intervention were: higher fleece, confinement, zero annual legume and body size options. The best locations (lowest annual GHG) were Mullewa, Cunderin, Southern Cross and Minnipa. The worst locations were Ellinbank, Mansfield and Coolac.

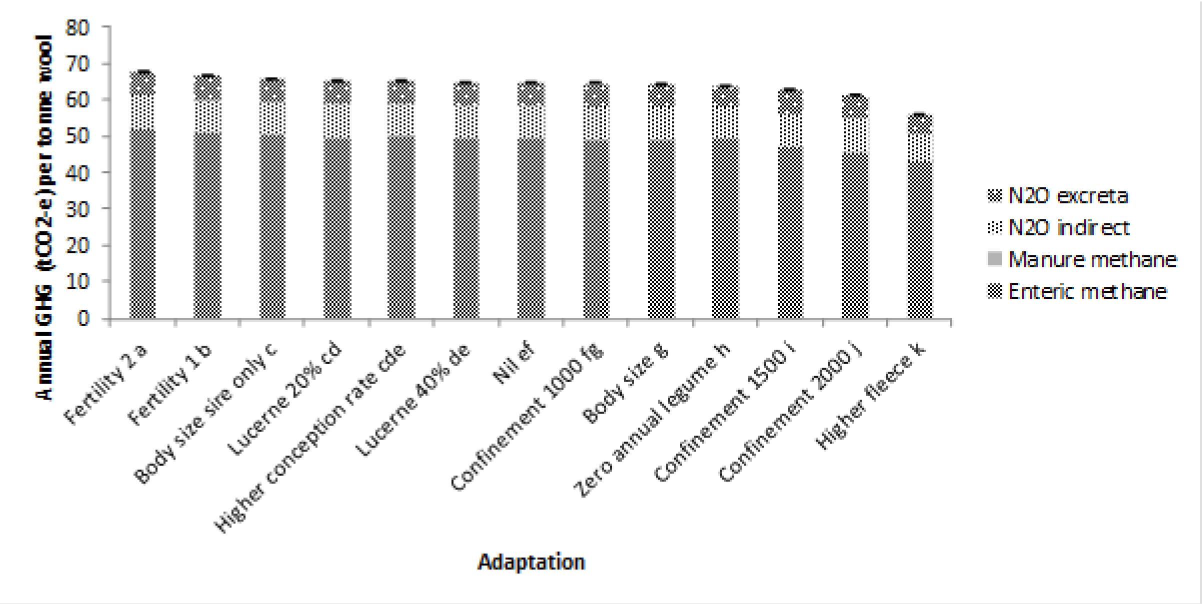

Figure 4a. The annual emissions per tonne wool for each strategy.

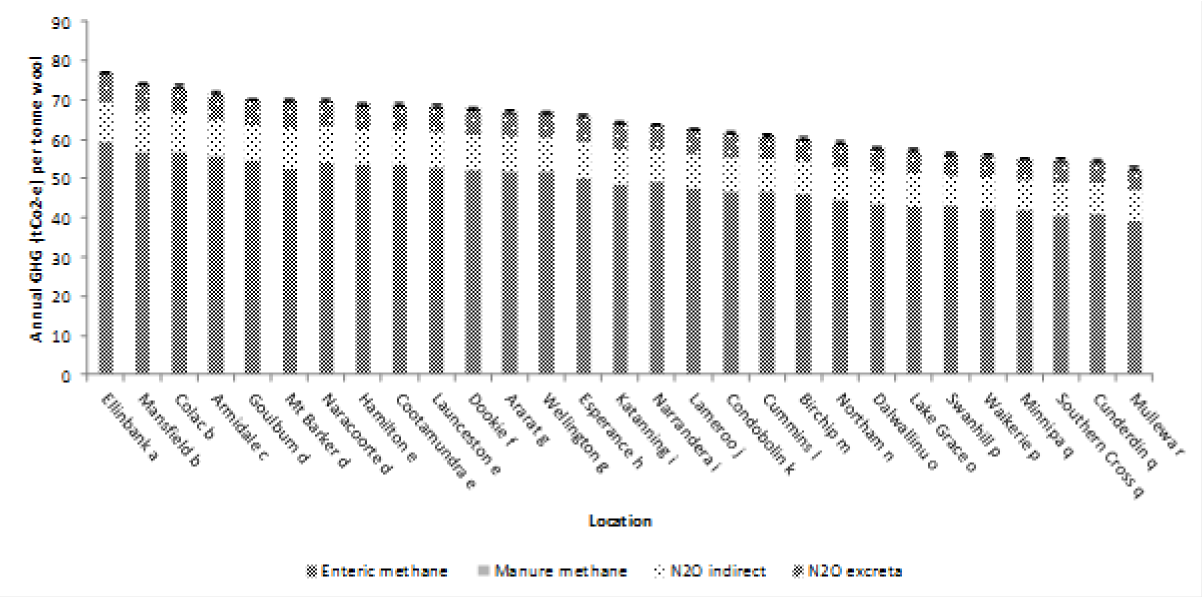

Figure 4b. The annual emissions per tonne wool at the various the locations modelled.

Per 1000 dse

The annual emissions per 1000 dse run (which corrects for farm effects) are shown in Figure 5a for the adaptations and Figure 5b for the locations. The interventions that were better than non-intervention were: zero annual legume, confinement and higher fleece. The best locations (lowest annual GHG) were Minnipa, Waikere, Swan Hill and Mullewa. The worst locations were Ellinbank, Armidale and Mansfield.

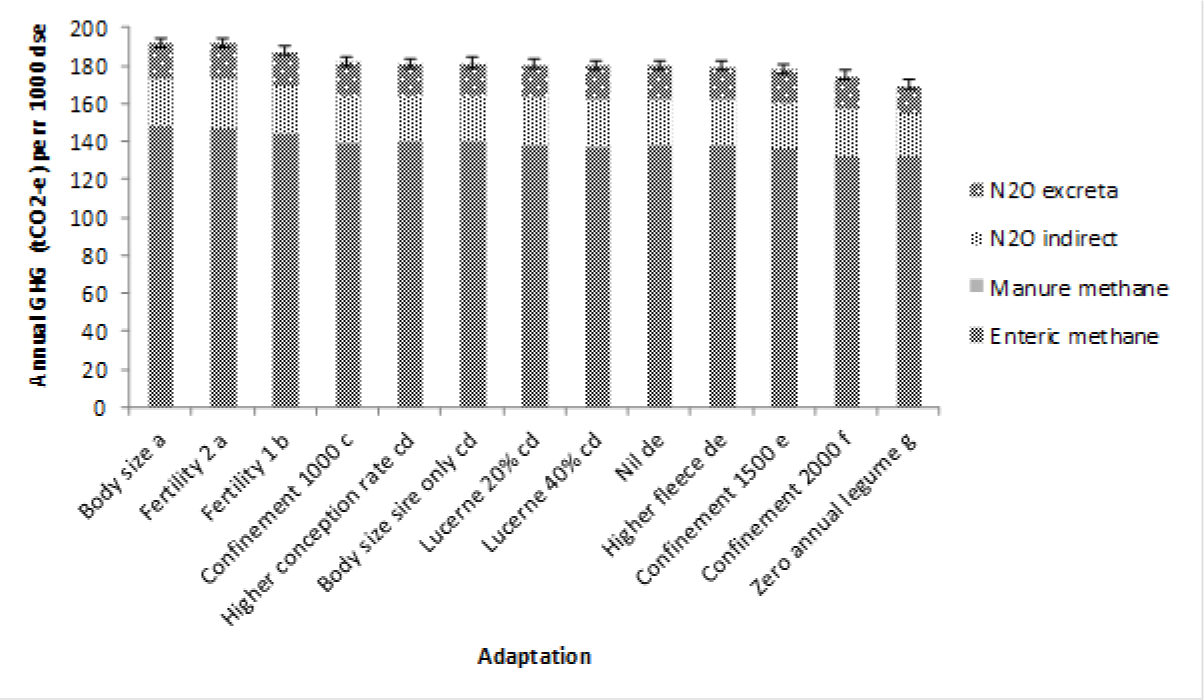

Figure 5a. The annual emissions per 1000 dse for each strategy

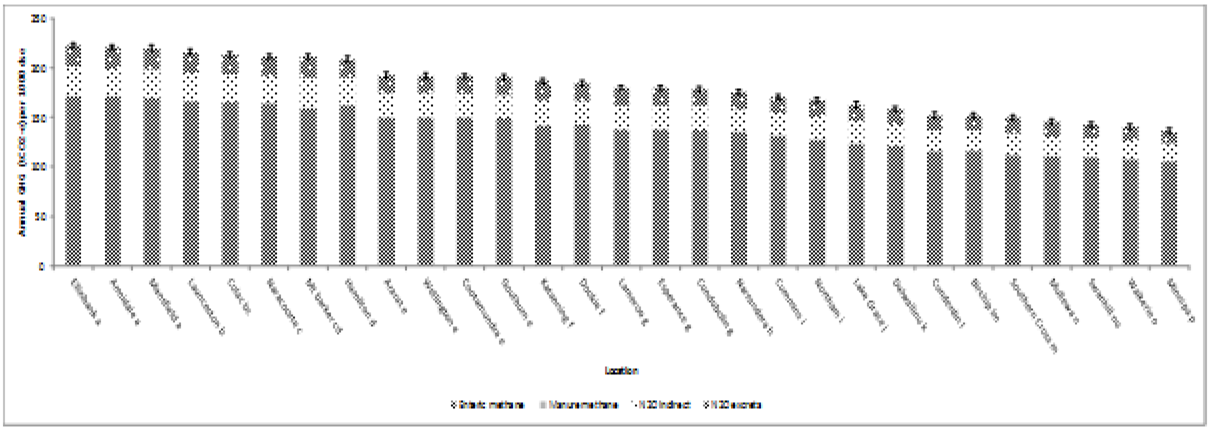

Figure 5b. The annual emissions per 1000 dse at the various the locations modelled.

Discussion

Adaptations

The adaptations that resulted in lower GHG from livestock related activity, across locations, enterprises and years, were consistently the removing annual legumes, confinement feeding, increasing the area of lucerne and higher fleece weight options, no matter how the GHG or EI were calculated.

Locations

The best locations that resulted in lower GHG from livestock related activity, across adaptations, enterprises and years were consistently Minnipa, Waikere, Swan Hill, Cunderin, Southern Cross and Mullewa. The worst locations were consistently Ellinbank, Armidale, Launceston, Coolac and Mansfield.

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D7. Project title

Whole farm responses to rising costs from greenhouse emissions and changes in climate

Organisation Department of Economic Development, Jobs, Transport and Resources (formerly Department of Environment and Primary Industries)

Primary contact Alexandria Sinnett

Executive summary

This study examined the impact of climate change on two representative beef farms. It demonstrated that climate risk will be another risk that farmers have to manage. A hotter and drier climate is expected to reduce profit, cash and wealth with the extent of the decrease dependent on the severity of the climate scenario. To remain profitable under the medium climate change scenario, only small changes to the farm business are required. However, to remain profitable under the high climate change scenario, significant changes to a farm business would be required.

This study has also shown that while a change to a farm business could be worthwhile economically (profits and returns could increase), the change might not be financially feasible (the business may not earn sufficient cash to meet debt servicing obligations). Analysis of options to change the farm system should consider, the human, technical, economic, financial and risk aspects of the change.

Background

Australia's mean temperature has warmed by 0.9°C since 1910. The impact of this warming is that the distribution of monthly temperatures has changed so there are now more hotter days and fewer cold nights (Bureau of Meteorology and CSIRO 2014). The climatic challenges faced by agriculture in the future have been described by Henry *et al.* (2012) and include changes in annual rainfall and changes in the frequency, duration and intensity of extreme weather events.

This changing climate is expected to have an impact on pasture growth. Increasing CO_2 in the atmosphere promotes pasture growth, but when this occurs with reduced rainfall, pasture growth is impeded (Moore and Ghahramani 2013). Eckard (2012) found 'current pasture systems are reasonably resilient to changes in average temperatures forecasted to 2050'. Pittock (2003) (cited in Cowie and Martin 2009) found that if rainfall declined by more than 10%, the expected impact will be reduced pasture growth.

A changing climate is also expected to have an impact on livestock farming in other ways; such as increased heat stress, reduced forage quality and potentially an increase in pests and diseases e.g. cattle ticks (Stokes *et al.* 2010 and Marcogliese 2001).

Farmers have adapted in the past, and will continue to adapt, to a changing climate and increased climate variability. Many climate adaptation options are similar to existing 'best practice' and don't require farmers to make radical changes to their operations in the near future (Stokes and Howden 2011). The costs and benefits of a range of climate adaptation options for the sheep and beef industries have been examined by Ghahramani and Moore (2013). Strategies Ghahramani and Moore (2013) investigated included increasing soil fertility, confinement feeding (placing animals in a feedlot during summer and autumn when pasture mass is low), and increasing the proportion of land under lucerne pasture. They found that increasing soil fertility and the addition of lucerne to the feedbase had the greatest impact on increasing farm profit. However, in their conclusion, Ghahramani and Moore (2013) stated that more significant changes to the farm system compared with those analysed in their study, will be required to recover production and profitability in the face of changing climates past 2050. They suggest that the type of change required for 2050 onwards ' …might involve combinations of incremental adaptations, transformational adaptations, new technologies, or a complete re-thinking of the feed-base ...'

Another way to consider adaptation is to do so from the perspective of managing the risks associated with a changing climate. Howden *et al*. (2008) argued that there needs to be a move from the rhetorical focus of adaptation to climate change toward the management of climate risk. Loch *et al.* (2012) went further, saying that farmers have to manage the risks of a variable climate within years as well as over time. However, managing climate risk is not done in a vacuum and there are other factors at play (Smit and Skinner 2002). As Smit and Skinner (2002) state:

> *Despite the important influence of climate change, including variability and extremes, adaptation in agriculture does not function and evolve with respect to these climatic stimuli alone. Non-climatic forces such as economic conditions, politics, environment, society and technology, clearly have significant implications for agricultural decision making, including adaptive decision-making.*

That is, as one would expect, farmers adapt their farm businesses in response to a number of risky variables – climate and non-climate related. It would be too narrow to focus on the ways farmers can cope with a variable climate without including the other risks that farmers have to contend with.

In a discussion with a panel of industry experts, comprised of farmers, scientists and consultants, about how a beef farmer located in either a high rainfall area, or a low rainfall area could manage their business in a hotter and drier climate, the ideas put forward for managing a hotter and drier climate were to:

- Create a business that allows for a flexible stocking rate such as:
    - Establishing a trading arm to the farm system (30% of the farm system)
    - Agisting stock
- Improve soil fertility
- Conserve more fodder in good years (and increase the amount of infrastructure on-farm to store fodder)
- Establish a good stock containment system (removing cattle from pasture and feeding them in a confined area)
- Include lucerne in the farm system
- Diversify the farm business by:
    - Including sheep in the farm system
    - Owning both farms and spreading the risk (using the higher value farm to finish stock and the lower value farm for the older less valuable stock)

A number of these suggestions have been explored by others, but the option of owning both the high and low rainfall properties and utilising the farms to feed different classes of livestock is an approach to re-thinking the current feedbase. This would enable the farm operator to spread the risk associated with climate change by using the higher value farm to finish stock and the lower value farm for the older, less valuable stock.

The propositions tested in this study were that:

1. Under a hotter and drier climate, livestock farm businesses will be less profitable than they are today in the absence of change.
2. Climate risk can be managed through operating two farms that are located in different climate zones

These propositions were tested using the case study method.

Method

Approach and research questions

The specific research questions investigated were:

1. How does a change in climate in 2020 and 2050 impact a representative beef farm located in a 'high rainfall' zone (Penshurst), or a low rainfall zone (Dookie)?
    a. What is the profitability (return on assets managed) and wealth (growth in equity), of the farm in the current environment (2014)?

   b. What is the return on assets managed and growth in equity if the farm was operated in the same way, but in a hotter and drier environment?
   c. Could the business still service debt obligations if it operated in a hotter and drier climate?
2. By how much does income need to increase to counteract the costs of climate change?
3. If the farmer owned both properties and used one for the breeding herd and the other for finishing the herd – would this increase the profitability of the business?

A mix of climate modelling, biophysical modelling, economic and financial modelling were used to answer these questions. Consideration of risk was incorporated using @Risk, an add-in program in Excel (Palisade 2013). The variability of future prices of beef, costs of supplementary feed and amounts of supplements fed were included by defining probability distributions for these key uncertain variables. Monte Carlo simulation was used to randomly select values for variable inputs from the specified probability distributions and to estimate distributions of whole farm outcomes over a run of years. The results presented in this analysis are based on 5,000 iterations of single-year 'runs' of the model of the farm business.

The climate modelling (as detailed in Taylor *et al.* 2015) provided a forecast of temperature, rainfall and CO_2 levels which was translated, using Weather Maker Pro, into a file that could be used in GrassGro. The five climate scenarios considered are presented in Table 1. (For a detailed discussion of each of these different scenarios and definitions of medium and high climate scenario see Taylor *et al.* 2015)

Table 1. Climate scenarios analysed for each representative farm.

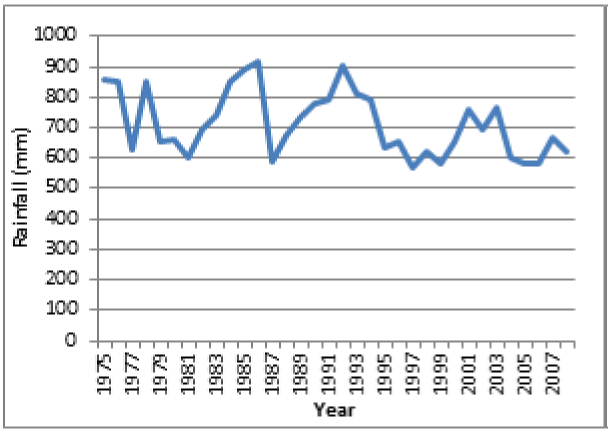
	Climate scenarios
Scenario 1	Based on past 40 years of historical climate data
Scenario 2	Based on projections for the relevant area in 2020 under medium climate change
Scenario 3	Based on projections for the relevant area in 2020 under high climate change
Scenario 4	Based on projections for the relevant area in 2050 under medium climate change
Scenario 5	Based on projections for the relevant area in 2050 under high climate change

GrassGro was used for the biophysical modelling of the farms. The economic and financial modelling were based on the principles of farm management economics (described in Malcolm *et al.* 2005).

The representative farms

The representative farms were based on data from the beef component of a mixed farm and cross-checked against average data for beef farms in Northern Victoria and Western Victoria in the Livestock Farm Monitor project (Waterman and Creese 2014).

The high rainfall farm is 290 hectares and located in Penshurst where the long-term average annual rainfall is 750 mm. The pastures are a mix of sown perennial and annual grasses and clovers. The pasture growth and rainfall is presented in Figure 1 and Figure 2. The average stocking rate across the property is 20.7 DSE/ha, equivalent to 1.5 cows/ha. On average 12 t DM/ha, of pasture is grown every year and 49% of this is consumed by the cattle. It was assumed the farmer owners had 80% equity ($1.1 million) in the business.



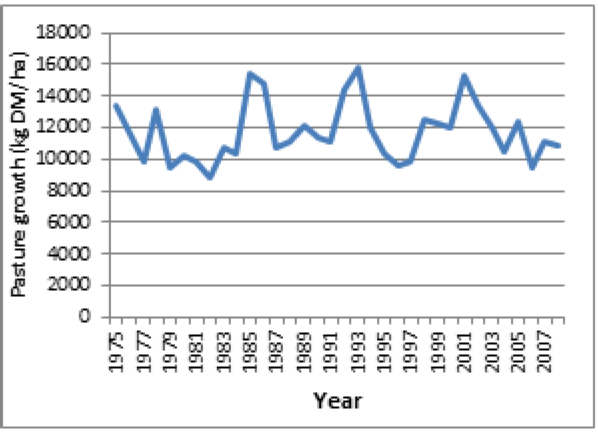
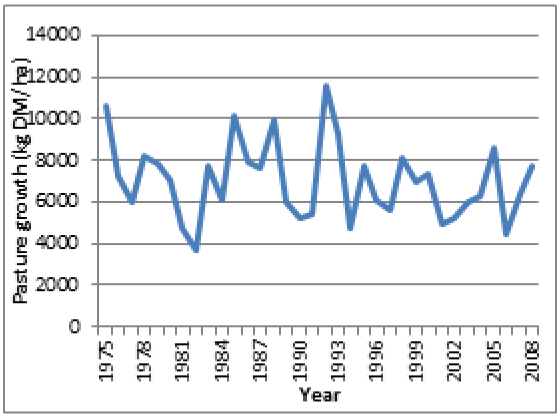


Figure 1. Pasture growth (kg DM/ha) on the high rainfall beef farm under historical climate conditions based on GrassGro modelling.

Figure 2. Rainfall (mm) based on historical climate data for Penshurst.

The low rainfall farm is 580 hectares and located in Dookie where the long-term average annual rainfall is 550 mm. The farm has red duplex soils with phalaris pasture. Pasture growth and rainfall is presented in Figure 3 and Figure 4. The average stocking rate across the property is 6.9 DSE/ha, equivalent to 0.5 cows/ha. On average 7 t DM/ha, of pasture is grown every year and 49% of this is consumed by the cattle. Compared with the Penshurst farm, the Dookie property is situated on less productive and more marginal land, and it was assumed the farm owners needed a higher level of equity in the business (90%) to operate profitably.



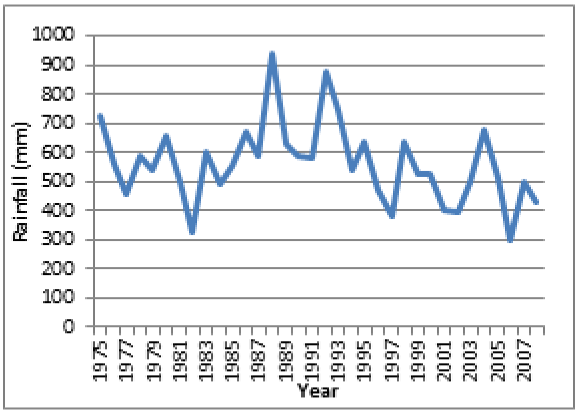


Figure 3. Pasture growth (kg DM/ha) (GrassGro) on the low rainfall farm under historical climate based on GrassGro modelling.

Figure 4. Rainfall (mm) based on historical climate data for Dookie

The final farm system considered was based on the farmer owning both the Dookie and Penshurst farms (as described above). In this combined farm operation, it was assumed that the majority of the breeding herd would be located at Dookie. At the time of weaning (5 months of age) the steers were transported to Penshurst and then finished at Penshurst. The weaner heifers remained on the Dookie farm. GrassGro modelling was used to estimate the change in feed requirements and supplementary feeding as a result of combining the high and low rainfall properties. The cost of transporting livestock between the properties was $82.22/tonne of liveweight transported (Goucher 2011).

The technical, economic and financial assumptions for each of the representative farms are presented in Table 2 to Table 4.

Table 2. Technical assumptions for each of the representative farms.

	Penshurst farm	Dookie farm	Combined farm
Herd details	435 breeders Spring calving, self-replacing	290 breeders Spring calving, self-replacing	722 breeders Spring calving, self-replacing
Land area	290 hectares	580 hectares	870 hectares
Target liveweight of steers sold	450 kg	450 kg	450 kg
Number of steers and heifers sold	244	160	404
Tonnes of supplement fed (historical climate)	0.6	0.5	0.4
Cull cows	20% of the herd	20% of the herd	20% of the herd
Mortality	2%	2%	2%
Beef dressing %	52%	52%	52%

Table 3. Economic assumptions for each of the representative farms

	Assumption
Beef price (based on a Beta General probability distribution)	Mean of $2.11/kg liveweight Standard deviation of $0.28
Variable costs ($/hd) excluding supplementary feed	$120/head
Price of supplementary feed (based on a Log Normal probability distribution)	Mean: $65 Standard deviation: 14
Amount of supplements fed	Tonnes fed varied based on GrassGro modelling
Overheads	Penshurst $130,000 (additional labour) Dookie $90,000 (no additional labour) Combined $205,000 (additional labour)

Table 4. Financial assumptions for each of the representative farms

	Penshurst farm	Dookie farm	Combined
Land price ($/ha)	$4,900	$4,000	$4,900 (Penshurst) $4,000 (Dookie)
Equity	80% ($1.1 million)	90% ($2.5 million)	Scenario 1: 90% equity ($4.3 million) Scenario 2: 52% equity ($2.5 million) $500,000 debt)
Debt	$400,000	$280,000	Scenario 1: $500,000 debt Scenario 2: $2.3 million debt
Loan conditions	15 year, 8% amortised loan	15 year, 8% amortised loan	15 year, 8% interest amortised loan

Results

Impact of the five climate scenarios on rainfall and supplements required

Under the 2020 and 2050 medium climate change scenarios, rainfall is expected to decrease on average by 2% and 5%, respectively, compared with historical rainfall on both the Penshurst and Dookie farms (Table 5). Under the high climate change scenarios, a greater decline in rainfall is expected; with a 6% decrease in 2020 and more than 10% in 2050 (Table 6).

Table 5. Decrease in the historical rainfall for the Penshurst (high rainfall farm) under the different climate scenarios.

Climate scenario	% decrease from base case		
	Minimum	Mean	Maximum
2020 medium climate change	1.1%	1.9%	2.4%
2020 high climate change	5.0%	6.0%	6.5%
2050 medium climate change	3.1%	4.9%	6.3%
2050 high climate change	13.6%	15.7%	17.1%

Table 6. Decrease in the historic rainfall for the Dookie (low rainfall farm) under the different climate scenarios.

Climate scenario	% decrease from base case		
	Minimum	Mean	Maximum
2020 medium climate change	0.1%	1.2%	2.2%
2020 high climate change	4.7%	6.3%	7.6%
2050 medium climate change	0.3%	3.3%	5.8%
2050 high climate change	12.8%	16.5%	20.1%

If the farmer operated either the Penshurst or the Dookie farms, the same amount of supplement, on average, would be fed under the historical climate and the medium climate change scenarios (Table 7). Under the high climate scenarios, in particular the 2050 high climate change scenario, more supplement is fed compared with the historical climate if the farmer owned only one of the farm businesses. If the farmer, owned both farming enterprises and specialised the activity on each, the amount of supplementary feed required per head would be less than owning only one of the properties (Table 7).

Table 7. The average amount of supplement fed (tonnes/head/year) for each of the climate scenarios for each of the different farm systems analysed

Climate scenario	Amount of supplement fed (t/head/year)		
	Penshurst farm	Dookie farm	Combined farm
Historical climate	0.6	0.5	0.4
2020 medium change	0.6	0.5	0.4
2020 high change	0.7	0.6	0.5
2050 medium change	0.6	0.5	0.4
2050 high change	1.3	0.9	0.8

Profit, cash and wealth from owning either the Penshurst farm (high rainfall farm) or the Dookie farm (low rainfall farm)

Operating the Penshurst farm system under a hotter and drier climate, decreased profit, cash and wealth compared with the historical climate scenario. The more severe the climate scenario, in particular 2050 high climate change, the greater decline in profit, cash and wealth, and the greater the variability. Under the historical climate, the Penshurst farm earned 1.8% return on the assets managed, while under the 2050 high climate change scenario, mean return on assets managed decreased to less than 1% with a much higher standard deviation (Table 8).

Table 8. Mean operating profit, wealth and return on assets managed under different climate scenarios for a beef farm located in Penshurst (high rainfall zone). Values in the brackets indicate standard deviation.

Climate scenario	Profit ($)	Return on assets managed (%)	Cash (Net Cash Flow after principal and interest) ($)	Wealth ($)
Historical climate	37,200 (31,000)	1.8 (1.5)	10,100 (31,000)	3,100 (29,000)
2020 medium change	36,600 (31,100)	1.8 (1.5)	9,500 (31,100)	2,600 (29,100)
2020 high change	32,800 (32,300)	1.6 (1.6)	5,700 (32,300)	-1,000 (30,400)
2050 medium change	35,800 (30,300)	1.8 (1.5)	8,700 (30,300)	1,800 (28,400)
2050 high change	19,700 (39,000)	1.0 (1.9)	-7,400 (39,000)	-13,700 (37,700)

Under the historical climate change scenario, the Penshurst farm has only a 60% chance of meeting principal and interest repayments. A hotter and drier climate reduces this likelihood even more. Under the 2050 high climate change scenario, the farmer has a 45% chance that they will be able to repay principal and interest.

If a farmer operated the Dookie farm system under a hotter and drier climate, profit, cash and wealth will also decline and variability will increase. The more severe the scenario (in particular 2050 high climate change), the greater decline and the greater the variability (Table 9). The Dookie farm earned a 1% return on the assets managed under the historical climate scenario, which declined when the farm was operated under a hotter and drier climate. Under a 2050 high climate change scenario, only a 0.4% return on assets managed was generated.

Table 9. Mean operating profit, wealth and return on assets managed under different climate scenarios for a beef farm located in Dookie (low rainfall zone). Values in the brackets indicate standard deviation.

Climate scenario	Profit ($)	Return on assets managed (%)	Cash (Net Cash Flow after principal and interest) ($)	Wealth ($)
Historical climate	27,700 (20,700)	1.0 (0.8)	15,200 (20,400)	3,700 (18,800)
2020 medium change	27,500 (21,000)	1.0 (0.8)	14,900 (21,000)	3,400(19,500)
2020 high change	23,600 (22,000)	0.9 (0.8)	11,100 (22,000)	-140 (20,500)
2050 medium change	26,900 (21,400)	1.0 (0.8)	14,400 (21,400)	2,900 (19,900)
2050 high change	11,900 (25,000)	0.4 (1.0	-540 (24,800)	-11,200 (23,800)

Like the Penshurst farm, the Dookie farm has a reduced likelihood of meeting principal and interest repayments in a hotter and drier climate.

The farm operator on the Penshurst farm, or on the Dookie farm would only need to increase income by a small amount (less than 1% for the medium climate scenario, and around 2% for the 2020 high climate change scenario) to return profit to levels similar to those under the historical climate scenario. But for 2050 high climate change, income would need to increase by a greater amount to return profit to the same amount before climate change. For the Penshurst farm, income would need to increase by 8% on average, and for the Dookie farm income, would need to increase by 11%, under the 2050 high climate change scenario.

Profit, cash and wealth from owning both the Penshurst and the Dookie farm

If the farmer operated both the Dookie and Penshurst farms under a hotter and drier climate, profit was greater than if the farmer owned only one of these properties. (Table 10). This is because the amount of supplement fed per head is less than when the farms are operated individually and overheads are spread across both businesses. The expected cash and wealth could also be greater, but is dependent on the amount of equity the farmer has invested in the business. If the farmer purchased the farm at Penshurst, but the only equity available was that in the Dookie farm ($2.5

million), this would reduce equity to 52% and the likelihood of being able to repay borrowed capital is less than 1%. If however, the farmer had 90% of the capital required, the chance of repaying borrowed capital is greater than 90% under the medium climate change scenario; and 75% for the 2050 high climate change scenario. Similarly, growth in wealth at 52% equity is unlikely; but at 90% equity, there is an 80% chance of equity increasing under the medium climate change scenario and a 60% chance in the 2050 high climate change scenario. If the terms of the loan were different to those assumed in the analysis, this could make the business more likely to afford the change.

Table 10. Operating profit, cash, and wealth under different climate scenarios and different starting equity for a beef enterprise with farms located in both Penshurst (high rainfall zone) and Dookie (low rainfall zone). Values in the brackets indicate standard deviation.

Climate scenario	Profit ($)	Cash (Net Cash Flow after principal and interest) ($)		Wealth ($)	
		90% equity	52% equity	90% equity	52% equity
2020 medium climate change	88,000 (54,000)	72,000 (54,000)	-140,000 (54,000)	42,000 (49,000)	-95,000 (54,000)
2020 high climate change	79,000 (56,000)	63,000 (56,000)	-150,000 (56,000)	34,000 (51,000)	-104,000 (56,000)
2050 medium climate change	87,000 (55,000)	71,000 (55,000)	-140,000 (55,000)	42,000 (50,000)	-96,000 (55,000)
2050 high climate change	58,000 (64,000)	42,000 (64,000)	-170,000 (64,000)	15,000 (60,000)	-125,000 (56,000)

Discussion

This research has shown that under a hotter and drier climate, a livestock enterprise will be less profitable than it is today (2015) if the business does not change. This finding is consistent with Moore and Ghahramani (2013) who also concluded that a hotter and drier climate reduced profitability of farms that did not adapt.

The effects of medium climate change on profit, cash and wealth is expected to be minimal, in comparison with high climate change. This could be because there will be higher concentrations of CO_2 and only a relatively small decline in rainfall. Howden *et al.* (2008) argued that when there is only a small decline in rainfall, primary production would largely be unchanged, but larger rainfall reductions may result in net reductions in production; this reasoning supports our findings.

It was found that the more severe the change in climate, the greater the reduction in the profit, wealth and return on investment. In particular, for the 2050 high climate scenario, where rainfall decreased by greater than 10% compared with historical climate, the representative farm analysed was less likely to meet interest and principal repayments and profitability was significantly reduced for both the Penshurst (high rainfall) and the Dookie (low rainfall) farms. This is consistent with the work of Moore and Ghahramani (2013) and Taylor *et al.* (2015), who both found that under the 2050 climate scenarios that profitability will be greatly reduced.

It was found that only a small increase in income; less than 2% for the medium climate change scenario would be needed to return profit to that under historical climate. Such an increase in income, could come from tactical changes to the farm business (as suggested by the panel of industry experts met at the beginning of the project). If however, the farm operated under a climate forecast like 2050 high climate change, incomes will need to increase by more than 10%. In such a situation, strategic changes would be required for the farm business and as Ghahramani and Moore (2013) suggested a ‘rethinking of the feedbase will be required’. Such a change could include owning and operating both the Penshurst and the Dookie farm.

The results showed that a change in climate increases the risk faced by the farm business. This finding is supported by Loch *et al*. (2012) who also found that the risk of climate variability is likely to increase under future climate change. Like Howden *et al* (2008), the researchers argue that climate risk is another risk that farmers have to manage and include in their decision making.

This study found that owning both the Penshurst and Dookie farms could increase the profit earned by the business, even under the 2050 climate change scenario. This spatial diversification has been discussed by Kingwell (2006) for wheat properties, who suggested that large businesses may be able to utilise spatial diversification and enterprise specialisation to lessen the adverse impacts of climate change.

One of the barriers to spatial diversification is finance (that is sourcing the capital required to invest in this other farm, or repaying the debt servicing obligations associated with this capital). In the discussion with the panel of industry experts, this option was suggested as something they would do if they won 'lotto'. This research has highlighted the point the farmer was making. If the farmer had 90% equity invested in the business, the business would earn sufficient cash under all climate scenarios to service debt, and wealth would grow more than if only one of the farm businesses were owned. If however, the farmer only had the equity invested in the Dookie farm, cash flow will not meet debt servicing obligations and wealth will decrease. John *et al.*(2005) also found that expensive capital investments may be difficult to undertake when there is a hotter and drier climate, as the repayment of this capital often relies on favourable seasons. This highlights the need to consider the whole of farm system – the human, the technical, the economic and the financial. One aspect is insufficient.

A limitation of this study is that all the potential costs of climate change were not included, such as the costs associated with increased heat stress, or an increase in pests and diseases. Further, this study did not consider the impact of extreme weather events on farm, as the climate modelling used in this study only accounted for an increase in temperature and reduction in rainfall. Future studies should include this effect, as businesses are likely to be able to manage an increase in mean annual temperatures (up to a point), but extreme weather events that will have the greatest impact on a farm business. Smit and Skinner (2002) found that the change in climate variability and the frequency of non-normal conditions matter just as much, or more than, changes in mean temperature and moisture conditions. Future research could address some of these limitations.

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D8. Project title

Steady state framework to analyse the profit, cash and wealth of a farm business

Organisation Department of Economic Development, Jobs, Transport and Resources

Primary contact Alexandria Sinnett

Executive summary

This project has produced an economic framework that can be used to consider the profit, cash, wealth and risk of different farm systems in the steady state. Output from biophysical models can be used as inputs into this framework. The framework can be used as a first step in answering questions such as ‘Is this a good idea?’ and ‘Should further economic and financial analysis be undertaken?’.

Background

The whole farm approach is required to answer questions such as ‘is it beneficial for a farmer to change his/her farm system to implement a particular mitigation option?’. The whole farm approach to analysing farm businesses refers to first considering all the elements that affect the performance of a farm business – human, technical, economic, financial, risk and institutional factors. Second, it means looking at the business, not in terms of the individual activities that make up the business, such as wheat, first cross lambs, or beef, but the activities and their part in the whole business. This method is set out in detail in the farm economics literature, in particular Makeham and Malcolm (1993), Malcolm (2004), and Malcolm (2005).

Unfortunately, the whole farm approach is often lost in biophysical modelling, and models used claim to include economic analysis, but this is often only a gross margin calculation. Gross margin only tells a part of the story and is insufficient for a farmer to use to make a decision. Heard *et al.* (2013) compared whole farm analysis with gross margin analysis for a decision on a sheep farm. They concluded: ‘… the whole farm approach enables decision makers to better weigh up the choice of livestock activities by considering the implications for economic efficiency of the business, cash flow, growth in wealth and risk.’

The aim of this project was to address this limitation of biophysical models, and to provide the WFSAM project team with a framework that could be used in-conjunction with biophysical models to provide a first look at the expected profit, cash, wealth and risk of a proposed change.

Method

The method and the discipline behind the framework is farm management economics (see Malcolm *et al.* (2005) for a detailed discussion on this method). The calculations to assess profit, cash and wealth are summarised in Figures 1 to 3.

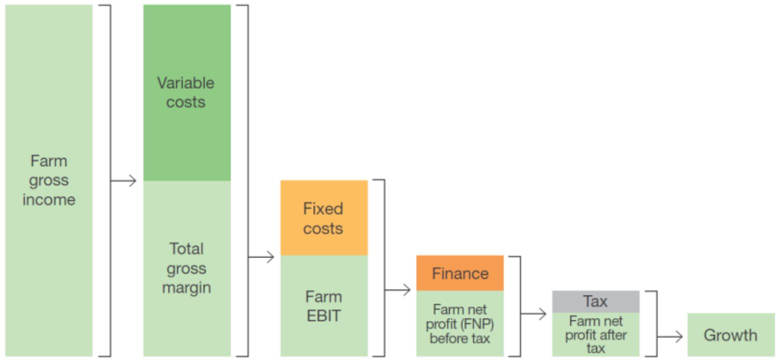

Figure 5. Method to assess profit and loss

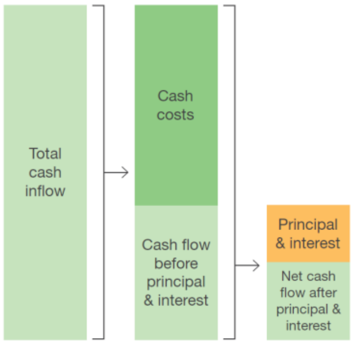

Figure 6. Method to assess cash flow

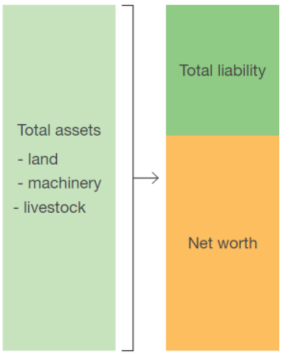

Figure 7. Method to assess balance sheet

The important metrics in farm management economics are:

- Return on assets managed – This measures the efficiency of the use of all capital in the business. It indicates the overall earning of the total farm assets, irrespective of capital structure of the business. It is calculated by expressing earnings before interest and tax, or operating profit as a percentage of the total assets under management in the farm business, including the value of leased assets.

- Return on equity – This is a measure of how efficiently equity is being used and measures the owner's rate of return on their own capital invested in the business. It is net farm income expressed as a percentage of total equity (one's own capital).

- Operating profit, or earnings before interest and tax – This is the profit produced by the mix of the resources of land, labour, capital, and management.

- Net cash flow before principal and interest – This information can be used to calculate how much debt a farmer could take on.

- Net cash flow after principal and interest – This tells the farmer if the business generates enough cash to meet debt servicing obligations.

- Growth in equity – This is whether the farmer will add to their equity, or decrease their equity.

Another key measure is risk. Risk matters because it has consequences. The consequences of risk ultimately determines whether the farm owners achieve their goals or not. In farm management economics, risk is defined as the volatility over time of key elements of the farm system such as crop yields, prices, interest rates, rainfall, pasture growth, annual profit, annual net cash flow and so on. Volatility is the variability around the average level that elements such as these can take in any year over a run of years. Some of the volatility of annual net profit, or annual net cash flow for instance, comes from volatility of yield and prices, but some comes from having to service debt, regardless of what may be happening with the weather and in the markets.

The key to risk analysis is using probabilities about future events happening in the relevant planning period. Probabilities are strengths of belief about how likely it is that something will, or will not happen. Farm budgets on computer spreadsheets can be combined with stochastic simulation tools and instead of putting into the budgets an average, or most likely yield, or price, or interest rate, probability distributions can be entered. The full range of possible prices, yields, interest rates and other probabilistic variables can then be tested in the farm budgets. The result is that instead of a single estimate for, say, annual operating profit, or cash available to service debt, probability distributions are estimated of the possible operating profits and debt servicing capacity. The analyst is in a position to say ‘there is 75% chance that the business can service this level of debt’. The framework that has been developed includes the ability to include risk using an add-in tool called Yet Another Simulation Add In (YASAI) (see Eckstein and Riedmueller 2002 for further details).

Results

An economic and financial framework has been developed to analyse a beef livestock enterprise (Figure 4). This framework has:

- a balance sheet at the start of the production year
- an expected profit budget for that year
- an expected cash flow budget
- a balance sheet at the end of the production year.

In the data sheet, the user enters information about the farm system, such as technical data and price and cost data. The user can enter the outputs from biophysical models into this data sheet. The user is guided through this process through a series of questions. The information in the data sheet, is linked into the balance sheet at the start and end of the year, the profit budget and the cash flow budget.

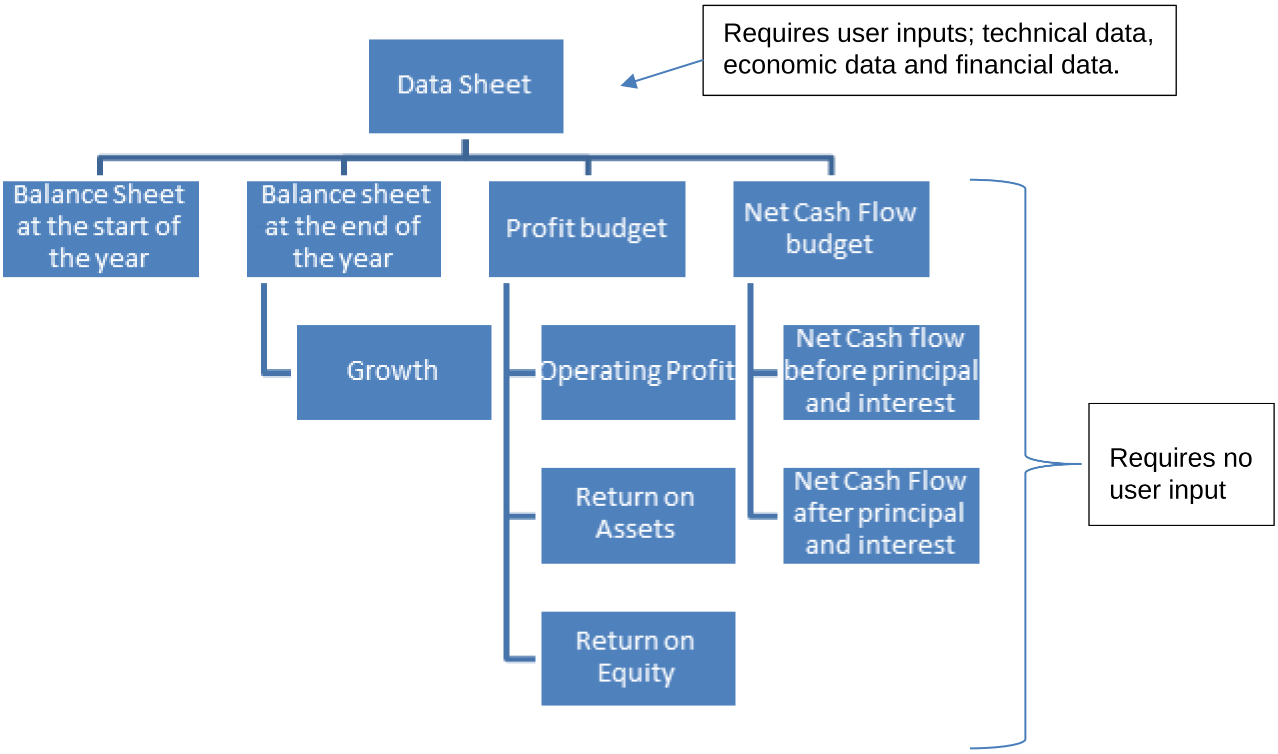

Figure 8. Schematic diagram of the framework

After the user has completed the data entry, the user can press simulate on the YASAI tab. This will provide the user with the key metrics, discussed above, in a table form. The user can graph these metrics (Figure 5).

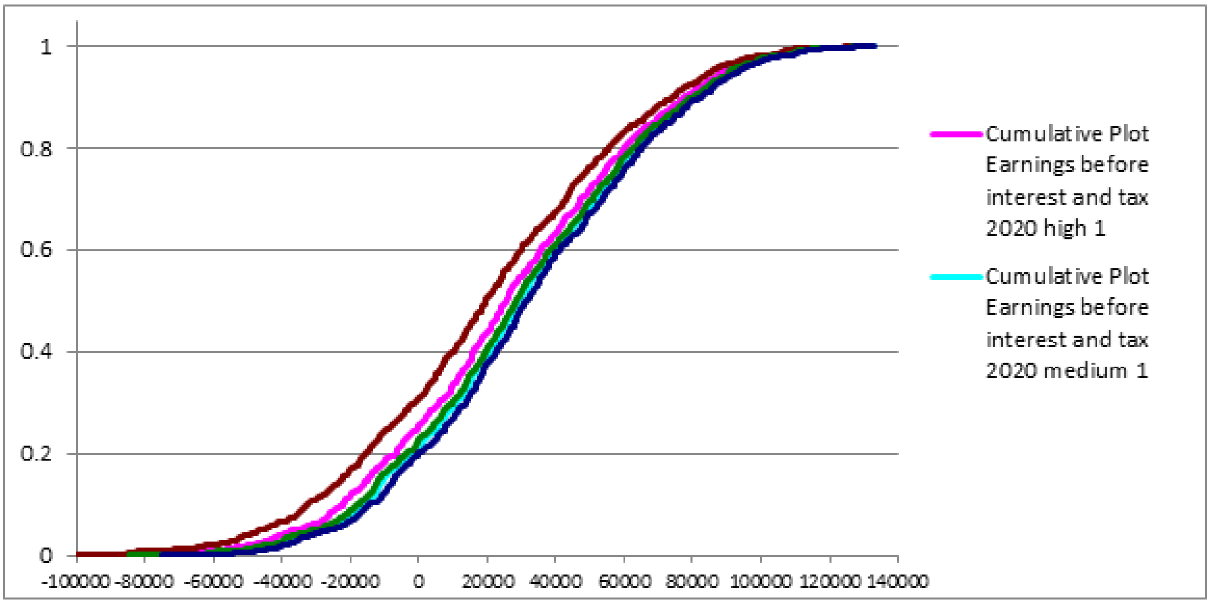

Figure 9. Example of the output generated from the framework.

Discussion

This tool has been developed for use by the project team to assess the profit, cash, wealth and risk implications associated with a change. It is the first step in calculating the economic and financial implications of a change. If the change looks profitable and affordable in the steady state, a full economic and financial assessment can be made (this is beyond the scope of this project).

At this stage, the framework has not been designed as a tool for audiences beyond the project team, as a strong understanding of excel is required. This framework is a skeleton of a budgeting model. It requires some user inputs to set up the framework for the question being investigated. It requires also the user to take relevant information from the biophysical model (for example data on stock numbers, tonnes of supplement fed, weight of stock sold) and use this as inputs in the livestock trading schedule. The budgets are linked to the information in the data sheets.

Future research needs

A workshop will be held with the WFSAM project team in June 2015 to test the useability of the model. Refinement of the model will be carried out after feedback is received at the workshop and the model will subsequently be made available to the project team for use in future analyses.

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D9. Project title

Carbon credits and economic return of environmental plantings on a prime lamb property

Organisation Department of Economic Development, Jobs, Transport and Resources (formerly Department of Environment and Primary Industries)

Primary contact Alexandria Sinnett

Paper under internal review – for consideration for publication in Land Use Policy

The carbon credits and economic return of environmental plantings on a prime lamb property

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Abstract

An approved farm action under the Carbon Farming Initiative (CFI) is for farmers to establish permanent tree plantations. For a livestock farmer who is considering establishing environmental plantings of trees for carbon sequestration, the question is 'what are the benefits and costs of growing trees instead of using that land to grow pasture to feed livestock?'. In this research, the case study approach and the methods of farm management economics were applied to assess whether growing trees for carbon on part of a prime lamb case study farm in south-west Victoria could be a better use of resources than using that land to graze livestock. The model was run to represent either 25 or 100 years with variation in output prices. Under the condition that the trees provided no other benefit on farm and the required rate of return on marginal capital was 6% real (10% nominal), the results indicated that the price of carbon would need to be \$132/t CO_2e. Alternatively, if the trees provided benefits in addition to carbon credits, the investment could be worthwhile to the business at a lower carbon price. Previous research has shown that shelter (in the form of trees, grass-hedge rows and other man-made structures) can reduce lamb mortality by reducing wind chill at lambing, through reduced wind speed. The benefits to a farm system from growing trees for carbon depends on the reduction in wind speed the trees create, the weather conditions, the price of lambs, the establishment cost of the trees, the price of carbon, and transaction costs. This paper has shown that for the representative livestock farmer, growing trees for carbon is unlikely to be as profitable as alternative uses of those resources.

Key Words: Benefit cost analysis, environmental plantings

Introduction

The Australian Government has committed to reducing greenhouse gases (GHG) by 5% below 2000 levels by 2020 (Hunt 2013). One scheme designed to help meet this GHG target is the Carbon Farming Initiative (CFI), which allows farmers and other land managers to earn Australian Carbon Credit Units (ACCUs) by storing or reducing greenhouse gas emissions. One way farmers can participate in the CFI is through environmental plantings; whereby farmers grow trees for carbon. Farmers who grow trees for carbon can potentially earn ACCUs to sell to the Australian Government. The process for doing this is currently being reviewed.

Past research has considered the area of land that could be available for reforestation projects within the arrangements of the Kyoto Protocol (for example, Mitchell *et al.* 2012). Polgalse *et al.* (2013) investigated the area of Australia that could be available for planting new forests based on an estimate of currently cleared land. They concluded that there is insufficient economic incentive to motivate large scale environmental plantings, but their study was not at the farm level and did not consider the other benefits that trees can provide within a farming system.

The key question from the perspective of a farmer grazing livestock is: ‘Am I better off using that land to grow trees rather than my usual grazing activity?’ Research has shown that farmers who grow trees in an appropriate location and plantation design also derive other benefits to their farming business, through protection of their livestock from either extreme heat or cold. Marai *et al*. (2007) found that extreme heat affects production and reproduction traits. Trees that are grown to protect livestock from extreme heat events may reduce these affects. Trees that are grown to protect livestock from cold can reduce lamb mortality (Hume *et al.* 2011 and Bird 1998). However, trees grown in an orientation and density for protection from cold may not be as efficient for the protection from heat stress (DEPI 2013) and vice versa. To protect against cold, shelter should aim to minimize wind speed (DEPI 2013), whereas to protect against heat, the shelter should allow for the cooling effect of the wind. In practise, farmers will plant trees in a location and select species as part of a process that will consider the environment and climate they farm within and the long term aims for their property. This will include consideration of the needs of current and future farming enterprises, topographical features on the farm, existing infrastructure (e.g. fencing/paddocks) and aesthetic aims. As the establishment of tree plantations is both costly and to a large degree permanent, the aim will be to achieve multiple outcomes. Therefore, given the significant investment required in establishment and the longer term considerations for the farm, other forms of shelter may have advantages. For example, grass hedgerow shelters can offer similar wind speed protection with lower establishment costs (EverGraze 2014). Land and Water Australia (2006) found that providing shelter using trees (established through natural regeneration[1]) could be profitable, but it may take years for cumulative net cash flow to be positive. In contrast, grass hedgerows have also been found to be profitable with a much shorter break even period in regions where lamb mortality is significantly reduced (Young *et al.* 2014). So for a farmer to grow trees instead of a grass hedgerow, the price of carbon must compensate for the higher establishment costs of the trees.

The proposition tested in this study was that a prime lamb farmer growing trees for carbon would benefit more than if the resources involved were used in some other way. This proposition was tested using the case study approach.

Method

Case study analysis

Use of case studies in farm economics is well established (Crosthwaite *et al.* 1997). Case study research can be used to generalise to theory, as well as inform farmers running similar systems, of their future options. The results from case studies will either add support to explanations of current theory, or will not be consistent with theory and challenge accepted wisdom. The case study method is appropriate for this analysis, as farm models often only represent reality in a partial way, whereas case studies can capture the important features of an actual farm (Malcolm *et al.* 2012).

The farm

A prime lamb enterprise located near Hamilton in south-west Victoria was selected as the case study farm. The business comprised 560 ha (400 ha on the home block and a 160 ha outblock), with an average stocking rate across the whole farm of 16.3 dry sheep equivalents (DSE)/ha. The flock comprised 3,000 Coopworth Composite ewes. Lambing was in mid-July and weaning was in early December. The average annual rainfall was 730 mm and the farm was located in an area of very high wind chill during the month lambing. The average July wind chill in unsheltered conditions in Hamilton is classed as very high (980-1000 kJ/m^2/hr.) (EverGraze 2014).

Shelter that is in the right location can reduce the speed of wind. Together, wind, rain and temperature make up chill index. At a chill index greater than 1000 kJ/m^2/hr. the risk of lamb mortality increases significantly (Donnelly 1984) (Figure 1). Therefore shelter, which reduces wind

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[1] Natural regeneration, does not include planting, it is the process of reintroducing vegetation to a site by naturally allowing seed, suckers or lignotubers to grow.

speed, can reduce chill index and subsequently lamb mortality (Donnelly 1984, Bird *et al.* 1984). Lambs that benefit the most from shelter are those with low birth-weights; usually twin/triplet born lambs (Watson *et al.* 1968, McLaughlin *et al.* 1970, Lynch and Alexander 1977, Bird *et al.* 1984 and Pollard 2006). Shelter can be in the form of grass hedgerows, artificial constructs, and trees and shrubs. The benefits of shelter from grass hedgerows or trees are expected to vary by the degree to which they achieve wind speed reduction that reduces the chill index and increases lamb survival (Broster *et al.* 2012 and Young *et al.* 2014).

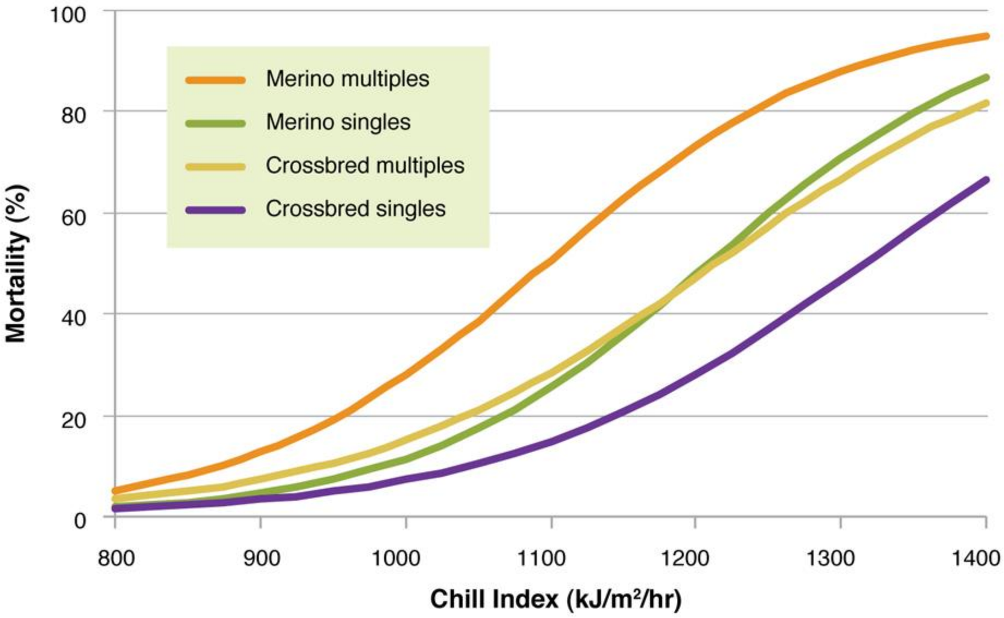

Figure 10. Relationship between the chill index and the mortality of single and twin lambs born to merino ewes and crossbred ewes (Young et al 2014, adapted from Donnelly 1984).

Research question & scenarios tested

The research question examined was ‘will growing trees for carbon be the most beneficial use of the resources involved?’ Answering this question is complex because there are a number of variables involved, including:

- The price of carbon
- The design of the environmental planting and the choice of plant(s)
- The growth rate of trees
- The establishment cost (subject to trees purchased, fencing required, labour required)
- Whether there are other benefits for the farm business

Given there are a number of variables to consider, a number of sub-questions and scenarios were developed for the case study farm. The sub-questions were:

1. Is the farmer more profitable growing a selection of trees that provide protection (shelter) over a larger area so more ewes could be sheltered, but the reduction in wind speed is less, so a smaller reduction in lamb mortality is achieved? (Planting A)
2. Is the farmer more profitable growing a selection of trees that provide protection (shelter) over a smaller area, but reduces wind speed to a greater extent and therefore achieve greater reduction in lamb mortality? (Planting B)
3. What is the expected return on extra capital invested if the farmer wanted to create shelter by growing grass-hedgerows for the purpose of reducing lamb mortality only, without benefits from the CFI?
4. What would the carbon price need to be for the farmer to earn 6% p.a. real return on the extra capital invested (equivalent to 10% nominal return when there is 4% p.a. inflation), if there were no other benefits from the trees for the farm business?

The budget framework

For this analysis, the question is whether a farmer should do one activity over another activity; graze land, or plant trees on that land. A partial budget is an appropriate method when considering a change to only part of the farm system (Malcolm *et al.* 2005). The partial budget approach was used to assess the effects on farm profit and risk from establishing trees on land that is currently used for grazing. The extra income and extra costs associated with the change were estimated, and the return on the extra capital invested was calculated. In addition, the impact on cash flow was analysed. The impact of risk was included using @Risk (Palisade 2013), an add-in program for Excel, where probability distributions for key variables can be defined, leading to a range in possible outcomes (Table 1).

Extra income resulted from:

- Selling the carbon that was sequestered by the trees, as ACCU every 5 years. The price of carbon was based on probability distributions with a mean of $25, or a mean of $10
- Selling extra lambs, using a distribution for lamb mortality based on expected lamb mortality with, or without shelter at various wind speeds (M. McCaskill pers. com. 2013). This enabled the number of extra lambs to be calculated.

Table 11. The type, median, 5th, 25th, 75th and 95th percentiles of input distributions used in the analysis.

Input costs/yields	Distribution type	P5	P25	P50	P75	P95
Lamb meat price (c/kg carcass weight, 45% dressing percentage).	Gamma	342	400	448	502	592
Skin price ($/ extra lamb)	Pert	3.85	7.77	11.25	14.93	19.70
Mortality reduction if wind speed was reduced by 99%	Normal	46%	48%	50%	52%	54%
Mortality reduction if wind speed was reduced by 75%	Extvalue	29%	30%	32%	33%	36%
Mortality reduction if wind speed was reduced by 60%	Uniform	22%	23%	24%	25%	26%
Mortality reduction if wind speed was reduced by 50%	Uniform	18%	19%	20%	21%	22%
High carbon price ($/t CO_2e)	InvgaussAlt	15.00	18.05	22.00	28.55	45.00
Low carbon price ($/t CO_2e)	InvgaussAlt	8.00	8.94	10.00	11.56	15.00

Extra costs resulted from:

- Capital costs associated with establishing the trees, or grass hedgerows, which depends on the price of the trees, the cost of planting, and the cost of permanent fencing. The estimates used in this analysis are supported by previous studies (Polglase et al. 2013; Young et al. 2014). Three establishment costs were considered; $1000/ha, $2000/ha and $3,200/ha. The lowest amount reflected a low cost direct-seeding method, while the highest cost included ripping and mounding of the soil, planting of tube stock and fencing.
- Auditing costs associated with establishing an environmental planting, which were based on Swainson (2013). It was assumed that the initial cost would be $5,000. Sharpe 2012 also estimated that initial accreditation and legal advice would cost $5,000. According to the Clean Energy Regulator pers comm.(2014), some sequestration projects may be exempt from ongoing audits if they are estimated to sequester less than 2500 tonnes of carbon annually, thus it was assumed that there were no ongoing costs for this planting.
- Income foregone; the opportunity cost of using that land to plant trees instead of using it to graze livestock.
- The costs associated with rearing the extra lambs including animal health, freight and cartage and selling costs.
- The cost of caring for the trees, repairs and maintenance of fencing and the labour associated with managing those trees.

Model Inputs

The assumptions specific to each of the research questions are given in Table 2. It was assumed that the planting will abide by the rules as set out in the Carbon Farming Methodology Determination 2012 (Dreyfus 2012). Further, it was assumed that the trees were grown to maximise shelter benefits that is, they were planted in a position that would have the correct orientation to the prevailing winds at lambing time, provide whole-of-paddock protection and have coverage that is low to the ground at lamb height. This required the use of permanent fencing for the tree plantation.

Table 12. Assumptions used in the analysis.

	Sub-question 1 Planting A	Sub-question 2 Planting B	Sub-question 3	Sub-question 4
Type of planting	Mixed species planting with greater height, but lower density planting	Mixed species planting, with trees that are not as tall, but greater density	Grass hedge rows	Mixed species planting
Area of shelter provided by 5.6 ha planted (ha)	72	54	56	No additional benefit to the farm system
Number of twin bearing ewes that could be carried	1290	970	1000	No additional benefit to the farm system
Conservative estimate of reduction in wind speed as a result of planting	60%	75%	75%	No additional benefit to the farm system
Best case estimate of reduction in wind speed as a result of planting	75%	99%	99%	No additional benefit to the farm system
Establishment costs tested ($/ha)	$1000, $2000 and $3200		$250	$1000, $2000 and $3200
Carbon prices tested ($/t CO_2e)	Two distributions were used, one with an average of $10 and the other with an average of $25			Breakeven carbon price was calculated

Wind Speed reduction from Shelter

The height and density of the trees alter the extent of the shelter zone (Bird 1998). For this study, it was assumed that the level of protection would be 10 times the height of the tallest tree in the planting (as EverGraze 2014 had assumed). The level of reduction in wind speed used in the analysis was based on findings from Bird *et al.* (1992) and EverGraze (2014). It was also assumed that the protection was the same across the paddock. Although this is a simplistic assumption, two different levels of reduction in wind speed were tested; a conservative and a best case estimate.

The work of McCaskill (pers.com 2013) was used to estimate the reduction in lamb mortality that could be expected if wind chill was reduced. For July each year between 1997 and 2012, McCaskill calculated the mortality of multiple lambs born to crossbred ewes for conditions in the open, or with shelter where lambs could seek areas with lower wind speeds. Using this information, the expected lamb mortality when shelter reduced wind speed by 99%, 75%, 60% and 50% was estimated. These estimates were used in the present study to calculate the *reduction* in mortality from reducing wind speed by this amount (99%, 75%, 60% and 50%), and a probability distribution was fitted around these results (Table 1).

It was assumed that the trees (and shrubs) would begin to offer some protection in three years after establishment and full protection after four years (Hume *et al.* 2011 and Johnson and Brandle 2009).

Stocking Rate

The sheltered paddocks were designed for maternity paddocks. EverGraze used a stocking rate of 20-40 ewes/ ha in their research on shelter. However, as stocking rate increases mis-mothering increases and survival may decrease (Robertson *et al.* 2012). Thus, it was assumed that 18 ewes/ha would be used in the analysis.

Carbon Credits

Under the CFI, there is an approved methodology for quantifying carbon sequestration by permanent environmental plantings of native species using the CFI reforestation modelling tool (RMT). The RMT was used to estimate the location-specific carbon sequestration rate and amount applicable to the case study farm over time, for a mixed species environmental planting established on the farm. It was assumed that both planting A and planting B sequestered the same amount of carbon. Further, it was assumed the number of saleable offsets (ACCUs) earned would be 5% lower than what was estimated due to the risk of sequestered carbon being released back into the atmosphere due to unforseen events such as bush fire. Payments were assumed to be made every five years, up to year 15. Currently, 15 years is the maximum time that credits can be claimed (Clean Energy Regulator pers. comm 2014). However, the stand of trees would need to be maintained for 100 years.

Planning horizon

Under the previous government, one of the rules for establishing an environmental planting was that it needed to be permanent and remain for at least 100 years. If a farmer wished to cancel their project before 100 years and remove the trees, they would need to hand back the same number of credits that had been issued for the project. These credits could be purchased at the prevailing market price, or taken from another project. Under the current government, it has been suggested that through the Direct Action Plan (DAP), the permanence rule would be reduced to 25 years. Thus two planning horizons were considered for this study; 25 years and 100 years.

Results

Using the RMT, the cumulative amount of carbon sequestered over time for both plantings analysed is presented in Figures 1a and b. At 25 years and 100 years, the accumulated carbon sequestered was 1305 t/CO_2e and 2158 t/CO_2e, respectively.

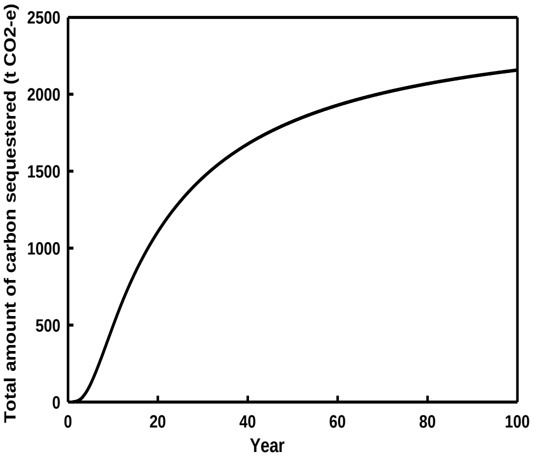

Figure 1(a). Cumulative amount of carbon sequestered over time in an environmental planting established on 5.6 ha of a case study farm in western Victoria.

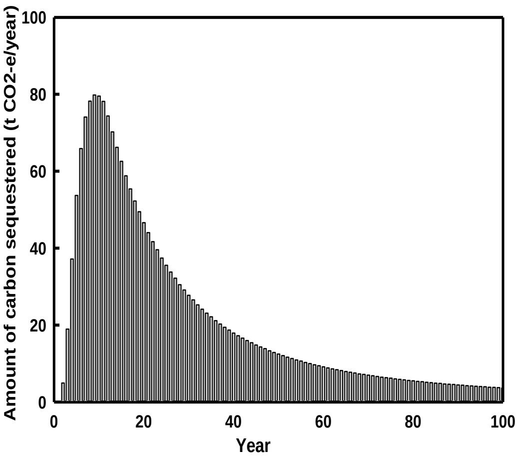

Figure 1(b). Annual amount of carbon sequestered in an environmental planting established on 5.6 ha of a case study farm in western Victoria.

Establishing an environmental planting which also provides shelter

The expected economic and financial outcomes from growing trees for carbon, with added shelter benefits are presented in Tables 3 to 6. These results show:

- The reduction in wind speed is a more important variable and has a greater influence on return on capital, than carbon price. For example, considering a scenario where the establishment cost of trees is \$2,000/ha and there is a 75% reduction in wind speed, the return on marginal capital is 7% under a carbon price distribution with a mean of \$25/t CO_2e. The return on marginal capital reduces to 5% when a carbon price distribution with a mean of \$10/t CO_2e is used. For the same establishment cost (\$2,000/ha) and the carbon price based around a mean of \$25/t CO_2e a reduction in wind speed from 75% to 99% increases return on marginal capital from 7% to 22%.
- For the two types of plantings considered, which were assumed to qualify under the CFI, the planting that had the greatest reduction in wind speed, but provided protection over a smaller area (Planting B) performed better economically and financially than Planting A, which offered shelter to more ewes, but with less wind speed reduction.
- The higher the establishment cost the lower the expected return on marginal capital and the longer it takes to earn a positive cumulative net cash flow.
- The time taken for the extra net cash flow to repay the extra capital invested, or the time taken for the investment to breakeven, is dependent on the wind speed reduction, and to a lesser extent the establishment cost and the carbon price.

Table 13. Marginal Internal Rate of Return on extra capital under average conditions and prices based on a planning horizon of 25 years for different average carbon prices, estimates of wind speed reduction provided by the trees and establishment costs.

Wind speed scenario	Carbon price (\$/t CO_2e)	Planting scenario	Establishment costs (\$/ha)		
			\$1,000	\$2,000	\$3,200
Conservative estimate of expected wind speed reduction provided by the trees	\$10	Planting A 60% reduction in wind speed	4%	2%	0%
		Planting B 75% reduction in wind speed	7%	5%	3%
	\$25	Planting A 60% reduction in wind speed	6%	4%	2%
		Planting B 75% reduction in wind speed	9%	7%	4%
Best case estimate of expected wind speed reduction provided by the trees	\$10	Planting A 75% reduction in wind speed	14%	11%	8%
		Planting B 99% reduction in wind speed	25%	21%	17%
	\$25	Planting A 75% reduction in wind speed	16%	13%	10%
		Planting B 99% reduction in wind speed	27%	22%	18%

Table 14. Number of years to reach a positive cumulative net cash flow under average conditions and prices based on a planning horizon of 25 years for different average carbon prices, estimates of wind speed reduction provided by the trees and establishment costs.

Wind speed scenario	Carbon price ($/t CO_2e)	Planting scenario	Establishment costs ($/ha)		
			$1,000	$2,000	$3,200
Conservative estimate of expected wind speed reduction provided by the trees	$10	Planting A 60% reduction in wind speed	25 years	Greater than 25 years	Greater than 25 years
		Planting B 75% reduction in wind speed	14 years	15 years	18 years
	$25	Planting A 60% reduction in wind speed	15 years	18 years	Greater than 25 years
		Planting B 75% reduction in wind speed	10 years	13 years	15 years
Best estimate of expected wind speed reduction provided by the trees	$10	Planting A 75% reduction in wind speed	9 years	10 years	11 years
		Planting B 99% reduction in wind speed	6 years	7 years	8 years
	$25	Planting A 75% reduction in wind speed	9 years	10 years	10 years
		Planting B 99% reduction in wind speed	6 years	7 years	8 years

A longer planning horizon, slightly increased the return on the extra capital invested. However, this was because it was assumed that there would be a reduction in lamb mortality every year for the 100 years.

Table 15. Marginal Internal Rate of Return on extra capital under average conditions and prices based on a planning horizon of 100 years for different average carbon prices, estimates of wind speed reduction provided by the trees and establishment costs.

Wind speed scenario	Carbon price ($/t CO_2e)	Planting scenario	Establishment costs ($/ha)		
			$1,000	$2,000	$3,200
Conservative estimate of expected wind speed reduction provided by the trees	$10	Planting A 60% reduction in wind speed	8%	7%	6%
		Planting B 75% reduction in wind speed	11%	9%	8%
	$25	Planting A 60% reduction in wind speed	9%	8%	7%
		Planting B 75% reduction in wind speed	12%	10%	8%
Best case estimate of expected wind speed reduction provided by the trees	$10	Planting A 75% reduction in wind speed	16%	14%	11%
		Planting B 99% reduction in wind speed	26%	21%	18%
	$25	Planting A 75% reduction in wind speed	17%	15%	12%
		Planting B 99% reduction in wind speed	27%	22%	19%

Table 16. Number of years to reach a positive cumulative net cash flow under average conditions and prices based on a planning horizon of 100 years for different average carbon prices, estimates of wind speed reduction provided by the trees and establishment costs.

Wind speed scenario	Carbon price ($/t CO_2e)	Planting scenario	Establishment costs ($/ha)		
			$1,000	$2,000	$3,200
Conservative estimate of expected wind speed reduction provided by the trees	$10	Planting A 60% reduction in wind speed	25 years	26 years	27 years
		Planting B 75% reduction in wind speed	14 years	15 years	18 years
	$25	Planting A 60% reduction in wind speed	15 years	18 years	26 years
		Planting B 75% reduction in wind speed	10 years	14 years	15 years
Best estimate of expected wind speed reduction provided by the trees	$10	Planting A 75% reduction in wind speed	9 years	10 years	11 years
		Planting B 99% reduction in wind speed	6 years	7 years	8 years
	$25	Planting A 75% reduction in wind speed	9 years	10 years	10 years
		Planting B 99% reduction in wind speed	6 years	7 years	8 years

Planting grass hedgerows instead of trees to provide shelter to lambing ewes

A grass-hedgerow could earn a higher return than either of environmental plantings under all scenarios tested, however, it would not qualify for the CFI. Establishing a grass-hedgerow could also be repaid in less than 10 years for all scenarios (Table 7).

Table 17. Marginal Internal Rate of Return on extra capital and number of years to reach a positive cumulative net cash flow under average conditions and prices based on a planning horizon of 25 years for a grass hedgerow for different average carbon prices, estimates of wind speed reduction provided by the trees and establishment costs.

Wind speed scenario	Marginal internal rate of return	Years to reach a positive cumulative net cash flow
Conservative reduction in wind speed (wind speed reduced by 75%)	26%	6
Best case reduction in wind speed (wind speed reduced by 99%)	59%	4

Establishing an environmental planting without any other benefits for the farm

The carbon price required to earn 6% real return (10% nominal, with 4% inflation), without any other benefits for the farm, was greater than $100/t CO_2e for all three establishment costs tested (Table 8). Further, the required carbon price was higher if the planting had to remain for 100 years.

Table 18. Carbon price required for the case study farmer to earn 6% real return on the extra capital invested.

	Carbon price required ($/t CO_2e)	
Establishment cost ($/ha)	Tree planting established for 25 years	Tree planting established for 100 years
$1,000	$132	$163
$2,000	$146	$177
$3,200	$163	$194

If such a carbon price was achieved, the capital could be repaid by year 10 (Figures 2 and 3). Figures 2 and 3 also show the expected impact on cumulative net cash flow of selling carbon. As the farmer will be paid for the carbon stored in years five, 10 and 15, with no additional income in the in-between years, the cumulative net cash flow increased and then decreases over the 25 year period.

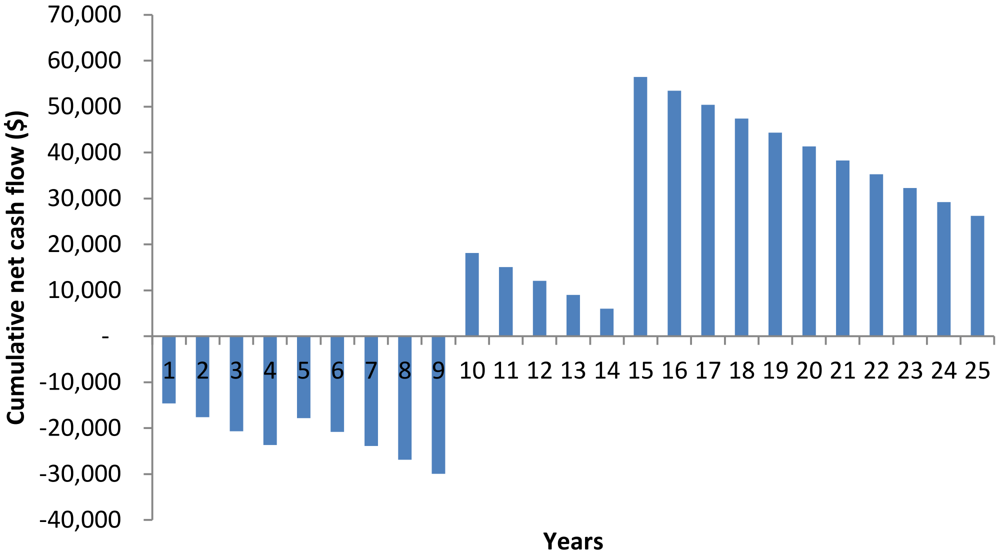

Figure 11. Cumulative net cash flow based on establishing an environmental planting on 5.6 ha for 25 years.

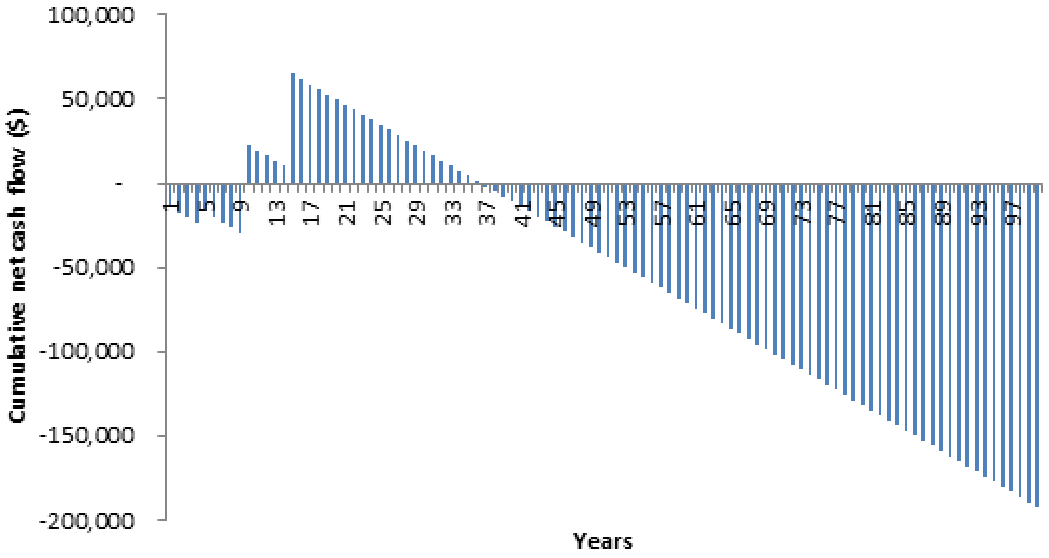

Figure 12. Cumulative net cash flow based on establishing an environmental planting on 5.6 ha for 100 years.

Discussion

Growing trees for carbon is not expected to be the best use of resources available under the likely carbon price received. The analysis reported here does not support the original proposition. In the Coalition Government's DAP policy paper, the indicative carbon price per tonne for carbon stored in trees is \$15. The results from this research showed that in order for trees grown for carbon sequestration to earn a real return of greater than 6%, a carbon price in excess of \$100/t CO_2e was required. This is significantly less than the Coalition's indicative carbon price. Further, it is also significantly lower than the EU carbon price. At the time of writing, the European carbon price was \$8.72/t CO_2e (€6/t CO_2e) (Hill 2014).

If the case study farmer was growing trees for carbon and also hoped to reduce lamb mortality then an environmental planting could be profitable. However, this is dependent on how much the trees could reduce wind speed. The greater the reduction in wind speed, the greater the decrease in wind chill index and subsequent effects on lamb mortality and the greater the benefit to the farm system. This concurs with the results of Broster *et al.* (2012) and Young *et al.* (2014). Growing trees that offer a reduced area of protection, but a greater decrease in wind speed has the potential to earn more than 10% return on extra capital invested. But, planting a grass-hedgerow (which would not qualify for the CFI) would be more profitable than planting trees. This is because of the high establishment costs associated with planting trees and the expectation that carbon price will be low. Young *et al.* (2014) also found that planting a grass-hedgerow could be profitable for a sheep producer, but depended on where the farm was located and the associated weather conditions and consequently, the degree to which lamb mortality could be reduced. The investment in trees is also expected to take longer to earn a positive cumulative net cash flow, compared with the time taken to earn a positive cumulative net cash flow from growing a grass hedge.

The results from the analysis could be considered optimistic, as it was assumed that lamb mortality decreased every year with the trees planted compared with no trees planted. In practice, lamb mortality may not decrease every year because the benefit of trees depends on the weather during lambing and the reduction in chill varies between years (Broster *et al* 2012). Robertson *et al.* (2011) found the increase in survival from trees will be small if the weather was mild during lambing. The Bureau of Meteorology (2014) predicts that the temperature in Australia will increase in future, with more hot days and fewer cold days. So, the benefits of trees in providing shelter from the cold may be less in the future than what was assumed in this study, particularly for the 100 year scenario.

This analysis has shown that there are some key factors that farmers need to account for when considering establishing an environmental planting, including the:

- Income foregone on the area that is planted to trees
- Area protected by the trees and the number of twin bearing ewes that can be sheltered
- Cost of establishing the planting and maintenance of the planting and fences
- Weather (temperature, rainfall and wind speed, which impact on wind chill index)
- Reduction in wind speed caused by the trees /shelter design and consequently, the reduction in lamb mortality that can be achieved.

Previous research has found that the effectiveness of trees on reducing lamb mortality is also dependent on factors such as the breed of sheep, reproduction rate, level of twinning, existing level of mortality, time of lambing, the farm's existing climate, the extent of wind speed reduction from the shelter and the effectiveness of the type of shelter (artificial, grasses, trees or shrubs) being used. Broster *et al.* (2012) also reported considerable variability in the reduction in wind speed and chill index because of similar reasons. This research has highlighted the complexity of determining the benefits and costs of establishing an environmental planting.

The reduced flexibility and uncertainty of the policy environment is a further barrier to farmers implementing environmental plantings on farm. An important unknown is the issue of permanence and therefore how long the farmer needs to maintain the environmental planting. Under Labour Government policy, this was 100 years, but under the Coalition government this could be reduced to 25 years. The risk for a farmer is, if they decided to harvest the trees before the end of the contract period, (25 years or 100 years) they would be required to replace the offset credits at that time.

The findings of this study also demonstrate the importance of evaluating a change on a case by case basis. The location of the planting, the area protected and the expected wind speed with and without trees will affect the expected outcome. Sharpe (2012) also explored whether environmental plantings were profitable and concluded that carbon credit projects can be a feasible and a financially attractive option for landowners in some circumstances. Like Sharpe (2012), we concur that landowners need to do their homework and understand the costs and risks involved before undertaking an environmental planting.

There may also be other benefits farmers may consider when planting trees, beyond the economic benefits from shelter and carbon credits. These may include the use of tree plantations for aesthetic reasons, as wildlife corridors and for habitat creation, for the control of erosion and the protection of soils and crops. All these benefits are beyond the scope of this study to consider, but farmers will trade additional perceived benefits off against the expense of establishment and lower returns from tree plantations.

In summary, for a farmer to earn a reasonable return from participating in the CFI through establishing an environmental planting, the trees would need to be selected (for density and height) and planted in a position that would generate the greatest reduction in wind speed. The farm would also need to be located in an area with a very high to extreme wind chill index. If the trees reduced the wind chill index, through reducing wind speed, this could decrease lamb mortality and reward the farmer with a reasonable return on the extra capital invested to plant the trees. Whether it is the best use of resources available will depend on the establishment costs, the price of carbon, the weather, the wind chill index before trees and after trees, which affects the number of extra lambs sold because of the trees, and the price of lambs. The consideration of other benefits from trees to the whole farm will also be important in decision making.

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D10. Project title

Generating saleable carbon offsets: is it economically feasible for Victorian dairy farmers?

Organisation Department of Economic Development, Jobs, Transport and Resources (formerly Department of Environment and Primary Industries)

Primary contact Clare Leddin

Paper under internal review – for consideration for publication in Land Use Policy

Generating saleable carbon offsets: is it economically feasible for Victorian dairy farmers?

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Abstract

With the recent establishment of the Emissions Reduction Fund in Australia to facilitate reaching the country's target to reduce its greenhouse gas emissions by 5% by 2020, a study on the feasibility of Victorian dairy farmers participating in the scheme was conducted. The potential viability of a carbon sequestration project and two emissions avoidance projects on dairy farms was investigated. For the analysis, three case study farms across the dairying regions in the state of Victoria were used. For the scenarios explored, it was found that the generation of saleable carbon offsets was very small. Coupled with the uncertainty and potential costs of such projects, it was concluded that a continued focus on the core business of producing milk in the most efficient way possible is likely to be the best option for most dairy farms in Victoria.

Key words: carbon, agriculture, dairy, offsets

Introduction

The Emissions Reduction Fund (ERF) is now the core component of the Australian Government's plan to meet its target of a 5% reduction in greenhouse gas emissions by 2020. The ERF builds on the Carbon Farming Initiative (CFI), which was previously described as a "world-leading offset scheme," (MacIntosh 2012).

Whilst the CFI aimed to provide opportunities for farmers and land managers to undertake 'projects' to generate saleable carbon offsets, the ERF now covers emission reduction activities across the economy. However, this paper will only focus on those relevant to the farming sector. Under the scheme, activities are broadly grouped into those which enable carbon to be stored (sequestration projects) or those that reduce greenhouse gas emissions (emissions avoidance projects). As the program is voluntary, farmers are able to decide whether participating in the ERF is feasible for their farming business.

This paper examines the feasibility of potential projects using case study farms across the three dairying regions of Victoria, Australia. The projects included a sequestration project (Environmental planting) and 2 emissions avoidance projects (reducing methane emissions from livestock (cows) and reducing nitrous oxide emissions from fertiliser and paddocks).

Theory

Greenhouse gas emissions from the agriculture sector in Australia
Australia's agricultural sector currently accounts for around 17% of the nation's greenhouse gas emissions (Department of the Environment 2014). It has been identified that this sector can also potentially offer opportunities to reduce or offset emissions from other sectors.

The Emissions Reduction Fund
Farmers who wish to participate in the ERF are required to set up a project under a methodology approved by the Australian Government. Successful implementation of a project provides the farmer with carbon credits (referred to as Australian Carbon Credit Units ACCUs). These credits can be sold via an auction process administered by the Clean Energy Regulator. The first auction is due to be held in April 2015. The Clean Energy Regulator is expected to set a minimum bid size of 2000 ACCUs (Hutchenson pers. comm.). ACCUs can also be bought by participants in the voluntary market who want to offset their emissions.

The following sections provide further background into the 3 potential project areas investigated.

Carbon Sequestration: Establishing an environmental planting
In certain circumstances, trees can offer benefits in a farming system. An example of this is the provision of shelter and shade for livestock. Under the ERF, farmers can also establish tree plantings for the purpose of sequestering carbon. As the purpose of establishing an environmental planting under the ERF is to store carbon, proponents must agree to a 'permanence obligation.' Under the CFI this was 100 years. Now, farmers have been offered a 25-year permanence option (Clean Energy Regulator 2014). Whilst this gives famers more flexibility about the long-term use of their land, they are only entitled to claim a lower percentage of the carbon sequestered compared to those with a 100 year permanence period. For projects with a 100 year permanence period, 95% of the carbon offsets can be claimed; with the remaining 5% retained by the Government as a 'risk of reversal buffer.' Where the 25 year option has been selected, farmers will be able to claim 75% of the offsets generated (a 20% reduction to cover the shorter 'permanence' period and the 5% 'risk of reversal buffer').

In order to plant trees, farmers need to remove land from agricultural production. Depending on what the land is used for, this could represent a significant cost. Farmers will only be willing to commit land to trees up to the point they see trees complementing their current farming system (Stewart and Reid 2006). Stewart and Reid (2006) claim agricultural research has found that planting trees for shelter on around 5% of the farm does not compromise agricultural productivity or capital value. They do, however, concede that trees can have differing impacts on agricultural profitability and resilience, and several scenarios exist (Figure 1). These scenarios range from a situation where a tree planting directly competes with agriculture to a scenario where, up to a point, profitability increases before the tree planting becomes competitive. This paper examines scenarios on case study farms where up to 5% of the farm is planted to an 'environmental planting' and discrete scenarios of where environmental plantings are established on single blocks of land to explore the opportunity cost should land need to be removed from agricultural production.

Insert Figure 1 near here.

Emissions avoidance: Reducing methane emissions from dairy cows through increasing the amount of oils in the diet
There has been a significant amount of research conducted on the efficacy of oil supplements to reduce methane emissions in dairy cows. For example, Moate *et al.* (2011) demonstrated that for every 1% increase in oil in the diet, enteric methane is reduced by 3.5%. Whilst this reduction sounds very promising, there are biological limitations in applying this strategy. For example, a cow can only have a maximum of 7% of oil/fat in the diet, and in southern Australia's pasture-based grazing systems at certain times of the year, her diet may already contain close to this amount of oil, and therefore it is not possible to add a specific oil supplement to her diet to reduce methane emissions. Hence, this strategy may only be effective at certain times of the year. These biological limitations

have formed the basis of assumptions outlined in the materials and methods. In light of these limitations, there is a need to investigate the potential for this strategy to be applied in a whole farm system context and quantify the number of carbon offsets that could be generated over a year and ascertain the likelihood of farmers adopting this strategy as an ERF project.

Emissions avoidance: Reducing nitrous oxide emissions from fertiliser and paddocks
An effective strategy to reduce nitrous oxide emissions is through the application of nitrification inhibitors (de Klein and Eckard 2008). In northern Victoria, these have been shown to reduce nitrous oxide emissions in cows' urine patches on pastures by 47% for 50 days in Spring and by 27% for 25 days in January (Kelly *et al.* 2008). Research in south-west Victoria has shown a 35-45% reduction in nitrous oxide emissions, with the period of effectiveness lasting approximately 70 days when applied in September and 100 days when applied in May (Kelly *et al.* 2012). A case study approach was used to investigate the emissions reduction potential and the farm-level impact of applying a nitrification inhibitor to pastures as a spray.

Materials and methods

A case study farm from each of the 3 key dairying regions (northern Victoria, southwest Victoria and Gippsland) in Victoria, Australia was used in the analysis (Table 1). All farms were pasture-based systems. Methane and nitrous oxide emissions from the farms were estimated using version 1.4 of the 'Dairy Greenhouse Gas Abatement (DGas) calculator (Christie *et al.* 2011), with results reported in carbon dioxide equivalents (CO_2-e).

Insert Table 1 near here.

Carbon Sequestration: Establishing an environmental planting
The analysis reported here used the approved methodology for "quantifying carbon sequestration by permanent environmental plantings of native species using the CFI reforestation modelling tool" (RMT).

The RMT was used to estimate the carbon sequestration over time for mixed species environmental plantings on the case study farms. For each farm, the approximate location (latitude and longitude) was used along with the planting area of a number of scenarios to get the location-specific sequestration rate and amount applicable to the farm and project. On each of the case study dairy farms, scenarios were tested whereby 1% or 5% of the total farm area owned by the farmer was planted to trees. On the farm in northern Victoria, an additional scenario where a small area of an out-block was planted to trees was tested. On the case study farm in Gippsland, an additional scenario was also tested. In this case, the scenario involved planting all the steep land being used to graze young stock to trees. These 2 additional scenarios were included to give some insight into the opportunity cost of an environmental planting in a 'real' farm situation. The establishment cost of an environmental planting used in the analysis was $2188/ha (Australian Farm Institute 2011).

Emissions avoidance: Reducing methane emissions from dairy cows through increasing the amount of oils in the diet
The research question examined the economic impact and opportunity for farmers feeding an oil supplement in place of some of the grain supplement during summer in the cows' diet. The approach taken involved estimating the farm reduction in methane emissions when 3 kg of the grain supplement in the cows' diet was replaced with an oil supplement. The following assumptions about the reduction in methane emissions were made: a 1% increase in dietary oil will reduce enteric methane by 3.5%, up to 7% of total oil in the diet can be fed and the cows' diet already contained 3% oil, the oil supplement will replace the existing supplement kg of dry matter (DM) for kg of dry matter in summer only (90 days), the cost of the oil supplement was the same as the grain supplement it replaced and no change to the feed delivery system in the dairy was needed. The oil supplement was assumed to have an estimated metabolisable energy (ME) content of 13.8 MJ/kg DM and replaced existing grain supplements on the farm that had energy estimates of 12.6, 12.5 and 13.2 for the Northern Victoria, Gippsland and south west Victorian case study farms, respectively. An estimate of the milk production benefit was made, assuming 1 litre of milk can be produced for every 5.5 MJ increase in

the cows' daily metabolisable energy consumption at 62% efficiency (CSIRO 2007). For this analysis, it was assumed the additional milk was of the same composition already produced on each of the case study farms.

Emissions avoidance: Reducing nitrous oxide emissions from fertiliser and paddocks through application of a nitrification inhibitor
The research question examined the economic impact and opportunity for Victorian dairy farmers applying a nitrification inhibitor to pastures as a spray. The approach taken involved estimating the annual reduction in nitrous oxide emissions when the inhibitor was applied to areas of the farm receiving nitrogen fertiliser. The potential reductions were estimated using the DGas calculator. From this, the potential income from the sale of carbon offsets was estimated. The following assumptions were made in the analysis: inhibitor was sprayed on the milking area only, cows grazed the areas the inhibitor had been applied during the period of its effectiveness , nitrous oxide emissions were reduced by 45% for 100 days when inhibitor was applied in May and 35% for 70 days when applied in September for the farms in Gippsland and southwest Victoria and reduced by 47% for 50 days when the inhibitor was applied in September and 27% for 25 days when applied in January in northern Victoria. It was also assumed nitrogen fertiliser was applied at the time the inhibitor was effective and the inhibitor was applied twice per year at a total cost of $165/ha/year. Additional feed was valued in terms of metabolisable energy on a comparative c/MJ basis with purchased supplementary feed. Dry matter yield increases used baseline pasture consumption data from each farm to calculate the amount of extra feed produced at yield increases of 5, 10, 15 or 20%.

Results

Carbon Sequestration project: Establishing an environmental planting
The amount of carbon that can be sequestered varies over time and location (Figure 2). From the time of establishment until about the tenth year, the amount sequestered each year increases, before declining (Figure 2). By the one hundredth year, the environmental plantings in all locations are predicted to sequester 1 t CO_2-e/ha/year or less. The farm located in the high rainfall area of Gippsland has the highest carbon sequestration potential, with the ability to sequester more than twice the amount of carbon per hectare than the farm in northern Victoria, and about 20% more compared to the farm in SW Victoria (Figure 2). Table 2 summarises the total amount of carbon sequestered over time should each of the case study farms be planted to either 1%, or 5% of trees and the saleable ACCUs accrued over a 25, or 100 year period. It can be seen that by year 25, 45% of the total potential ACCU's of a 100 year project have been sequestered.

Insert Figure 2 and Table 2 near here.

If it is assumed land is to be removed from agricultural production, there is a significant cost in doing this. Two examples of the opportunity cost of establishing the environmental planting on land previously used for agriculture are as follows:

Example 1:
The 16 ha of land on the northern Victorian farm was previously used to grow Lucerne that was harvested and conserved and subsequently fed to the milking herd. This area of land yielded 20 t DM/ha/year. Assuming this was valued at $250/t, the income foregone for the 16 ha block is $80,000/year (Table 3). Whilst it is acknowledged there would be costs associated with growing and harvesting this crop each year, the income foregone is far more than what could be earned from carbon offsets, even in the year where the planting is sequestering the most carbon.

Example 2:
The land on the Gippsland case study farm was previously used for grazing young stock. As this was steep hill country, the estimated pasture consumption was 1.9 t DM/ha. In this case, 123.5 t pasture DM is foregone at a total value of $27,170 (assuming pasture is valued at $220/t DM). Whilst in some years, the value of carbon offsets may be greater than this, because of the changing rate of sequestration over the time, overall this option is unlikely to be economic.

Insert Table 3 near here.

Emissions avoidance projects

Table 4 shows that across the case study farms, methane emissions were reduced by 29-39 t CO_2-e/farm/year if the feeding oils strategy was applied, whilst decreases in nitrous oxide emissions from the use of nitrification inhibitors were 50-85 t CO_2-e/farm/year. At an optimistic carbon price of $25/ t CO_2-e, the estimated income from the sale of ACCUs from these strategies would be up to $975/farm/year for feeding oils and $2125/farm/year for the use of nitrification inhibitors on the case study farms. This table also shows the maximum value of potential production benefits for the case study farms analysed was $9,251/farm for the feeding oils strategy and $8,922 for the use of the nitrification inhibitors strategy.

Insert Table 4 near here.

Discussion

Carbon sequestration projects

The key limitation to evaluating a carbon sequestration project is being able to forecast unknown factors such as long-term carbon price, the occurrence of events that could compromise the environmental planting (such as bushfire or disease) and quantifying the potential value to the farm system in addition to the generation of carbon offsets. For example, the provision of shade and shelter to livestock and whether grazing will be possible once the planting has been established.

In all of the case study farms analysed, it would take more than 10 years to generate sufficient ACCUs to meet the minimum bid criteria, if 5% of the farm were planted to trees. The minimum of 2000 ACCUs would never be reached if only 1% of the farm was planted to trees. These findings suggest if farmers were to implement carbon sequestration projects of this size, some level of aggregation with other landholders may need to occur.

The results in this study suggest that Victorian dairy farmers are unlikely to participate in an environmental-plantings project under the ERF. The opportunity cost of land that has been used for grazing, or growing forage for conservation on the dairy farms in this study is greater than the benefits that would be obtained from establishing an environmental planting. There may be exceptions on some farms where there is less productive land, or if the suggestion of Stewart and Reid (2006) holds true (planting trees on ≤5% of a farm does not compromise agricultural productivity or value). The question, however, remains as to whether shelter belt type plantations meet the requirements of plantations established to generate ACCUs. Furthermore, under the methodology for environmental plantings with the permanence requirements, the absence of a clear economic benefit and a number of ‘unknowns’ around carbon price mean that very few, if any, dairy farmers would pursue such a carbon sequestration project. Another risk is the potential change in land value as a result of establishing an environmental planting on land previously used for agriculture. These risks have not been incorporated into this analysis and hence the results should be considered as a ‘best case’ scenario under this methodology.

Emissions avoidance projects

The benefit of an ‘emissions avoidance’ project over a carbon sequestration project under the ERF is that no ‘permanence rules’ apply. This means that farmers could choose to participate in some years, but not others.

The reduction in methane emissions for each of the case study farms was modest and the potential to achieve a production benefit will vary widely between farms. Variable responses to oil and fat supplementation have been reported in the literature, with milk yield responses influenced by a number of factors including basal diet, stage of lactation, energy balance and amount of supplemental fat (NRC 2001). In the study reported here, the estimate of production benefit is at the upper limit of what’s possible. There is a chance that no production benefit will be observed in practice and there may even be negative effects on concentrations of milk protein and fat (Moate *et al.* 2011). To put the potential production benefit in context, at an estimated long-term milk price of $4.77/kg protein and fat, the range in annual milk income from the case study farms analysed is approximately $600,000 to $1,200,000. This further suggests that farmers are unlikely to pursue the relatively small additional income from a production benefit that may or not be observed, or from the sale of ACCUs. Similar to the carbon sequestration projects examined on the case study farms, feeding cows an oil supplement would not generate enough ACCU's to be sold as a single package to the ERF. The farmer would need to be involved in some aggregation program with other farmers.

In the case of nitrification inhibitors, pasture DM yield increases may be possible under certain conditions. In the study reported here, a range of DM yield increases were tested within the range of what has been achieved in New Zealand. In New Zealand, pasture DM yield benefits of up to 36% from nitrification inhibitors applied to urine patches have been observed, with an estimated 21% increase in annual dry matter yield at the paddock scale (Moir *et al.* 2007). As the estimated cost of applying the inhibitor was $20,000-$30,000 per farm per year in this study, there was no net benefit of growing additional feed, in most scenarios where a potential yield increase was assumed, even if it were biologically possible. Pasture yield benefits in the order of what has been observed in New Zealand would be necessary to achieve a net production benefit on these farms. However, pasture yield benefits of this magnitude have not been observed to date in Victoria. For example in south-west Victoria, pasture yield benefits between 0 and 15% have been found when the inhibitors are applied to urine patches but these are unlikely to be significant at the paddock scale (Kelly, 2011). Similar to the feeding oils strategy, insufficient ACCUs would be generated (from farms of the scale analysed) to be sold as a single package to the Emissions Reduction Fund. Even if the two emissions avoidance strategies were combined for the one farm, at best only about 6% of the minimum amount of required ACCUs for a viable auction bid would be generated within a year.

In summary, the likelihood of farmers adopting the strategies described on the basis of the sale of carbon offsets alone is remote, particularly when the annual costs of participating in such a scheme are estimated to be in the order of $2,500 per farm per year (Australian Farm Institute, 2011).

Conclusion

As there are costs for farmers to participate in the Emissions Reduction Fund scheme in return for an estimated relatively small and uncertain return, a continued focus on the core business of producing milk in the most efficient way possible is likely to be the best option for most dairy farms in Victoria. Efficient systems of dairy production will minimise greenhouse gas emissions.

Acknowledgements

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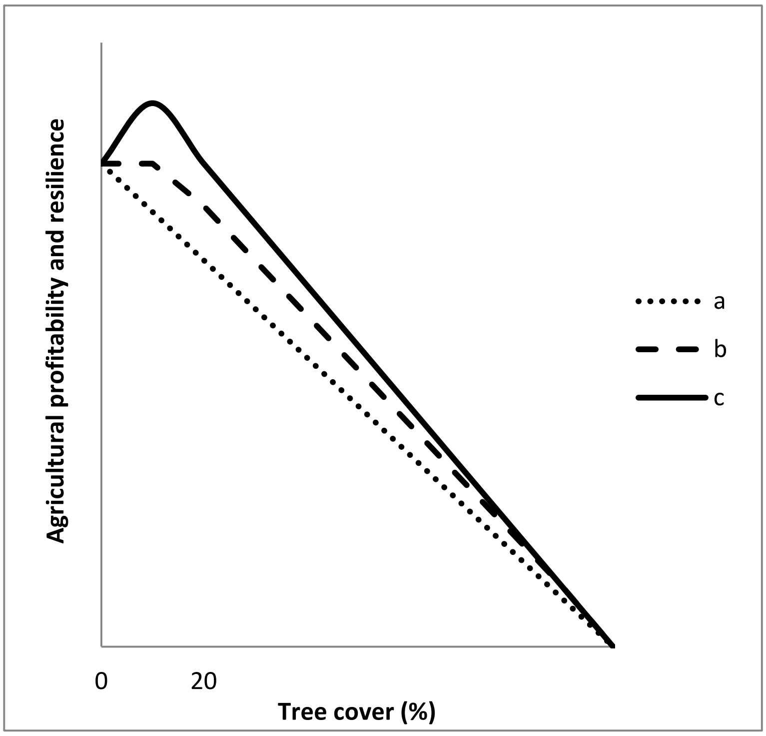

Figure 1. Possible impact on agricultural profitability of increasing farm tree cover for different scenarios: (a) competitive: any increase in tree cover results in a reduction in agricultural profitability; (b) initially supplementary: increasing tree cover does not impact on agricultural production until a threshold is achieved; (c) initially complementary: agricultural profitability increases with increasing tree cover before coming competitive. Adapted from Stewart and Reid (2006).

Table 1. Key details of case study farms used

Farm	Farm area (ha)		Milking cows		Farm milk solids (t protein+fat/annum)	Nitrogen applied (t/annum/farm)
	Milking area	Outblock area	No.	liveweight (kg)		
Nth Vic	129	411	390	650	252.8	17.75
Gippsland	140	105	380	520	182.8	30.38
SW Vic	177	-	288	535	125.7	31.68

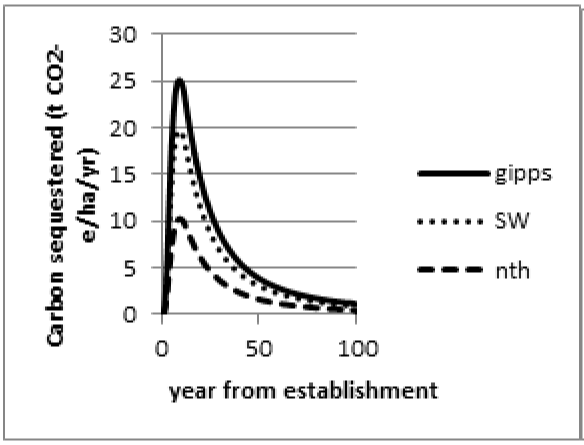

Figure 2 (a) Annual amount of carbon sequestered (t/CO_2-e/ha/year) in each

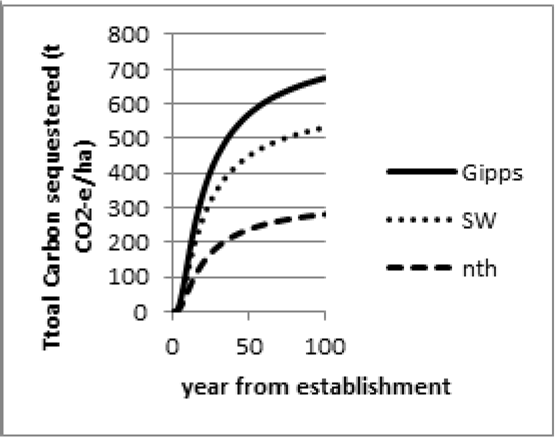

Figure 2 (b) Cumulative amount of carbon sequestered (t/CO_2-e/ha) over a 100 year

Table 2. Total amount of carbon sequestered over time for different scenarios regarding the percentage of farm planted to trees, and different permanence options under the Emissions Reduction Fund.

Case study farm	Scenario	Cumulative amount carbon sequestered (t CO_2-e)		Number of saleable ACCUs	
		By year 25	By year 100	25 year option	100 year option
Nth Vic	1% farm area (4.29 ha)	724	1,203	543	1,143
	5% farm area (21.45 ha)	3,620	6,014	2,715	5,713
Gippsland	1% farm area (2.55 ha)	1,000	1,651	750	1,568
	5% farm area (12.75 ha)	5,002	8,254	3,751	7,841
SW Vic	1% farm area (1.77 ha)	569	940	427	893
	5% farm area (8.85 ha)	2,845	4,699	2,134	4,464

Table 3. Two examples of the opportunity cost of removing land from agricultural production on the case study farms in northern Victoria and Gippsland.

Scenario	Opportunity cost ($/year)	Cumulative amount carbon sequestered (t CO_2-e)		Total saleable ACCUs	
		By year 25	By year 100	By year 25	By year 100
Part outblock Nth Vic (16 ha)	80,000	2,700	4,486	2,025	4,262
Hilly outblock Gippsland (65 ha)	27,170	26,541	43,796	19,905	41,606

Table 4. Reduction in methane and nitrous oxide emissions on the 3 case study farms when the emission avoidance strategies are applied on farm and potential benefits from the sale of Australian Carbon Credit Units

	Northern Victoria	Gippsland	SW Victoria
Greenhouse gas emissions (baseline)(t CO_2-e/year)			
Methane (CH_4)	1734	1443	1139
Nitrous Oxide (N_2O)	481	470	355
Strategy 1: Feeding an oil supplement			
Reduction in CH_4 emissions (t CO_2-e/year)	34	39	29
Potential annual value of offsets @$10/t CO_2-e	340	390	290
Potential annual value of offsets @$25/t CO_2-e	850	975	725
Estimated potential increase in milk income[1]($/farm/year)	7956	9251	3142
Strategy 2: Using a nitrification inhibitor			
Reduction in N_2O emissions (t CO_2-e/year)	50	85	69
Potential annual value of offsets @$10/t CO_2-e	500	850	690
Potential annual value of offsets @$25/t CO_2-e	1250	2125	1725
Estimated net value of additional feed ($/farm/year) at yield increases of:			
5%	-16,652	-15,648	-19,673
10%	-12,019	-8,197	-8,066
15%	-7,387	-745	-610
20%	-2,754	6,706	8,922

[1] Assuming additional energy is converted to milk and milk price is $4.77/kg protein and fat.

D11. Project title

A comparative analysis of Greenhouse Gas Emissions from beef cattle grazing irrigated *Leucaena leucocephala* (Lam.) de Wit cv. Cunningham crops in northern Australia

Organisation The University of Melbourne

Primary contact Chris Taylor

Paper under internal review – for consideration for publication in Land Use Policy

A comparative analysis of Greenhouse Gas Emissions from beef cattle grazing irrigated *Leucaena leucocephala* (Lam.) de Wit cv. Cunningham crops in northern Australia

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Abstract

This study provides a gate-to-gate Life Cycle Assessment (LCA) that focuses on the greenhouse gas (GHG) emissions from steers grazing on irrigated *Leucaena leucocephala* (Lam.) de Wit cv. Cunningham (Leucaena) crops and a surrounding farm property in northern Australia. It involves modeling the GHG emissions from the steers and comparing these emissions with alternative herd management pathways on the farm property. The herd consists of 1250 steers, which are bred on a nearby property and walked to the property analysed in this study. The steers graze start grazing the *L. leucocephala* crops when they are 16 months old and continue for around 240 days. At the conclusion of grazing *L. leucocephala*, the steers are sold. The alternative management pathways consist of the steers grazing on the bush paddocks until the time of sale (as a baseline) and two consisting of the steers grazing on expanded Leucaena Crops. The results show significant long-term average reductions in GHG emissions between the existing and alterative Leucaena Crop management pathways (P<0.05), each with reductions of 73% and 53% of GHG emissions respectively. The long-term average reductions of GHG emissions is also significant (P<0.05) per live weight tonne (LWT) produced for the existing and expanded Leucaena Crop management pathway, with reductions of 81% and 93%, respectively. Expanding the Leucaena Crop by clearing native vegetation results in a 9% increase of long-term average GHG emissions, but a reduction of 81% in GHG emissions per LWT. The significant reductions can be attributed to 1) the higher growth rates in the steers, with steers achieving the preferred sale weight in less time; 2) the net primary productivity of Leucaena; and 3) the increased soil carbon content under the crop.

Introduction

Agriculture releases comparatively large quantities of greenhouse gases (GHG) into the atmosphere (Smith et al 2007). These emissions are expected to increase in coming decades, due to escalating demands for food and shifts in diet. In response, several economies are planning, implementing or refining domestic mitigation actions to reduce greenhouse gas emissions (Kossoy et al 2014). Improved management practices and emerging technologies may permit a reduction in emissions per unit of food (or of protein) produced (Smith et al 2007).

Livestock production and management makes up a large proportion of agricultural greenhouse gas emissions, which are estimated at 7.1 Gt CO_2-eq per annum and represents 14.5% of all anthropogenic GHG emissions (Gerber et al 2013). Beef cattle comprise 41% of livestock emissions, which is the by far the largest of the sector. Given the large proportion of GHG emissions originating from beef cattle production and that consumption of meat products are projected to increase (Alexandratos and Bruinsma 2012), reducing GHG emissions from production and processing of beef cattle will become increasingly important, particularly in line with global efforts to mitigate rising GHG emissions and market preference towards less GHG intensive forms of food production (Smith et al 2007; Garnaut 2008).

The beef cattle sector has been identified as having opportunities to reduce its GHG emission intensity (Smith et al 2007). The Australian Federal Government has introduced voluntary agricultural emission avoidance projects, as part of its Carbon Farming Imitative (CFI) and its current Emissions Reduction Fund, where it awards and pays businesses that take steps in reducing their GHG emissions, such as reducing enteric methane emissions or protecting native vegetation. This can form an income for a farm (Commonwealth of Australia 2014b).

In this context, there is interest in testing alternative management strategies of beef cattle and their respective GHG emission profiles. In particular, there has been growing interest in the use of *Leucaena leucocephala* (Lam.) de Wit cv. Cunningham (Leucaena) as a forage crop for beef cattle, where research indicates that the crop has the capacity to increase carbon stocks in the soil (and hence carbon sequestration) (Radrizzani et al 2010; Conrad 2014) and reduce enteric emissions (Kennedy and Charmley 2012). Leucaena is a productive perennial legume tree that typically grows with companion pasture grasses in subtropical and tropical regions (Radrizzani et al 2010; Harrison et al in review). The goal of this study is to model the impact of alternative grazing management pathways on the GHG emissions of a property, with a particular focus on the use of Leucaena as a forage crop.

Methods

This study models the GHG emissions resulting from steers grazing on a Leucaena crop with companion pasture grasses on a case study farm, located in the Burdekin River region of northern Queensland (Figure 1). The results are compared to baseline management strategies that are commonly implemented by small farm enterprise across northern Australia, which consist of cattle grazing cattle on rangeland and modified pasture. This study works within the parameters of the case study farm, which has an irrigated Leucaena crop established for foraging, in order to provide realistic scenarios of management.

The Site

The case study farm is Byrne Valley, which is located along the banks of the Burdekin River, 43km southwest of Home Hill in northern Queensland (Figure 1). The farm covers an area of around 12,000 ha and consists of grazed native vegetation and pasture, modified pasture, crops planted with *Leucaena leucocephala* (Lam.) de Wit cv. Cunningham (Leucaena) and un-grazed native vegetation. The Leucaena crop is flood irrigated and the water is supplied from the Burdekin Irrigation scheme (Heatley pers comm.). The bush paddocks are lightly wooded and have been classified by the National Vegetation Information System (Department of Environment 1999) as Eucalyptus Woodland. Much of the farm consists of sparse tree cover (10-30 percent cover) (Geoscience Australia 2011), but land in the vicinity of the Burdekin River consists higher tree coverage (50 percent cover). The property has been grazed since the late 1890s and early 1900s (Heatley pers comm.). Around 1,000 to 1,500 steers graze on the property at Byrne Valley.

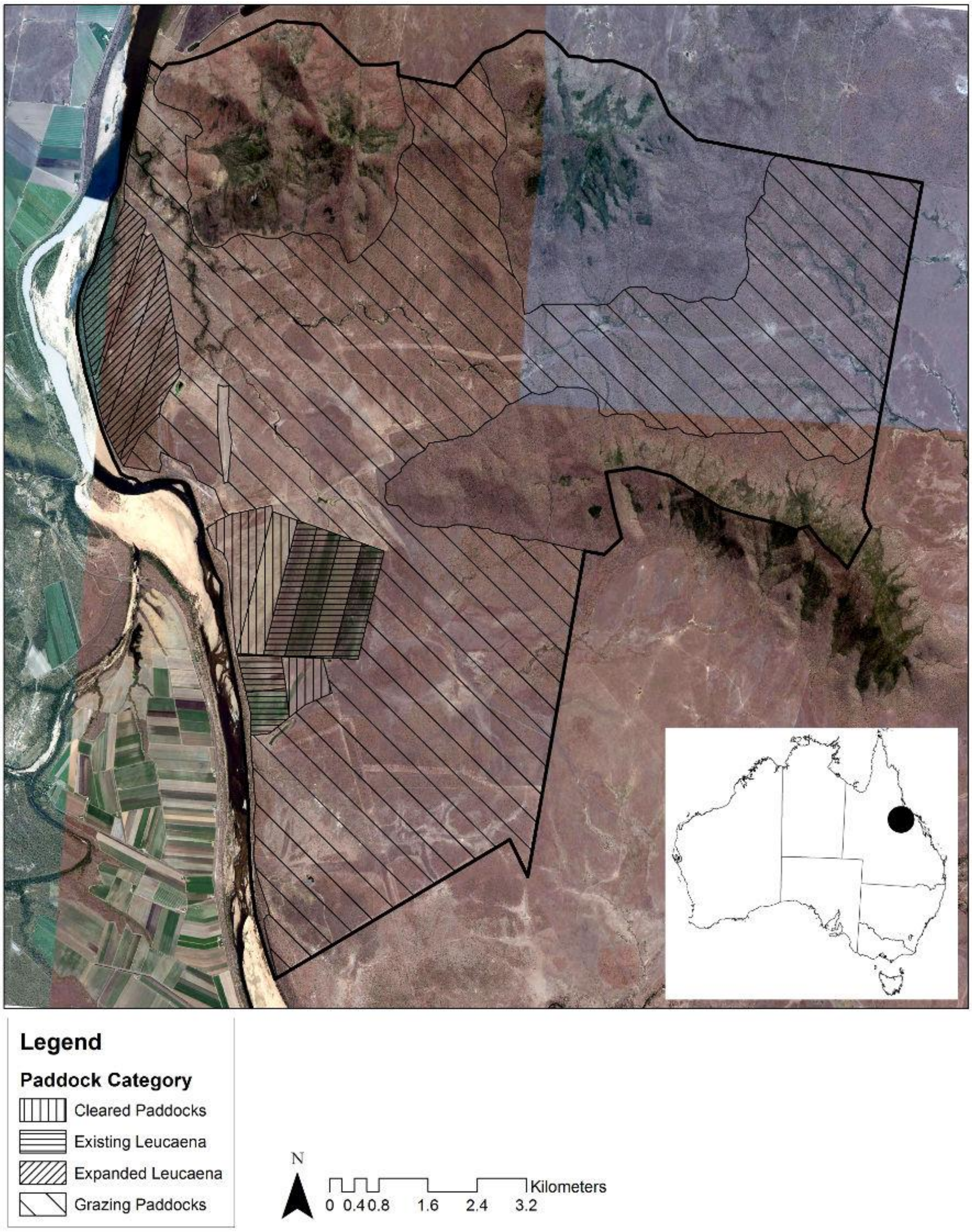


Figure 1: Byrne Valley Farm and location

The majority of the Byrne Valley farm is used for steers grazing in native pasture and vegetation (covering 8,495 ha). The existing Leucaena crops (covering 386 ha across 6 paddocks) and the modified pasture paddocks (covering around 261 ha across three paddocks) were previously cleared of native vegetation in 1970 for the purposes of rice crop establishment (Heatley pers comm.). The previously cleared areas that are not planted with Leucaena are currently used for grazing (Figure 2).

Farm and production pathways

There are four management pathways used in this study. The first was to model existing farm management, which includes the steers grazing on bush paddocks and the existing Leucaena crops. This pathway is referred as the 'Existing Leucaena' management pathway. The second models a baseline ‘pre-Leucaena crop’ condition as a baseline for comparison with other pathways. This consists of the steers grazing the bush paddocks and it was the farm management pathway up to the establishment of the existing Leucaena crop between 1999 and 2002. This pathway is referred as the ‘Baseline’ pathway. The third management pathway consists of the expanded Leucaena crop with bush paddock grazing. This consists of planting the previously cleared modified pasture with Leucaena and clearing native vegetation to establish a further 414 ha of Leucaena crops. Overall, this increases the Leucaena cropped area from 386 ha to 1,061 ha. This pathway is referred as the ‘Expanded Leucaena’ pathway. The fourth management pathway consists of the previous cleared modified pasture being planted with Leucaena, but the native vegetation to be cleared in the previous pathway is retained and the expanded Leucaena crop proposed for that area does not proceed. This pathway is referred as the ‘Alternative Leucaena’ pathway.

Figure 2: Byrne Valley Farm Paddocks – Bush Paddocks used for grazing (top left); previously cleared paddocks (est. 1970) proposed for Leucaena planting (Milans Block) (top right); Existing Leucaena crop (bottom left); Thick woody vegetation in proximity to the Burdekin River (bottom right) (Photos: Chris Taylor)

The existing Leucaena crops were established on five paddocks. The first paddock was developed starting 1999, with the second paddock commencing 2000, the third and fourth in 2001 and the last paddock commencing development in 2002. Planting of the Leucaena crop was carried out in the April of these years. The steers were introduced to each Leucaena paddock for light grazing in the July, followed by a heavy graze in the November of the establishment year. The steers spend two weeks grazing on each paddock. Once the steers have grazed all of the five paddocks in sequence, they are returned to the first paddock, which has recovered from the previous grazing. The time grazing Leucaena is 240 days.

The steers are bred on the nearby Rangemore property and walked to Byrne Valley over a distance of 14 km. Around 1,000-1,500 steers enter Byrne Valley at 6 months of age around June and graze the native pastures until the following April, where they enter the Leucaena crop. For the purposes of this analysis, 1,250 steers were modeled as the average of the range (Table 1). They enter the Byrne Valley bush paddocks at around 152kg per head and enter the Leucaena crop at around 302kg per head. They are sold at 550 kg per head upon exiting the Leucaena paddocks.

Table 1: Baselines and scenarios to be compared (current management strategy shaded)

	Baseline	**Existing Leucaena Bush Paddocks**	**Existing Leucaena Plots**	**Expand Leucaena Scenario Bush Paddocks**	**Expand Leucaena Scenario Plots**	**Alt Expand Leucaena Scenario Bush Paddocks**	**Alt Expand Leucaena Scenario Plots**
Property	Bush Paddocks	Bush Paddocks	Leucaena Crops	Bush Paddocks	Leucaena Crops	Bush Paddocks	Leucaena Crops
Number of Cattle (n)	1,250	**1,250**	**1,247**	**3,434**	**3,431**	**2,094**	**2,091**
Landed Weight (kg)	152	152	302	152	302	152	302
Turnoff Weight (kg)	550	302	550	302	550	302	550
Weight Gain (kg)	398	150	248	150	248	150	248
Days Carried (n)	1,095	304	240	304	240	304	240
LWG (kg/day)	0	0.49	1.03	0.49	1.03	0.49	1.03
Annual Mortality Rate (%)	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Mortalities (n)	12	3	3	3	3	3	3
Number of Cattle (n) following Mortality	**1,238**	**1,247**	**1,244**	**3,431**	**3,428**	**2,091**	**2,088**
Total LWT (t)	**681**	**377**	**684**	**1,036**	**1,885**	**631**	**1,148**
Area Grazed (ha)	**9,556**	**9,170**	**386**	**8,495**	**1,061**	**8,909**	**647**
Stocking Rate hd/ha	**0.13**	**0.14**	**3.22**	**0.40**	**3.23**	**0.23**	**3.23**

The intended commencement of the Expanded Leucaena crop pathway was set for April 2015. In the area currently under native vegetation, the standing eucalyptus woodland was planned for clearing and debris to be burnt at the end of May. The site was to be laser levelled and the Leucaena crop planted in April 2016. Similarly to the existing Leucaena crop, the cattle were intended to lightly graze the new Leucaena crop, followed by a heavy grazing in November. The grazing cycle of the crops was to commence in April 2017. It was intended to introduce an additional 2,184 steers following the establishment of the new Leucaena crop, taking the total output of steers on the farm to 3,431 head.

The alternative Leucaena crop pathway is also intended for commencement at April 2015. It is excludes the area under native vegetation and includes the areas under that were previously cleared and not under Leucaena. The sequence of planting, grazing and management is identical to the Expanded Leucaena pathway. It is intended to introduce an additional 844 steers following the establishment of the new alternative Leucaena crop, taking the total output of steers on the farm to 2,091 head.

Greenhouse Gas Analysis and Gate-to-Gate Life Cycle Analysis

This study applies the National Inventory Reporting method for Greenhouse Gas Emissions, as used by the Australian Government (Commonwealth of Australia 2014), and Gate-to-Gate Life Cycle Analysis (Jiménez-González et al 2000). The National Inventory Method consists of estimating greenhouse gas emissions and sinks using a combination of country-specific and IPCC methodologies and Emission Factors (Commonwealth of Australia 2014). These methods are consistent with the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories and Good Practice Guidance on Land Use, Land Use Change and Forestry and are comparable with international practice. The study uses the agricultural and forestry components of the National Inventory Method, consisting of the Beef Greenhouse Accounting Framework for Northern Australia (B-GAFN) (Eckard et al 2008) and the Full Carbon Accounting Model (FullCAM) (Richards 2001).

The greenhouse gas emissions were calculated by using B-GAFN, which consists of a series of calculators that require inputs to model the potential emissions from specific agricultural activities. The calculators provide a greenhouse gas emission profile for each property of the beef cattle production process. The calculators break down the GHG emissions into the various sources on the properties (Eckard et al 2008). The FullCAM framework is an integrated compendium model that provides the linkage between various sub-models. It has components that deal with the biological and management processes which affect carbon pools and the transfers between pools in forest, agricultural, transitional (afforestation, reforestation, deforestation) and mixed forestry and agricultural systems. The exchanges of carbon, loss and uptake, between the terrestrial biological system and the atmosphere are also accounted (Richard 2001). The integrated suite of models consist of the physiological growth model for forests (3PG), the carbon accounting model for forests developed by the Australian Greenhouse Office (AGO) (CAMFor), the carbon accounting model for cropping and grazing systems (CAMAg), the microbial decomposition model (GENDEC) and the Rothamsted Soil Carbon Model (Roth C). These models have been developed for the various purposes of predicting and accounting for soil carbon change in agriculture and forest activities, the determination of rates of decomposition of litter and the prediction of growth in trees (Richards 2001).

The method and results study are arranged within the framework of a Gate-to-Gate Life Cycle Assessment (LCA) (Jiménez-González et al 2000). LCA has become a widely applied method of analysis in agriculture (Horne et al 2009; Biswas et al 2010; Brock et al 2012). LCA addresses the environmental aspects and potential environmental impacts throughout a products life cycle from raw material acquisition, through production and final disposal (ISO 2006). Although LCA encompasses multiple impact categories, inclusive of land use, water and global warming, taking a 'Cradle to Grave' approach (Jolliet et al 2003), this study employs a Gate-to-Gate LCA, where the impacts occurring within the property boundary are considered (i.e. the steers entering and existing the farm property boundary). This is a feasible and plausible LCA alternative when factual or literature information is not available for a study (Jiménez-González et al 2000). Furthermore, changes to management were occurring within the Byrne Valley farm boundary, consisting of GHG emissions.

The study is guided by the principles and frameworks outlined in International Standard ISO 14040 'Environmental management – Life Cycle Assessment – Principles and Framework' (ISO 2006). The study states its goal (introduction), its scope, the product system, functional unit, boundary of the system analyzed. The results are explained through a Life Cycle Inventory analysis, which involves the collection and input of data, and the Life Cycle Impact Analysis, which calculates the environmental impact. For this Gate-to-Gate LCA, the impact is the weight of CO_2-e emissions (tonnes), because this was identified as the largest impact factor of the farm.

Scope of study

The scope of the study consists of the product system, functions of the product system, the functional unit, the system boundary, impact categories, data requirements, assumptions and limitations. These are largely derived from the requirements described in ISO 14040.

Product system

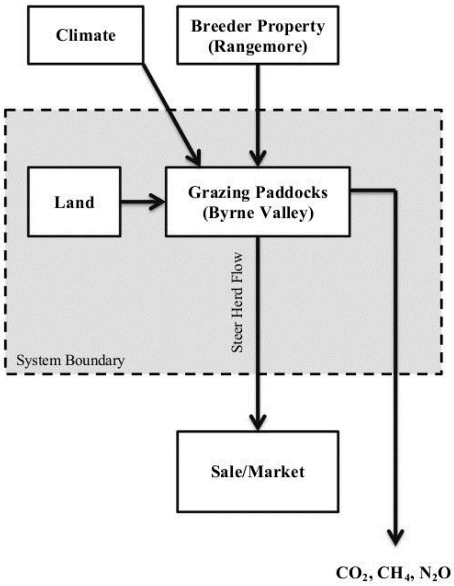
The product system is the collection of unit processes with elementary and product flows, performing one or more defined functions (ISO 2006). The product system for this analysis consists of the existing management pathway at Byrne Valley, the Expanded Leucaena Crop pathway, Alternative Leucaena management pathway and these are compared against the baseline management pathway.

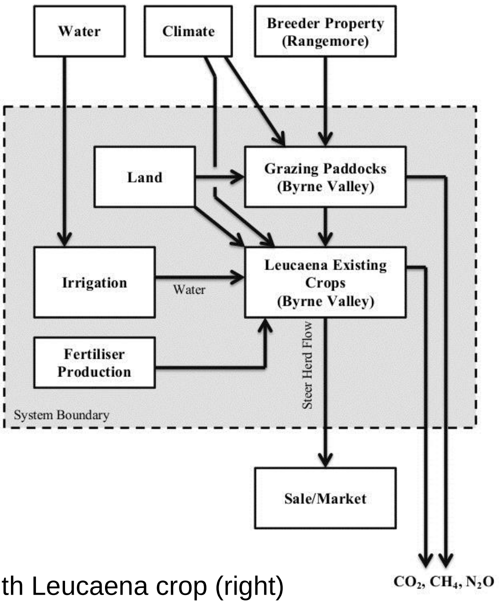
Functional unit

The functional unit details the quantified performance of a production system for use as a reference unit. Its primary purpose is to provide a reference to which the inputs and outputs are related (ISO 2006). The primary purpose of the Byrne Valley farm is to graze steers from weaners to steers at the preferred weight of 550kg/head. Based on these parameters, the live cattle are considered the final product of the process. This study uses the live weight tonnes (LWT) of cattle produced as the functional unit.

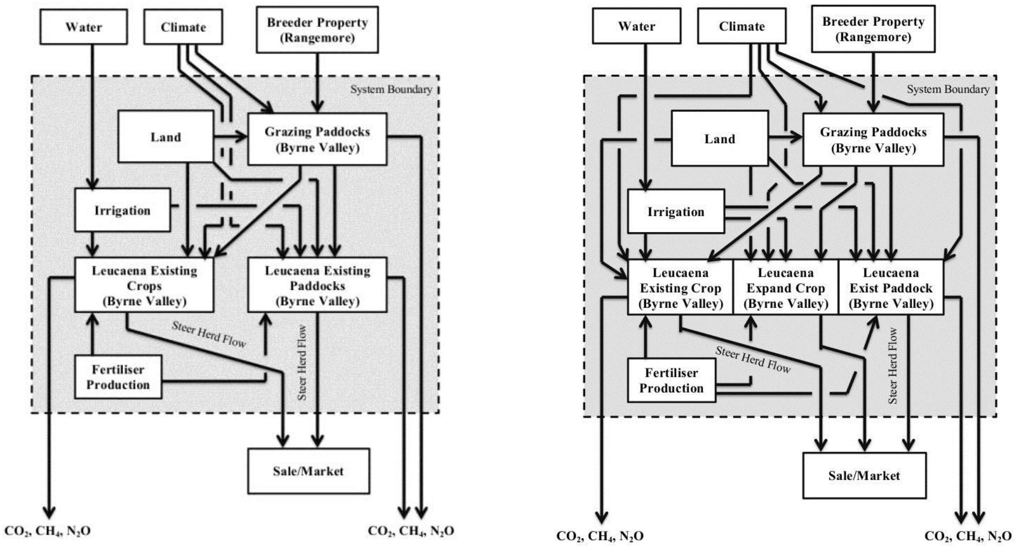
System boundary

The system boundary defines the unit processes to be included and modeled in the study (ISO 2006). In this study, the system boundary was determined by identifying unit processes that were changed between the respective baselines and scenarios of herd management. Under the Existing Leucaena management pathway, unit processes that were included in the system boundary consisted of steers grazing the native pastures (bush paddocks) and the existing Leucaena crop, with land being provided to both. Irrigation was provided to the Leucaena crop from an external water source (Burdekin Dam). Fertiliser was accounted for in its application to the Leucaena crop. The Rangemore breeding property and the source of irrigation are located outside the system, because these are considered consistent irrespective of management pathway. The outputs are the steers at the point of sale and the GHG emissions from the process. Under the Expanded Leucaena crop management pathway, the native pastures (bush paddocks) and the expanded Leucaena crops are included in the system boundary. Under the Alternative Leucaena management pathway, the bush paddocks and the expanded Leucaena crop, excluding the planned area for development under native vegetation, are included in the system boundary. The baseline management pathway includes bush paddock grazing (Figure 3).





Baseline: Scenario (left) and existing management with Leucaena crop (right)



Expanded Leucaena Scenario (left) and Alternative Leucaena Scenario (right)

Figure 3: Production system and system boundaries for the management pathways

Impact categories

Impact categories describe the classes representing the environmental issues of concern to which the life cycle inventory analysis results may be assigned (ISO 2006). This study focuses only on the impact of GHG emissions, resulting from the production of steers grazing Byrne Valley. Other impact categories, including land occupation or mineral extraction, are not covered by this study.

Limitations of the study

The LCA only addresses the environmental issues that are specified in the goal and scope and it is not a complete assessment of all environmental issues of the product systems (ISO 2006). As this study only provides a Gate-to-Gate LCA of the carbon stock of the property, the emissions from the steers and the management pathways, other environmental impacts (and their resulting emissions) are not covered. It is assumed that greenhouse gas emissions resulting from these impacts are relatively minor when compared to the GHG emissions from the unit processes identified within the system boundary. The purpose was to provide a comparison between a baseline herd management, the Existing Leucaena crop management pathway and alternative management pathways. Further study can include these other impact categories to provide a more comprehensive overview of emission intensity of the management pathways.

Results

Life Cycle Inventory Analysis

The Life Cycle Inventory Analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of the product system (ISO 2006). Data was collected directly from farm management at Byrne Valley. This included cattle numbers for the herd, landed and exit weights, days carried on pastures and crops and mortality rates. Climate data inputs were collected from the SILO database (Jeffery et al 2001), allometric partitioning and growth rates of Leucaena were obtained through a literature review and calculating the forage requirements of the steers (MLA 2006) and the allocation and biomass estimates of Eucalyptus *populnea* (Burrows et al 2000).

Climate Inputs

Climate data input was sourced from the SILO database for the Millaroo weather station, approximately 4.5km south of the Byrne Valley property (Jeffery et al 2001). The site is part of the Wet/Dry Northeastern Tropics Agro-ecological Region of Australia. This region is characterised by a marked seasonal rainfall distribution, with significant wet (summer) and dry (winter) seasons (Willams et al 2002). The site experiences a high degree of year-to-year variation in rainfall, as expressed in a high coefficient of variation, with the greatest variation occurring in the dry season, peaking in September (Figure 4).

Carbon stock of native vegetation

The native vegetation across Bryne Valley mostly consists of sparse woodland cover (DLCD 2011). The tree species that are dominant across the property are primarily Clarkson's Bloodwood (*Corymbia polycarpa)* and Poplar Box (*Eucalyptus populnea)* (Boland et al 2006; Heatley pers comm.). Allocation data and biomass estimation was entered for Poplar Box (Burrows et al 2000). This was the closest estimate of above ground biomass in relation to the Byrne Valley property, which features mostly intact woodland (largely unmodified by previous clearing or logging). The initial woodland conditions were entered into FullCAM as intact mature woodland with 30 percent ground cover (DLCD 2011) (Table 2).

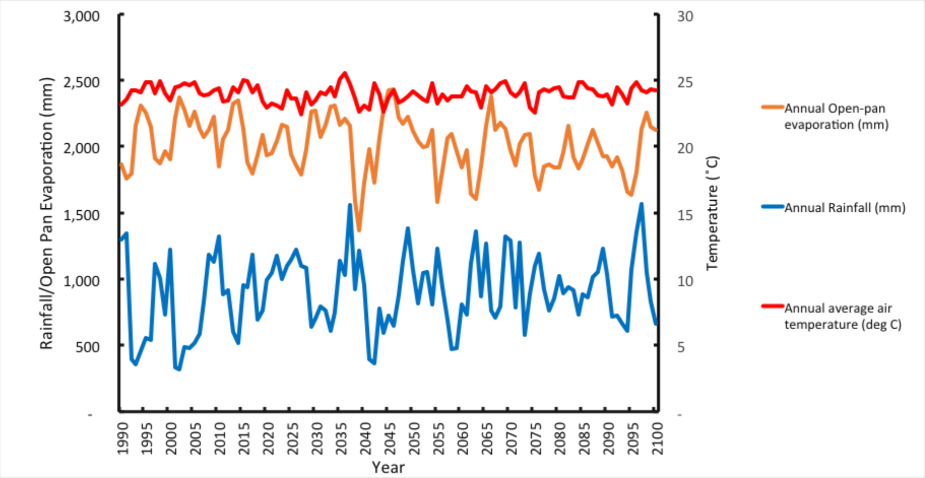
Table 2: *Eucalyptus populnea* allocation

Allocation	**Leaf**	**Branch**	**Bark**	**Stem**	**Course Roots**	**Fine Roots**
Sample Weight (t/ha)	2.60	29.70	12.70	35.70	9.50	10.10
Allocation in relation to Stem	0.07	0.83	0.36	1.00	0.27	0.28

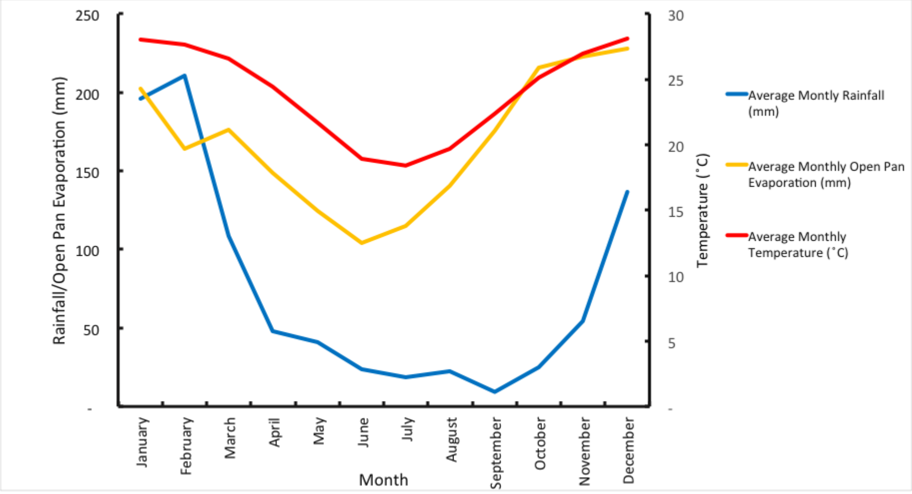
Growth rates of Leucaena

To determine the growth rates of the Leucaena crop and the companion tropical grass, annual growth rates and allometric partitioning to growth stages were required specific to the local conditions on Byrne Valley. At the time of the analysis, this data was unavailable. In its absence, a reverse calculation was conducted to determine the growth of the Leucaena crops and recovery rates following grazing to satisfy the metabolisable energy (ME) requirements of the steers. The live weight of the steers and their live weight gain (LWG) was matched to the ME requirement for the steers to maintain activity and growth (MLA 2006) (Table 3).

Annual rainfall, open pan evaporation and mean temperature for Millaroo over simulation period



Monthly average rainfall, open pan evaporation and mean temperature for Millaroo



Monthly Coefficient of Variation (%) rainfall, open pan evaporation and mean temperature for Millaroo

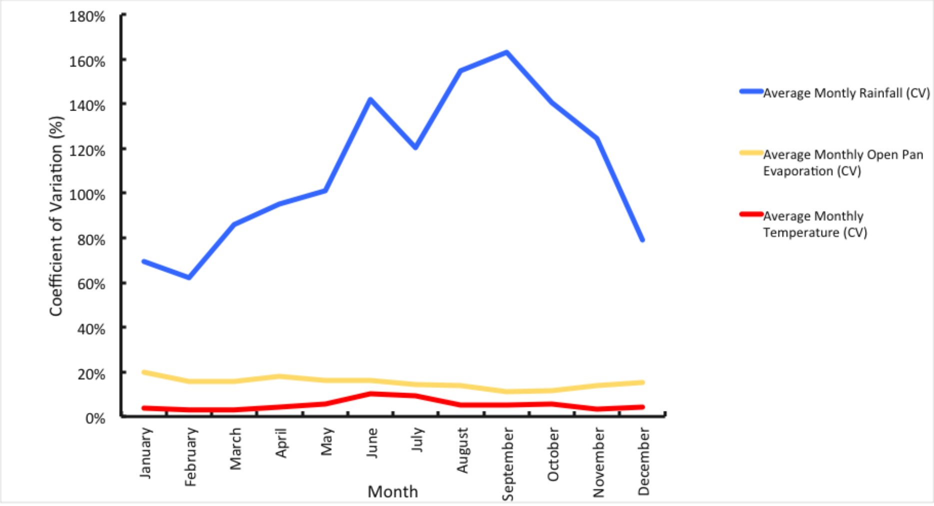


Figure 4: Climate data for Millaroo weather station

Table 3: Metabolisable Energy Requirements of Steers from Tropical Grass and Leucaena Crops (Source: MLA 2006).

Tropical Grass				***Leucaena leucocephala* (Lam.) de Wit cv. Cunningham**			
ME	**LWG**	**LW**	**ME required**	**ME**	**LWG**	**LW**	**ME required**
7	0.2	200	36	7	0.75	400	96
7	0.2	300	48	7	0.75	500	111
7	0.2	400	58	7	0.75	600	126
7	0.5	200	47	9	0.75	400	81
7	0.5	300	61	9	0.75	500	94
7	0.5	400	73	9	0.75	600	107
9	0.2	200	34	9	1	400	103
9	0.2	300	44	9	1	400	119
9	0.2	400	54	9	1	600	134
9	0.5	200	42				
9	0.5	300	54				
9	0.5	400	65				
			51.3				**107.9**

An average ME requirement was calculated for the bush paddock pasture, which consisted of an average of 51.33 MJ/kg per LWG. The estimated ME intake of the pasture grass on the bush paddocks has been estimated as 8.13 MJ/kg DM (MLA 2006). Over the period of 304 days that the 1,247 steers graze the bush paddocks, the required MJ required per steer is estimated as 7,700 MJ/steer, bringing the required intake to be 9,601,900 MJ for all steers. This equates to around 1,181.77 t DM of grass required, equating to around 0.16 t DM/ha. It is recognized that sustainable pasture consumption rates of tropical pasture for the region is around 25% of DM. This equates the growth required of the pasture to be 0.65 t DM/ha (Table 4).

Table 4: Tropical Grass Biomass required sustaining Metabolisable Energy requirements for steers

Allocation	**Value**	**Unit**
Steers	1,247	head
Steer start wt	152	kg/hd
Steer end wt	302	kg/hd
LWG	150	kg/hd
Term	304	days
LWG/day	0.49	kg LWG/day
Bush Paddock Area	7,227	ha
ME of Grass	8.13	MJ ME/kg DM
ME requirement	**51.33**	**MJ/kg LWG**
MJ required/steer	7,700.00	MJ/steer
MJ for all steers	9,601,900.00	MJ/all steers
Grass required/steer	947.69	kg DM /steer
Total Grass required	1,181.77	t DM Grass required
Predicted Grass consumed	**0.16**	t DM Grass required/ha
Predicted Leaf Growth	**0.65**	t DM Grass required/ha

Table 5: Leucaena Biomass required to sustain Metabolisable Energy requirements for steers

***Leucaena leucocephala* (Lam.) de Wit cv. Cunningham**		
Allocation	**Value**	**Unit**
Steers	1,244	head
Steer start wt	302	kg/hd
Steer end wt	550	kg/hd
LWG	248	kg/hd
Term	240	days
LWG/day	1.03	kg LWG/day
Leucaena Area	386.31	ha
ME of Leucaena	8.50	MJ ME/kg DM
ME requirement	**107.89**	**MJ/kg LWG**
Fraction of Leucaena Intake	0.35	Fraction
MJ required/steer	9,364.76	MJ/steer
MJ for all steers	11,649,755.91	MJ/all steers
Leuceana required/steer	1,101.74	kg DM /steer
Total Leucaena required	1,370.56	t DM Lecucaena required
Predicted Leucena consumed	**3.55**	**t DM Lecucaena required/ha**
Tropical Grass between rows		
Allocation	**Value**	**Unit**
ME of Tropical Grass	8.13	MJ ME/kg DM
ME requirement	**51.33**	MJ/kg LWG
Fraction of Leucaena Intake	0.65	Fraction
MJ required/steer	8,274.93	MJ/steer
MJ for all steers	10,294,017.07	MJ/all steers
Grass required/steer	1,018.45	kg DM /steer
Total Grass required	1,266.96	t DM Grass required
Predicted Grass consumed	**3.28**	**t DM Grass required/ha**
Predicted Leaf Growth	**13.12**	**t DM Grass required/ha**

In the Leucaena crops, the 1,247 steers entering would require 107.89 MJ/kg LWG (Table4). Around 35 percent of forage would come from the Leucaena crops, with the remainder sourced from companion pasture (Dalzell et al 2006). The ME of Leucaena is an average of 8.5 MJ ME/kg DM. The required MJ consumption from the Leucaena crop would need to be 9,364.76 MJ/steer, with a total consumption being 11,649,756 MJ for the herd. The ME of Leucaena is estimated at 8.5 MJ ME/kg DM and 3.55 t DM of Leucaena would need to be consumed per hectare (Table 5). The companion grass species to the Leucaena comprise 65 percent of the intake for the steers. Around 1,102 kg DM/steer would be required to meet the remaining 51.33 MJ/kg LWG required for the time grazing. It is estimated that around 3.28 t DM/ha of grass would need to be grazed to meet this demand. Based on 25 percent of pasture being consumed, it is estimated that 13.12 t DM/ha would need to be grown per annum (Table 5).

The dry matter (DM) weight (t/ha) of the components of Leucaena (leaves, branches, bark, stem, course and fine roots) for the first four years of growth on the Leucaena crops were defined in a study estimating its biomass and allometric partitioning (Rengsirikul et al 2011). It was assumed that the partitioning of Leucaena would be the same as observed on other sites. The sample weight from these studies was noted (Table 6). The allometric partitioning was calculated in relation to the stem (Value input 1.0). For example, a 0.22 allocation to the leaves would equate to 2.02 t/ha if the stem biomass would be 9.17 t/ha. Where Leucaena data could not be obtained or calculated, FullCAM settings for

Acacia mangium we used as a substitute. This was considered to be the closest species to Leucaena that had been profiled for FullCAM (Shelton pers comm.).

Table 6: Allocation of *Leucaena leucocephala* (Lam.) de Wit cv. Cunningham for first four years of growth

Allocation	**Leaf**	**Branch**	**Bark**	**Stem**	**Course Roots**	**Fine Roots**
1st Year Sample Weight (t/ha)	2.02	2.19	0.00	9.17	1.49	0.76
1st Year Allocation in relation to Stem	0.22	0.24	0.00	1.00	0.16	0.08
1st Year Fraction in relation total A/G Biomass	0.15	0.16	0.00	0.69	-	-
1st Year Fraction Consumed	0.90	0.90	0.00	0.50	0.00	0.00
2nd Year Sample Weight (t/ha)	3.61	3.86	0.00	15.66	2.54	1.31
2nd Year Allocation in relation to Stem	0.23	0.25	0.00	1.00	0.16	0.08
2nd Year Fraction in relation total A/G Biomass	0.16	0.17	0.00	0.68	-	-
2nd Year Fraction Consumed	0.90	0.90	0.00	0.15	0.00	0.00
3rd Year Sample Weight (t/ha)	3.46	12.43	0.00	39.62	6.42	3.30
3rd Year Allocation in relation to Stem	0.14	0.29	0.00	1.00	0.16	0.08
3rd Year Fraction in relation total A/G Biomass	0.10	0.20	0.00	0.70	-	-
3rd Year Fraction Consumed	0.90	0.90	0.00	0.15	0.00	0.00
4th Year Sample Weight (t/ha)	3.32	21.01	0.00	63.57	10.30	5.30
4th Year Allocation in relation to Stem	0.05	0.33	0.00	1.00	0.16	0.08
4th Year Fraction in relation total A/G Biomass	0.04	0.24	0.00	0.72	-	-
4th Year Fraction Consumed	0.90	0.90	0.00	0.15	0.00	0.00

The DM biomass for each tree component was calculated on the 3.55 t DM/ha required to be consumed for forage, as calculated in Table 5. This involved multiplying the components with the inverse of the proportion of those components consumed (Table 6). It was observed that around 90 percent of leaf and branch biomass and between 15 and 50 percent of the stem biomass was consumed following each grazing of the Leucaena paddocks. Based on this partitioning, the Leucaena crop would require growing 5.67 t/ha of above ground DM biomass in its first year (Table 7). Following grazing, 2.12 t/ha remain in the form of ungrazed plant material, much of it in the stem. For the following year, the crop would need to grow an additional 6.92 t/ha of biomass to meet the ME requirements of the steers in the second year. This increase is due to the smaller proportion of the stem being grazed and more growth in leaf and branch material being required. These above ground estimates were entered into the FullCAM framework as growth increments.

Table 7: Annual biomass requirements *Leucaena leucocephala* (Lam.) de Wit cv. Cunningham for first four years of growth

Category	**Year 1**	**Year 2**	**Year 3**	**Year 4**
A/G Biomass required from Start (t/ha)	5.67	9.05	9.45	9.92
A/G MAI (t/ha) remaining	2.12	5.50	5.90	6.38
A/G Biomass (t/ha) grown from previous	**5.67**	**6.92**	**3.95**	**4.02**

Carbon stock of the Byrne Valley

The carbon stock of the Byrne Valley farm at 1990 was calculated approximately around 684,825 t C. The establishment of the existing Leucaena crop resulted in an increase of that stock of approximately to an average of 688,584 t C, an increase of 3,759 t C. As the existing Leucaena crops were established on previously cleared land, the carbon stock of these paddocks has been increased from 7.86 t C/ha to around 14.71 t C/ha (an increase of 6.85 t C/ha) (Figure 4).

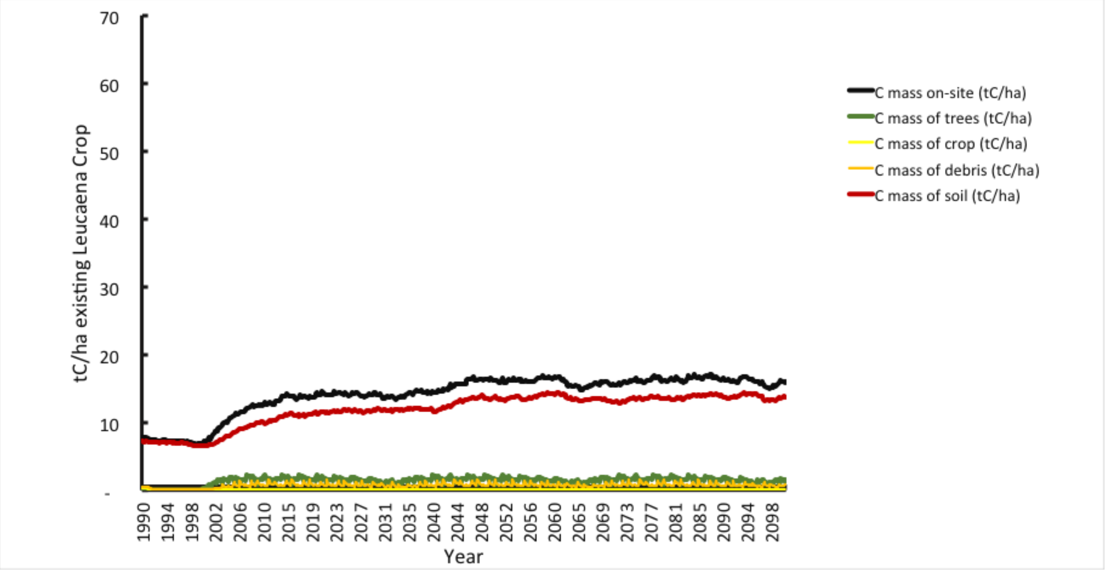


Figure 4: Carbon stock of Existing Leucaena Crop

For the Expanded Leucaena pathway, the clearing of native vegetation will result in a drop of the overall carbon stock from 691,419 t C at the time prior to clearing to around 674,228 t C (a reduction of 17,191 t C). At the plot level, the carbon stock was around 59 t C/ha up to the time of clearing. Following clearing, the carbon stock declines to an average of 14.72 t C/ha (a decline of 43.93 t C/ha). Following the establishment of the Leucaena crop, there are marginal increases in the carbon stock, fluctuating around 1.29 t C/ha between the grazing and cutting rotations of the Leucaena crop (Figure 5)

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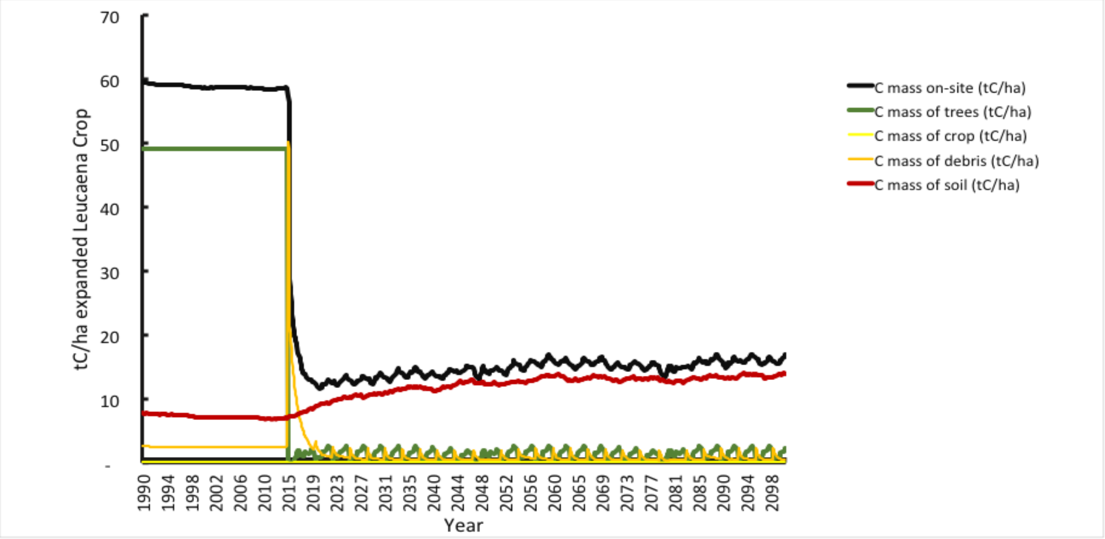

Figure 5: Carbon stock of Expanded Leucaena Crop

The alternative Leucaena pathway results in the highest increases of the carbon stocks, where remaining previously cleared paddocks are planted with the Leucaena and the existing extent of native vegetation is maintained. Overall, 5,169 t C increases the carbon stocks of the farm.

Management of farm management pathways

There are four management pathways described in this study. The first is the existing Leucaena crop management pathway, representing the existing conditions of the property. The existing conditions of the farm consist of bush paddocks and 386 ha of Leucaena crops. The steers enter the Byrne property at the age of 6 months from the nearby Rangemore property in every June and spend 305 days on the bush paddocks. In April of the following year, the steers are then moved onto the Leucaena crop to graze for 240 days. There are five paddocks and each paddock is grazed once for two weeks and the herd is then moved to the next paddock. Following each grazing, the paddock is irrigated. After the final paddock is grazed, the steers are then moved back to the first paddock and the grazing cycle is repeated thereafter. Each paddock may be grazed up to four times each year (Table 8). At the conclusion of the 240 days on Leucaena, the steers are sold to market.

The Leucaena crops were established in a staggered sequence over a period of three years. The first Leucaena paddock was established in 1999, the second was established in 2000, the third and fourth paddocks were established in 2001 and the fifth paddock was established in 2002. The existing Leucaena crops were established on previously cleared paddocks that were originally developed for rice cropping in 1970. The first Leucaena crop was planted in April 1999 and it is planted in 4m wide rows with companion tropical grass in between (Figure 2). The crop is lightly grazed in July and heavily grazed in November. For the following years, the Leucaena crop is subject to rotational grazing every eight weeks. After the third year, the Leucaena trees become woody and crowns exceed the access of the steers. The Leucaena crop is cut back to 10 cm AGL and regrows via coppicing. This cycle is repeated every three years. After 30-40 years, it has been observed that the productivity of the Leucaena decreases. The crop is replaced using the same sequence as to establish it.

For the expanded Leucaena management pathway, the cropped area consists of previously cleared paddocks and 414 ha of land currently under native vegetation. The area under native vegetation was to be cleared commencing April 2015. The debris resulting from the clearing was to be heaped and burnt at the end of May. Similarly to the existing Leucaena crop, the site was to be planted with the Leucaena crop in the following April and then lightly grazed in July. It was to be heavily grazed in November and subject to the grazing cycle starting April of 2017 (Table 8). The previously cleared paddocks were to be established with Leucaena at the same time as the areas currently under native vegetation. The alternative management pathway employed the same sequence of Leucaena establishment without the inclusion of areas currently under native vegetation.

The baseline management pathway consists of grazing solely on the bush paddocks and the areas previously cleared. The steers enter the Byrne Valley property at the age of 6 months and the steers graze for three years, where they are sold to market.

Table 8: Expanded Leucaena Paddock – modeled event sequence

Date	Event	Leaves Affected (%)	Branches Affected (%)	Stems Affected (%)	Root Affected (%)
1 April 2015	Initial Clearing of Eucalyptus populnea - No product Recovery	100	100	100	100
31 May 2015	Site Preparation - Windrow and Burn	100	100	100	100
3 April 2015	Plant *Leucaena leucocephala* (Lam.) de Wit cv. Cunningham	-	-	-	-
3 July 2016	First Light Graze	30	30	10	0
1 November 2016	First Heavy Graze	90	90	50	25
2 April 2017	First Year Graze (1)	90	90	50	25
31 May 2017	First Year Graze (2)	90	90	50	25
30 July 2017	First Year Graze (3)	90	90	50	25
28 September 2017	First Year Graze (4)	90	90	50	25
2 April 2018	Second Year Graze (1)	90	90	15	25
31 May 2018	Second Year Graze (2)	90	90	15	25
30 July 2018	Second Year Graze (3)	90	90	15	25
28 September 2018	Second Year Graze (4)	90	90	15	25
2 April 2019	Third Year Graze (1)	90	90	15	25
30 May 2019	Third Year Graze (2)	90	90	15	25
30 July 2019	Third Year Graze (3)	90	90	15	25
29 September 2019	Third Year Graze (4)	90	90	15	25
28 November 2019	Stem Cutting	100	100	95	25
1 April 2047	Initial Clearing of *Leucaena leucocephala* (Lam.) de Wit cv. Cunningham	100	100	100	100
30 May 2047	Chopper Roller	100	100	100	100

Steer inputs for the B-GAF Calculators

The modeling of GHG emissions was calculated using the B-GAFN calculator. The required inputs consisted of steer numbers, live weight, LWG, crude protein (CP), dry matter digestibility (DMD) and enteric methane reduction in Leucaena (% relative to pasture). The steer numbers are detailed in Table 1. The live weights were calculated by dividing the LWG over the period of grazing in seasonal increments (Table 9). The Daily LWG was calculated by dividing the LWG over the period of grazing with the number of days in that period. The crude protein and dry matter digestibility for grazing the bush paddocks were derived from the National Inventory Reporting default settings (Commonwealth of Australia 2014). The percentage reduction relative to pasture in enteric methane from consuming Leucaena was derived from Harrison et al (in review).

Table 9: Inputs for the B-GAF calculators for steers grazing bush paddocks and Leucaena crops

		Bush Paddocks		**Leucaena Crop**	
		Weaners	**Steers**	**Steers**	**Units**
Live weight	Spring	-	197.25	460	kg/head
	Summer	-	242.00	-	kg/head
	Autumn	-	286.75	302	kg/head
	Winter	152.00	-	366	kg/head
	Average	152	242	376	kg/head
Daily Live weight gain (LWG)	Spring	-	0.49	1.03	kg/day
	Summer	-	0.49	-	kg/day
	Autumn	-	0.49	1.03	kg/day
	Winter	0.49	-	1.03	kg/day
	Average	0.49	0.49	1.03	kg/day
Crude Protein (CP)	Spring	5	5	9.00	%
	Summer	15	15	10.50	%
	Autumn	11	11	12.00	%
	Winter	6	6	12.86	%
	Average	9	9	11	%
Dry matter digestibility (DMD)	Spring	55	55	58.30	%
	Summer	65	65	58.95	%
	Autumn	58	58	59.60	%
	Winter	52	52	63.00	%
	Average	58	58	59.96	%
Enteric Methane Reduction in Leucaena (% relative to pasture)	Spring	-	-	16.46	%
	Summer	-	-	12.98	%
	Autumn	-	-	27.20	%
	Winter	-	-	23.10	%
	Average	-	-	19.94	%

Measured methane emissions of steers grazing Leucaena and unmodified pastures as well as pasture nutritive characteristics were adopted from field experiments, as described in Harrison et al (in review). These experiments were part of a larger research program aiming to determine the effects of Leucaena on enteric methane production. Estimates of methane emissions (total paddock CH_4 g/d) for each group of animals grazing Leucaena and pasture were generated and expressed on an average animal basis for each treatment. Measurements indicated that emissions from cattle with access to Leucaena were up to 27% less than those from cattle grazing pasture, depending on time of year (Harrison et al in review).

Life Cycle Impact Analysis

The Life Cycle Impact Analysis calculates the GHG emissions that result from the herd and their grazing on the native pastures and the Leucaena crops. There were two main impact categories: the first impact category was the direct GHG emissions from the steers; and the second was the GHG emissions resulting from land use change and the emissions resulting from the land as a result of the grazing.

Direct GHG emissions from the steers

The GHG emissions of the 1,250 steers that are grazed and fed through the baseline management pathway were 5,793 tonnes of CO_2-e. This equated to an emissions intensity of 8.51 tonnes of CO_2e for every live weight tonne of cattle produced (Table 10). When compared to the existing management strategy of the steers grazing on Leucaena, herd GHG emissions reductions were achieved. These were 2,740 t CO_2e for total farm GHG emissions and 0.47 t CO_2e/LWT for GHG emissions intensity. The change factors were 0.47 against baseline GHG emissions for both categories (Table 11).

Table 10: Baseline GHG emissions from steer herd

Outputs	**Year Byrne Valley Year 1 t GHG Emissions /farm**	**Year Byrne Valley Year 2 t GHG Emissions /farm**	**Year Byrne Valley Year 3 t GHG Emissions /farm**	**Total t GHG Emissions t/System**
CH4 - Enteric	1,189.74	1,827.04	2,398.48	5,415.26
CH4 - Manure	0.97	1.39	1.76	4.11
N2O - N Fertiliser	0.00	0.00	0.00	**0.00**
N2O - Indirect	28.04	38.87	50.85	117.76
N2O - Dung, Urine	61.17	84.66	110.48	256.31
Net Farm Emissions t CO_2e	**1,279.93**	**1,951.96**	**2,561.57**	**5,793.45**
Total Emissions	**1,279.93**	**1,951.96**	**2,561.57**	**5,793.45**
Emissions Intensity CO_2e /t LWT				**8.51**

Table 11: Existing Leucaena Crop GHG emissions from steer herd

Outputs	**Byrne Valley t GHG Emissions /farm**	**Leucaena Cattle t GHG Emissions/farm**	**Total t GHG Emissions t/System**	**Herd GHG Emission Change Factor from Baseline**
CH4 - Enteric	1,113.91	1,461.14	2,575.05	0.48
CH4 - Manure	0.88	1.19	2.07	0.50
N2O - N Fertiliser	0.00	0.00	0.00	**0.00**
N2O - Indirect	25.01	25.95	50.96	0.43
N2O - Dung, Urine	54.67	57.59	112.26	0.44
Net Farm Emissions t CO_2e	**1,194.47**	**1,545.87**	**2,740.34**	**0.47**
Total Emissions	**1,194.47**	**1,545.87**	**2,740.34**	**0.47**
Emissions Intensity CO_2e /t LWT			**4.01**	**0.47**

The increase of steers with the Expanded Leucaena crop management pathway resulted in an increase of GHG emissions to 7,546 t CO_2-e, with a change factor of 1.30 against the baseline management pathway. However, the GHG emissions intensity remained the same as the Existing Leucaena Crop at 4.00 t CO_2-e, with change factor of 0.47 against the baseline management pathway (Table 12).

Table 12: Expanded Leucaena Crop GHG emissions from steer herd

Outputs	**Byrne Valley t GHG Emissions /farm**	**Leucaena Cattle t GHG Emissions/farm**	**Total t GHG Emissions t/System**	**Herd GHG Emission Change Factor from Baseline**
CH4 - Enteric	3,064.80	4,026.35	7,091.16	**1.31**
CH4 - Manure	2.43	3.27	5.70	**1.39**
N2O - N Fertiliser	0.00	0.00	0.00	**0.00**
N2O - Indirect	68.81	71.51	140.32	**1.19**
N2O - Dung, Urine	150.42	158.70	309.12	**1.21**
Net Farm Emissions t CO_2e	**3,286.46**	**4,259.84**	**7,546.30**	**1.30**
Total Emissions	**3,286.46**	**4,259.84**	**7,546.30**	**1.30**
Emissions Intensity CO_2e /t LWT			**4.00**	**0.47**

The Alternative Leucaena Crop management pathway resulted in a smaller decrease in total herd GHG emissions, compared to the baseline. This consisted of 4,676 t CO_2-e and a change factor 0.81 against the baseline management pathway. The GHG emissions intensity further decreases at 4.07 t CO_2-e/LWT with a change factor of 0.48 against the baseline management pathway (Table 13).

Table 13: Alternative Leucaena Crop GHG emissions from steer herd

Outputs	**Byrne Valley t GHG Emissions /farm**	**Leucaena Cattle t GHG Emissions/farm**	**Total t GHG Emissions t/System**	**Herd GHG Emission Change Factor from Baseline**
CH4 - Enteric	1,867.82	2,452.46	4,320.28	**0.80**
CH4 - Manure	1.48	1.99	3.48	**0.84**
N2O - N Fertiliser	0.00	0.00	0.00	**0.00**
N2O - Indirect	120.56	43.55	164.12	**1.39**
N2O - Dung, Urine	91.67	96.67	188.34	**0.73**
Net Farm Emissions t CO_2e	**2,081.54**	**2,594.67**	**4,676.21**	**0.81**
Total Emissions	**2,081.54**	**2,594.67**	**4,676.21**	**0.81**
Emissions Intensity CO_2e /t LWT			**4.07**	**0.48**

Total GHG Emission balance of Byrne Valley

The GHG emissions balance (combined GHG emissions from steers and land use) for the baseline management pathway fluctuated between being a sink and source of GHG emissions, with 25 years over the modeled 112-year period being a sink (Figure 6). However, over the time of the simulation, most years resulted in the farm as a net source of GHG emissions and this is evident when the GHG impact is viewed cumulatively (Figure 7). The establishment of the existing Leucaena crop resulted in the property acting as a net sink for 51 of the 112 simulated years. This increase was attributable to increasing the carbon stock of the farm through the establishment of the crop on previously cleared land. Although cumulatively, the existing Leucaena crop management pathway remains a net source of emissions, the farm's increased capacity to act as a sink is expressed as lower cumulative GHG emissions (Figure 7).

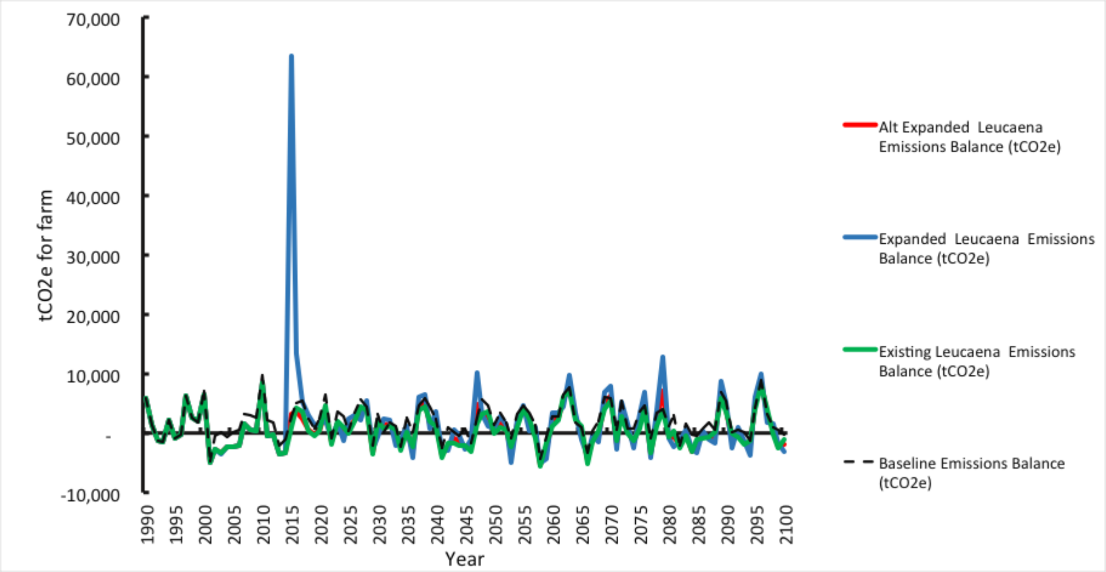

Figure 6: Total CO_2e emissions balance from herd and property per year

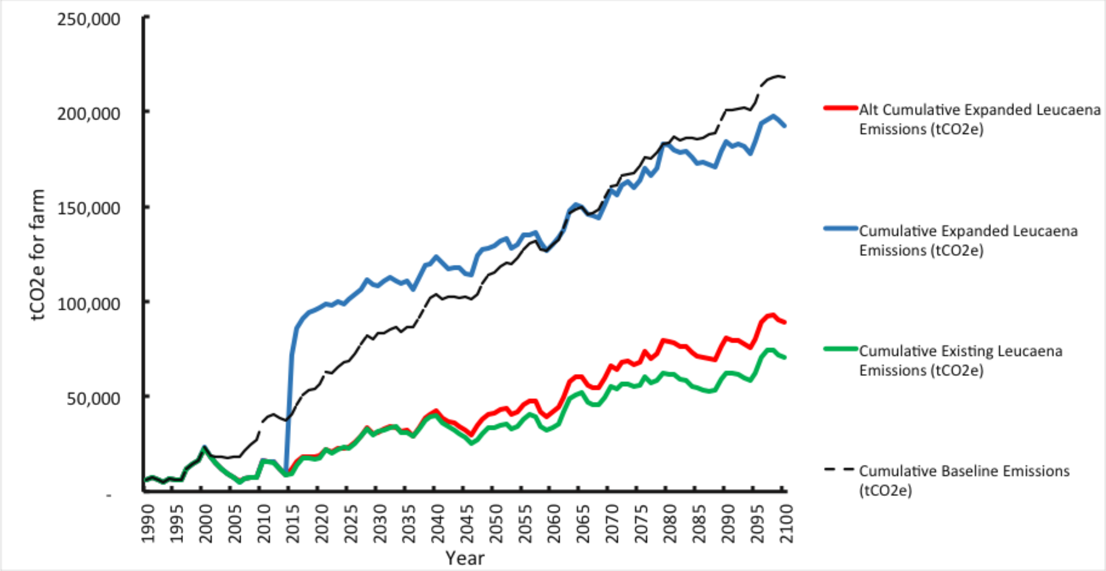

Figure 7: Cumulative CO_2e emissions from herd and property commencing 1990

For the expanded Leucaena management pathway, there is a short-term pulse of GHG emissions from the farm of 55,864 t CO_2e, emitted over a one-year period (Figure 6). This has a cumulative impact, where GHG emissions exceed the baseline management pathway by 31,642 t CO_2-e. The cumulative GHG emissions return to baseline levels by 2059 and decrease thereafter. However, there were 48 years where the farm acted as a sink over the 112-year simulation period.

The alternative Leucaena management pathway resulted in a decline in GHG emissions against the baseline management pathway. There were 51 years where the farm acted as a sink. However, the increase in steer numbers resulted in the cumulative GHG emissions being higher than those of the existing Leucaena management pathway (Figure 7).

To test whether changes GHG emissions impact were significant between the management pathways, a single factor analysis of variance (ANOVA) was used (Sokal and Rohlf 2012). The implementation of the existing Leucaena management pathway against the baseline resulted in a significant reduction in GHG emissions (P = 0.0004) (Table 14). The alternative Leucaena management strategy also resulted in a significant reduction in GHG (p = 0.008). However, the implementation of the Expanded Leucaena management pathway resulted in no significant reduction (P = 0.967).

GHG Emission Intensity

The GHG emissions intensity per LWT produced resulted larger reductions between the baseline and Leucaena management pathways. The Existing Leucaena management pathway resulted in an average reduction of 86 percent when compared against the baseline. The alternative Leucaena management pathway resulted in a larger average decrease of GHG emissions per LWT produced of 93 percent. The Expanded Leucaena management pathway resulted in a decrease in GHG emissions of 81 percent (Figure 8).

Table 14: Total Farm GHG Emissions Single Factor ANOVA (P<0.05)

Baseline and Existing Leucaena						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	106587533.5	1	106587533.5	12.9563566	0.000401132	3.887906055
Within Groups	1661785210	202	8226659.457			
Total	1768372744	203				
Baseline and Expanded Leucaena						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	57969.64	1	57969.64	0.001706836	0.967094152	3.896741962
Within Groups	5773745314	170	33963207.73			
Total	5773803283	171				
Baseline and Alternative Leucaena						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	58634193.17	1	58634193.17	7.27710373	0.007687766	3.896741962
Within Groups	1369750001	170	8057352.945			
Total	1428384194	171				

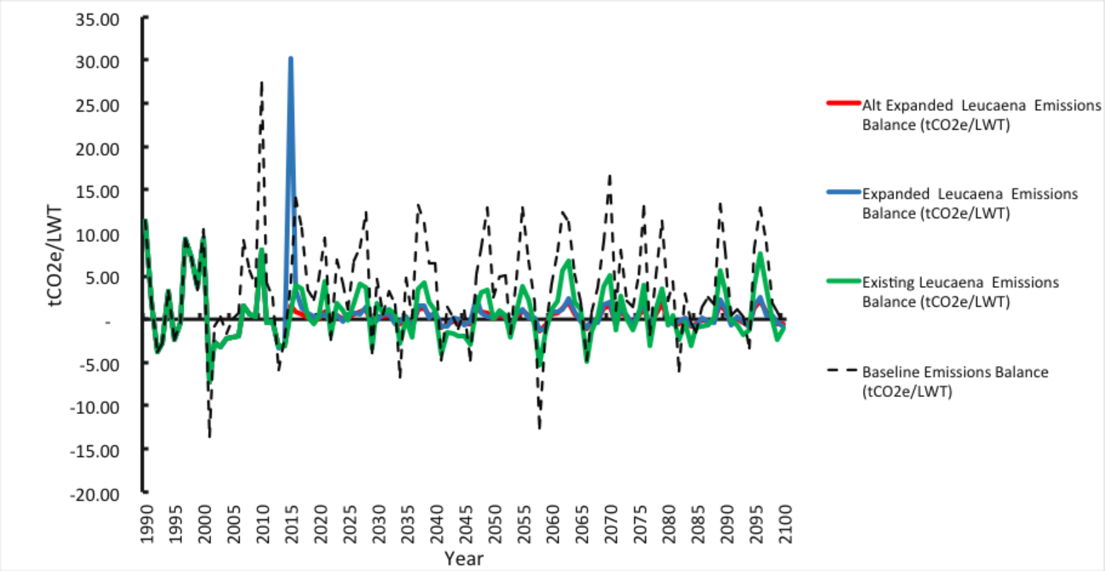

Figure 8: CO_2e emissions intensity balance per live weight tonne output from herd and property per year

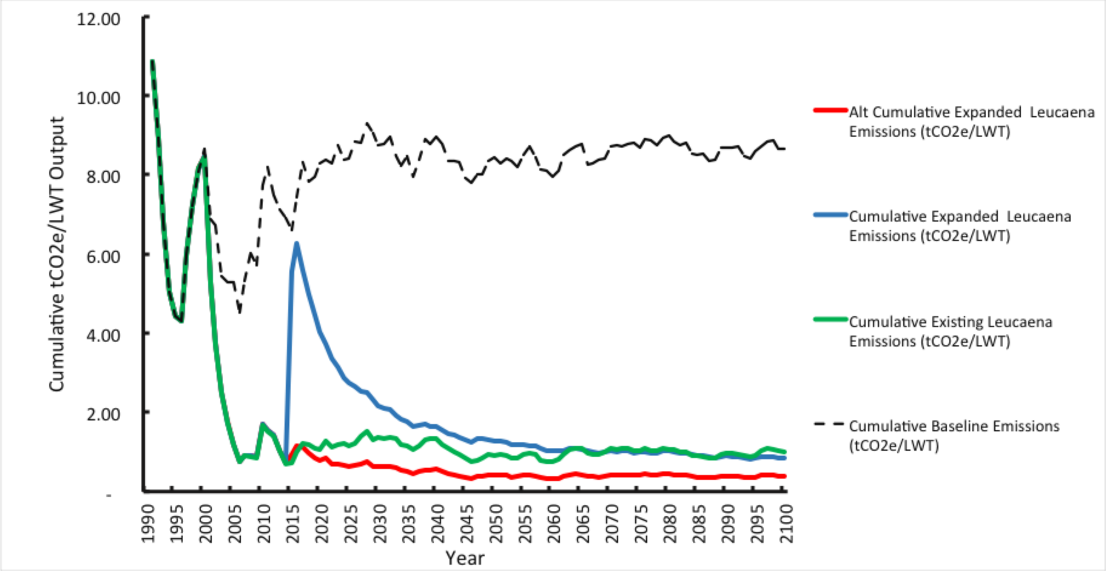

Figure 9: Cumulative CO_2e emissions intensity per live weight tonne output from herd and property commencing 1990

The cumulative GHG emissions intensity of the steers (the cumulative emissions per cumulative LWT produced) resulted in reductions against the baseline for all management pathways using Leucaena (Figure 9). The Expanded Leucaena management pathway, while increasing the whole farm GHG emissions, resulted in a decrease in GHG emissions intensity. The GHG emissions pulse resulting from the land clearing to establish the expanded crop did not exceed the cumulative GHG emissions per LWT produced in the baseline.

The implementation of the existing Leucaena management pathway against the baseline resulted in significant reductions in GHG emissions intensity per LWT produced for all management pathways using Leucaena (Table 15).

Discussion and conclusion

The Modeling and the Gate-to-Gate LCA used in this study has shown overall reductions in whole farm GHG emissions where Leucaena crops had been established on previously cleared land. There was an overall increase in whole farm emissions where native vegetation was to be cleared for Leucaena crop establishment. However, all management pathways using Leucaena showed significant reductions in GHG emissions intensity per LWT produced. This overall decline was a result on the efficiency of the Leucaena crop in enabling the steers to achieve their preferred weight for sale in a shorter period of time when compared to grazing bush paddocks, the reduced enteric methane emissions as a result of the steers foraging Leucaena and the capacity of the Leucaena crop to rapidly accumulation biomass in its early stages of growth.

When integrating these reduced GHG emission reductions into the policy framework of the Australian government, the property may be eligible for credits and rewards under the Emissions Reduction Fund. Under the Herd Methodology, the reduction in Enteric Methane as a result of cattle grazing Leucaena would possibly result in the farm being able to claim carbon credits. However, there are some deficiencies. One such example is the ‘Native Forest Protection (Avoided Deforestation)’ Methodology, whereby any areas that were under native forest on 31 December 1989 and that were under native forest at all times between 1 January 1990 and project commencement, will be ineligible on the Byrne Valley Farm for credits because the permit to clear the forest for the Leucaena crop was issued after the designated cut-off date of 1 July 2010 (Commonwealth of Australia 2013). This applies to any property that has permits to clear native vegetation after this designated date. Furthermore, the clearing of any native vegetation on the property will render the farm ineligible for credits for enteric methane reduction under the Emissions Reduction Fund. Therefore, there is little incentive for the Alternative Leucaena management pathway to be selected over the Expanded Leucaena pathway, based on the potential to engage in the ERF.

Table 15: Single Factor ANOVA for Emissions Intensity (P<0.05)

Baseline and Existing Leucaena

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	535.9045818	1	535.9045818	23.54605767	2.4347E-06	3.887906055
Within Groups	4597.488336	202	22.75984325			
Total	5133.392918	203				

Baseline and Expanded Leucaena

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	462.2978385	1	462.2978385	22.20255035	5.07951E-06	3.896741962
Within Groups	3539.711939	170	20.82183493			
Total	4002.009777	171				

Baseline and Alternative Leucaena

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	601.2370313	1	601.2370313	39.00767908	3.27011E-09	3.896741962
Within Groups	2620.260875	170	15.41329926			
Total	3221.497906	171				

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Appendix D10: A comparative analysis of Greenhouse Gas Emissions from beef cattle grazing irrigated Leucaena leucocephala (Lam.) de Wit cv. Cunningham crops in northern Australia

Table A1. Whole farm carbon balance at intervals

Year	Baseline (t CO_2e)	Existing Leucaena (t CO_2e)	Existing Leucaena Change Factor	Expanded Leucaena (t CO_2e)	Expanded Leucaena Change Factor	Expanded Leucaena against Existing Leucaena Change Factor	Alternative Leucaena (t CO_2e)	Alternative Leucaena Change Factor	Alternative Leucaena against Existing Leucaena Change Factor
1990	5,929	5,929	1.00	5,929	1.00	1.00	5,929	1.00	1.00
2000	7,072	6,383	0.90	6,464	0.91	1.01	6,404	0.91	1.00
2010	9,688	8,465	0.87	8,535	0.88	1.01	8,486	0.88	1.00
2020	2,401	307	0.13	1,320	0.55	4.30	352	0.15	1.15
2030	3,169	1,895	0.60	-587	-0.19	-0.31	987	0.31	0.52
2040	2,306	1,068	0.46	3,537	1.53	3.31	2,032	0.88	1.90
2050	1,324	-29	-0.02	713	0.54	-24.91	363	0.27	-12.69
2060	2,802	1,225	0.44	3,427	1.22	2.80	2,062	0.74	1.68
2070	5,891	5,432	0.92	7,912.	1.34	1.46	6,258	1.06	1.15
2080	1,135	-649	-0.57	-906	-0.80	1.40	-742	-0.65	1.14
2090	5,482	3,559	0.65	5,188	0.95	1.46	4,095	0.75	1.15
2100	-178	-1,153	6.47	-3,212	18.02	2.78	-1,898	10.65	1.65
Average	1,965	535	0.27	2,135	1.09	3.99	930	0.47	1.74
StD	2,775	2,972		7,806			3,021		
CV	141%	556%		366%			325%		

Table A2. Farm carbon intensity balance at intervals

Year	**Baseline (t CO_2e/LWT)**	**Existing Leucaena (t CO_2e/LWT)**	**Existing Leucaena Change Factor**	**Expanded Leucaena (t CO_2e/LWT)**	**Expanded Leucaena Change Factor**	**Expanded Leucaena against Existing Leucaena Change Factor**	**Alternative Leucaena (t CO_2e/LWT)**	**Alternative Leucaena Change Factor**	**Alternative Leucaena against Existing Leucaena Change Factor**
1990	11.45	11.45	1.00	11.45	1.00	1.00	11.45	1.00	1.00
2000	10.39	9.33	0.90	9.45	0.91	1.01	9.36	0.90	1.00
2010	27.34	7.98	0.29	8.05	0.29	1.01	8.00	0.29	1.00
2020	4.64	0.29	0.06	0.33	0.07	1.14	0.09	0.02	0.31
2030	4.65	1.79	0.38	-0.15	-0.03	-0.08	0.25	0.05	0.14
2040	6.51	1.01	0.15	0.89	0.14	0.88	0.51	0.08	0.51
2050	2.56	-0.03	-0.01	0.18	0.07	-6.63	0.09	0.04	-3.38
2060	4.12	1.15	0.28	0.86	0.21	0.75	0.52	0.13	0.45
2070	16.62	5.12	0.31	1.99	0.12	0.39	1.57	0.09	0.31
2080	2.19	-0.61	-0.28	-0.23	-0.10	0.37	-0.19	-0.09	0.30
2090	8.05	3.36	0.42	1.30	0.16	0.39	1.03	0.13	0.31
2100	-0.50	-1.09	2.16	-0.81	1.60	0.74	-0.48	0.95	0.44
Average	3.70	0.51	0.14	0.70	0.19	1.37	0.24	0.07	0.47
StD	6.01	2.94		3.38			0.77		
CV	163%	576%		481%			318%		

D12. Project title

Carbon neutral livestock farming in south eastern Australia: Implications of carbon policy on greenhouse gas accounting

Organisation The University of Melbourne

Primary contact Natalie Doran-Browne

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Carbon neutral livestock farming in south eastern Australia: Implications of carbon policy on greenhouse gas accounting

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Keywords: sheep, wool, agroforestry, greenhouse gas emissions, methane, nitrous oxide

Abstract

Ruminant livestock production generates higher levels of greenhouse gas emissions (GHGE) compared with other types of farming. Therefore it is desirable to reduce or offset those emissions wherever possible. While mitigation options exist that reduce ruminant GHGE, through the use of feed management, flock structure or breeding management, these options only reduce the existing emissions by around 10-20% whereas planting trees enables livestock emissions in their entirety to be offset, reducing agricultural emissions. Trees can introduce additional co-benefits that may increase production such as reduced salinity and therefore increased pasture production, shelter for animals or reduced erosion. This study analysed the carbon balance of a sheep case study farm in south eastern Australia to determine if the farm was carbon neutral. The existing carbon accounting rules for Australia were then applied to determine the carbon balance of the farm when carbon policy was implemented. Data were gathered from the case study farm in south eastern Australia. The IPCC methodology, as described in the Australian National Inventory, was used to calculate GHGE from livestock, energy and fuel, as well as to calculate carbon sequestration in the trees and soil. This method used localised Tier 2 Australian emission factors where possible and where these local values did not exist, generic Tier 1 values were used instead. The results showed that on the case study farm over a period of 30 years, on average seven times more carbon was sequestered in trees and soil than was produced from livestock and energy, the majority of the carbon sequestration being in trees. This study demonstrated that a wool farm with a relatively low stocking rate of 8 ewes/ha only required 15% of the farm in tree cover for the farm to be carbon neutral. Further research would be beneficial on the carbon neutral potential of farms in more fertile, high rainfall areas that commonly have higher stocking rates than the current study.

Introduction

Agriculture contributes 10-12% of all anthropogenic greenhouse gas emissions and is the main source of anthropogenic methane (CH_4) and nitrous oxide (N_2O) (Smith *et al.* 2007). Livestock products generate higher levels of greenhouse gas emissions (GHGE) than other types of farming (Garnett 2009). Therefore it is desirable to reduce or offset those emissions wherever possible. While mitigation options exist that reduce ruminant GHGE, through the use of feed management, flock structure or breeding management, the best case scenario using these options will only reduce emissions by 20-45%, whereas planting trees enables livestock emissions to be offset in their entirety. Various policy measures throughout the world have recognised the possibility of agriculture to reduce or sequester emissions, such as using carbon offset schemes that encourage farmers to mitigate greenhouse gas emissions or offset emissions through the sequestration of carbon in trees or soil. (GHGE) (DCCEE 2012; Commonwealth of Australia 2014).

Sustainable farming has become increasingly important to ensure farming areas remain productive and ideally increase their productivity into the future but developing policies that support sustainable agricultural production continues to be a challenge (Pretty *et al.* 2010). Trees provide important co-benefits to carbon sequestration such as reduced salinity, increased pasture and crop production (Lin *et al.* 2013), windbreaks, shelterbelts for animals in winter to improve survival, reduced soil erosion and increased biodiversity (Brandle *et al.* 2004). Salinity in Australia is a particularly important issue because salt is present in naturally high levels in the subsoils of Australian agricultural land (John *et al.* 2005). Although groundwater tables in Australia were once in equilibrium, after European settlement clearing trees from agricultural land was seen as a necessity to intensify agricultural production (Eichhorn *et al.* 2006). After native vegetation was cleared more rainfall entered the groundwater, causing water tables to rise and salt to mobilise, creating dryland salinity (Rengasamy 2002). Planting trees absorbs excess water, lowering the water tables and reducing salinity (John *et al.* 2005). In Switzerland, planting trees on fertile land reduced soil erosion and nitrate leaching by 78% and 46%, respectively, in addition to sequestering C and improving biodiversity (Kaeser *et al.* 2011). Trees planted in strips as part of an agricultural system also increased productivity per area by 30% compared to monoculture crops (Kaeser *et al.* 2011). The purpose of this study was to calculate the carbon balance of a wool farm to determine whether the farm was carbon neutral, and therefore the livestock and energy emissions were offset by the carbon sequestered in the trees and soil.

Methods

The case study farm, Talaheni

Talaheni Farm is a small (250 ha) sheep farming enterprise 50 km north of Canberra (34°57’S, 149°10’E) that specialises in ultrafine wool but also has beef cattle and farm forestry. The terrain is rolling to hilly with the flatter areas (100 ha) most suited to grazing and the slopes containing the majority of trees (mainly *Eucalyptus polyanthemos* and *Eucalyptus macrohyncha*). Average rainfall (1912-2012) for the site is 625 mm.

When Talaheni was purchased in 1980 it was a non-viable farm due to previous unsustainable management practices. The property, like many other farms in the region, had major dryland salinity (Scown 2000) which reduced plant growth and deteriorated soil health, also reducing plant survival (Rengasamy 2002). To improve the dryland salinity the slopes at Talaheni were revegetated to lower the water table and improve salinity in the soils. Revegetation was achieved by intensively grazing selected areas and then removing the sheep to allow tree seeds to readily establish on the disturbed ground. In areas where trees numbers were too low to provide sufficient seed, seedling were planted in row strips with species such as Red Box (*Eucalyptus polyanthemos*) that produced quality timber.

Mid-slopes were ideal for native perennial species (*Microlaena stipoides*) and the hilltops were revegetated with native trees. The lower slopes and flats had deeper soils that retain more moisture than the slopes and were planted with phalaris *(Phalaris aquatica*). Selective thinning was used for more vigorous and sustainable tree stocking rates. An estimated 200,000 trees were revegetated from seedlings, compared with about 20,000 seedlings planted by hand. Additionally, paddocks were strategically fenced for better management, especially during periods of drought.

Modelling the Talaheni site

The whole farm, mechanistic, biophysical model, GrassGro (Freer *et al.* 1998) was used to model the Talaheni farm, and this model has been validated elsewhere (Clark *et al.* 2000). The model used 50 years of SILO data drill daily weather data sets (see http://www.longpaddock.qld.gov.au/silo/) for the Talaheni farm. The modelled pasture represented the major grass species at the site, being annual grass (*Lolium rigidum*), microlaena (*Microlaena stipoides*), phalaris (*Phalaris aquatica*) and Subterranean clover (*Trifolium subterraneum*). The model was run from January 1960 to December 2012, with the first three years being discarded to allow the parameters in the model to settle.

The stocking rate was 5.0 ewes/ha but the stocking rate in dry sheep equivalents (1 DSE = 8.8 MJ/day, the energy required to maintain a 50 kg non-lactating sheep) fluctuated depending on the available feed and animal liveweights each year. Long-term average outputs were compared for the past 50 years (1963-2012) and also more recently (2000-2012) to compare the effects of reduced rainfall due to climate change. Additionally, two individual years were examined that represented a dry year (2006) and a year of high rainfall, determined by farmer experience.

The IPCC methodology (IPCC 2006), as described in the Australian National Inventory (DIICCSRTE 2013) was used to calculate farm emissions. The sources of GHGE modelled were enteric CH_4 from livestock and CH_4 from manure, N_2O from soil cultivation, dung and urinary depositions, as well as indirect N_2O as a result of N losses via leaching, runoff and ammonia volatilisation. Farm emissions were calculated as t CO_2e/farm and emissions intensity (t CO_2e/t clean fleece wool (CFW)). Since sheep farms produce multiple products in the form of wool and meat, a percentage of emissions were allocated to each product. Mass allocation was used where emissions are assigned according to the percentage of product sold by weight (Casey and Holden 2005).

Modelling tree and soil carbon sequestration

The FullCAM model (Richards and Evans 2004) was used to calculate C storage in trees and soil at Talaheni on an annual basis. The FullCAM model was designed to assist in calculating Australia's National Carbon Accounting System and is a point-based model relevant to Australian conditions. The areas (ha) of trees planted or revegetated from seed at Talaheni were estimated by determining the tree borders on LandSat and Google maps, then transferring the bordered images in GIS (see Table 1) and finally entered into the FullCAM model. The majority of the 250 ha site was cleared between 1860 and 1880, therefore in FullCAM the year 1870 was chosen to clear the majority of trees on the slopes and smaller pockets of land were cleared in the 1970s (Table 1). On the farm 100 ha was dedicated to farming, an additional 115 ha had trees, 30 ha remained as virgin forest and 5 ha of land was dedicated to roads and buildings. The FullCAM model was run from the time that trees were cleared in 1870 forward to the year 2070.

Soil carbon under the pastures was calculated at the same rate as on the slopes up until 1982 when the first trees were planted. From 1982 soil organic carbon was estimated to be at 1.0% based on measurements at the Talaheni farm.

Carbon accounting rules

Carbon accounting rules currently include carbon sequestered in trees after January 1st, 1990 because the base year for Kyoto accounting is 1990. Therefore, the amount of carbon sequestered in trees and soil was also estimated post 1990. For the purpose of comparison the soil carbon sequestration was kept the same for the complete analysis and the post-1990 analysis.

Results

The majority of GHGE at Talaheni were produced in the form of enteric CH_4 from livestock (Table 2). The second highest source of emissions was from indirect and direct N_2O emissions, followed by pre-farm emissions. Carbon dioxide emissions from energy and fuel were the lowest source of emissions on the farm. Livestock produced more than three times the amount of emissions in a wet year (138 t CO_2e) compared with a dry year (41 t CO_2e), despite pre-farm emissions being higher in dry years due to greater levels of supplementary feeding. The amount of meat and wool increased with higher rainfall and consequently total emissions and emissions intensity increased too.

At Talaheni 115 ha of land was either planted with trees or had trees revegetating it and therefore the farm had a good ability to sequester carbon. Based on the modelling it was estimated that 35,000 to 40,000 t CO_2e and 5,000 to 25,000 t CO_2e have been sequestered in soils and trees, respectively, between 1980 and 2012 (Fig. 1)

When calculating the emissions cumulatively from 1980 GHGE were offset completely from the year 1985 (Fig. 2). Most of the C sequestration occurred in trees, with soil contributing little C sequestration over the period from 2000 to 2012. In the year 2012, 209 and 278 t CO_2e was sequestered in trees and soil, respectively, a total of 3.5 times more carbon than was emitted by the farm.

The carbon balance of the farm was also calculated using national carbon accounting rules which excluded sequestration in trees that were planted prior to 1990. This resulted in only 5.6 ha of land that was planted with trees being included in the analysis instead of 115 ha of trees. The results showed that the farm still exceeded carbon neutrality, but required an additional 18 years to reach carbon neutrality in 2003 (Fig. 3). Furthermore, there was a greater reliance on soil carbon sequestration to offset the other farm emissions. In 2012, there was only 913 t CO_2e sequestered from trees planted post-1990, compared with 19,065 t CO_2e sequestered when all trees were included (Fig. 2).

Discussion

Although soils sequestered a higher level of carbon than trees, soil carbon levels stayed with a relatively small range over 200 years when compared with the carbon sequestered in trees, which increased rapidly as the trees grew (Fig. 1). The soil carbon levels were influenced by the tree activity and steadily declined after land clearing in 1870 and then increased again after 86.4 ha of land was revegetated in 1982. Since 1980 carbon sequestration in trees was greatest in more recent years as the trees grew larger and sequestered more carbon (Fig. 1). As trees revegetated and continued to grow carbon sequestration would increase, assuming that farming management and animal stocking rates remained the same. Should further clearing occur or stocking rates change, the results for the future would different. Soil sequestration followed the tree activities, decreasing after tree clearing and sequestering more carbon in the soil after trees were planted due to the increased root and litter material available.

The carbon balance of the farm had substantially smaller sequestration potential when the existing policy framework was applied that adhered to current Kyoto accounting rules. Instead of being able to claim the actual carbon offset amount of $8472 (using a carbon price of $24/t CO_2e) in 2012, only sequestration in trees planted from 1990 would be included, which would equal $4272.

Although carbon accounting rules do not allow all the existing carbon to be claimed as a carbon offset, Talaheni has experienced other economic benefits as a result of planting and revegetating over 200,000 native trees, namely the reduction in water table levels which eliminated saline seeps as well as improved biodiversity. Increasing the biodiversity on the farm is likely to produce healthy populations of native ants, which are bio-indicators of environmental health (Majer 1983; Hoffmann and Andersen 2003). Other management initiatives such as fencing land of similar soil types to aid grazing management, or using the sloped areas as drought holding paddocks to allow pastures on the flats to recover more quickly with rain, were implemented to improve the farm's performance. Environmental initiatives such as planting trees to reduce salinity have helped to increase productivity at Talaheni. Since 1983 there has been a steady increase in stocking rate of 0.15 DSE/ha/year on average and cattle weaning weight has also increased by 1 kg/year as pasture management and pasture availability have improved.

The GHGE from livestock was driven by stocking rate (Table 2), with more emissions produced in years of higher rainfall due to greater availability of pasture and higher animal intake of pasture. Emissions intensity was much higher with greater rainfall because pasture availability was higher and animal intake increased during these years, creating greater liveweight gain and higher emissions. During these years, wool production did not increase enough to compensate for the additional emissions. This result in emissions intensity is the opposite of when the final product is directly linked to feed intake, such as meat or milk production. When the final product is meat or milk, increased production from good quality feed in years of high rainfall usually produces a greater amount of product than emissions and emissions intensity decreases. This result may be different if economic allocation were used instead of mass allocation because more emissions would be allocated to wool production with economic allocation, however the data were unavailable to calculate emissions using economic allocation. Pre-farm emissions were driven mainly by supplementary feed, which is why pre-farm emissions were 11 times higher in the dry year of 2006 than the wet year in 2012 (Table 2)

Conclusion

This study analysed the carbon balance of the wool farm Talaheni, the wool farm in south eastern Australia with a relatively low stocking rate of 8 ewes/ha. From 1980 to 2012 the farm sequestered on average 7 times more CO_2e/year in trees and soil than it produced from livestock and CO_2 emissions.

The study shows that there is potential for productivity benefits through environmental management that includes planting trees. As a result of the additional trees and management on the property, the Talaheni farm, would have reduced salinity, increased soil carbon and also increased the productivity and profitability of the farm and was therefore more likely to be sustainable.

The Talaheni site has relatively low stocking rate compared with high rainfall areas of Australia and therefore more land may be required for sequestration in areas that have higher stocking rates. Further research on carbon neutral farms in high rainfall zones would be beneficial.

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Table 1: Events modelled in FullCAM to calculate tree and soil C sequestration.

Farm area	Year	Land size (ha)	Tree stocking rate (sph)	Proportion of trees (%)
Uncleared forest	1870	30.0	<500	<75
Cleared forest	1975	5.3	0	100
Cleared forest	1978	11.6	0	100
Revegetated	1982	82.9	>1,500	<75
Planted trees	1984	0.7	<500	<75
Planted trees	1985	0.6	<500	<75
Planted trees	1987	0.6	<500	<75
Planted trees	1988	0.5	<500	<75
Planted trees	1989	3.7	>1,500	>=75
Planted trees	1994	0.5	<500	<75
Planted trees	1998	1.0	<500	<75
Planted trees	2000	0.5	<500	<75
Planted trees	2002	1.0	<500	<75
Revegetated then thinned	2004	3.5	>1,500	>=75
Planted trees	2005	1.8	<500	<75
Planted trees	2010	0.3	<500	<75
Planted trees	2011	0.5	<500	<75
Total area of tree plantings		145.0		

sph, stems per ha.

Table 2: Annual estimates of farm GHGE and sequestration for long-term average results (2000-2012 and 1963-2012) as well as selected years (2006, 2012) representing low and high rainfall (rf), respectively.

Outputs (t CO_2e/farm)	Unit	2006 (low rf)	2000-2012	1963-2012	2012 (high rf
Rainfall	mm/annum	326	577	617	723
Stocking rate	DSE/ha	7.2	8.1	8.4	9.7
Wool produced	kg CFW	1,510	1,391	1,463	1,627
Meat produced	kg CW	1,882	2,158	2,227	2,770
CO_2 – Energy	t CO_2	3	3	3	3
CH_4 – Enteric	t CO_2e	22	63	68	103
CH_4 – Manure	t CO_2e	0.00	0.01	0.01	0.02
N_2O – Indirect	t CO_2e	3	11	12	18
N_2O – Dung, Urine	t CO_2e	2	8	9	13
Pre-farm emissions	t CO_2e	11	6	5	1
Total emissions	t CO_2e	41	91	97	138
Allocation percentage	% to wool	45	39	40	37
Emissions Intensity	t CO_2e/t CFW	12.2	25.5	26.5	31.4
C Sequestration Trees	t CO_2e	-160	-227	-325	-209
C Sequestration Soil	t CO_2e	-241	-169	-83	-278
Net carbon balance trees only	t CO_2e	-119	-136	-228	-71
Net carbon balance trees & soil	t CO_2e	-360	-305	-311	-349

CFW, clean fleece wool; CW, carcase weight; DSE, dry sheep equivalents.

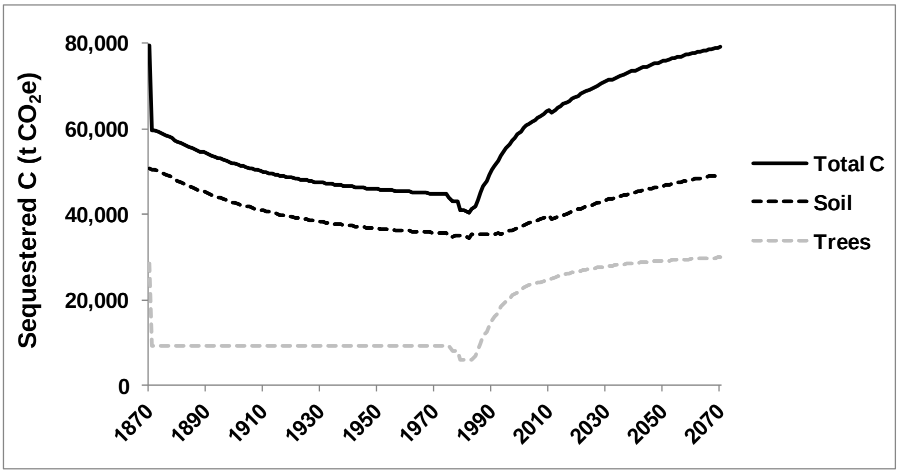

Fig. 1: Estimation of C sequestered in trees and soil at Talaheni farm from clearing in 1870 and projected to 2070 using current conditions.

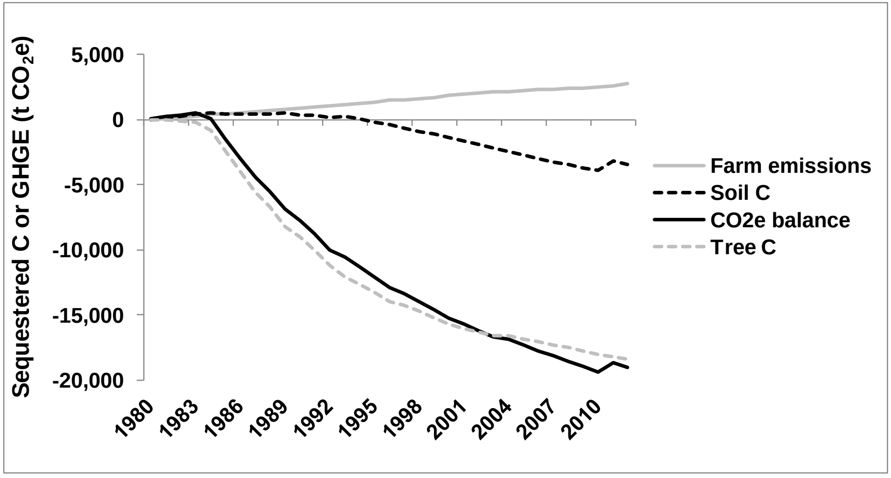

Fig. 2: Cumulative C balance from 1980 to 2012 including farm emissions (on-farm CH_4, N_2O, CO_2 and pre-farm emissions), tree C sequestration and soil C sequestration, presented in CO_2e.

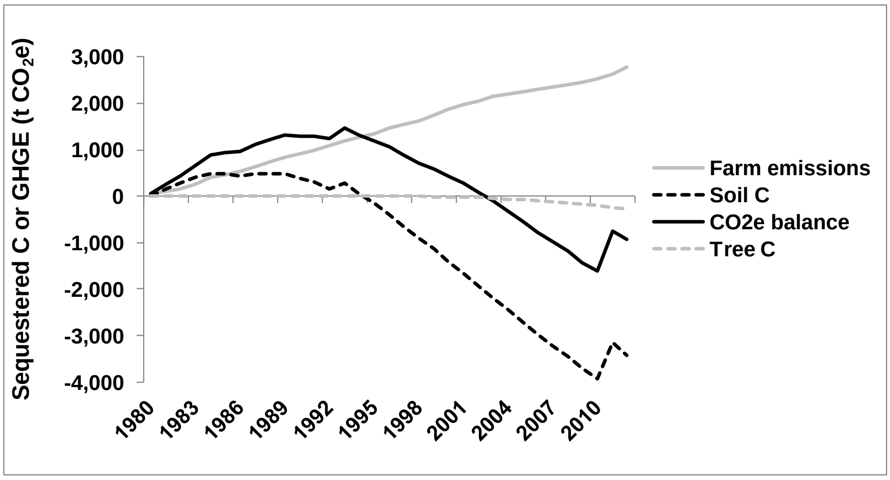

Fig. 3: Cumulative C balance from 1980 to 2012 including farm emissions (on-farm CH_4, N_2O, CO_2 and pre-farm emissions), soil C sequestration and tree C sequestration from only from trees planted after 1990.

D13. Project title

Carbon neutral farming on intensive sheep and beef farms in south eastern Australia

This study is not complete. Results are currently being finalised

Organisation The University of Melbourne

Primary contact Natalie Doran-Browne

Executive summary

Previous studies on carbon neutral farming have shown that low-stocking rate farms, such as Talaheni in New South Wales, can be carbon neutral or carbon positive by sequestering more carbon than is emitted from the farm. However, the carbon neutrality of farms with a high stocking rate has yet to be studied. Intensive sheep farms often have stocking rates 2.5 times higher (DSE/ha) than less intensive farms (Browne *et al.* 2011). Therefore, the challenge is to sequester enough carbon to offset the higher level of emissions that these additional animals produce. This study aimed to calculate whether intensive sheep and beef enterprises could offset their total emissions from livestock, energy and transport through carbon sequestration in trees and soil. Additionally, under the Emissions Reduction Fund the ability to offset carbon depends on the year that trees were planted. Therefore, carbon neutrality is sensitive not only to the number of animals and land available for trees, but also to climate policy.

Method

Jigsaw Farms is a 4900 ha wool, prime lamb and beef farm in southwest Victoria that was used as the case study for this research. Jigsaw Farms was named due to the numerous parcels of land that the farm consists of, having gradually been purchased to expand the farm area. This paper concentrates on the section of the farm in Hensley Park. From 2000 to 2014 the amount of land used for each type of livestock production has changed substantially (Table 1). Around 930 ha of permanent environmental plantings, as well as commercial agroforestry plantations have been established at Jigsaw Farms.

Table 1: The size, stocking rate, sale information and supplement fed on wool, prime lamb (crossbred) and beef enterprises at Jigsaw Farms.

Enterprise	**Wool**		**Crossbred lambs**		**Beef**			
Year	**2000**	**2001-04**	**2005-07**	**2008-14**	**2000**	**2001-04**	**2005-07**	**2008-14**
Enterprise size (ha)	620	960	230	1150	70	105	1760	110
Stocking rate (DSE/ha)	20.3	20.9	20.8	20.8	21.0	20.5	21.2	19.7
Stocking rate (ewes or cows/ha)	6.0	7.2	11.4	10.6	1.5	1.4	1.5	1.4
Weaning percentage (%)	71	74	105	126	90	93	93	94
Month of calving/lambing	Aug	Aug	Jul	Jul	Aug	Aug	Aug	Aug
Young stock sale age (months)	24	24	5-8	5-8	13-15	13-15	13-15	13-15
Heifer/ewe sale wt(kg LW)	59	64	45	45	351	361	349	344
Steer/wether sale wt (kg LW)	71	77	45	46	400	415	399	394
Meat sold (kg LW/ha)	322	316	470	436	290	325	323	322
Wool sold (kg CFW/ha)	46	46	39	40	n/a	n/a	n/a	n/a
Fibre diameter (µ)	18.4	18.3	25.1	26.7	n/a	n/a	n/a	n/a
Supplementary feed (t/ha)	0.28	0.00	1.06	0.94	2.82	0.86	4.19	2.46
Type of supplement fed	B	B	B/M	B/M	H/S	H/S	H/S	H/S

B = Barley; H = Hay; M = Mixture of 50% Barley, 20% Lupin, 20% Vetch, 10% Molasses; S = Silage

The dominant tree species planted for agroforestry was *Corymbia maculata.* The majority of the original farmland was cleared in 1880 and trees subsequently planted from 2000 to 2006 (Table 2). The farm receives an average 675 mm of annual rainfall and has predominantly phalaris and clover pastures. The whole-farm model GrassGro (Freer *et al.* 1998) was used to model the livestock systems. This model has been validated elsewhere (Clark *et al.* 2000; Cohen *et al.* 2003). Greenhouse gas emissions (GHGE) were calculated using the IPCC methodology (IPCC 2006), as described in the Australian National Inventory (DIICCSRTE 2013). Carbon sequestration in trees and soil was calculated using the FullCAM model (Richards and Evans 2004).

Table 2: The permanent revegetation and agroforestry planting activities at Jigsaw Farms.

Year	Permanent revegetation (ha)	Agroforestry (ha)
2000	8.3	
2001	22.1	
2002	31.85	56.75
2003	28.8	34.8
2004	38.3	60.2
2005	14.6	60.1
2006	7.6	16.9

Results

The modelling of livestock, GHGE and carbon sequestration in trees and soils is currently being finalised. Preliminary results for livestock GHGE are shown below in Table 3 and the sequestration for agroforestry presented in Figure 1.

Table 3: Greenhouse gas emissions produced by wool, prime lamb (crossbred) and beef enterprises at Hensley Park, Jigsaw Farms.

Enterprise	Year	Area (ha)	GHGE (t CO_2e/year)	GHGE (t CO_2e/ha)
Wool	**2000**	620	2140	3.5
	2001-04	960	4075	4.2
Crossbred	**2005-07**	230	640	2.8
	2008-14	1150	3903	3.4
Beef	**2000**	70	358	5.1
	2001-04	105	614	5.8
	2005-07	1760	8486	4.8
	2008-14	110	571	5.2
Total emissions	**2000**	690	2498	4.0
	2001-04	1065	4689	4.9
	2005-07	1990	9126	4.6
	2008-14	1260	4474	3.9

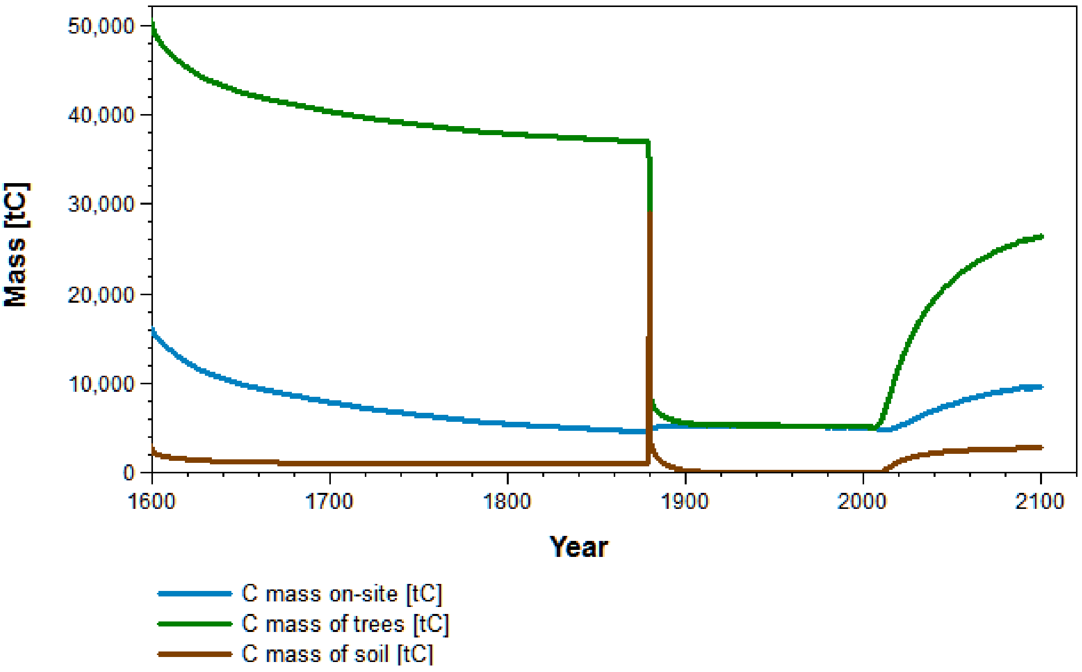

Figure 1: Carbon sequestration in the trees and soil used as agroforestry at Hensley Park, Jigsaw Farms.

Next steps

These results are very preliminary and have not yet been tested with and confirmed by the farmer. Therefore, at this early stage, no interpretation of the results is appropriate. The final results will be refined and analysed further and then published in a peer reviewed paper in an international journal.

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D14. Project title

A comparative analysis of on-farm and pre-farm greenhouse gas emissions from three beef cattle herds in Northern Australia

Organisation The University of Melbourne

Primary contact Chris Taylor

Paper under internal review – for consideration for publication in Land Use Policy

A comparative analysis of on-farm and pre-farm greenhouse gas emissions from three beef cattle herds in Northern Australia

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Abstract

This study provides a partial Life Cycle Assessment (LCA) that focuses on the greenhouse gas emissions (GHG) of three herds bred and grown across northern Australia. It involves modeling the greenhouse gas emissions of the herds as a baseline and comparing these to the greenhouse gas emissions of alternative scenarios, also modelled under a partial LCA. The herds consist of steers (one herd) and heifers (two herds). The baseline is modelled on actual herds being bred, grown and fed to the point of sale. The alternative scenarios are based on increased time at a backgrounding property for the steers and increased time at a feedlot for heifers. The results show reductions of greenhouse gas emissions of 14% between the baseline and scenario for steers and a reduction of 29% between the baseline and scenario for the heifer herd that would have grazed at Nebo. There was a decrease in greenhouse gas emissions of 4% for the heifer herd bypassing the Roma background property. The variances in the heifer herds can be explained by time spent by the herds grazing on channel or background properties (and associated LWG) versus time spent in the feedlot. The study identified breakeven thresholds for the greenhouse gas emissions between the baselines and scenarios and these ranged between 220-226 days for the heifer cattle and 203 and 604 days for the steers (depending on whether low LWG kg/hd/day is experienced on one or both properties), which means that bypassing these properties, if the cattle are to spending longer time grazing, will result in a net reduction in emissions for the herds.

Introduction

Agriculture releases significant amounts of greenhouse gases (GHG) into the atmosphere (Smith et al 2007). These emissions are expected to increase in coming decades, due to escalating demands for food and shifts in diet. Measures to mitigate the increase GHG emissions into the atmosphere are of critical importance to avoid dangerous anthropogenic interference with the climate system, which will adversely impact agricultural productivity (Rogner et al 2007). In response, several economies are planning, implementing or refining domestic mitigation actions to reduce greenhouse gas emissions (Kossoy et al 2014). Improved management practices and emerging technologies may permit a reduction in emissions per unit of food (or of protein) produced (Smith et al 2007).

Livestock production makes up a large proportion of agricultural greenhouse gas emissions, which are estimated at 7.1 Gt CO_2e per annum and represents 14.5% of all anthropogenic GHG emissions (Gerber et al 2013). Beef cattle comprise 41% of livestock GHG emissions, which is by far the largest of the sector. Given the large proportion of GHG emissions originating from beef cattle production and that consumption of meat products are projected to increase (Alexandratos and Bruinsma 2012), reducing emissions from the production and processing of beef cattle will become increasingly important, particularly in line with global efforts to mitigate rising GHG emissions and market preference towards less GHG intensive forms of food production (Smith et al 2007; Garnaut 2008).

Australia has around 28 million head of cattle across 71,000 farms (ABARES 2013; Gleeson 2012). Although this represents a relatively small percentage of total world cattle numbers, the national herd contributes around 18% of global trade in meat and veal products, making it the second largest exporter after Brazil (ABARES 2013; Malau-Aduli and Holman 2012). Direct greenhouse emissions from the national beef cattle herd (enteric fermentation, manure management and beef cattle feedlot emissions) have increased from 34 Mt CO_2-eq in 1990 to 40 Mt CO_2-eq in 2012 and represents around 7.6% of Australia's total emissions (NIR 2013).

The beef cattle industry is identified as being vulnerable to the biophysical impacts of climate change (Garnaut 2008). Conversely, the sector has been identified as having opportunities to reduce its GHG emission intensity (Smith et al 2007). A number of Australian beef cattle producers have responded by committing to reducing the greenhouse gas emissions of their respective herds (Bentley et al 2008; AACo 2014; Teys Australia 2014). The Australian Federal Government has introduced voluntary agricultural emission avoidance projects, as part of its Carbon Farming Initiative, where it awards credits to farms that take steps in reducing their GHG emissions, such as reducing enteric methane emissions. This can form an income for the farm (Commonwealth of Australia 2011).

In this context, there is interest in testing alternative management strategies of beef cattle and their respective GHG emission profiles. A number of studies have modeled or reviewed the greenhouse gas emissions of beef cattle and compared these to the greenhouse gas emissions of other livestock, using a combination of Life Cycle Assessment (LCA) and greenhouse gas inventory reporting (Browne et al 2011; Gerber et al 2013; Vries and Boer 2010). However, many of these do not compare current management practices with alternative strategies and often work to a 'snapshot' of farm conditions, not taking into account the variability of the agricultural context. Therefore, the goal of this study is to determine whether and to what extent anthropogenic GHG emissions can be reduced in beef cattle herds across Australia, while maintaining current productivity in terms of the number of cattle and live weight tonnes produced. It will compare the GHG emissions of three beef cattle herds against alternative scenarios of herd management and to varying degrees of productivity (i.e. variable daily live weight gain (LWG kg/head/day), so as to take account of year-to-year variation in farm productivity experienced across northern Australia.

Methods

This study models the current management practice of three herds of beef cattle managed by a large beef cattle company operating in Queensland and the Northern Territory, Australia. It calculates the greenhouse gas emissions of alternative scenarios of herd management and compares these to current management practice. It also compares these scenarios to varying levels of productivity. This study works within the parameters of a large beef cattle company, in order to provide realistic scenarios of management that would be considered by a beef cattle enterprise as commercially viable.

Herds and production pathways

There are three herds selected for this study, one comprising 5,000 steers and two heifer herds, each also comprising 5,000 cattle. The three herds have been bred at a large property near Camooweal (Table 1) and consist of Brahman cattle. The steers under current management (baseline) are transported to a property at Boulia, which is located in the Channel Country of south western Queensland. The cattle are then transported to a background property near Emerald in eastern Queensland and then to a feedlot, near Dalby, in southeast Queensland. The alternative scenario bypasses the Boulia property, and steers are transported from the breeder property direct to the background property at Emerald, then to the feedlot near Dalby.

The two heifer herds consist of current management practice (baselines) with heifers being transported from the breeder property near Camooweal to background properties located near Roma and Nebo for grazing. They are then transported to the feedlot near Dalby. The alternative scenarios consist of the background properties being bypassed, where the two heifer herds are transported directly from the breeder property to the feedlot near Dalby.

Study region

In addition to the northern half of Western Australia, the region of which the beef cattle enterprise grows and manages its beef cattle contains nearly 60% of the Australia's beef cattle herd. Beef cattle enterprises throughout the region are mostly large (>5400 head of cattle) and many control the stages of production from calving to finishing (Burrow 2014; Bentley et al 2008). The beef cattle properties throughout northern Australia are mostly used for breeding and grazing. They have low stocking rates in order to sustain economically viable herds. Cattle are either transported to finishing properties and abattoirs in eastern and southeast Queensland or to ports for live export (Gleeson et al 2012). The finishing properties consist of backgrounding properties and feedlots. Backgrounding properties are located in the higher rainfall and more productive regions of eastern Queensland and cattle graze on modified pasture. Stocking density is greater than the properties across northern Australia (ABS 2010). The majority of feedlots are located in southeast Queensland, which is a major grain-growing region and supply of grain feed is in close proximity. The cattle are transported via road on trucks (Higgins 2013).

Study sites

The study looked at a number of sites that are representative of the pathways in which beef cattle are bred, grown and finished by the enterprise and generally throughout northern Australia. The properties consist of Breeder, Channel Country, Background and Feedlot. For commercial in confidence reasons, the identity of the beef cattle enterprise and its properties will be not be disclosed. Nearby towns will be used as the reference points. However, the data used is based on the throughputs of the properties managed by the enterprise.

Breeder property

The study site uses the region surrounding Camooweal as representative of the breeder property for the heifers and steers (-19°55', 138° 7'). The site is located 12km east of the Queensland and Northern Territory border in the Arid Beef Cattle Zone, where extensive cattle production occurs over most of the region (AusVET 2006) (Figure 1). The region is dominated by the largely treeless plains of Mitchell grass on relatively fertile cracking clay soils, which extend into the Northern Territory. Few sown pastures support cattle grazing and browsing mostly occurs on native perennial grasses, naturalised tropical and subtropical grasses, shrubs and native trees (Gleeson et al 2012). Prolonged drought can result in relatively high reduction in the number of heifers and breeders. The normal pattern of turnoff is through the winter until October. There are large variations in sale weights, where season and price are the major influences. When feed supplies are plentiful, cattle are held to higher weights. More than 80 per cent of rain falls during summer to early autumn (AusVET 2006).

Boulia

Boulia is representative of the Channel Country properties and it is also located in the Arid Zone (-22°55', 139°55') (Figure 1). Steers are often transported to this region for growing out prior to sending them to backgrounding properties or directly to a feedlot. Following big wet seasons in the north, the Channel Country experiences wide-slow floods, resulting in high protein feed traditionally used for finishing bullocks (AusVET 2006). During good seasons or flooding in the channel country, large numbers of cattle are purchased for finishing. Purchasing rather than breeding allows stocking rates to accommodate the highly variable conditions (Gleeson et al 2012).

Emerald and Roma

Emerald and Nebo are backgrounding properties for steers and heifers, respectively (Figure 1). Both properties are located in the central Queensland region. The region is regarded as some of the best land for agriculture in Australia, with good soils and equitable climate (AusVET 2006). The Darling Downs and central highlands region has around 23% of Queensland's beef enterprises and carries 10%

of the state's beef cattle herd. Native pastures (generally under woodlands of eucalypt, cypress pine and mulga) cover more than 70% of the region (Gleeson et al 2012).

Nebo

The Nebo property is used for backgrounding heifer cattle. It is located in the tropical northeast coast region of Queensland, which takes in the east coast from Far North Queensland to Grafton on the north coast of NSW (Figure 1). Most beef enterprises in this region are small and non-commercial. Climate is moist and temperate with uniform rainfall, long hot summers and mild winters. Most areas have an annual rainfall of between 800 and 1200 millimetres. Much of the region that is available to cattle is infertile and better suited to breeding and growing rather than finishing. High herd fertility allows most producers to turn off weaners. These are bought by growers who want to on-sell to feedlots and local producers with better country that can finish steers and heifers for the domestic market. Year-round turn-off is possible, although the feed supply is summer dominant (AusVET 2006).

Dalby Feedlot

Dalby is representative of the feedlot site (Figure 1).

Transportation of cattle between sites

Distances between sites were measured using ArcGIS 10.2 (ESRI 2011). Transportation of cattle was mapped according to the herd and whether is represented in the baseline or scenario. Distances travelled range from 262km to 1,524km (Figure 1).

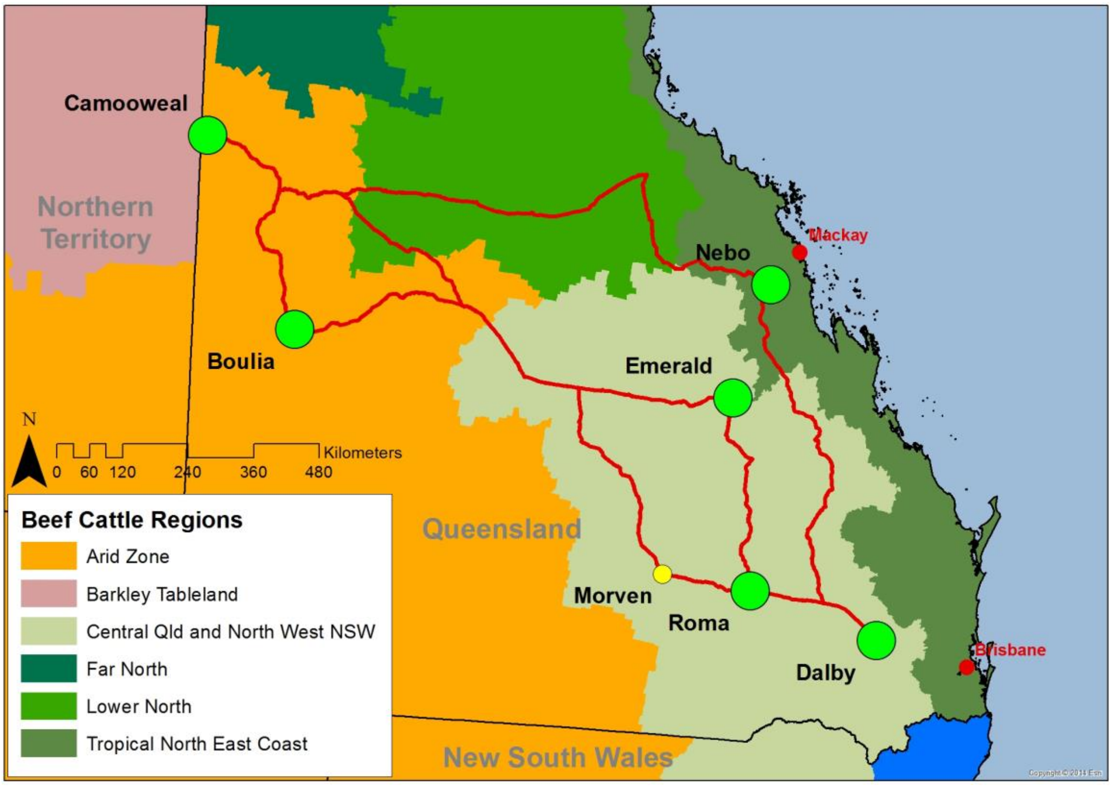


Figure 1: Location of properties and their respective transport routes

Greenhouse Gas Analysis and Partial Life Cycle Analysis

This study applies a partial Life Cycle Assessment (LCA) of the three herds. LCA has become a widely applied method of analysis in agriculture (Horne et al 2009; Biswas et al 2010; Brock et al 2012). LCA addresses the environmental aspects and potential environmental impacts throughout a products life cycle from raw material acquisition, through production and final disposal (ISO 2006). Although LCA encompasses a number of impact categories, inclusive of land use, water and global warming (Jolliet et al 2003), this study only models and compares the GHG emissions (global warming impact) of the herd's baselines against the GHG emissions of alternative scenarios of herd management, which makes it a partial LCA. The study is guided by the principles and frameworks outlined in International Standard ISO 14040 'Environmental management – Life Cycle Assessment – Principles and Framework' (ISO 2006) and the Intergovernmental Panel on Climate Change (IPCC) methodology (1997). The study states its goal (introduction), its scope, the product system, functional unit and the boundary of the system analysed. The results are explained through a Life Cycle Inventory Analysis, which involves the collection and input of data, and the Life Cycle Impact Analysis, which calculates the environmental impact. For this partial LCA, the impact is the weight of CO_2e emissions (tonnes).

Scope of study

The scope of the study consists of the product system, functions of the product system, the functional unit, the system boundary, impact categories, data requirements, assumptions and limitations. These are largely derived from the requirements described in ISO 14040.

Product system

The product system is the collection of unit processes with elementary and product flows, performing one or more defined functions (ISO 2006). The product system for steer baseline and scenario tracks the steers (as weaners) from the breeder property at Camooweal to the point of sale at the abattoir/processing (Figure 2).

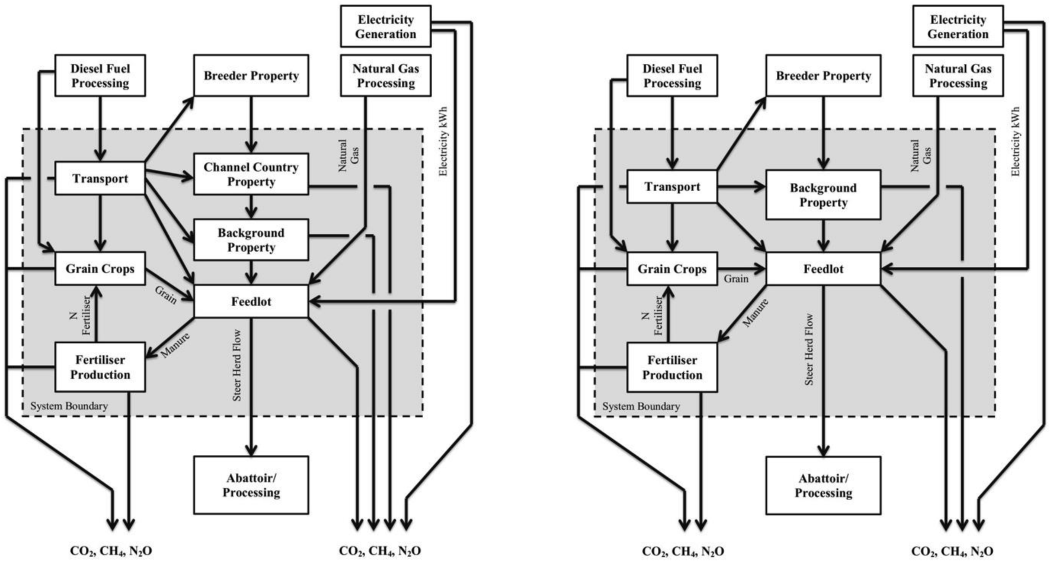


Figure 2: Production system and system boundary (shaded) for steers showing baseline (left) and scenario (right)

The production system for the heifer scenarios commences at the Camooweal breeder properties and proceeds through to the point of sale at the abattoir/processing (Figure 3). These systems are similar to each other, because they both involve the herds grazing via a background property (either Roma or Nebo) and they are further grown at the Dalby feedlot. The scenarios for both heifer herds consist of bypassing the background properties and spending a greater proportion of time at the feedlot.

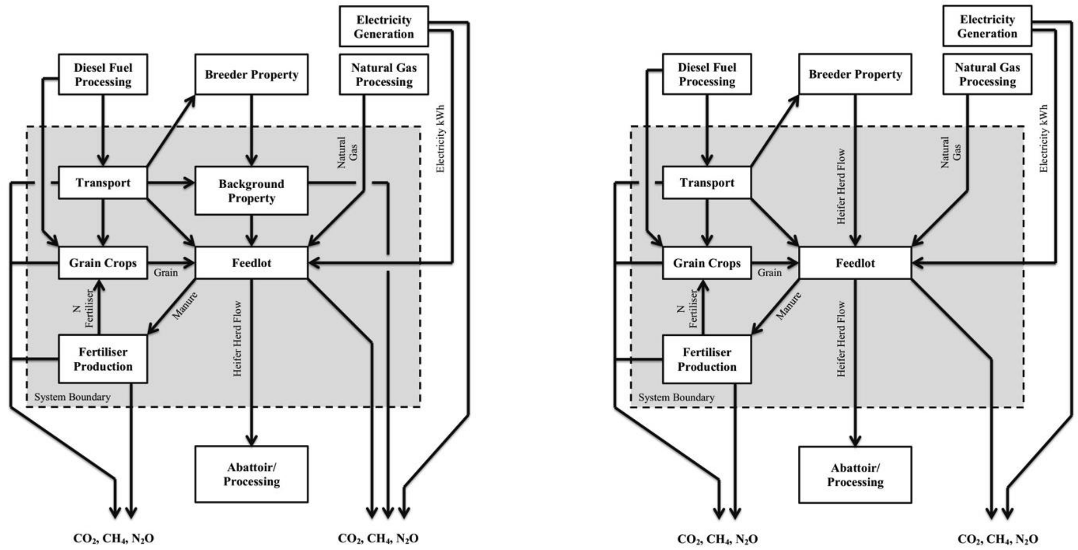


Figure 3: Production system and system boundary (shaded) for heifers showing baselines for herds background grazing via Roma and Nebo (left) and the scenarios for both herds bypassing the background properties (right)

Functional unit

The functional unit details the quantified performance of a production system for use as a reference unit. Its primary purpose is to provide a reference to which the inputs and outputs are related (ISO 2006). The primary purpose of integrated beef cattle companies is to breed and grow beef cattle for sale. Many do not conduct further processing (i.e. slaughter, boning, processing of meat). Based on these parameters, the live cattle are considered the final product of their process. This study uses the live weight tonnes (LWT) of cattle produced as the functional unit.

System boundary

The system boundary defines the unit processes to be included and modelled in the study (ISO 2006). In this study, the system boundary was determined by identifying unit processes that were changed between the respective baselines and scenarios of herd management. Unit processes that were included in the modeling of the steers consisted of the channel country property near Boulia, the background property near Emerald, the Feedlot near Dalby, the crops providing grain and silage to the feedlot and transport of the steers and feedstock between the properties. These unit processes were identified as changing between the baseline and scenario. Unit processes outside the system boundary were the breeder property near Camooweal and further downstream processing past the feedlot gate. These were considered as constant, irrespective of the baseline and scenario.

The unit processes included in the system boundary for the heifer baselines and scenarios were the background properties, feedlot, crops providing grains and silage to the feedlot and transport of cattle and feedstock between the properties. Similarly to the steer baseline and scenario, the breeder property near Camooweal and further downstream processing from the feedlot gate were located outside the system boundary, because these were considered constant unit processes. Other elements outside the system boundary for all the herds included the production of diesel fuel to be used in transport and operation of farm machinery and the production of natural gas.

Impact categories

Impact categories describe the classes representing the environmental issues of concern to which the life cycle inventory analysis results may be assigned (ISO 2006). This study focuses only on the impact of greenhouse gas emissions, resulting from the production of beef cattle across the three herds. Other impact categories, including land occupation or mineral extraction, are not covered by this study.

The greenhouse gas emissions were calculated by using the Greenhouse Accounting Frameworks (GAF) for Australian Beef and Grain Farms. These frameworks consist of a series of calculators that require inputs to model the potential emissions from specific agricultural activities. The calculators provide a greenhouse gas emission profile for each property of the beef cattle production process. The calculators break down the GHG emissions into the various sources and where they are coming from on the properties (Eckard et al 2008). They are based on the Australian National Greenhouse Gas Inventory method, as published on the Australian Government Department of Climate Change and Energy Efficiency in April 2012. Three calculators were specifically used for the channel country, background properties, feedlot and crops supplying feedstock to the feedlot. These calculators consist of: 1) the Beef Greenhouse Accounting Framework Northern (B-GAFN) (Eckard et al 2008) for greenhouse emissions from Channel Country and Background properties; 2) Feedlot Greenhouse Accounting Framework (F-GAF) (Ozkan and Eckard 2012) for greenhouse emissions from the Dalby Feedlot; and 3) Grains Greenhouse Accounting Framework (G-GAF) (Eckard 2009).

Emission breakeven thresholds between baselines and scenarios

The greenhouse gas emissions between properties will vary according to their respective LWG/day rates and overall productivity. Although data derived from specific sites were used in the inventory analysis, the regions surrounding the properties are extensive and multiple sites may exhibit different productivity rates. For example, one Channel Country property consisting of Cooper Clover dominated pastures can yield LWG rates of 1.5-1.75 kg/head/day of cattle, while Channel Country properties dominated by Peabush pastures may only yield LWG rates of +/- 0.1 kg/head/day (Department of Primary Industries and Fisheries 2007). This can influence the greenhouse gas mission intensity of the herd, depending on the days grazing on the property to achieve the desired weight gain.

To determine whether a baseline or scenario is either more or less emissions intensive, this study modelled the three herds under different rates of productivity by altering the time on the property and its LWG kg/head/day. Each herd model was run 5 times, with each model run time increasing by one season. The resulting trends in days on farm and LWG are correlated against the GHG emissions change factor, with one (1.0) determining the breakeven threshold. This is where the GHG emissions of the baseline and its alternative scenario are equal. Where the change factor is <1.0, the alternative scenario is less GHG emissions intensive than its baseline. Conversely, where it is >1.0, the alternative scenario is more GHG emissions intensive than its baseline. All other inputs were constant in the model. A regression of best fit (r^2) was fitted to the modelled change factors against days spent on the properties and the LWG kg/head/day. The gradient of the regression is indicative of the change factor intensity of GHG emissions per day and LWG of the herd. The correlations and determination of break-even emissions intensity can assist farmers and beef cattle companies in deciding whether to maintain current management practices or implement alternative scenarios.

Limitations of the study

The LCA only addresses the environmental issues that are specified in the goal and scope and it is not a complete assessment of all environmental issues of the product systems (ISO 2006). As this study only provides a partial LCA of the three herd baselines and their respective scenarios, other environmental impacts (and their resulting emissions) are not covered. It is assumed that GHG emissions resulting from these impacts are relatively minor when compared to the GHG emissions from the unit processes identified within the system boundary. The purpose was to provide a comparison between baseline beef cattle management pathways and alternative scenarios. Further study can include these other impact categories to provide a more comprehensive overview of emission intensity of the management pathways.

Results

Life Cycle Inventory Analysis

The Life Cycle Inventory Analysis involved data collection and calculation procedures to quantify relevant inputs and outputs of the product system (ISO 2006). Data collection involved obtaining company data directly from the representative integrated beef cattle enterprise and collate its stocks and flows through elements in the system. This included cattle numbers for the herds, landed and exit weights, days carried on properties and mortality rates (Table 1).

An inventory analysis was conducted for transport of cattle and feedstock between the properties. Data for distances travelled between properties was generated and major roads were identified using spatial data obtained from Geoscience Australia (2013). Distances were calculated between properties via the major road network (Figure 1).

Data was obtained from the beef cattle enterprise on the types of vehicles used in the transport of cattle between properties. For transport between the breeder properties to the background properties (including via the Channel Country property near Boulia), a 6-deck trailer was used. For transport between the background properties and the feedlot, a 4-deck trailer was used. Where cattle were transported directly between the breeder property and the feedlot, cattle were transferred from the 6 deck trailers to the 4 deck trailers at Morven (Figure 1). The total number of trips required to transport cattle between properties was calculated (Table 2). Average numbers of cattle per deck were derived from Higgins (2013).

Table 1: Input parameters for Steers

Steers					
	Baseline			Alternative Scenario	
Property	Boulia	Emerald	Dalby	Emerald	Dalby Feedlot
Type	Channel Country	Background	Feedlot	Background	Feedlot
Number of Cattle (n)	5,000	4,923	4,896	5,000	4,950
Landed Weight (kg)	210.00	350.00	465.00	210.00	465.00
Turnoff Weight (kg)	350.00	465.00	671.00	465.00	671.00
Weight Gain (kg)	140.00	115.00	206.00	255.00	206.00
Background Farm Days Carried (n)	350.00	200.00	103.00	440	103.00
LWG (kg/day)	0.40	0.58	2.00	0.58	2.00
Mortality Rate (%)	1.60	1.00	0.30	1.00	0.30
Mortalities (n)	77.00	27.00	4.00	50.00	4.00
Number of cattle after mortalities (n)	4,923.00	4,896.00	4,892.00	4,950.00	4,946.00
Total LWT (t)	**1,723.05**	**2,276.64**	**3,282.53**	**2,301.75**	**3,318.77**
Heifers (Nebo)					
Property	Nebo	Dalby		Dalby	Dalby
Type	Background	Feedlot		Feedlot	Feedlot
Number of Cattle (n)	5,000	4,975		5,000	
Landed Weight (kg)	190.00	330.00		190.00	340.00
Turnoff Weight (kg)	330.00	445.00		340.00	445.00
Total Weight Gain (kg)	140.00	115.00		150.00	105.00
Days Carried (n)	429	77		136	70
LWG (kg/day)	0.33	1.50		1.10	1.5
Mortality Rate (%)	0.50	0.30		0.30	
Mortalities (n)	25.00	15.00		15.00	
Number of cattle (n) following mortalities	4,975.00	4,960.00		4,985.00	
Total LWT (t)	**1,641.75**	**2,207.20**		**2,218.33**	
Heifers (Roma)					
Property	Roma	Dalby		Dalby	Dalby
Type	Background	Feedlot		Feedlot	Feedlot
Number of Cattle (n)	5,000	4,975		5,000	
Landed Weight (kg)	190.00	330.00		190.00	340.00
Turnoff Weight (kg)	330.00	445.00		340.00	445.00
Total Weight Gain (kg)	140.00	115.00		150.00	105.00
Days Carried (n)	250.00	77		136	70
LWG (kg/day)	0.56	1.50		1.10	1.50
Mortality Rate (%)	0.50	0.30		0.30	
Mortalities (n)	25.00	15.00		15.00	
Number of cattle (n) following mortalities	4,975.00	4,960.00		4,985.00	
Total LWT (t)	**1,641.75**	**2,207.20**		**2,218.33**	

The total number of trips was summed per pathway to calculate the cumulative distance travelled to transport the herd. The average fuel consumption per trailer was derived from Higgins (2013), where a truck towing a 6 deck trailer consumes, on average, 1.1 1itres of diesel fuel per kilometre and a truck towing a 4 deck trailer consumes, on average, 0.79 litres of diesel fuel per kilometre. Feedstock supplied to the feedlot was derived from the integrated beef cattle company data detailing that grain supplied for Dalby feedlot is sourced within a 200km radius of the feedlot. Maize silage is grown on cropland directly surrounding the feedlot, which was owned and managed by integrated beef cattle company. The average distance calculated for the transport of silage was estimated to be on average 1 kilometre (Table 2).

Table 2: Inputs for transport of cattle between properties and the transport of grain to feedlot

Steers					
	Baseline			**Alternative Scenario**	
From Property	Camooweal	Boulia	Emerald	Breeder	Emerald
To Property	Boulia	Emerald	Dalby Feedlot	Emerald	Dalby Feedlot
Distance from Previous Point (km)	495.00	934.00	672.00	1,229.00	672.00
Total summed distance (km)	10,855.26	38,317.35	31,635.69	26,951.75	27,720.00
Fuel Consumed for the transport of cattle (litres)	**12,049.34**	**30,079.12**	**24,834.02**	**29,916.45**	**21,760.20**

Heifers (Nebo)				
From Property	Camooweal	Nebo	Camooweal	Morven interchange
To Property	Nebo	Dalby	Morven interchange	Dalby
Distance from Previous Point (km)	1,342.00	835.00	1,351.00	435.00
Total summed distance (km)	29,429.82	39,943.51	29,627.19	14,309.21
Fuel Consumed (litres)	**32,667.11**	**31,355.66**	**23,257.35**	**11,232.73**

Heifers (Roma)				
From Property	Camooweal	Nebo	Camooweal	Morven interchange
To Property	Nebo	Dalby	Morven interchange	Dalby
Distance from Previous Point (km)	1,524.00	262.00	1,351.00	435.00
Total summed distance (km)	33,421.05	12,533.17	29,627.19	14,309.21
Fuel Consumed (litres)	**37,097.37**	**9,838.54**	**23,257.35**	**11,232.73**

Data for feedstock was obtained from the beef cattle enterprise. This included dry matter intake (DMI) and ‘as fed’ volumes. The proportion of the feedstock was determined by the ration that the herd was assigned. There was a grower ration and a finisher ration. Each consisted of different proportions (i.e. the grower ration has a higher proportion of silage and hay, the finisher ration has a higher proportion of wheat). The total grain and silage volumes were calculated as the products of the total number cattle in the herd and the total time spent in the feedlot.

Table 3: Inputs for the production feedstock for steers at Dalby Feedlot

	Wheat Baseline	Wheat Alternative Scenario	Silage Baseline	Silage Alternative Scenario	Total Baseline	Total Alternative Scenario
Steers						
Total Grain Used in feedlot for batch (t)	5,545.16	5,606.37	1,141.20	1,152.86	6,686.36	6,759.22
Area utilised for wheat cropping (ha)	2,918.50	2,950.72	219.46	221.70	3,137.97	3,172.42
Diesel Fuel Consumed (Litres)	**17,411.79**	**17,603.99**	**17.92**	**18.10**	**17,429.70**	**17,622.09**
Heifers (Nebo)						
Total Grower Grain in feedlot for batch (t)	-	2,044.08	-	3,692.53	-	5,736.60
Area cropped (ha)	-	1,075.83	-	710.10	-	1,785.93
Total Finisher Grain in feedlot for herd (t)	3,239.87	2,973.05	666.23	611.36	3,906.10	3,584.41
Area utilised for wheat cropping (ha)	1,705.20	1,564.77	128.12	117.57	1,833.32	1,682.33
Diesel Fuel Consumed (Litres)	**10,173.20**	**15,753.79**	**10.46**	**67.57**	**10,183.66**	**15,821.36**
Heifers (Roma)						
Total Grower Grain in feedlot for batch (t)	-	2,044.08	-	3,692.53	-	5,736.60
Area cropped (ha)	-	1,075.83	-	710.10	-	1,785.93
Total Finisher Grain in feedlot for batch (t)	3,239.87	2,973.05	666.23	611.36	3,906.10	3,584.41
Area utilised for wheat cropping (ha)	1,705.20	1,564.77	128.12	117.57	1,833.32	1,682.33
Diesel Fuel Consumed (Litres)	**10,173.20**	**15,753.79**	**10.46**	**67.57**	**10,183.66**	**15,821.36**

The area required to grow feedstock (wheat grain and silage) was calculated by the average wheat and maize grain yield (t/ha) within 200km of the feedlot. This estimate was generated by referring to the Australian Bureau of Statistics (ABS) 2011 agricultural census, where commodity production area planted data was collected at Australian Standard Geographical Classification (ASGC) Statistical Area Level 2 (Pink 2010). The volume of grain and silage by each herd was converted into the area cropped. For example, if 4,892 steers require 5,545.16 tonnes of wheat grain and the average wheat grain yield is 1.9 t/ha, then 2,918.50 hectares are required to grow that volume at the average yield. The diesel fuel required to farm the wheat and maize silage crops was derived from the Australian Life Cycle Inventory Database (ALCAS 2012) (Table 3). These provided the average diesel fuel consumption rates per hectare of land cropped for the major phases of crop cultivation, growing and harvesting (Table 4). Total fuel consumption for area cropped to supply the sample herds was calculated.

Table 4: Fuel used on crops to provide grain feed

	Broadacre crop diesel use (litres/ha)	Area utilised for wheat (ha)	Area utilised for maize (ha)	Total Wheat diesel Use (litres)	Total Maize diesel use (litres)	Combined Diesel Use (litres)
Steers						
Baseline	29.55	2,918.50	219.46	86,241.76	6,485.11	92,726.87
Scenario	29.55	2,950.72	221.70	87,193.73	6,551.34	93,745.07
Heifers (Nebo)						
Baseline	29.55	1,705.20	128.12	50,388.54	3,785.96	54,174.50
Grower Scenario	29.55	1,075.83	710.10	31,790.77	20,983.49	52,774.26
Finisher Scenario	29.55	1,564.77	117.57	46,238.81	3,474.17	49,712.99
Heifers (Roma)						
Baseline	29.55	1,705.20	128.12	50,388.54	3,785.96	54,174.50
Grower Scenario	29.55	1,075.83	710.10	31,790.77	20,983.49	52,774.26
Finisher Scenario	29.55	1,564.77	117.57	46,238.81	3,474.17	49,712.99

The GHG emissions resulting from the production of urea fertilizer was derived from Wood and Cowier (2004). It was assumed that urea fertiliser was applied to wheat crops throughout the region. An average estimate of 1.99kg of CO_2e emitted per kg of urea was calculated based on the values reported in Wood and Cowier (2004). Total embodied greenhouse gas emissions were calculated by factoring in the total area cropped (Table 5).

Table 5: Greenhouse Gas Emissions resulting from producing fertiliser

	Baseline Area Sown	Grower Scenario Area Sown	Finisher Scenario Area Sown	Finisher Baseline Emissions (t)	Grower Scenario Emissions (t)	Finisher Scenario Emissions (t)
Steers	3,137.97	-	3,172.42	580.78	-	587.19
Heifers (Nebo)	1,833.32	1,785.93	1,682.33	339.33	214.09	311.39
Heifers (Roma)	1,833.32	1,785.93	1,682.33	339.33	214.09	311.39

The emissions for fertilizer production were only calculated for wheat crops and not for maize silage. It was assumed that wheat was sourced from off-farm sources and that fertilizer is manufactured and delivered to those farms. However, maize crops surround the Dalby Feedlot and it utilized manure that was a by-product of the cattle feeding in the feedlot for fertilizer. Manure was applied across the maize crops and it was estimated that around 200 kg N was applied through this process. The emissions from the production of the manure were factored in the modeling of the feedlot emissions, thus were omitted from Table 5.

The Dalby Feedlot featured a mill where feedstock delivered to the site was processed and organised into assigned feed rations. In 2013, this mill used 446,069 kWh of electricity and 340,368 litres of Liquid Natural Gas. The volume of LNG used was calculated on a unit per tonne of feedstock-produced basis. The throughput of feedstock through the Dalby feedlot was 70,000 for 2013 (Table 6). The amount of gas used per tonne of feedstock was 4.86 litres. The total amount of natural gas used was the product of the total amount of feedstock consumed by the herds. GHG emissions from the total of natural liquid gas used were calculated using the methods described in the Australian National Greenhouse Accounts (2012). The following formula was used to estimate greenhouse gas emissions from the combustion of Liquid natural gas:

$$E_{ij} = \frac{Q_i.EC.EF_{ijoxec}}{1000} \qquad \text{Equation (1)}$$

Where E_{ij} was the emissions of gas type (j), (carbon dioxide, methane or nitrous oxide), from gaseous fuel type (i) (CO_2-e tonnes), Q_i was the quantity of fuel type (i) (cubic metres) EC was the energy content factor of fuel type. Q_i was expressed as litres and it was multiplied by the energy content factor (EC) of 25.3 Gj/KL. EF_{ijoxec} was the emission factor for each gas type (j) (which included the effect of an oxidation factor) for fuel type (i) (kilograms CO_2-e per gigajoule of fuel type (Table 6).

Similarly to the liquid natural gas used, the electricity used was calculated on a kWh consumed per tonne of feedstock produced. This value was 6.37 kWh per tonne of feedstock (Table 6). The total amount of kWh used for each herd was the product of the total amount of feedstock consumed. The resulting greenhouse gas emissions from electricity generation were calculated via the Beef and Feedlot Greenhouse Accounting Frameworks (Eckard et al 2008; Ozkan and Eckard 2012).

Table 6: Kilowatt-hours of Electricity and Greenhouse Gas Emissions resulting Liquid Natural Gas used for feedstock production fed to heifers via Nebo at the Dalby Feedlot Mill

Energy Input	Herd and Location	Baseline	Scenario grower	Scenario finisher
Kilowatt-hours of Electricity	Steers via Emerald	49,769.05	-	50,318.42
	Heifers via Nebo	24,891.28	36,556.00	22,841.37
	Heifers via Roma	24,891.28	36,556.00	22,841.37
Liquid Natural Gas (Litres)	Steers via Emerald	60.18	-	60.85
	Heifers via Nebo	30.10	44.21	27.62
	Heifers via Roma	30.10	44.21	27.62

Life Cycle Impact Analysis

The Life Cycle Impact Analysis calculated the greenhouse gas emissions that result from the herds. The impact emissions were grouped into the herds and their respective baseline and scenario categories. The overall GHG emissions of the 5,000 steers that were grazed and fed through their baseline were 20,660.64 tonnes of CO_2e. This equated to an emissions intensity of 6.29 tonnes of CO_2e for every live weight tonne of cattle (Table 7). The channel country property at Boulia featured the greatest proportion of these emissions, followed by the feedlot (including pre-farm greenhouse gas emissions) and then the background property.

The alternative scenario, which removed the channel country property from the process, resulted in a 13% reduction in the total greenhouse gas emissions and 14% reduction in the GHG emissions intensity (tCO_2e/tLWT) (Table 8). The reduction in GHG emissions was the result of the steers bypassing the Channel Country property near Boulia (where growth rates are relatively low at 0.4 kg/day) and directly transported to the background property near Emerald (LWG = 0.58 kg/day). For the background property, there was a near doubling of emissions from the baseline (6,172.83 tCO_2-e) to the scenario (11,385.42 tCO_2-e). However, these increases were offset from the avoided emissions of the steers bypassing the Channel Country property to produce the overall reduction in GHG.

The overall greenhouse gas emissions of the 5,000 heifers that were grazed via the background property at Nebo and fed through their baseline was 12,718.82 tCO_2e. This equated to an emission intensity of 5.76 tonnes of CO_2e for every live weight tonne of cattle (Table 7). The greatest proportion of on-farm/feedlot emissions occurred on the background property (69%), where the herd spent 429 days. The alternative scenario, which removed the background property from the process, resulted in a 29% reduction in the total greenhouse gas emissions and intensity (4.07 tCO_2e/tLWT) (Table 8).

The overall greenhouse gas emissions of the 5,000 heifers that were grazed via the background property at Roma and fed through their baseline was 9,393.75 tCO_2e. This equated to an emission intensity 4.26 tonnes of CO_2e for every live weight tonne of cattle (Table 7). The greatest proportion of emissions occurred on the background property (59%), where they spent 250 days. The alternative scenario, which removed the background property from the process and it had the herd transported directly to the feedlot, resulted in only a 4% reduction in the total greenhouse gas emissions and emissions intensity (4.07 $tCO_2e/tLWT$) (Table 8). This smaller reduction of emissions, when compared to the larger reduction of emissions modelled in the Nebo herd, was the result of the offset in emissions that would otherwise occur on the background property being near equal to the increase of emissions resulting from the feedlot and the pre-feedlot GHG emissions. The herd spends nearly half the amount of days grazing on the Roma property than what the comparative herd spends grazing at Nebo. The GHG emissions intensity of the background grazing at Roma is 1.11 tCO_2e for every live weight tonne of cattle, nearly half the value of the Nebo property, which is 1.75 tCO_2e for every live weight tonne of cattle.

Table 7: Greenhouse Gas Emissions for baseline (tCO_2e)

	Outputs	**Channel Country t CO_2e/ farm**	**Background t CO_2e /farm**	**Feedlot t CO_2e / Farm**	**Total t CO_2e/System**
Steers	Farm Emissions	7,998.77	6,172.83	4,661.34	18,832.94
	Grain Crop Emissions	-	-	1,186.74	1,186.74
	Other Emissions	-	-	1,827.71	1,827.71
	Total Emissions	**7,998.77**	**6,172.83**	**6,489.05**	**20,660.64**
	Emissions Intensity CO_2e /t LWT	-	**-**	-	**6.29**
	Outputs	**Nebo t CO_2e/farm**		**Dalby t CO_2e/property**	**Total t CO_2e/System**
Heifers via Nebo	Farm Emissions	8,766.62		2,849.67	11,616.28
	Grain Farm Emissions	-		733.10	733.10
	Other Emissions	-		1,102.54	1,102.54
	Total Emissions	**8,766.62**		**3,952.20**	**12,718.82**
	Emissions Intensity CO_2e /t LWT	-		**-**	**5.76**
	Outputs	**Year Roma t CO_2e/farm**		**Dalby t CO_2e/property**	**Total t CO_2e/System**
Heifers via Roma	Net Farm Emissions	5,540.80		2,790.37	8,331.17
	Grain Farm Emissions	-		693.15	693.15
	Other Emissions	-		1,062.58	1,062.58
	Total Emissions	**5,540.80**		**3,852.95**	**9,393.75**
	Emissions Intensity CO_2e /t LWT	**-**		**-**	**4.26**

Table 8: Greenhouse Gas Emissions for scenarios (tCO_2e)

	Outputs	**Background t CO_2e/farm**	**Feedlot t CO_2e/farm**	**Total t CO_2e/farm**	**Change Factor from Baseline**
Steers	Net Farm Emissions	11,385.42	4,703.57	16,088.99	0.85
	Grain Farm Emissions	-	1,199.45	1,199.45	1.01
	Net Feedlot Emissions	-	1,847.49	1,847.49	1.01
	Total Emissions	**11,385.42**	**6,551.06**	**17,936.48**	**0.87**
	Emissions Intensity CO_2e /t LWT	**-**	-	**5.40**	**0.86**
	Outputs	**Grower Feedlot t CO_2e/farm**	**Finisher Feedlot t CO_2e/farm**	**Total t CO_2e/ Feedlot**	**Change Factor from Baseline**
Heifers (via Nebo in baseline)	Net Farm Emissions	3,444.07	**2,538.07**	5,982.14	0.51
	Total Emissions	1,804.08	**635.46**	2,439.55	3.33
	Other Emissions	2,062.38	**974.47**	3,036.85	2.75
	Total Emissions	**5,506.45**	**3,512.54**	**9,018.99**	**0.71**
	Emissions Intensity CO_2e /t LWT	**-**	**-**	**4.07**	**0.71**
	Outputs	**Grower Feedlot t CO_2e/farm**	**Finisher Feedlot t CO_2e/farm**	**Total t CO_2e/ Feedlot**	**Change Factor from Baseline**
Heifers (via Roma in baseline)	Net Farm Emissions	3,444.07	2,538.07	**5,982.14**	0.72
	Grain Farm Emissions	1,804.08	635.46	**2,439.55**	3.52
	Other Emissions	2,062.38	974.47	**3,036.85**	2.86
	Total Emissions	**5,506.45**	**3,512.54**	**9,018.99**	**0.96**
	Emissions Intensity CO_2e /t LWT	**-**	**-**	**4.07**	**0.96**

Breakeven threshold between baseline and scenario greenhouse gas emissions

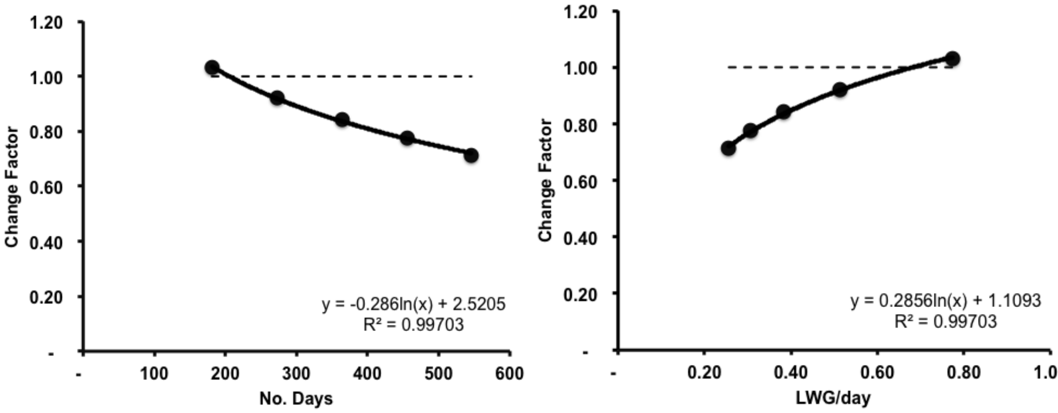
The breakeven thresholds for greenhouse gas emissions intensity were almost identical for the heifer herds. For the heifer herd through the Nebo property, the resulting break-even threshold for days on background property was 220 days with a LWG of 0.63 kg/head/day. A natural logarithm regression was the best fit for the points (r^2 = 0.9995 for both Nebo and Roma). If the weight gain of 140kg were achieved across more than 220 days, bypassing the heifer cattle around the Nebo property and sending them directly to the feedlot would result in a net reduction of GHG emissions. Conversely, if the weight gain were to be achieved in less than 220 days, bypassing with cattle around the Nebo property would result in a net increase in GHG emissions (Figure 4). A similar pattern was identified for the Roma property, which resulted in a break-even threshold of 226 days with a LWG of 0.62 kg/head/day. If the weight gain of 140kg is achieved across more than 226 days, bypassing the heifer cattle around the Roma property and sending them directly to the feedlot would result in a net reduction of GHG emissions and, conversely, if the weight gain were to be achieved in less than 220 days, bypassing the background property near Roma would result in a net increase. The gradient of the natural logarithm regression curves were relatively steep for the heifer cattle (-0.46 and -0.468 for Nebo and Roma, respectively), indicating that the avoided or added GHG emissions per day spent on the background property in the baseline compared to the feedlot in the respective scenarios was higher than the steers in comparison with their respective scenarios.

The breakeven threshold for steers, the time spent on the Channel Country properties was 203 days, but with a similar LWG to the heifers at 0.68kg/head/day. Where LWG was low for both the Boulia and Emerald properties, the avoided emissions were smaller between the baseline and the scenario. A natural logarithm regression was the best fit for the points (r^2 = 0.997). If the weight gain of 140kg were to be achieved across more than 203 days, bypassing the steers around the Boulia channel country property and direct to the background property at Emerald would result in a net reduction of GHG emissions. Conversely, if the weight gain were achieved in less than 203 days, bypassing with cattle around the Boulia channel country property would result in a net increase in GHG emissions (Figure 4). The gradient of the natural logarithm regression for the steers was nearly half of that for the heifers (-0.286), indicating that indicating that the avoided or added GHG emissions per day spent on the background property would be less than the heifers in comparison with their respective scenarios.

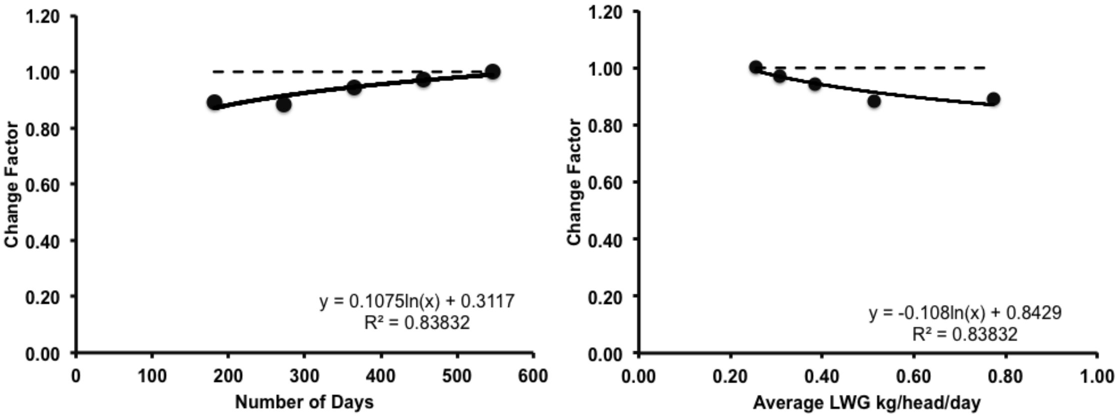
When LWG is low on both steer properties, the benefits of bypassing the Boulia property diminished. In contrast to when the LWG is low only on the Boulia property, low LWG on both properties resulted in an inverted logarithm regression, where the gradient of the regression was positive. This meant that bypassing the Boulia property was greatest when there was little to no decline in LWG on both properties. With declining LWG, the more days spent on both properties resulted in the avoided GHG emissions between the baseline and scenario becoming smaller, to the point where they became negligible at 604 days. However, the avoided GHG emissions with fewer days at Boulia were relatively small, as indicated by the lower gradient on the fitted natural logarithm regression (0.1075). This can be explained when LWG on both properties was high, the steers spent only 74% of the time grazing of what they would otherwise graze on both properties. When the LWG on both properties was low, bypassing the Boulia property would result in the same number of days grazing on the background property to gain the same live weight.

These trends indicated that the determination of GHG emission reduction for the three herds, between their respective baselines and scenarios, was largely dependent on the productivity of the property that was to be bypassed. The key variable was the number of days spent grazing at the background properties for the heifers and days spent grazing in the Boulia Channel Country for the steers. The trends also indicated the GHG emissions change factor per day was greater for heifers in comparison to the steers. This meant that if backgrounding properties were of low productivity, bypassing the heifer cattle around them and proceeding directly to the feedlot resulted in greater rates of emissions reduction when compared to the rates observed in the steers. Conversely, if heifer cattle were bypassed around backgrounding properties of high productivity and delivered directly to the feedlot, then rate of increase in emissions would be greater than the steers.

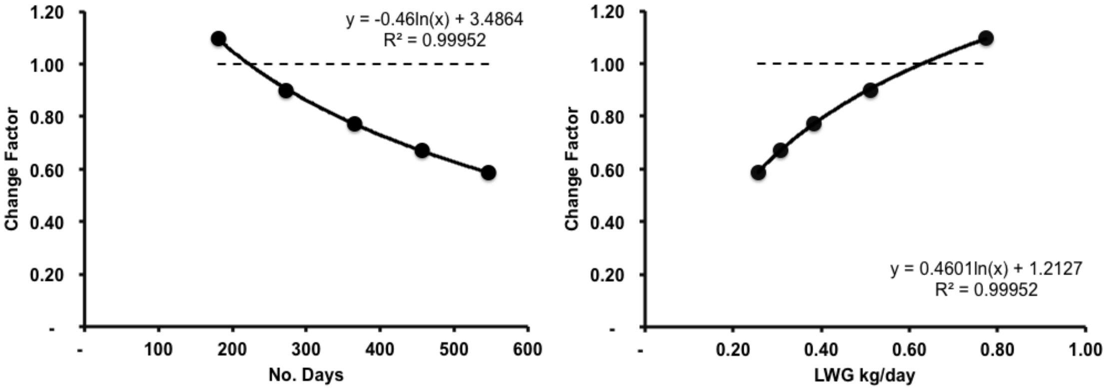
Drought impacts Steers at the Boulia property



Drought impacts Steers at Boulia and Emerald properties



Drought impacts heifers at the Nebo property



Drought impacts heifers at the Roma property

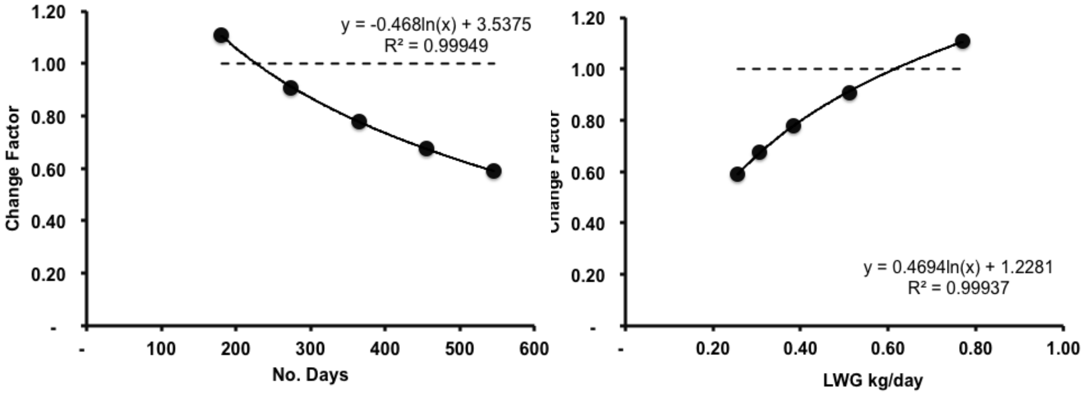


Figure 4: Correlation between the change factor of greenhouse house emissions of the baseline and scenarios and the number of days spent grazing on properties (left) and live weight gain (LWG) (kg/day) on those properties (right)

Discussion

The results of this study has shown that the scenarios of steers and one of the heifer herds grazing and feeding, when compared to their baselines, featured a net reduction in their respective GHG emission profiles. The remaining heifer herd has shown a marginal increase in its emissions profile. The critical factor in determining the reduction of GHG emissions depended on the time spent on either the Channel Country or background properties or the relative LWG. For the steers, it was the increased time spent at the backgrounding property at Emerald (at 0.58 kg LWG/day), in place of time spent at Boulia Channel Country property (at 0.4 kg LWG/day), which resulted in a net reduction of GHG emissions. Growth rates were higher at Emerald and the cattle spent overall less time grazing and they were transported to the feedlot at a younger age. For the heifers, the removal of grazing on the background properties resulted in the herds spending longer times at the feedlot, with an increase of 130 days. The Nebo scenario showed a large reduction in GHG emissions (-29%) when compared to the Roma scenario (-4%). The key difference was the time spent on the backgrounding properties and their respective LWG. More time was spent on the Nebo property to gain the exit weight, resulting in greater GHG emissions intensity per live weight tonne of cattle than Roma at that stage of growing. The longer the time spent grazing at the backgrounding properties, the greater the opportunity of emissions reduction if the heifers were transported directly to the feedlot.

The study modelled the potential of GHG emission reductions under differing LWG rates and the times cattle spent grazing on properties. The change factor per day of either GHG emissions reduction or increase was greater for the heifers in comparison to the steers and greater when only one property experienced lower LWG rates, as opposed to both properties experiencing LWG rates. These rates can vary from property to property and from year-to-year. Often, variation in rainfall and its distribution is a key driver in LWG variation. For example, a study found that rainfall variation resulted in LWGs in 20–50 kg difference between years with fewer but more intense rainfall events and years with more even rainfall distribution. Weight gains can be low due to poor rainfall distribution, reduced pasture availability and declines in inherent pasture productivity (O'Reagain *et al* 2009). The modelled logarithm regression curves in this study can provide an indication to base decisions on specific herd management scenarios with the intent of reducing GHG emissions.

The results of this study were modelled around large integrated cattle companies that own and/or manage multiple properties spanning multiple climatic and environmental zones. These enterprises cover a substantial proportion of the northern Australian beef cattle herd. For example, the largest cattle producer in the region is the Australian Agricultural Company (AAco), which controls 665,600 head of cattle on 18 properties (as of 31 December 2011) (Gleeson *et al* 2012). Other large private companies, such as S. Kidman & Co Ltd, Stanbroke Pastoral Company Pty Ltd, NAPCo Pty Ltd and Consolidated Pastoral Company Pty Ltd have holdings of cattle on a smaller scale than AAco. Collectively, these companies and others like them collectively hold approximately 2.25 million head or 25 per cent of beef cattle in the region (Gleeson *et al* 2012; Bentley *et al* 2008). The wide spatial spread and large herd sizes of these beef cattle enterprises allows for flexibility and adaptation to changing environmental and biophysical conditions. If a region is impacted by drought or other factors that result in lower LWG rates, other properties that are not as impacted can be utilised to enhance avoided GHG emissions, as well as maintaining or enhancing productivity. However, smaller beef enterprises, which collectively also own and manage a large proportion of the northern Australian beef cattle herd, do not own multiple integrated properties and they are spatially restricted. This problem could be addressed by these smaller beef cattle enterprises forming larger cooperatives with other smaller enterprises and forming their own integrated property networks for net GHG emissions reduction in cattle herd management.

The benefits of GHG emissions reduction to either integrated beef cattle enterprises can be further explored under various market based mechanisms that recognize and remunerate efforts in GHG emissions reduction. For example, the Australian Governments Carbon Farming Initiative (CFI) provides financial incentives for avoided emissions in the form of avoided enteric methane emissions (Commonwealth of Australia 2011). However, a comprehensive cost benefit analysis would be required to compare the value of the avoided emission with the increased cost of lot feeding, in the case of the heifer herds, owing to the increase time at the feedlot.

This study has shown that large GHG emission reductions can be achieved through alternative management scenarios of herd management, within commercially viable parameters. These emission reductions were dependent on LWG rates at each property and the time spent on these properties. Beef cattle enterprises across northern Australia can refer to these modelled herd baselines and scenarios as a guide to determine management decisions on whether to bypass certain properties or to maintain current strategies, with the express intent of minimizing GHG emissions from their herds of beef cattle. Given that they own and manage a large proportion of northern Australia's beef cattle herd, opportunities to substantially reduce its overall GHG emissions, without impacting productivity, appear commercially feasible and possible.

Acknowledgements

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D15. Project title

Developments to AgMod as part of the WFSAM project

Organisation IMJ Consultants

Primary contact Ian Johnson

Introduction

This document describes recent model developments to DairyMod and the SGS Pasture Model (AgMod) as part of the WFSAM project. The main subject areas are:

- Biophysics developments and GHG dynamics
- Urine patch dynamics and Greenseeker fertilizer technology whereby fertilizer N is not applied to urine patches in the paddock.
- Flock and herd management
- Incorporation of crops
- Batch processing and parameter set comparison

As well as these core activities, there has been a considerable focus on incorporating model features and data handling capacity in response to the requirements of users.

Biophysics and GHG dynamics

Development of the biophysical model structure has continued throughout the project as required for model use and application. The main areas described in this section relate to nutrient dynamics and the impacts on greenhouse gas dynamics.

1. Leaching

Leaching is central to the nitrogen dynamics in the system. Until now, leaching has been calculated by assuming that nitrate moves through the soil layers on a *pro-rata* basis with water. That is, if in any time-step 5% of the water moves from one layer to another, then 5% of the nitrate will also move. When the nitrogen distribution across the paddock is treated as uniform, this gives results that appear realistic. However, if it is applied to the heterogeneous model with urine patches implemented, it results in a greater requirement for fertilizer and therefore amounts of leaching that are not realistic.

I have therefore modified the leaching component with the introduction of a *leaching dispersion coefficient*. At the start of the day, the inorganic nutrient available for leaching is calculated from the total solution nutrient concentration and the soil water content in each layer. Only water in excess of field capacity will move through infiltration and the associated solution nutrient will be available for infiltration.

The proportion of nitrate available for leaching is calculated based on the fraction of water in excess of field capacity.

Nutrients in solution move with the water as the water moves through the soil profile. The range of pore sizes in the soil is related to soil water characteristics, so that the proportion of large pores that contain water increases as soil water content increases and, conversely, as the soil dries down the water is located mainly in the smaller pores. A threshold water content that defines the actual water that moves through infiltration is assumed and it is then assumed that the solute that moves is restricted to that which is in this water.

The proportion of nutrient that can move is related to the critical soil water content being defined as

$$\theta_{crit} = \theta_{fc} - \eta\left(\theta_{fc} - \theta_w\right) \quad (1)$$

where θ_w and θ_{fc} are the wilting point and field capacity respectively and η is the *dispersion coefficient*, in the range 0 to 1. Note that, when $\eta = 0$, $\theta_{crit} = \theta_{fc}$, and for $\eta = 1$, $\theta_{crit} = \theta_w$. The proportion of nutrients that can then leach on a given day is now given by

$$\gamma = \begin{cases} \dfrac{\theta - \theta_{crit}}{\theta_{sat}}, & \theta > \theta_{crit}, \\ 0, & \theta \le \theta_{crit}, \end{cases} \quad (2)$$

where θ_{sat} is the saturated soil water content and θ is the soil water content at the start of the day. This effectively means that the drier the soil, the less nutrients are available for movement. At the end of the day the remaining nutrients are mixed with any fresh water that has been moved into the profile. Thus, for example, a flush of water through the profile in one day will not be able to take all of the nitrate. Also, increasing η will, in general, increase the leaching. The default value for η is 0.5 which, as discussed in the detailed documentation, is close to -100 kPa for a wide range of soil types.

This approach gives control over the leaching through the single dispersion coefficient and provides a relatively simple way to explore leaching dynamics. Note that since the dispersion coefficient, η, is defined in terms of soil water content parameters, it is prescribed on the soil water interface in the model.

2. Denitrification associated with volatilization

The volatilization and denitrification components of the model have been adapted to incorporate denitrification losses of N_2O associated with nitrification of ammonium. This uses a relatively simple approach whereby a fixed proportion of N is lost as N_2O during nitrification, with default value 2%.

3. Nitrification inhibitors

The process of nitrification inhibition, whereby the rate of nitrification is reduced through the application of inhibitors has been implemented. However, it should be noted that since the project began the use of nitrification inhibitors is no longer a management option due to possible leaching and pollution by the inhibitors. Nevertheless, the model does incorporate these effects which may be of value in future research.

Nitrification inhibitors are characterised by:

- The initial effect on reducing the reaction rate, with the default being to reduce the rate to 20% of the normal rate,
- The effective duration of the inhibition
- A curvature coefficient that defines the time-course of the efficacy of the inhibition

Users can implement up to four inhibition applications by date and can select which paddocks to apply them to.

Urine patch dynamics and Greenseeker fertilizer application

Urine patches are known to be an important factor in the study of nitrogen dynamics in pastures, including possible impacts on pasture production. Explicit treatment of urine patches has been explored in AgMod by using the multiple paddock structure of the model to simulate individual urine patches that are generated on each grazing day, as reported by Snow et al. (2009).

While this work was done with the previous version of the model, the SHP (single heterogeneous paddock) has been implemented in the current version. The SHP provides insight into the impacts of urine patches on pasture and nitrogen dynamics, but is of limited practical value due to computational requirements. It is therefore not accessible for general release of the model, but for development purposes only. As a practical alternative, I have developed an implicit scheme to incorporate the effects of urine patches on the system in which the paddock is divided into 'patch' (P) and 'bulk' (B) portions which are simulated separately with the area of the patch proportion increased by grazing activities and decreased using a time-based decay approach. The implicit approach might not be suitable for detailed studies but it does capture the larger effects and the computational requirements are only double that of a homogenous paddock and do not limit whole-system studies.

The scheme has been previously implemented in the model but has been refined to improve plant nitrogen uptake and fixation by legumes to ensure that any soil N limitation in the bulk (B) portion of the soil is not overcompensated for by high soil N in the patch (P) component.

Urine returns are calculated as part of the animal routines, and the P component of the paddock is defined in relation to these returns. The mathematical approach, illustrated in Fig. 1, is based on the following assumptions:

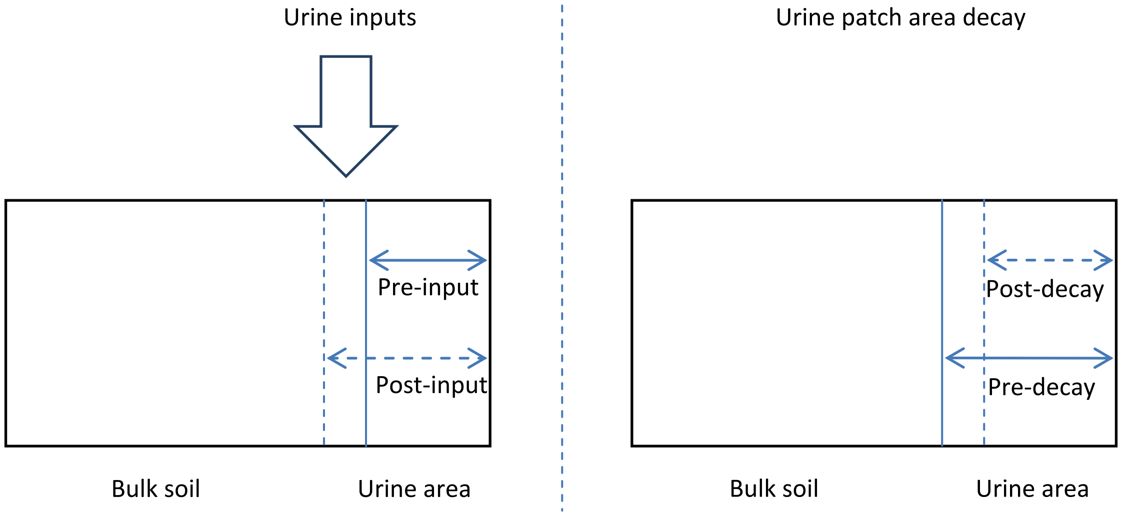
- The paddock is divided into 'patch' (P) and 'bulk' (B) portions.
- The urine patch area and N amount for any day is calculated from the basic animal parameters described above under the assumption that there is no patch overlap in a day.
- The distribution of these urine patches covers the patch and bulk on a pro-rata basis. Thus, for example, if 10% of the paddock is classed as patch prior to animal inputs, and the inputs cover 5% of the paddock then 0.5% of the N goes to the existing patch component and 4.5% goes to the bulk.
- The new patch area is now calculated in terms of the existing patch area and the inputs to the bulk area.

The scheme would eventually result in the whole paddock shifting from bulk to patch. To overcome this, a single decay parameter is defined which accounts for the re-assimilation of the patch area into the bulk area. The default value is 2% per day although this parameter may need further exploration. Defining this parameter as λ, the portion λ of the patch area is reincorporated into the bulk area. It is then assumed that the N content of this component that is reincorporated is:

$$W_{p,\lambda} = W_b + \lambda\left(W_p - W_b\right) \tag{3}$$

where the W terms are mass of nitrogen, kg ha^{-1}, the subscripts p and b refer to patch and bulk respectively, and $W_{p,\lambda}$ is nitrogen in the area being reincorporated. The actual N moved is then multiplied by the reduction in patch area. This equation is applied to each layer in the soil profile. Note that including the λ parameter in eqn **Error! Reference source not found.** implies that the distribution of N concentration within the patch component is linear.

Figure 1. Implicit urine patch dynamics scheme. See text for details.



An additional component in this area of model development has been to use the P and B portions of the paddocks to refine fertilizer management. This is to facilitate model application to the ‘Greenseeker technology’ whereby high N zones due to urine patches are identified and N fertilizer applications are not made in these regions. In addition, note that one fertilizer management strategy available in the model is to apply fertilizer in response to soil N status. In practice, soil N tests should not be taken from areas that are obviously affected by urine.

- The model now has the option to base the soil N test on the whole paddock, so that it includes bulk and patch areas, or just the bulk area.
- Fertilizer N can be applied either to the whole paddock or just the bulk area. This is consistent with the Greenseeker technology.

Example simulations

Analysis with the SHP has shown that in high N systems, incorporating urine patches leads to increased fertilizer N requirements and N leaching. This is consistent with general understanding of the impacts of urine patches on the system where N concentrations far exceed plant requirements.

In order to explore the impact of urine patches on system behaviour, and the potential of the Greenseeker fertilizer technology, it is useful to explore a Gippsland dairy simulation that Brendan Cullen and I have been working on. The simulation has been defined to reflect the case study analysis that Brendan has been working with and for which there are data for milk production and intake. I shall not be presenting a detailed data comparison analysis, other than to use the milk production data that Brendan has provided for the 2011/2012 lactation cycle.

The simulation is defined as follows:

- 30 paddocks
- 22 perennial ryegrass (model default)
- 8 paddocks a mixture of annual ryegrass (model default) and chicory as developed by Brendan.
- paddock area 3.67 ha, so that the total farm is 110.1 ha
- stock numbers, designed to represent a spread of calving:
    - 100 calving 15 July
    - 202 calving 15 August
    - 50 calving 10 September
- stock parameters have been modified slightly from the defaults
- Paddock rotation according to the pasture dry weight system, with some modification from the defaults
- All ryegrass paddocks can be cut in the date range 1 July to 31 Dec: the early date to start implementing cutting allows paddocks to be removed from the grazing cycle in a realistic way.
- Apply 45 kg N after the paddock has been grazed.
- Apply 30 kg N if the soil N concentration in the top 15 cm (soil test) falls below 5 mg kg^{-1}.

The additional fertilizer strategy is to ensure that if there is a relatively long period between grazings for any particular paddock then it will not become too N deficient. This is necessary when running long-term simulations. Applying a fixed amount of fertilizer N may not be the most efficient fertilizer regime, but it is one which is widely applied. Alternative options in the model are to use the daily-equivalent – there is potential to explore this and other options in more detail. However, the strategies used here provide insight into the behaviour of the urine patch dynamics scheme combined with the Greenseeker technology.

The simulations have been run from 1901 to 2013 with 2 loops to reduce impacts of the choice of soil organic matter initial conditions. However, for milk production only the lactation cycles from 2011 to 2013 have been included as this reflects the range of available data.

Simulations have been run according to the following:

- Uniform: Homogeneous paddock
- Het UF: Urine patch scheme implemented with fertilizer N applied to the entire paddock
- Het BF: Urine patch scheme implemented with fertilizer N applied to the bulk area only, that is excluding the urine patch area.

Note that with the urine patch scheme, the soil test value is taken from the bulk soil only.

Simulated and observed milk production for the 2011/12 lactation cycle are shown in Fig. 2 and it can be seen that there is close agreement between the model and data, with little difference between the different approaches for the treatment of N dynamics.

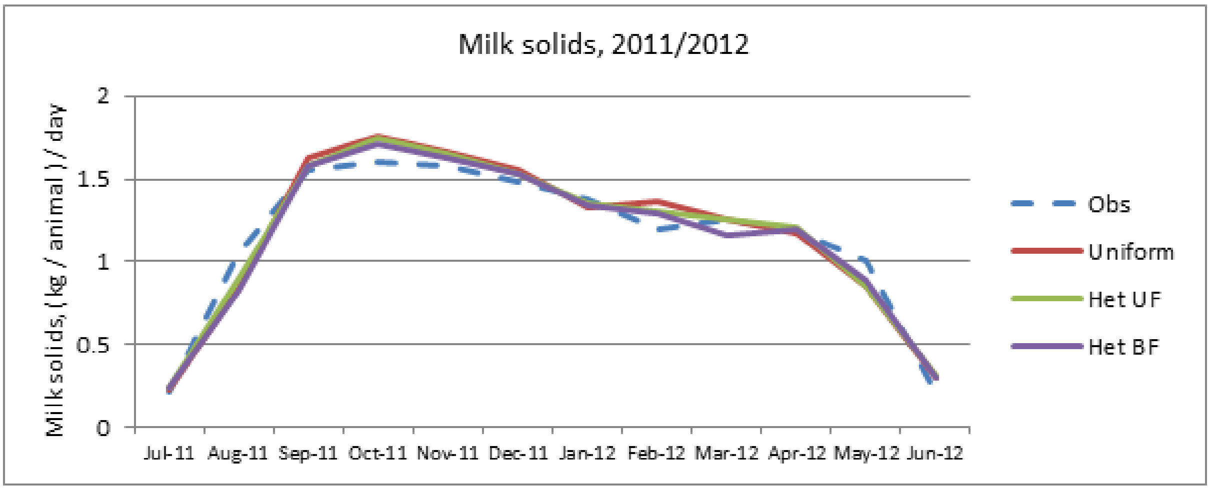


Figure 2: simulated and observed milk production for the 2011/2012 lactation cycle for the homogeneous paddocks. ‘Obs’ refers to experimental observation and the other terms in the legend are described in the text.

The long-term average N dynamics for each simulation are illustrated in Fig. 3 for fertilizer inputs, leaching, volatilization and denitrification (N_2O) outputs. (The fertilizer inputs are quite high but are consistent for grazing systems in this region with no legume present.) It can be seen that the dynamics vary between the different schemes. Perhaps the most striking difference is that leaching under the uniform scheme is significantly lower than for the heterogeneous paddock, which is consistent with the more complex SHP approach. Losses from the system are dominated by volatilization and leaching. The model provides scope to explore these dynamics – for example, lower fertilizer inputs are likely to reduce leaching losses.

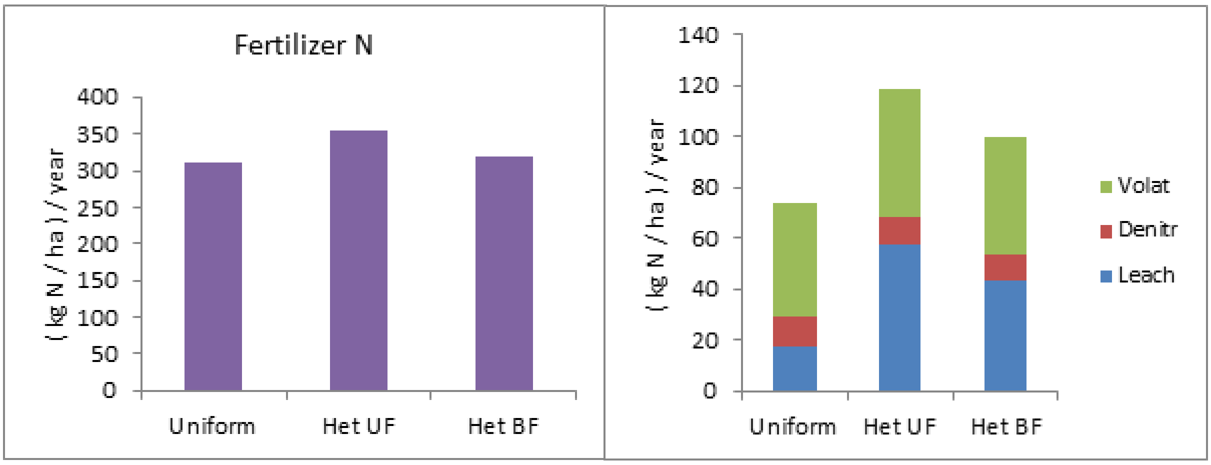


Figure 3: simulated N dynamics for the simulations – see text for details.

The Greenseeker technology has potential in reducing both fertilizer inputs and losses. In Fig. 4 the percent reduction in fertilizer inputs and losses through volatilization, denitrification and leaching are shown for the Het BF in comparison to Het UF fertilizer application: that is, by only applying fertilizer to the bulk soil rather than to the whole paddock including the urine patch area. These results are encouraging and show that inputs and losses are noticeably reduced. In practice, the actual benefit in applying the Greenseeker technology is likely to vary depending on the details of the fertilizer management.

It is of interest to look at the proportion of the farm as well as individual paddocks that are affected by urine patches. This is a 30 paddock simulation and so not all paddocks are shown here (they can be readily plotted in the model interface). In Fig. 5, the patch proportion for the whole farm and paddock 2, which is chosen arbitrarily, are shown for 2011 and it is clear that while the patch proportion is relatively stable across the whole farm, it is highly variable for individual paddocks as influenced by grazing frequency. Figure 5 is for the Het UF fertilizer application although it should be noted that the Greenseeker scheme (Het BF) has little impact on patch proportion.

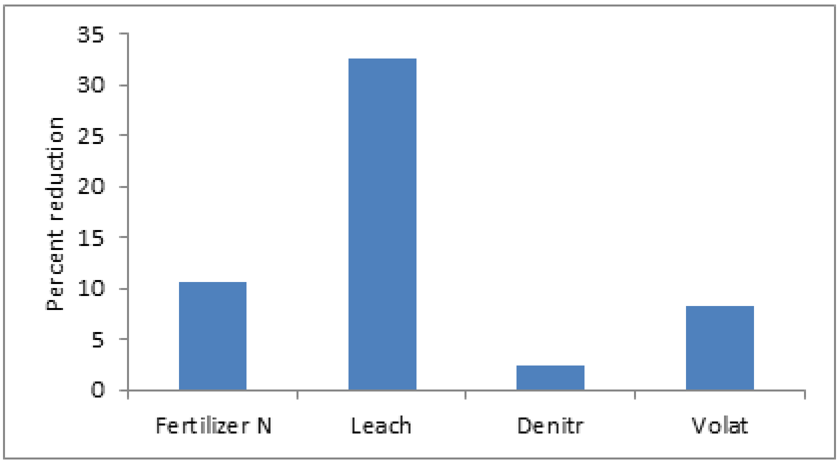


Figure 4: simulated reduction in N dynamics for the Het BF scheme in comparison to the Het UF scheme – see text for details.

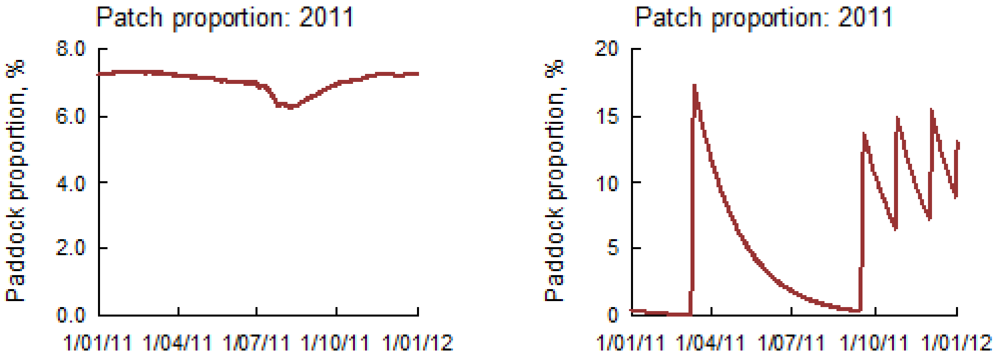


Figure 5: simulated whole-farm urine patch proportion (left) and for paddock 2 (right) for the Het UF fertilizer application.

The illustrations of N dynamics above show long-term averages, but it must be noted that there can be significant variation between years as is clear from Fig. 6 where the annual leaching losses for the whole farm and paddock 2 are shown. The variation is large and highlights that it is important to be aware that extrapolating short-term experimental data to long-term studies may give misleading results.

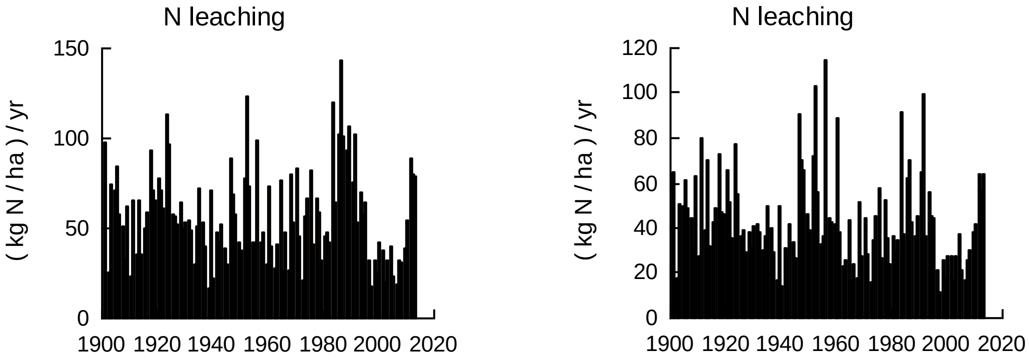


Figure 6: simulated N leaching for the whole-farm (left) paddock 2 (right).

Flock and herd management

Flock and herd management have been further developed to apply to a flexible range of practical management strategies for Australian sheep, cattle and dairy systems.

1. Weaner systems for sheep and cattle

Up to 3 simultaneous systems for weaner stock can be defined. This requires the following parameters to be prescribed:

- Number of animals
- Date and weight to bring stock in
- Date or weight to remove stock

Consider as an example a lamb system. If the parameters for bringing stock in are 1 April at 20 kg then the model grows animals under non-limiting conditions to 20 kg and incorporates these in the simulation on 1 April. If the conditions to remove the stock are 30 November or 45 kg then animal growth is calculated as part of the whole system in the model and will be removed (for example, sold) if the weight reaches 45 kg or on 30 November, whichever occurs first.

Each set of animals is characterised by its ID number – note that ID-1 is reserved for the ‘mature wethers steers’ option.

Care should be taken to ensure the animal numbers make sense. For example, with 30 paddocks of 1 ha and a desired stock density of 10 steers ha^{-1} then the total number of animals must sum to 300.

When the simulation runs, graphical and data output are available for each animal ID class as well as the average over all animals. This is analogous to the paddocks where graphs and data output for individual paddocks or the whole farm are accessible

Note that animal intake can be plotted or exported for the paddock – that is per ha – which is available under the ‘Plant’ graphs, or per animal which can be found under the ‘Stock’ graphs.

2. Flock / herd dynamics and breeding stock replacement

The flock and herd dynamics are described here for a ewe/lamb system with the cow/calf approach being identical. The number of ewes, lambing date and lambs per ewe are defined, along with criteria for removing lambs which are the same as for the weaner system. Parameters are defined for:

- Lamb female proportion, %
- Ewe replacement rate, % / year,
- Lamb death rate, % / year,
- Lamb replacement age, years

These parameters are then used to calculate the number of lambs at each lambing that need to be retained for replacement of the breeding flock when they reach replacement age. At each lambing, the existing lambs move into the next age category, while at breeding stock replacement occurs.

The overall flock and herd numbers vary dynamically in response to the model parameters. The breeding flock are identified by their ‘ID’ number, as are each age category of lambs. As for the weaner systems, graphical and data outputs for each animal ID, and averages over all animals, are accessible.

2.1 Multiple calving dates for dairy systems

Up to 12 calving dates for dairy systems can be defined, with corresponding lactation lengths and animal numbers. These are defined in the ‘Stock’ tab on the ‘Management’ page. Note that each set of animals is characterised by its ‘ID’ number. As for the sheep and cattle weaner systems, graphical and data outputs for each animal ID, and averages over all animals, are accessible.

2.2 *Supplement and feed management*

Supplementary feed components are:

- Concentrate
- Mixed ration
- Forage

For each of these, the NDF (neutral detergent fibre) and protein percentages can be specified, along with NDF digestibility. The model assumes that all NDS (neutral detergent solubles), which is everything apart from the NDF, has a digestibility of 85%. Using this information, the model calculates the total digestibility. ME available from the feed is calculated in the model in terms of feed composition as well as other animal metabolic parameters.

Feed management is now quite flexible. Four animal metabolic stages are considered:

- Growing
- Mature/empty
- Pregnant
- Lactating, which may include pregnant

For each of these stages, any sequence can be prescribed for the following:

- Pasture
- Minimum concentrate
- Maximum concentrate
- Minimum mixed ration
- Maximum mixed ration
- Maximum forage

Obviously not all components need be specified. The only constraints are that maximum concentrate cannot precede minimum concentrate, and similarly for mixed ration.

A maximum total intake can also be prescribed. This may be useful to avoid overfeeding the animals when there is plenty of pasture available. For example, if the maximum mixed ration is prescribed to account for times when there is no pasture available, it may be necessary to limit the mixed ration when pasture intake is relatively high.

The feeding sequence is prescribed on a monthly basis, although it is easy to copy one sequence to other months. The feeding sequences are simply prescribed by ‘dragging and dropping’ – this should be self-evident on the ‘Feed management’ tab of the ‘Management’ page.

This flexibility in feed management allows the main feeding regimes used throughout Australia to be simulated.

In summary, it is possible to prescribe the feeding sequence for each month of the year and for all physiological phases of the animal. This can result in many feed sequence combinations.

Note that care must be taken to ensure the intended feeding strategies are copied correctly between months.

(a) Substitution

The treatment of substitution – that is, a reduction in pasture intake in response to supplement intake – has been refined and is much simpler than in the previous version. Substitution will only occur in response to supplement that is fed prior to pasture. Thus, for example, if a minimum concentrate is fed followed by pasture, and then more concentrate, substitution is calculated in relation to the minimum concentrate only. Obviously, total intake is constrained by animal intake capacity. There is a single substitution coefficient prescribed for the animal on the ‘Stock’ module under the ‘Biophysics’ page. This is the substitution that occurs when pasture availability is non-limiting, and the default is 0.8.

Crops

A generic cereal crop, that can be C_3 or C_4 is included. Crops can be run as a single paddock simulation or incorporated into a multiple paddock grazing system. The parameters for defining the crop (under the 'Biophysics' page of the model interface) are similar to those for pasture species, but now there is an extra set of parameters for 'Crop development'. The default crops are winter wheat, spring wheat and maize which can be used to construct parameter sets for C_3 or C_4 cereals with or without a vernalization requirement. It is important to select sensible sowing dates for the crops.

1. Single paddock crop simulations

Single paddock crop simulations are useful to explore the general behaviour of the model. The crop and sowing date are selected. When running a long-term crop simulation, a nitrogen fertilizer regime should be implemented.

Phase duration is calculated using the usual T-sum, or day-degree, approach. In order to help with the estimation of the day-degrees, I've added an extra graph under 'Climate', 'Summary' to show the average monthly temperature sum (day-degrees).

(a) Simulation output

The grain yield and details can be accessed both through the graphs and Excel export:

- Graphs:
  - Left click menu on any graph, 'Plant', 'Summary' offers graphs for annual grain yield, harvest index (HI), and protein content.
- Output:
  - The same variables can be selected under the 'Paddock data' export options.

NOTE that annual crop yields are reported for the year in which the harvest is actually done. This means, for example, if there is a late harvest in early January and then the following season the harvest is in December, there may be a year with zero yield followed by a year with yield comprising two harvests.

(b) Illustrations

The simulations have been run for winter and spring wheat at Moree, NSW. The sowing dates are 15 March and 15 May for winter and spring wheat respectively. 40 kg N is applied when the soil test value falls below 10 mg kg^{-1}, restricted to 1 April to 30 Nov. The simulations have been run from 1901 to 2013 with 2 loops to reduce impact of soil organic matter initial conditions.

Figure 7 shows the grain yield, corresponding HI and grain protein content for winter (WW) and spring (SW) wheat. The long term average yields are 2.99 and 2.34 t ha^{-1} for WW and SW respectively, with corresponding HI values 0.35 and 0.43. These averages are consistent with regional crop yields. However, it is clear that there is substantial variation in yields and HI, which is characteristic of cropping systems in this region.

To consider crop growth at contrasting regions, the corresponding yields and HI for WW grown at Elliott (Tas) and Horsham (Vic) are shown in Figs 8 and 9. The average yields are 5.76 and 3.91 t ha^{-1} for Elliott and Horsham respectively, with corresponding HI values 0.42 and 0.33. Again, these values are consistent with regional wheat yields. It is apparent that yields and HI vary less at Elliott than both Moree and Horsham. It can also be seen that at Horsham there are occasional years where yield is extremely low due to crop failure through lack of water which can occur in this region.

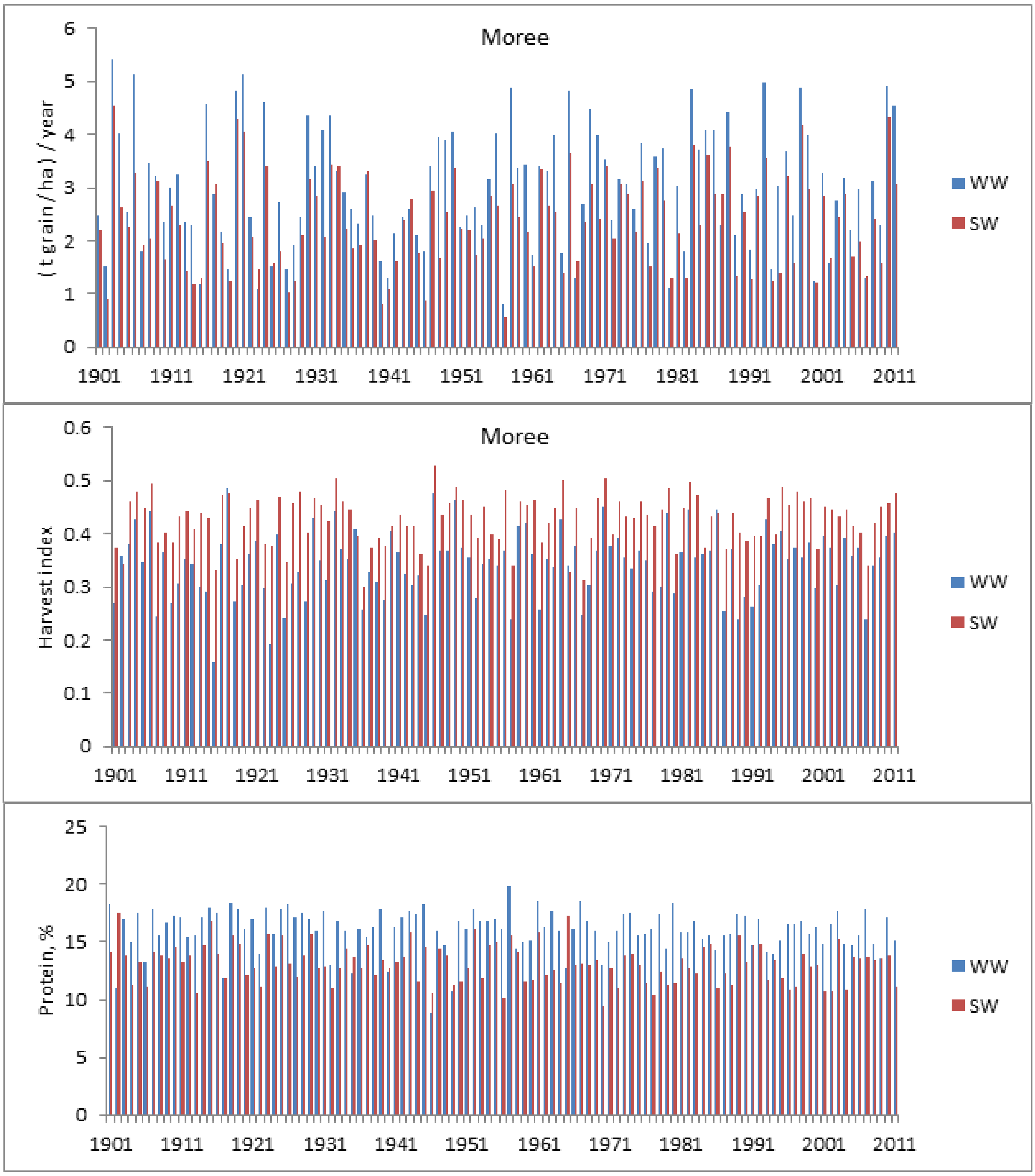


Figure 7. Simulated crop yields (top), harvest index (middle) and grain protein concentration (bottom) for winter wheat (WW) and spring wheat (SW) grown at Moree, NSW.

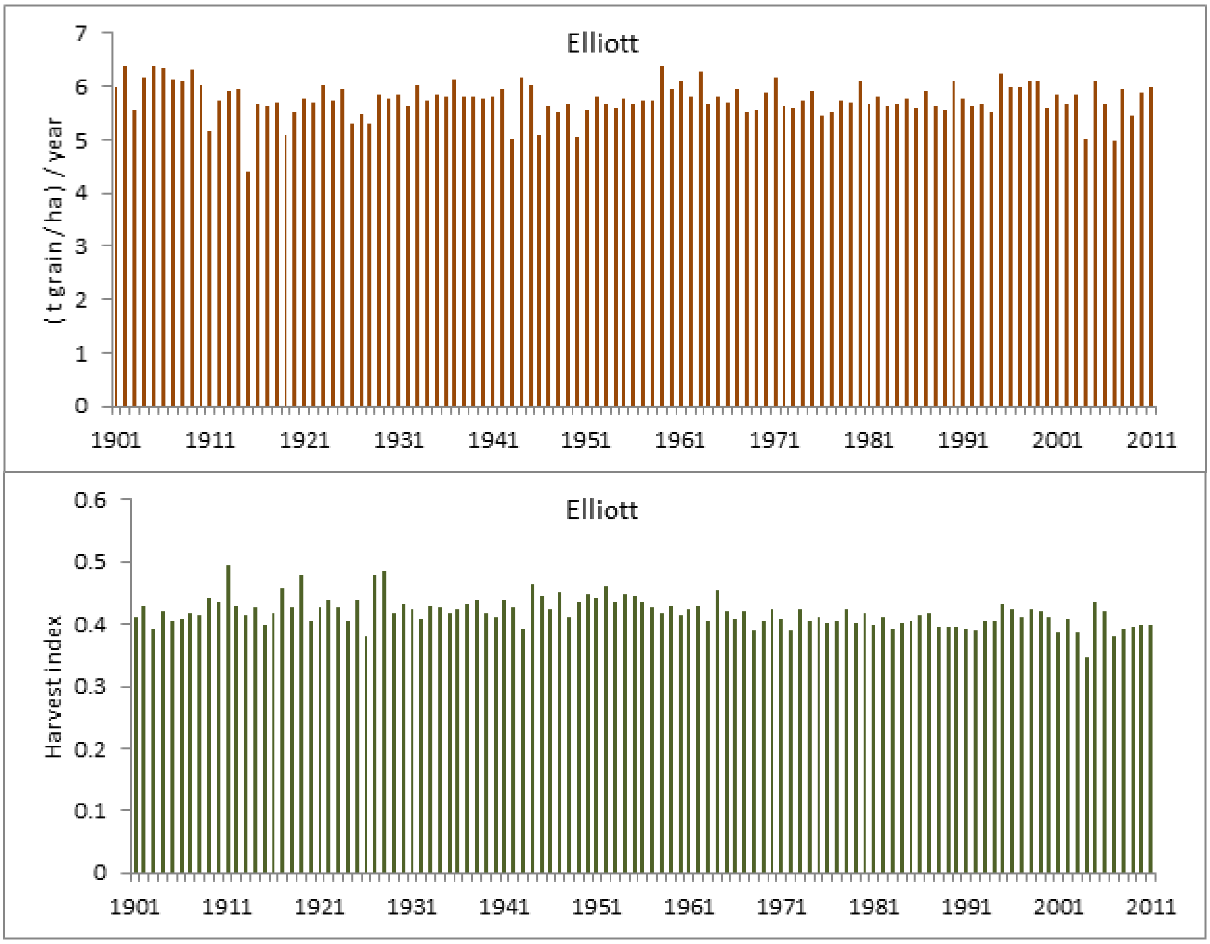


Figure 8. Simulated crop yields and harvest index for winter wheat grown at Elliott, Tas.

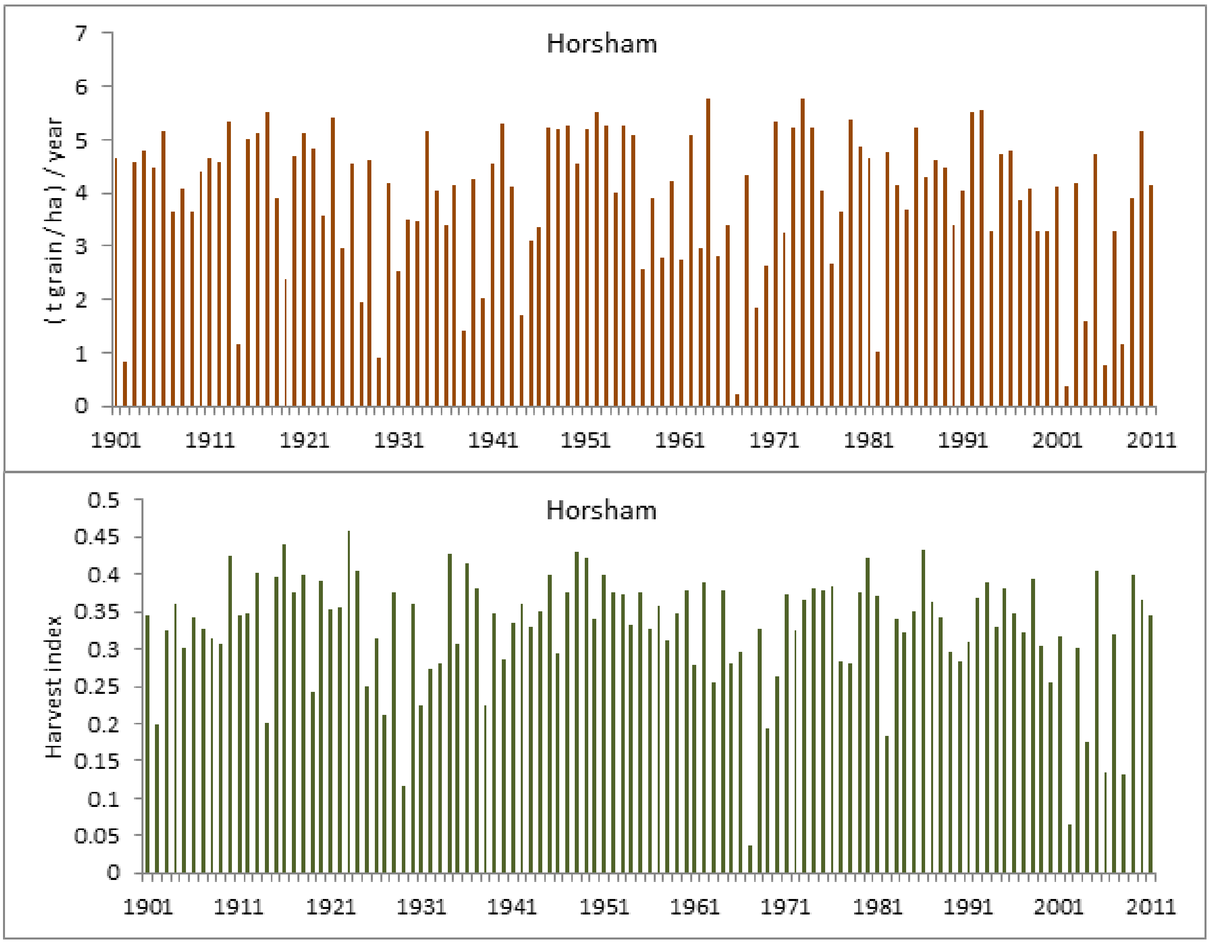


Figure 9. Simulated crop yields and harvest index for winter wheat grown at Horsham, Vic.

These illustrations demonstrate that the crop model component works well and gives results that are consistent with yields and harvest indices at a range of locations.

2. Grazed forage crops

Crops can also be incorporated into the multiple paddock grazing systems. Crops can be grazed at the boot phase – grazing after this will result in crop senescence due to removal of the plant growing point. Crops can then be harvested either at soft dough, which is appropriate for silage, or at maturity in which case it is harvested either for grain or hay.

Double cropping can be included where the sowing date of the second crop is determined by the harvest date of the first crop.

Users select a crop paddock other than paddock 1 as this is reserved as a holding paddock for some grazing management options.

Batch simulations: AgMod Batch

A program for running DairyMod and SGS Pasture Model simulations in batch has been written. This uses the same model code as the core models and can be found on the IMJ web page – there is a link on both model pages.

When simulations are loaded, the grid at the bottom of the screen will show:

- File name
- Output file name
- Model (DM or SGS)
- Status

The output file has the same name as the simulation file but with the usual Excel extension (.xlsx). Output files can either be in the same folder as the simulation file or a specified folder and this option applies to all the simulations that are being run.

Files can be removed from the grid and therefore from the list of simulations to be run. When a file is loaded, the climate file is checked. If there are any problems these will be indicated in the ‘Status’ column.

When ‘Run’ is clicked, the simulations are run in turn. If the simulation runs successfully, then the ‘Status’ will be ‘Done’ otherwise it will show an error.

Output files will overwrite files of the same name without asking. If a file with the same name as the output file is open when the program tries to save the file, this will give an error.

If ‘Cancel’ is pressed, it may take some time to stop the simulations running, particularly in the middle of a large export.

When ‘Run’ is clicked, the program will attempt to run all simulations even if they have already been run.

Interface and data developments

Throughout the project there have been numerous modifications and developments to the model interface and data handling routines – both graphical display and data output to Excel. These have been largely in response to user requests or as part of the development process. For example, there are specific graphs and data export categories for GHG dynamics components, since the model includes all carbon, methane and nitrous oxide dynamics.

Comments

All model developments as described in the modelling component for the WFSAM project have been achieved. In addition, there has been an on-going interaction with users which has allowed refinements to the model, interface, and data handling, to ensure the model continues to meet the needs of researchers.

The modelling work in the WFSAM project has focussed on important areas of the model biophysical structure and management options, as well as graphical and reporting features, that are central to the study of Australian livestock and dairy grazing systems, with a particular emphasis on greenhouse gas dynamics. The model provides a comprehensive description of the plant, soil water, soil organic matter and nutrient, and animal dynamics, as well as complex management options relevant to the grazing industries. It gives a complete balance of the carbon and nitrogen components of the system, including gaseous losses of methane and nitrous oxide. The model is well positioned to continue to play a role in grazing systems research.

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APPENDIX I. Publications

Below is a list of all the publications attributed to this project. The list does include a few papers initiated under the previous Southern Livestock Adaptation project, funded by the same investors, but neither reported nor completed under that project.

1. Journal papers (37)

Alcock, DJ, Harrison, MT, Cullen, BR, Rawnsley, RP, Eckard, RJ (2014) Can animal genetics and flock management be used to reduce greenhouse gas emissions but also maintain productivity of wool-producing enterprises? *Agricultural Systems*, **132**(0), 25-34. doi: http://dx.doi.org/10.1016/j.agsy.2014.06.007

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Christie, K. M., Rawnsley, R. P., Harrison, M. T., & Eckard, R. J. (2014). Using a modelling approach to evaluate two options for improving animal nitrogen use efficiency and reducing nitrous oxide emissions on dairy farms in southern Australia. *Animal Production Science*, **54(12)**, 1960-1970. doi: http://dx.doi.org/10.1071/AN14436

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4. Presentations and media

Presentations

- 13 to 15 November 2012, 5th Australasian Dairy Science Symposium, Melbourne, Clare Leddin. 5 February 2013, The AARES pre-conference workshop, Sydney. Topic: "Options for carbon farming", Richard Eckard.
- 4 February 2013, Comparing on-farm greenhouse gas emissions from agricultural enterprises in south eastern Australia, Australian Agricultural and Resource Economics Pre-conference Workshop, Sydney, Natalie Doran-Browne.
- 14 February 2013, PIARN Masterclass, Canberra. Topic: "Mitigate, Adapt or Feed - Do we have to choose?", Richard Eckard.
- 16 April 2013, Post Graduate Certificate Showcase, Melbourne. Topic: "Update on Research and Policy - Greenhouse Gasses from Agriculture", Richard Eckard.
- 17 April 2013, Dairying for Tomorrow coordinators meeting, Melbourne. "Nitrogen best practice for sustainable dairy farming", Richard Eckard.
- 7 May 2013, Tasmanian Land Sector Round Table, Hobart. Topic: "Agriculture and climate change - Global / National / State context", Richard Eckard.
- 14 and 15 May 2013, National Livestock Methane Program meeting, Townsville. "The WFSAM Project", Richard Eckard.
- 16 July 2013, Australian Wine Industry Technical Conference, Sydney. Title: How will the carbon farming initiative affect the vineyard?, Richard Eckard.
- July 2013, University of Cranfield, UK. Title: Calculating on-farm greenhouse gas emissions and the economic viability of carbon offsets in south eastern Australia, Natalie Doran-Browne.
- 10 September 2013, Extension and Outreach Training, FtRG Science Update, Richard Eckard.
- 15 to 19 September 2013, 22nd International Grasslands Congress, Modelling adaptation and mitigation strategies for southern livestock industries of Australia, Richard Eckard.

- 15 to 19 September 2013, 22nd International Grasslands Congress, Does increasing ewe fecundity reduce whole-farm greenhouse gas emissions intensities? Matthew Harrison.
- 3 October 2013, National Livestock Methane Program meeting, Hahndorf. WFSAM update, Richard Eckard.
- 21 October 2013, Cross-Campus Climate Change Connections Symposium, University of Melbourne. Title: Options for mitigating greenhouse gas emissions from livestock farms, Natalie Doran-Browne.
- 28 October to 1 November 2013, Post Graduate Certificate in Climate Change for the Primary Industries. Case studies from WFSAM included in course content, Richard Eckard.
- 8 and 9 January 2014, Presentation by Richard Eckard, on Australian policy, the CFI and WFSAM modelling to:
    - Alberta Environment and Sustainable Resource Development
    - Alberta Agriculture and Rural Development
    - Climate Change Central
    - University of Alberta
    - Alberta Meat and Livestock Agency
- 4 March 2014 - presented on the DGAS- Feeding Dietary Fats calculator at the Extension and Outreach Carbon Farming training workshop in Adelaide, Karen Christie.
- 6 March 2014 - trained the dairy-specific Extension and Outreach Carbon Farming project teams in the use of Dairy COST in Adelaide, Karen Christie.
- 7 March 2014, Webinar for the Sefton's E&O project, on agricultural emissions and the state of R&D, Richard Eckard.
- 27 March 2014, guest speaker at the Ag Institute - SA Division, Workshop for consultants, speaking on Climate Change – Facts and Fiction, Richard Eckard.
- 11 June 2014, presented to Warragul Beef Cheque Group, Warragul, Richard Eckard.
- 25 June 2014, Northern Grazing Systems Modelling workshop, Brisbane, Richard Eckard.
- 22 to 24 July 2014, New South Wales Grasslands conference, Inverell, Brendan Cullen.
- 22 August 2014, The Leucaena Network meeting in Brisbane, and presented modelling analyses and results on the effects of Leucaena on whole farm production, greenhouse gas emissions and profitability. Approximately 20 attendees including farmers, MLA representative and other researchers, Matthew Harrison.
- 2 September 2014, Dinner speaker, Young Farmers Network, Southern Carbon Bus Tour, Richard Eckard.
- 3 September 2014, The CFI, Young Farmers Network, Southern Carbon Bus Tour, Richard Eckard.
- 8 to 12 September 2014, Dietary oils to mitigate methane, ISNH/ISRP/ASAP Conference, Canberra, Natalie Doran-Browne.
- 8 to 12 September 2014, Increasing ewe genetic fecundity improves whole-farm production and reduces greenhouse gas emissions intensities: 2. Economic performance. ISNH/ISRP/ASAP Conference, Canberra, Christie Ho.
- 25 September 2014, Carbon farming in grazing lands, Webinar, Longreach, Richard Eckard.
- 7 October 2014, Nitrous oxide research update, Carbon Farming Extension and Outreach national conference, Carrara, Gold Coast, Richard Eckard.
- 14 October 2014, CCRSPI webinar on Mitigation research - Future needs, Richard Eckard.
- 30 October 2014, Yeoman Society Luncheon - current state of carbon farming initiatives, Richard Eckard.
- 7 November 2014, Nitrogen management & pasture day, Ellinbank, Richard Eckard.
- 13 to 15 November 2014, invited keynote speaker, 7th Symposium on Strategic Management of Pasture and 5th International Symposium on Strategic Management of Pasture Invited keynote speaker, Viçosa Federal University, Vicosa, Brazil, Richard Eckard.
- 5 December 2014, Measuring & Mitigating Emissions from Cropping Systems, Burnett Mary, Qld, Webinar presentation, Richard Eckard.
- 10 February 2015, Climate Change impacts on food production, Celebrity Chefs briefing, Melbourne, Richard Eckard.
- 12 February 2015, Nitrous oxide research update, key issues and warnings nutrient decision support systems, Fertcare Accredited Advisor System Manager Meeting, Melbourne, Richard Eckard.
- 13 March 2015, The ERF explained and the future for carbon reduction and trading, Carbon Farming Knowledge, Adelaide oval, Richard Eckard.

- 14 April 2015, Science and policy update, Post Graduate Course in Climate Change in Primary Industries Showcase, Melbourne, Richard Eckard.
- 5 to 7 November 2014, MLA Pasture Update, Calala and Narrabri (NSW), Brendan Cullen.
- 5 November 2014, Cross-campus Climate Change Connections, Parkville, Natalie Doran-Browne
- WFSAM Workshop, 1st and 2nd May 2013, "Informing approaches to mitigation modelling." Presentations were given by:
    - Brendan Cullen - The effect of earlier mating and improving fertility on emissions intensity of beef production in a northern Australian herd.
    - Karen Christie - Modelling additional pasture production associated with using nitrification inhibitors on dairy pastures.
    - Natalie Browne - Method of calculating greenhouse gas emissions. This would include items such as the definition of product, metrics and co-product allocation.
    - Richard Rawnsley - Modelling approaches to improving NUE in pasture based dairy systems.
    - Matthew Harrison - Does increasing ewe fecundity reduce greenhouse gas emissions intensities of prime lamb enterprises?
    - Brendan Cullen - Can soil carbon accumulation offset methane and nitrous oxide emissions when transitioning from cropping to livestock production?
    - Richard Rawnsley - Demonstration of the COST tool.
    - Christie Ho & Alexandria Sinnett - Appropriate Economic indicators to use in mitigation modelling.
- WFSAM Workshop, 19th and 20th November 2013. Presentations were given by:
    - Natalie Browne - Forage legumes; Wambiana
    - Karen Christie - Dairy COST; Sheep COST
    - Brendan Cullen and Richard Eckard - Northern beef Systems; Feeding nitrates; Soil carbon modelling
    - Matt Harrison - High fecundity ewes; Prime lamb and wool systems, AgMip
    - Alex Sinnett and Christie Ho - Economic frameworks
    - Richard Rawnsley - Modelling dairy systems
- 8th International workshop on Modelling Nutrient Digestion and Utilization in Farm Animals Conference, Cairns. 15 to 17 September 2014. Papers presented by:
    - Richard Eckard, Karen Christie, Natalie Doran-Browne and Matthew Harrison, to approximately 100 researchers from 18 countries.

Radio and TV interviews

- 27 March 2014, Climate change and options for farmers to respond, ABC Rural, South Australia, Richard Eckard.
- 20 June 2014, Importance of soil temperature for pasture growth, ABC Rural Radio, NSW, Victoria, Richard Eckard.
- 11 July 2014, Carbon credits: trading in hot air explained, ABC Rural Radio, Kimberley Richard Eckard.
- 24 July 2014, The Project, Channel 10, Impact of beef consumption on environment Richard Eckard.

Popular press

- 22 March 2013, Reducing methane from dairy cows: it’s all in the oil, The Conversation, Richard Eckard.
- 26 April 2013, 'Steps towards cutting dairy gases', The Tas Country newspaper article, Karen Christie.
- 12 June 2014, Farmer protects nitrogen investment, The Australian Dairy Farmer, Richard Eckard.
- 26 June 2014, Carbon farm for ’right reasons’, Stock and Land, Richard Eckard.
- 17 October 2014, Young Carbon Farmers southern carbon bus tour 2014 – Richard Eckard, https://www.youtube.com/watch?v=xYkW86Gyv3k
- 24 February 2015, It’s not enough to go vegetarian to fight climate change, The Conversation, Richard Eckard.

APPENDIX IIA - WFSAM Workshop 1: Informing approaches to mitigation modelling

A Filling the Research Gap mitigation workshop was held on 1st and 2nd May 2013 in Melbourne focused on "Informing approaches to mitigation modelling". The purpose of the workshop was:

- To develop improved modelling capacity for the DAFF Filling the Research Gap program, through developing an agreed pro-forma, ensuring that modellers are planning and designing modelling experiments with similar level of thought and planning as field experiments.
- To ensure that modellers under the Filling the Research Gap program are making correct and appropriate use of data from the various measurement programs in challenging and validating their models, leading to further model improvement and improved confidence in the modelling outputs.
- To develop an agreed modelling pre-experimental protocol pro-forma.

Day 1 of this workshop involved presentations from researchers conducting mitigation modelling, with a view to informing the workshop of the scope of modelling being conducted and the various approaches used. Day 2 was a facilitated workshop session that aimed to developed a FtRG mitigation modelling planning protocol.

This workshop was attended by 32 researchers representing the majority of scientists involved in mitigation modelling and grazing systems, both in Australia and New Zealand.

This workshop was organised collaboratively between the FtRG "Facilitation of Improvement in Systems Modelling Capacity for Carbon Farming Futures" and "Whole Farm Systems Analysis of greenhouse gas abatement options for the Australian grazing industries (WFSAM)" projects. A name list of those that attended and their host organisation is provided below.

Presentations on day 1 of the workshop

- Brendan Cullen - The effect of earlier mating and improving fertility on emissions intensity of beef production in a northern Australian herd – WFSAM
- Steven Bray - Application of an interface between the Breedcow herd model and FarmGAS for scenario testing in Northern Australia
- Karen Christie - Modelling additional pasture production associated with using nitrification inhibitors on dairy pastures - WFSAM
- Melissa Rebbeck - Model output differences - interpretation and application discussion - AOG
- Val Snow- Mitigation modelling at AgResearch – different scales and approaches- New Zealand
- Natalie Browne - Method of calculating greenhouse gas emissions. This would include items such as the definition of product, metrics and co-product allocation. PhD - WFSAM
- Douglas Alcock - Potential effects of animal management and genetic improvement on enteric methane emissions, emissions intensity and productivity of sheep enterprises at Cowra and Hamilton
- Richard Rawnsley - Modelling approaches to improving NUE in pasture based dairy systems - WFSAM
- Malcolm McPhee - Trevenna work low vs. high productivity - FtRG.
- Matthew Harrison - Does increasing ewe fecundity reduce greenhouse gas emissions intensities of prime lamb enterprises? WFSAM
- Brendan Cullen - Can soil carbon accumulation offset methane and nitrous oxide emissions when transitioning from cropping to livestock production? WFSAM
- Richard Rawnsley - Demonstration of the COST tool - WFSAM
- Christie Ho & Alexandria Sinnett - Appropriate Economic indicators to use in mitigation modelling – WFSAM

Name list attending the workshop

CSIRO: Andrew Moore, Sandra Eady, Afshin Gharharmani, Guillaume Harvard, Zhongkui Luo, Hongtao Xing

NSW DPI: Douglas Alcock, Malcolm McPhee

University of Melbourne: Marcelo Benvenutti, Natalie Browne, Brendan Cullen, Rich Eckard, Cameron Ludemann

DEPI Victoria: Christie Ho, Alexandria Sinnett, Tom Jackson

DAFF QLD: Steven Bray

DCCEE: Rachel Burgess

TIA: Karen Christie, Matthew Harrison, Richard Rawnsley

MLA: Tom Davison

AgResearch: Samuel Dennis, Kathryn Hutchinson, Val Snow, John Rendel, Ronaldo Vibart

SARDI: Melissa Rebbeck

QUT: David Rowlings, Clemens Scheer, Leigh Trevaskis

USQ: Rod Glass

1. Mitigation Modelling Workshop – survey results

Survey open from 6 – 12 May

18 respondents

1. How useful and engaging did you find the presentations on day 1? Please rank presentations out of 5, where 1 is 'poor' and 5 is 'excellent'.

Rank	1	2	3	4	5
No. of responses	0	0	1	12	5

2. How useful and engaging did you find the workshop session on day 2? Please rank presentations out of 5, where 1 is 'poor' and 5 is 'excellent'.

Rank	1	2	3	4	5
No. of responses	0	0	2	12	4

3a. Do you plan to change your planning of future modelling studies following the workshop?

- Yes: 14
- No: 4

3b. Why / why not:

For the 'yes' responses:

- A standard modelling planning template would be very beneficial for my work
- I will use modelling to enhance the outputs of my real on ground case studies. I will grass gro to use this and may not need to use the GHA tools or SGS as originally planned.
- I am new to modelling so the planning of my upcoming modelling work will incorporate things I learnt in the workshop
- Always is an evolving process and hence will be helpful in future modelling studies.
- I understand the processes better now of what is required for modelling from seeing presentation that are similar to what I am doing
- Will look at adopting/adapting the pro-forma for usage in our work
- Be a little more structured and think about end user or implementer

- Discussion highlighted some issues that I had not previously considered.
- Workshop highlighted some of the traps that can easily be fallen into that need consideration prior to modelling. That said, we all generally have to re-run our modelling 'experiments' based on the results sometimes highlighting areas which needed more consideration
- 1. Use of WFSAM protocol before setting out on any modelling 2. Additional discussion with colleagues on which analyses are feasible, and what the research question primarily relates to.
- Greater understanding of who is doing what nationally, I feel we are better able to create linkages.
- I can see the need to carefully plan the study before starting.

For the ‘no’ responses:

- I will still focus on the processed-based agricultural system model in the future.
- I think we had already thought through and developed a similar process to that discussed. However gaining affirmation of that process was good.
- Coming from an Inventory perspective, many of the issues discussed on day 2 are already implemented as part of standard practice within DIICCSRTE.
- Already use case study farms to calibrate analysis and the (economic) modelling I do appears to be in line with best practice

4. Would you use a standard modelling planning template if we provided this?

- Yes: 18
- No: 0

5. What was the most useful part of the workshop for you / your work?

- Discussing with others.
- First I would like to clarify my answer to question 4 above. A planning template would be a useful cross check, even if it was not used directly. Building and renewing collaborative relationships. This is important for myself living and working in a regional area. Highlighting my projects, activities and achievements to a wider audience and hearing about other projects outside my patch. It is good to help broaden modellers perceptions outside of 'model-world'.
- Getting comments and feedback about my work
- The discussion session on day 2 and the opportunity to discuss problems and issues with colleagues at the end of the workshop.
- The discussions on day 2
- Opportunity to engage with extension staff and researchers on the modelling work they have been doing. See what tools they have been using. Discuss metrics. See how the group is presenting results. - there did seem to be a standard amongst some on how results are presented. I think this was good and yes always could be improved.
- Looking at ways of planning and implementing (e.g. methodology) emissions research
- The informal discussions - that would not have happened without the workshop - and the moderated discussion about the modelling process.
- Putting names to faces and establishing some good contacts. Also seeing how other groups / people approached the modelling of GHG
- Built contacts with other modellers and was updated with their research.
- day 1- Getting feedback from a well informed and diverse group of people. informal discussions about ideas and approaches.
- Listening to modellers views and perspective of inventory data and methods. listening to modellers who aren't constrained by international policy obligations.
- Interaction with people from other institutions to inform the process of modelling
- The presentations, both for their information per se and the feedback they stimulated.
- Discussing problems I face with other researchers. The idea of developing a template to guide future modelling is good because it would increase confidence that modelling includes appropriate treatment of the most important variables.
- The understanding gained from day 1

- The presentations on day 1 gave a great overview of approaches to modelling, but day 2 sorted out how we should plan these.

6. Can you suggest any improvements we could make to future modelling workshops?

- Concentrate more on one part and deep discussion.
- Would be good to share some success stories and learnings of applying the modelling template.
- I think it is important to organize the workshops in the most efficient way to achieve the purpose of the workshop. The purpose of this workshop was to develop improved modelling capacity through developing a pre-experimental protocol pro-forma. I think that the presentations on day 1 made little contribution to that purpose as the presentations were mainly about the outcomes of modelling instead of the process of modelling. I think that it would have been more beneficial if, on day 1, the modellers had an opportunity to explain how they go about planning and designing modelling experiments and how they use data to challenge and validate their models.
- Provide clear aims to speakers about expected topics. While many presentations were interesting I found only a few that related to my work and only a few that presented problems for discussion.
- Some of the presentations on day 1 could have had a bit more emphasis on the planning phase of their work
- Consider breaking into small groups for a couple of 1-2 hour sessions so that people focusing on specific types of modelling can discuss their work and requirements in more detail.
- I think that the format was appropriate for the topic matter this time but the group was quite large. Depending on future topic matter, I would consider using some small-group sessions + report back to allow some of the quieter people to get a word in. Also a short session requiring some reflection might help consolidate the learning for some people. I found the acoustics in the room a little challenging so it would help perhaps if people were reminded that they were talking to the whole group not just the person who asked the question and happens to be a meter away,
- Day 1 was good as it outlined where groups were at. Day 2 seemed to be dominated by a few, which is always difficult with a largish group. Perhaps an alternative would be to break into groups to discuss each topic and then report back to the group. This may dilute the dominant few, and thereby provide an opportunity for others to contribute.
- some more 'hands-on' elements, e.g. training in use of tools, but it is difficult with a large and diverse group.
- DICCSRTE could provide a valuable contribution in terms of lessons learned and what we would do differently if we had our time again.
- No, I think the number of attendees was at the maximum but a great blend of people from locations / institutes / areas of expertise (economics, modelling, real farm systems etc).
- None
- Perhaps a slightly more structured discussion on day 2 - i.e. working through an example analysis from start to finish - would help to crystallise some of the concepts being discussed. Overall though, I thought the format worked very well.
- I would use small groups for greater engagement in day two, I don't feel like I heard enough from the group on the day. Rod Glass

Appendix IIB: WFSAM Workshop Report 2. Training Workshop: Mitigation modelling

A Filling the Research Gap mitigation training workshop was held on 19-20th November 2013 at the Best Western Airport Motel and Convention Centre in Melbourne. This workshop was jointly hosted by Facilitation of Improvement in Systems Modelling Capacity for Carbon Farming Futures and Whole Farm Systems Analysis of Greenhouse Gas Abatement Options for the Australian Grazing Industries (WFSAM).

Purpose

The purpose of the workshop was:

- To build on the modelling skills develop in earlier workshops, through presenting case studies and provide opportunity for peer review of these.
- To develop greater understanding of the theoretical and technical aspects of mitigation modelling.

Participation

The workshop was attended by 16 agricultural sector researchers actively engaged in developing models and using mitigation modelling in their research. 42 invitations were distributed, 18 accepted to attend (43%) and 16 attended (38%, with 2 cancellations received on day 1 of the workshop).

Format

Day 1 of the workshop included presentations from researchers conducting mitigation modelling, focusing on how these studies were conducted in terms of models and tools.

Day 2 of the workshop comprised hands-on training sessions, access to modelling experts, plus discussion and feedback on future developments required.

The models and updates presented at the workshop

Ian Johnson	AgMod
Andrew Moore	Ausfarm
Karen Christie & Natalie Browne	COST
Brendan Cullen	Breedcow; SGS model
Rich Eckard	B-GAF & B-GAF nitrates
Natalie Browne	SGS model in northern Australia
Steve Bray & Dionne Walsh	GRASP model
Christie Ho & Alex Sinnett	Economic frameworks including @RISK
Matt Harrison	GrassGro
Richard Rawnsley	UDDER, DairyPredict, FarMax

Workshop evaluation

A total of 16 researchers attended the workshop and 12 participants completed and returned the workshop evaluation.

The primary value indicated from the workshop was networking (6), with new learning (5) and speaker line-up (4) also of high value (noting that two respondents selected more than one or all options).

Where participants were invited to state the extent to which they agreed or disagreed with the value of the workshop, all of the responses fell into the s*trongly agree (47%)*, *agree (44%)* or *neutral (8%)* categories, with none occurring in the *disagree or strongly disagree* fields.

- Participants strongly agreed that the workshop was relevant to their work; was valuable for networking; increased their skills and knowledge; and enabled them to plan to adapt and change their modelling approaches. They also strongly agreed that the length of the workshop was appropriate and that the level of information-sharing and the unstructured format of day 2 were valuable.
- The majority agreed that the workshop met their learning needs and that they have confidence to use the knowledge gained from the workshop to make changes to their modelling approaches. They also agreed that the structure of day 1 was appropriate for their needs.

In the three final open questions, where participants could respond as they wished:

- Of most value to participants at the workshop (11 responses from 12), 45% cited networking and discussion with colleagues; 45% cited learning about, approaches to and comparison of various models. Others valued working with case studies and receiving feedback on their models.
- For topics for future workshops (7 responses from 12), respondents would appreciate approaches to model realistic farm scenarios; modelling issues required by industry; detailed nutrition modelling and modelling effects of fat, tannins and nitrates onn methane.
- Of the 5 responses suggesting improving future events, 3 felt that the workshop was worthwhile as presented, 1 respondent recommended keeping day 2 unstructured with experts available and 1 respondent would appreciate a venue closer to public transport.

Summary - model needs and future developments

Following the workshop, participants were asked for their input on model needs, performance and future developments. The following key points were highlighted:

For investors:

- Current models and tools do not allow for direct modelling of current and imminent CFI diet supplementation strategies e.g oils, nitrates and tannins.
- There is a need for on-going training of teams in the various models, especially AgMod.
- There is also a need for a strategy to support and maintain the models used.
    - UDDER is no longer supported or developed and is thus likely to cease being used. There may need to be a transitional plan from UDDER to AGMod or FarmMax to pick up these features.
    - GRASP has a number of variants in circulation, but no single person taking responsibility for training, development or support. There is a need to consolidate these various versions and perhaps develop a more friendly user interface.
    - AGMod is indirectly supported through short-term sub-contracts using project funds only.
- Succession planning is required for all these models.
- Pre-experimental modelling should become more a standard requirement before funding field work. Thus will not only ensure that treatments are carefully considered, but also that the correct data is collected to allow post experiment modelling and refinement of models.
- There is a need for a review of models within each industry to understand where they fit and where they are going in terms of industry needs. Perhaps this will lead to more industry ownership over these models e.g. northern beef industry, through MLA to own GRASP, Dairy to own DairyMod.

For model users:

- There is a need to actively manage parameter assumptions in all models. A standard or transparent approach to this should be considered.

Outcomes and recommendations

- The participants strongly affirmed the value of holding workshops to improve skills in mitigation modelling, mainly through continued development of knowledge about various models and approaches and increasing in skills and confidence in modelling.
- Participants also valued networking and engagement opportunities arising from the workshops.
- The key outcome will be improved quality of mitigation modelling, plus a more informed and consistent approach to mitigation studies.

First name	Surname	Organisation
Steven	Bray	DAFF, QLD
Natalie	Browne	University of Melbourne
Karen	Christie	University of Tasmania
Brendan	Cullen	University of Melbourne
Tom	Davison	Meat & Livestock Australia
Rich	Eckard	University of Melbourne (Facilitator)
Matthew	Harrison	University of Tasmania
Christie	Ho	Department of Primary Industries Victoria
Ian	Johnson	IMJ Consultants P/L
Cameron	Ludemann	University of Melbourne
Andrew	Moore	CSIRO
Richard	Rawnsley	University of Tasmania
Melissa	Rebbeck	SARDI
Alexandria	Sinnett	Department of Primary Industries Victoria
Chris	Taylor	University of Melbourne
Mitchell	Trickey	Australian Wool Innovation (day 1 only)
Dionne	Walsh	NT Department of Primary Industries & Fisheries

Workshop 2 - Agenda

Training workshop: Mitigation modelling

Tuesday 19 and Wednesday 20 November 2013

Best Western Airport Motel & Convention Centre
33 Ardlie Street, Attwood, Victoria

Purpose:

- Build on the modelling skills developed in earlier workshops, through presenting case studies and provide opportunity for peer review of these.
- Develop greater understanding of the theoretical and technical aspects of modelling.

Day 1: Tuesday 19th November 2013

10:00	Arrival and Coffee/Tea
10:30 10:40	Introductions, agenda & purpose **Session 1.1: Biophysical models update** AgMod – Ian Johnson ▪ Overview (25 min) ▪ Discussion - Limitations, appropriateness and future developments (20 min)
11:25	Ausfarm – Andrew Moore ▪ Overview (25 min) ▪ Discussion - Limitations, appropriateness and future developments (20 min)
12:10	COST – Karen Christie, Natalie Browne (35 min) ▪ Overview including a case study or two (25 min) ▪ Discussion - Future developments (10 min)
12:45	Lunch
13:30	**Session 1.2: Cases studies demonstrating tools** Case studies where combinations of modelling approaches been used to address key questions - how they have pulled modelling approaches together. Focus on methodology and assumptions as the objective is learning. 1. Northern beef Systems (30 min) a) Breedcow – Brendan Cullen b) B-GAF & B-GAF nitrates – Rich Eckard 2. Wambiana (20 min) a) SGS model – Natalie Browne 3. Forage legumes (20 min) a) Spreadsheets – Natalie Browne 4. Northern Grazing systems (20 min) a) GRASP model – Steve Bray, Dionne Walsh

15:30	**Session 1.3: Cases studies demonstrating tools** 1. Economic frameworks including @Risk -- Christie Ho, Alex Sinnett (20 min) a) High fecundity ewes b) Environmental plantings 2. Soil carbon modelling a) SGS model -- Brendan Cullen (15 min) 3. High fecundity ewes, Prime lamb and wool systems a) GrassGro – Matt Harrison (20 min) 4. Modelling dairy systems a) UDDER, DairyPredict, FarMax - Richard Rawnsley (25 min)
16:50 17:30	**Session 1.4: Discussion on case studies and gaps** ▪ Identify gaps or limitations in the modelling - Lack of research data and assumptions - Lack of appropriate models or model capability ▪ Identify future developments needed in models
19:00	Workshop dinner

Day 2: Wednesday 20th November

8:30	**Session 2.1: Hands-on' training day** Bring your own data, simulations, models etc and self-organise to work through problems, with other experts in the room.
10:00	Morning tea
10:30	**Session 2.1: Hands-on' training day (cont)**
12:30	Lunch
13:30 14:30 15:30	**Session 2.2: Report back session** Each group or individual reports on progress from the day: ▪ What was being modelled? ▪ What progress was made? ▪ What is next from here? ▪ What additional resources or assistance needed? **Session 2.3: Summary discussion about model needs, performance and future developments.** END

Appendix IIC: Workshop 3: Modelling - livestock production systems of northern Australia

25th and 26th June 2014, Watermark Hotel, Brisbane.

Present:

Cameron Allan, Andrew Ash, Steve Bray, John Carter, Robyn Cowley, Lindsay Bell, Ken Day, Natalie Doren-Browne, Richard Eckard, Ben Henderson, Beverley Henry, Bob Karfs, Di Mayberry, Neil Macleod, Peter O'Reagain, Lester Pahl, David Phelps, Danielle Rodriguez, Joe Scanlan, Chris Stokes, Grant Stone, Dionne Walsh, Giselle Whish.

Facilitator - Warren Mason

Presentations:

- **Cameron Allan** – Overview of the workshop and the concepts presented in the workshop discussion paper.
- **Joe Scanlan** - The Northern Grazing Systems Project – findings and lessons.
- **Richard Eckard** - What insights can we draw from a similar livestock modelling project across southern Australia?

Aim:

To recommend to MLA and partners how a modelling project can be designed so that it answers immediate industry questions (around production, profit, sustainability in differing regions) and satisfies the longer term objective of providing the livestock industry and stakeholders in northern Australia with the capacity to do pre and post-experimental modelling, use models more prospectively, and identify research or capacity gaps in northern Australia.

Using models "prospectively" means confidence is required in models, and the portability of output to the northern industry. This opens up the question of data sources and should also assist in determining what (biophysical) research is needed, where, and shortcomings in the models.

Scope of a project

- Build on previous approaches in the Northern Grazing Systems project utilising the simulation models, GRASP, ENTERPRISE and SGS plus other models/tools that inform grazing based production systems addressing soil x water x nutrient x pasture x animal x economic dynamics.
- Grazing systems include consideration of enterprise mix (e.g. breeder / steer), and accommodate different climate possibilities and land condition scenarios.
- Emphasis is on the productive and relatively intensively managed areas of Qld, the NT and the Kimberley/Pilbara regions.
- Include all interested partners (e.g. QDAFF, CSIRO, NTDPI and University staff) that actively use and develop models related to the northern grazing industry.
- Involve producers in an ongoing manner.

Strawman outputs of a development project - to be refined:

- Modelled 'answers' to some current northern livestock industry questions.
- Improved models and tools for answering northern livestock industry questions.
- Improved modelling capability within the research community servicing the northern livestock industry.
- Clear directions for future R&D (modelling and on-round) for the northern livestock industry.
- Improved linkages with other livestock/NRM initiatives across Northern Australia.

Summary of lessons/suggestions/instructions from Cameron, Joe and Richard

- The job is to develop a collaborative modelling project, built on previous projects/approaches to address key industry questions, and that will be ready to start on July 1 next year.

- The project must work towards building both model capability and modelling capacity and engage strongly with the grazing industries. There is some recognition that we have lost a nucleus of model users and will need some catchup.
- The project must focus on the key questions that are important to the northern grazing industries - with any model development a supporting activity.
- A clear lesson from the NGS was that it is critical to set and manage expectations but there is some tension between a project being stongly planned and managed vs being responsive to (perhaps changing) industry questions and needs.
- Modelling projects must be planned with the same rigor and many of the same processes as field experiments.
- Industry questions have been and will be a combination of short (tactical) and long term (strategic) at differing scales. NGS focus was at a 30 year time horizon, rather than supporting short term decisions (where models may have greater capacity).
- We need to better incorporate economics into the modelling activities because economics tends to dominate medium term outcomes.
- Modelling (as well as extension providers and producers) should be integrated into all major experimentation projects. This is required to build confidence in the role of models in supporting decision making.
- Need to better incorporate ‘big data’ – and ‘small data’ as there is a lot of fragmented data out there that would be very useful for modelling activities if it were made available. Funders need to ensure that all projects provide open access to data.
- Focus should be on "multiple tools" rather than a "super model" – ie suite of tools and then select the most appropriate tool for the job.
- It is critical to create a community of practice across organisational boundaries to provide the framework for on-going collaboration, information sharing and collective effort on industry projects.
- The Northern and Southern grazing industries (and the modelling projects that support them) have more commonalities than differences and we need to capture more value from N/S collaboration.

Workshop session 1

Q1 *- What are the current northern livestock industry* ***questions*** *that modelling could address?* After the questions were collated, then:

Q2 *- What is the* ***capability*** *of current models and tools to answer those questions across the 5 key regions of interest?*

Capability scores were:

- Little or no current modelling capability around this question.
- Reasonable modelling capability but models would need some modification(s).
- Good current modelling capability to address this question.

Paddock level questions

- What combination(s) of strategies optimise turnoff – includes capital considerations and resource considerations and long term implications. (capability score 1-2 – the gaps would be in genetics, mixtures of pastures and pasture quality).
- What is the gap between potential and actual paddock performance across the northern grazing industry. (2 – connections between pastures and livestock responses may need development).

- What is the impact of spatial distribution within paddocks - includes considerations of infrastructure, economics and animal behaviour (2 – need to be able to model spatial distribution of grazing for improved land condition).
- How can we better include tree/grass and/or forage/carbon interactions in models (1-2 – some of these interactions need to be put into GRASP, esp for the Mitchell grass areas; limited to Burdekin and Maranoa Balonne).
- How does fire influence production and sustainability - how will the frequency, intensity and timing of fires be influenced by climate change – includes consideration of 'what is currently possible' (2 – timing changes difficult, there are interdependent data sets, ignition is a challenge, wind data is missing from SILO).
- How do we present producers with better knowledge about paddock supplementation strategies and likely effects? That is, what is the marginal value of additional energy or protein or minerals (2+ - Aussie Grass can do this pretty well across all regions).

Enterprise level questions

- What is the impact of starting date (real not modelled starting date/position/condition – run of years etc) on risk (economic and resource) at enterprise and regional levels. That is, "how effective over a range of years would implementing practice X be ?" (2 – Calibrated for some management options and data sources in some regions).
- How does enterprise mix affect risk, responsiveness to drought and economic outcomes (eg proportion breeders, trading stock) (2 – good growth estimates but there is no synchronisation with biophysical feedback between livestock and pastures. No validation of the livestock model (NABSA) across most regions).
- How can we cope better with interannual rainfall variability (2.8 – we have good ability to model this across all regions but there is some need for improvement in the land condition response and the temporal variability in costs and prices).
- How do we improve stocking rate strategies that account for different regions having different recovery rates? That is, understand how quickly to destock or re-stock) (2 – limited data on recovery rates, some existing some not yet used. Sensitivity analysis and prospecting to guide whether new data to be collected).
- How do we optimise land use for economic/resource outcomes – includes mix(es) of land use that might include other products (agricultural and carbon) and not just cattle? (<2 – some good modelling capability but would need to include a spatial aspect and an optimisation capability).
- How can we supplement modelled outcomes with practical considerations such as animal health, genetics or nutrition? (1.5 - would have to manually adjust reproduction rates, death rates etc).
- How do we better inform critical decision times and the implications of those decisions, including the development of indicators? (2-3 – close to having the capability but would need to make soil moisture operational for short term biomass predictions – subsquent discussion suggested this limitation is not major. Qld okay, uncertain about the VRD).

Regional/industry level questions

- Where (across/within enterprises) could we make the largest gains (in profit/productivity) while protecting the resource base? This would include testing existing drivers and potential drivers and involve sensitivity testing, potential for premiums and meeting marketing specs. (2 – could do some with GRASP but would need a new look-up table. Need to include other model options because of the wide range of questions).
- What is the likely impact of current or new policies (ie land use policies that might include drought, carbon, land use etc) on industry viability and land condition? (<2 – viability is the key constraint esp on the livestock reproduction side).
- Can we (how can we) better predict whole of industry outcomes? (<2 – Aussie grass has little economics and scale challenges with woody information).

- What is the water use efficiency of the northern grazing industry? (2+ this would be based on industry level stats rather than modelling. Would need ABS data such as kg of beef; RUE (rainfall use efficiency) and water-point evaporation + consumption).
- How can we better inform real estate and financial institutions to provide realistic valuations and ROI targets? (2 – biophysical modelling capability across some regions, would require work to make it compelling for the target audience. Paddock GRASP would be a good starting tool).
- Can we better match animal supply and demand along the supply chain? (1 – little modelling ability(... ask the USDA for their predictions?). Need to include local as well as the overall supply chain).

Workshop session 2

What are the appropriate outputs that we would expect to see from a project that was focussed on the key industry questions outlined above? The aim was to replace the strawman outputs suggested in the workshop discussion paper.

Suggested project outputs

- Modelled insights to some key industry questions.
- An improved suite of models and tools – includes concepts of validation, calibration, rigor, protocols.
- An improved (and continuing/on-going) modelling capability for northern livestock industry (incudes development of a community of practice).
- Clear directions for future R&D (modelling and on-ground) and decision support needs (plus generated demand for on-going modelling effort).
- Improved linkages with other livestock/NRM initiatives across Northern Australia.
- Peer reviewed publications.
- Open acces to models, data and meta data.
- Clear project messages for extension to industry and for policy.

Workshop session 3

From our knowledge, experiences and discussions so far, what are the critical elements that we want to see reflected in this proposed modelling project? That is, in our minds what is the project starting to look like?

Our picture of the project

- It must be focussed on industry questions and those questions must be related to long term profitability and sustainability of the northern grazing industries.
- It must be multi agency, multi region, multi scale and multi discipline.
- Data assimilation will be critical, with some accessible repository and protocols for future assimilation and access.
- The project must take a systems approach.
- Comparison of models will be a key part of the tool selection process when deciding which tools to apply to which industry questions – a toolkit approach.
- There needs to be rules to underpin confidence that the models and tools are appropriate for the question(s) at hand. The bar needs to be set not too high or not too low and there needs to be an overt examination/explanation of the limitations.
- The project needs a well defined scope (specifying not only what is in but also what is out and why its been left out) and sequencing within realistic timeframes.
- The project should be participatory, with involement of all key stakeholders including producers and extension agents through the life of the project.
- There must be enough time to do the specified activities.
- The project must not create a modelling silo – ie it should be integrated with other R,D,E etc activities.

- There should be demonstrable linkages and couplings between models and scales.
- There should be clear process for version management – especially for GRASP – and a budget for developments that are needed to address the industry questions.
- There needs to be clear linkages, roles and responsibilities across the project – individual need to be clear about who is responsible for what.
- The project should use (develop?) a risk/probability framework for the presentation of results.
- Livestock production, economics and efficiency must be key outputs.
- The project must not be just about GRASP – the particular question needs to dictate the choice of models or other tools.
- The project must include training.

Workshop session 4

Given the collective picture that we have now developed around what the project might 'look like', what would be the critical elements to make such a project a success, and secondly what are the pitfalls that might undermine such a project. In both areas what needs to be done to ensure they are addressed?

Black Hat - *what will undermine success ?*

Not getting the industry questions right – *it's unlikely 'industry' would have come up with the same list of questions we did!*
- Cross reference with MLA planning.
- Cross reference with recent industry planning processes, recent reports etc. for alignment rather than initiating a new round of 'consultation'.
- Ensure the project planning process revisits/refines the questions in the light of above comments.

Modelling capacity is too thin – *both within and between organisations and developers, power users and casual users are fragmented*
- Identify potential modellers and develop by mentoring and other support.
- Develop a core group tasked with certain tasks which might include model development, a help desk, and version control.

Project goal may be lost or misinterpreted - *depending on individuals role and perspectives whether researchers, modellers or extension people.*
- Need a steering committee to keep a focus on the project goal and to keep it real.

Lack of clarity re what the project will achieve – *including lack of clarity re what individuals will be doing.*
- Must have clear objectives and constant checking that things are on track.

Dependency on too few skilled people – *limited overall capacity and/or capability*
- Need to build in mentoring, training, PhD's, post docs etc.

Inability to access data – *including the context of the data and having data cleaned up before modellers access it.*
- Interact strongly with researchers (data custodians) to ensure understanding of modelling purpose.
- Acknowledgement of data sources and co authorship to encourage sharing.
- Some legal agreements may be needed to enable exchange.
- Current and future R&D contracts should require data sharing.

Insufficient time allocation of key people
- Must be negotiated.

Not being able to access models and correct versions
- Define access issues and limitations and negotiate.

Yellow Hat - what is critical to success?

Needs to be focussed on key industry questions
- Engage stakeholders from the beginning.
- Refine questions over time with producers and other strategic thinkers.

Must have strong industry support
- Need industry 'ownership' of the project questions.
- Big investments needed.
- MLA to negotiate with others/act as project broker.
- Encourage active stakeholder involvement in a constructive way.
- Establish a steering committee with clear oversight/engagement rolls.

Need heavily dedicated core people
- Budget for some 100% FTEs, perhaps young staff, PhD students etc. who can be mentored by senior staff with smaller time commitments.
- Aim to increase the capacity of all participants and participating organisations.
- Engage other clients who may have interest.

Need for model maintenance and updating
- There must be a budget for model development.
- There must be a process for version control/consolidation of versions.

Need a protocol for each modelling task
- Draft a standard protocol early in the project.

Integrate with other RD&E activities where there is common focus
- Tie model results in with existing, on-ground RD&E that is focussed on the same/similar industry questions.
- Researchers, modellers and extension agents encouraged to constantly interact.

Project needs to be really focussed and stick to it
- Thorough scoping.
- Strong leadership / champion.
- Match the scope to the resources.

Project will need a critical mass
- Need a core modelling group.
- Combined with dispersed users and 'back up' eg with data and software specialists and systems scientists.
- Build and maintain a community of practice that includes on-going training and professional development.

New delivery process for project messages
- Might be Apps, Webinars, YouTube etc.
- Develop with extension and comms people – build them into the team.

Workshop session 5

What needs to happen from here to deliver a project that could start on July 1, 2015 and deliver the outputs agreed so far by the workshop group?

Four key actions were identified by the workshop group as needing immediate attention if a body of work (project, program or other name) is to be put together for a potential start on July 1, 2015.

- The workshop notes need to be written up and circulate to all to provide a summarised account of the workshop discussions and conclusions.

Action – Write up the workshop notes asap and dispatch.

- Formally identify the client and stakeholder base for the project – who might be involved, from the perspectives of planning, targeting, funding, participation, collaboration, oversight etc. Without this being clear, it will not be possible to undertake actions 3 and 4 below.
- Create the compelling case that will be needed to convince those not at the workshop and the potential funders/contributors/participant (identified in item 2 above) of the value that could be generated from the sort of project the workshop envisaged.

Action - by 14 July participants to provide (to Cameron Allan), a value proposition statement for their organisaton's senior management: *What are the benefits to your organisation of getting this "work area" in shape ?*

- Scope out what needs to be done following the workshop in order to have a compelling body of work ready to start in July 2015. This must include marshalling the institutional support as well as the financial and human resources that are needed to complete this planning work.

Action. The workshop nominated a ‘project development team’ with representation from each of the key oranisations that would anticipate playing a significant part in the body of work the workshop envisages. Members of the group are: Andrew Ash (convenor), Bob Karfs, Ken Day, Dionne Walsh, Richard Eckard, Beverly Henry and Cameron Allan. Andrew Ash will (at least initially) convene the group by mid July.

Action. All workshop participants agreed to assist the ‘project development team’ with both the tasks outlined above and with other issues that arise during the planning process.

Appendix III: Details of the sub-contracted model developments in DairyMod and SGS.

Project summary

The objectives of the project are to provide necessary modifications and refinements to the SGS Pasture Model and DairyMod, collectively referred to as ‘AgMod’ for the " Whole farm systems analysis of greenhouse gas abatement options for the southern Australian grazing industries (WFSAM)" project.

Phase 1 (completed by 31 Jan 2013):

- Implement improved treatment of volatilization
  - Liaise primarily with Rich Eckard;
- Implement nitrification inhibitors
  - Liaise primarily with Karen Christie and Richard Rawnsley
- Extend GHG reporting to include off-site losses due to nitrate leaching and ammonium volatilization
  - This will involve improvements to reporting procedures including customized data export to Excel

Phase 2 (completed by 31 May 2011):

- Incorporate flock and herd management to allow for lambs/calves pre- and post-weaning.
- Individual management options for ewes/cows and lambs/calves
- Grazing rules such as separate rotations or set stocked on different paddocks
- Replacement rules for ewes/cows

This phase will involve liaising with the WFSAM team to ensure the developments meet their needs.

Phase 3 (completed by 30 June 2013):

- Implement the single heterogeneous paddock (SHP) in AgMod
- Provide technical report for the urine patch approximation scheme that implements the impact of urine patches on the system dynamics without having to model them explicitly as in the SHP

This development will allow the approximation scheme for urine patches to be compared with the SHP to assess its efficacy in dealing with the effects of urine patches on system dynamics. The technical report will be sufficiently detailed to be implemented in a paper.

Phase 4 (completed by 31 November 2013):

Design and incorporate a system of dynamic flock and herd management into AgMod: There is currently a focus in the WFSAM project on exploring the mitigation potential of a range of flock and herd management strategies. These will be incorporated in the model in collaboration with the WFSAM team. This will initially focus on replicating the work on beef systems based on the recent Longreach study and sheep production systems based on the Hamilton study, to allow a whole herd and flock structure to be simulated dynamically in the model. The model will allow dynamic management options to respond to factors such as current pasture availability. Long-term simulations will provide information as to both the mitigation potential and associated risk of the management strategies.

The details of this component of the project will necessarily evolve throughout the project as our understanding of the potential of these approaches to management increases.

Phase 5 (completed by 28 February 2014):

Incorporate crops into AgMod, including grazed crops and double cropping. Forage crops are an integral part of many grazing systems and have the potential to play a significant role in mitigation strategies. The annual species in AgMod will be adapted to define a generic cereal crop. This will be incorporated into the management to allow it to be grazed as well as harvested for grain and hay. Double cropping will also be implemented to allow more than one crop to be grown in a calendar year.

Incorporating crops in this way will allow exploration of mitigation management strategies for on-farm grain and hay production to be integrated into the whole farm management.

Phase 6 (completed by 31 May 2014):

Targeted N fertilizer application: Implement the ‘Greenseeker technology’ (Smart N) whereby high N zones due to urine patches (currently implemented in the model) are identified and N fertilizer applications are not made in these regions.

Smart N technology is complex and may not identify all urine patches (accuracy), so that N may be applied on some patches, or not applied where it is intended to be (false positives). The model will allow exploration of both accuracy and false positives to assess the impact of errors in the technology.

Phase 7 (completed by 30 October 2014):

- Implement options for:
    - batch running of simulations
    - direct comparison of model parameter sets

This phase will involve liaising with the WFSAM team to ensure the developments meet their needs.

Phase 8 (completed by 30 March 2015):

- Develop and refine the stock management modules to allow stock numbers to be simulated dynamically as emergent properties of the model.

This phase will involve liaising with the WFSAM team to ensure the developments meet their needs.

On-going user support and model refinement

There is a continual need for the implementation of on-going model developments which often arise through interactions with the expert user group. As part of this contract, this user support will be provided to the WFSAM project team.