Final report

Delivering Integrated Management System (IMS) options for CN30

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Prepared by: Richard Eckard, Peter Grace, Warwick Badgery
University of Melbourne, Queensland University of Technology and New South Wales Department of Primary industries

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Abstract

The Integrated Management System (IMS) project evaluated new and emerging options for achieving CN30 in a farming systems context, identifying gaps in knowledge required to capture these in the National Greenhouse Gas Inventory (NGGI) and new carbon methods and appropriate pathways for the adoption of these technologies.

The IMS project team conducted a number of reviews (bromoform, 3-NOP, tropical legumes, temperate legumes), meta-analysis (3-NOP, oils), farmer case studies (Jigsaw farms, Dunkeld Pastoral company and Tipperary) and interviews with farmers to understand adoption pathways.

The project has updated greenhouse gas accounting protocols, developed predictive equations for crediting methane reduction, provided clear information for farmers on sequestration offsets and practical information on soil carbon, legumes and dietary supplements as a mitigation strategy. These are all summarised in a series of peer reviewed papers and reports which would provide the integrity required for industry recognition. Findings were communicated with farmers at numerous field days, industry conferences common science conferences and policy briefings.

Further research should focus on the development of methods for farmers to be recognised for methane reduction, plus ensure appropriate bottom up accounting protocols can capture this mitigation. The project established the role of whole farm systems approaches to understanding mitigation potential, an approach which is now captured in the Zero Net Emissions Agriculture CRC.

Executive summary

Background

This IMS project aimed to identify new and emerging mitigation and sequestration options, drawn from national research projects, together with other international research, evaluating these in a farming systems context, identifying gaps in knowledge that need to be addressed, working with industry and the Commonwealth to identify accounting protocols required to capture these in the NGGI, developing and publishing the underpinning science and logic required for ACCS methods and identify appropriate pathways for the adoption of these technologies, either through to the farm or into policy.

Objectives

The IMS project drew on the findings of relevant national and international research, filling the key research gaps in information to:

- Identify new and emerging mitigation and sequestration options that can deliver towards the CN30 target, evaluating these in a farming systems and supply-chain context.
- Identifying accounting protocols appropriate to capture new mitigation actions at farm, supply chain and national inventory scale, developing the underpinning science and logic required for their adoption from farm through to policy.
- Review international developments in the definition and assessment of carbon neutrality, providing advice on alignment and refinements required, as relevant to the Australian red meat industry.
- Identify appropriate pathways for the adoption of new mitigation technologies by farmers, industry and policy.
- Identify potential research gaps emerging, feeding these back into the CN30 research priorities.
- Conduct activities to achieve objectives outlined in MLA/DCCEW Grant Agreement MERLMLA000001.

Methodology

Under the guidance of the Synthesis Task Group, the IMS project identified mitigation and sequestration options that can deliver towards the CN30 target, including identifying appropriate accounting protocols, and evaluated these in a farming systems and supply-chain context.

- A number of farm case studies highlighting potential innovations and mitigation options;
- conducted meta-analysis focused on the bromoform, 3-NOP and dietary oils;
- published analyses and reviews of soil carbon, temperate and tropical legumes;
- improved greenhouse gas accounting protocols and captured these in the MLA carbon calculator and the AIA environmental accounting platform.
- These were communicated with farmers at numerous field days, industry conferences, common science conferences and policy briefings.

Results/key findings

Farm systems analysis is required to integrate component research to understand the whole of implications of various research developments. This is required to inform policy, avoid unanticipated outcomes from various best practise recommendations, and give farmers confidence to adopt new practices. It is also essential to advise MLA on pathways to achieve the goal of CN30.

A conclusion from this work is that it is essential to continue for the whole of agriculture which will now occur under the new Zero Net Emissions Agriculture CRC.

Benefits to industry

The project has updated greenhouse gas accounting protocols, developed predictive equations for crediting methane reduction, produced clear information for farmers on sequestration offsets and practical information on soil carbon, legumes and dietary supplements as a mitigation strategy. These are all summarised in a series of industry reports and peer reviewed papers, which would provide the integrity required for industry recognition.

Future research and recommendations

Further research should focus on the development of offset methods for farmers to be recognised for methane reduction plus ensure appropriate bottom-up accounting protocols can capture this mitigation. The project established the role of whole farm systems approaches to understanding mitigation potential, an approach which is now captured in the Zero Net Emissions Agriculture CRC.

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1. Background

The Australian red meat and livestock industry has set a target of achieving carbon neutrality by 2030 (CN30). Achieving this target will require widespread adoption of new and existing research. Significant research has been conducted and continues on mitigation options to reduce greenhouse gas (GHG) emissions. However, it is imperative for the industry and policy to understand the whole of farm system, life cycle and whole of industry outcomes of various mitigation technologies on overall GHG emissions, productivity and profitability. Likewise, for farmers or industry to receive recognition for their mitigation actions, appropriate accounting protocols will need to be developed to transparently capture these actions in the Livestock Emissions Framework (LEF), currently under development and being supported by the Department of Industry, Science, Energy and Resources (DCCEW) Methane Emissions Reduction in Livestock (MERiL) grants. These should feed into the National Greenhouse Gas Inventory (NGGI) and new ACCS methods (developed in consultation with DCCEW) to generate Australian Carbon Credit Units (ACCUs). Incentives for industry adoption may then range from improved market access for demonstrated low emissions production, through to formal incentives from the sale of ACCUs to government or other non-carbon market incentive mechanisms. The CN30 roadmap identifies these priorities under work area 4; Integrated Management Systems.

This IMS project aimed to identify new and emerging mitigation and sequestration options, drawn from national research projects (e.g. Carbon Storage Partnership - CSP, Emissions Avoidance Pathways - EAP; MERiL, Low Emissions Supplements to Grazing Animals at Scale - LESsGAS), together with other international research (e.g. ERA-GAS, NZAGRC), evaluating these in a farming systems context, identifying gaps in knowledge that need to be addressed, working with industry and DCCEW to identify accounting protocols (LEF) required to capture these in the NGGI, developing and publishing the underpinning science and logic required for ACCS methods and identify appropriate pathways for the adoption of these technologies, either through to the farm or into policy.

This project aligned with activities outlined in MLA/Department of Industry, Science, Energy and Resources (DCCEW) Grant Agreement MERLMLA000001 with regards to supporting development of DCCEW's Livestock Emissions Framework (LEF) and methods for estimating enteric methane emissions reductions applicable at multiple scales.

The target audience for this research is a combination of informing government policy on future carbon methodologies, and industry professionals and farmers providing them with evaluated options for reducing emissions. The data generated has been and will continue to be used to underpin future policy development, carbon offset methodology and pathways towards CN30.

2. Objectives

The IMS project drew on the findings of relevant national and international research, filling the key research gaps in information to:

- Identify new and emerging mitigation and sequestration options that can deliver towards the CN30 target, evaluating these in a farming systems and supply-chain context.
    - Output: Peer reviewed papers and communication of the information has been achieved as reported in the appendices of this final report;

- Identifying accounting protocols appropriate to capture new mitigation actions at farm, supply chain and national inventory scale, developing the underpinning science and logic required for their adoption from farm through to policy;
  - Output: A publication of accounting protocols is provided in the appendices and has been captured in existing farm accounting tools.
- Review international developments in the definition and assessment of carbon neutrality, providing advice on alignment and refinements required, as relevant to the Australian red meat industry.
  - Output: Peer reviewed paper and communication of the information has been achieved as reported in the appendices of this final report;
- Identify appropriate pathways for the adoption of new mitigation technologies by farmers, industry and policy;
  - Output: Progress reports; workshops and consultations with relevant producer groups has been achieved as reported in the appendices of this final report.
- Identify potential research gaps emerging, feeding these back into the CN30 research priorities.
  - Output: Progress reports and updates for policy and industry have been delivered on the regular schedule as reported in the appendices of this final report
- Identify potential research gaps emerging, feeding these back into the CN30 research priorities.
  - Output: potential research gaps have been identified in this final report.
- Conduct activities to achieve objectives outlined in MLA/DCCEW Grant Agreement MERLMLA000001
  - Output: achieved and detailed in this final report.

3. Milestones

A summary of the aggregate milestones for this project were as follows:

- Synthesis task group (STG) convened with priorities identified and allocated.
- IMS annual team workshop convened.
- Allocated analyses completed and reported to stakeholders for review.
- Policy briefing for DCCEW/DAFF/MLA.
- Papers submitted for publication.
- Accounting frameworks for emissions reduction developed.
- Research outcomes communicated to producers; consultation with producer groups and stakeholders via webinars and events.
- Livestock emissions framework developed for mitigation options.

4. Methodology

Under the guidance of the Synthesis Task Group, the IMS project identified mitigation and sequestration options that can deliver towards the CN30 target, including identifying appropriate accounting protocols, and evaluated these in a farming systems and supply-chain context.

- A number of farm case studies highlighting potential innovations and mitigation options;
- conducted meta-analysis focused on the bromoform, 3-NOP and dietary oils;
- published analyses and reviews of soil carbon, temperate and tropical legumes;
- improved greenhouse gas accounting protocols and captured these in the MLA carbon calculator and the AIA environmental accounting platform.

- These were communicated with farmers at numerous field days, industry conferences, common science conferences and policy briefings.

4.1 Connecting component research to outcomes

The CN30-IMS project has been a vital thread joining together and collectively analyses all of the existing and emergent abatement strategies developed through local (CSP, EAP, MERiL) and international (e.g. ERA-GAS, NZAGRC) research, to determine their potential impact on production, profit and GHG emissions at the whole farm level, refinement required in the NGGI, and their suitability for development into a ACCS method. These analyses were used to identified key gaps in knowledge required to progress the research through to adoption.

The IMS project operated at two levels:

- Establish and coordinate an IMS Synthesis Task Group (STG), who had oversight over all CN30 relevant research, assessed policy implications and facilitated industry adoption. This STG provided direction to the IMS Project Team. The STG directed work to be conducted to achieve the outcomes of MLA/DCCEW Grant Agreement MERLMLA000001.
- An IMS Project team – the STG provided strategic direction and prioritise tasks for the project team, with the project team reporting back to the STG on progress and project outputs.

4.2 The IMS Synthesis Task Group (STG)

The IMS project established and coordinated a STG to provide direction to the CN30-IMS project team. This STG was comprised of industry (MLA), government (DCCEW) and selected scientists representing the IMS project and relevant areas of research to ensure that all possible pathways for research informing policy were considered. Given the more strategic role of the STG, essentially sitting apart from the CN30-relevant projects, the key stakeholders in the CSP, EAP, MERiL and IMS projects, together with partner research providers, determined the STG membership.

The STG met quarterly to discuss and prioritise emerging mitigation options that require whole farm systems analysis, life cycle analysis, potential for incorporation into the LEF, new NGGI accounting protocols and/or further development of ACCS methods. At these quarterly meetings, CN30 aligned research teams (e.g. CSP, EAP, MERiL, Nexus, CN30-IMS, Method to Market) and relevant external research (e.g. PIPAP, Farm-scale Natural Capital Accounting project, Cool Soil Initiative, CMI Landscape Taskforce etc.) was invited to present an update of their research for discussion and consideration. The IMS project team members also attended updates and team meetings of the CSP, EAP, MERiL, Nexus projects, in order to remain current with the status of the research, feeding this back into the IMS Project Team where required. Members of the STG also tabled other relevant projects and data sources that can feed into the IMS project analysis.

The STG identified potential pathways through to industry and on-farm adoption and ensure that the analyses are communicated through to existing industry adoption mechanisms. Consultations occurred with targeted groups (e.g. farming systems groups), advisors and aggregators to ground-truth mitigation options, access regional datasets (e.g. soil C) and ensure models are appropriately calibrated. This was an important producer engagement activity to communicate project outcomes and evaluate feasibility and barriers to adoption of mitigation options. This includes building producers' capacity to enable the transition towards carbon neutrality and understanding the perspectives and information needs of producers, and constraints and incentives to implementing sequestration options.

4.2.1 Specific roles of the Synthesis Task Group

Prioritising emerging mitigation options that require further analysis by the IMS project team. This included:

- A full farm systems, life cycle or supply chain analysis of an identified mitigation option, recommending how this can be captured in the LEF/NGGI and/or underpin a ACCS method to recognise their adoption by livestock producers (e.g. establishment of tropical legumes);
- A systematic literature review or meta-analysis required to underpin development of the LEF and/or changes to the NGGI to account for targeted mitigation options (e.g. the meta-analysis of dietary oils and methane that was conducted to develop the equation underpinning the dairy supplements method; similar was be applied to Desmanthus, 3-NOP and Asparagopsis, as examples),
- Identifying the potential adverse impacts on environment and animal and human health and welfare in Australian production systems, and
- The development of accounting algorithms and new/novel sources or activity data required for the LEF/NGGI, to underpin a ACCS method (if relevant) or determine the carbon footprint or neutrality status of a farm business, region or supply chain.
- Based on the outputs of the IMS Project Team and the activities to be funded by the MLA and MERiL grants, provide science advice to MLA, industry and government on:
    - The science, algorithms and data sources required to justify and underpin the LEF, a new or modified ACCS method and/or capture identified mitigation actions in the NGGI;
    - New, novel or surrogate sources of the data required by the LEF, NGGI and an ACCS method to estimate abatement or sequestration, and
    - Guidance on the accounting and certification of the carbon footprint or neutrality status of a farm, supply chain or industry.
- Identify research and data gaps essential to deliver abatement on farm, including accounting for mitigation actions in the inventory and through ACCS methods, including:
    - Identify and develop new and emerging mitigation options, and
    - Identify new, novel or surrogate data sources to support the NGGI and ACCS methods.
- Advise on the allocation of funding to MLA and DCCEW to complement/modify CN30 relevant projects (e.g. CSP, EAP, MERiL, LESsGAS) to help fill those gaps identified by the STG.
- Support the collection of data from the EAP and MERiL/LESsGAS program research projects that engage Australian livestock producers in research and education on the emissions and productivity impacts from the use of feed technologies.

4.3 The IMS Project Team

Each research partner in the IMS project contributed dedicated research capacity to an IMS project Team (either funded by the IMS project or provided as in-kind by the partner). This dedicated research capacity worked under close supervision of senior scientists within their organisation to provide the specific analyses prioritised by the STG, as agreed with individual research providers.

New regionally relevant mitigation options that require farm systems and/or supply chain analysis was constantly identified throughout the life of the IMS project (realistically these were mainly identified by the IMS project team), with these options submitted to and prioritised through the STG and delegated to the proposing members of the IMS project team for further analysis. This analysis aimed to understand the whole farm mitigation potential, life cycle and productivity impacts of the mitigation option in a farm systems and/or supply chain context, where possible leveraging existing analyses and publications from previous research (e.g. WFSAM, RELRP, SCARP, NORP) or developed under current research (e.g. Nexus, CSP, EAP, MERiL etc.). These farm system analyses were published in collaboration with the originating research team, as part of the peer-reviewed evidence required to underpin development of the LEF, changes to the NGGI or the development of new ACCS methods, thereby value-adding to their research through addressing key gaps in translating their research through to the next user.

The IMS project team also identified optimal research directions to support the LEF, conduct meta-analysis and data sharing to underpin the LEF, identify appropriate dose-response and productivity-response relationships from the use of feed technologies in Australian production systems, potential improvements to the NGGI, new ACCS methods, improvements to existing ACCS methods, providing the science required to support these developments. This analysis also included identifying the key activity data and appropriate accounting protocols and algorithms that would be required to underpin an ACCS method or an NGGI improvement.

The protocol, models and tools used in this analysis were context-specific and depended on the analysis being conducted, while ensuring that methods used are not inconsistent with the NGGI. For example, the evaluation of the mitigation potential of temperate legumes in sheep systems in southern Australia may require the GrassGro model to establish the farm system and dynamic flock composition, the SB-GAF tool (fully consistent with NGGI) to determine the emissions, but also the RothC or FullCam models to evaluate the soil carbon implications (noting the soil carbon routines in FullCam, APSIM and SGS are all derived from RothC, so not inconsistent but not fully tested). Likewise, the evaluation of the mitigation potential of a tropical legume (e.g. Desmanthus, Leucaena) in beef systems in northern Australia may require linking the GRASP model, with the BreedCow Dynama model to establish the farm system and herd composition, the SB-GAF tool to determine the emissions, the Enterprise model to calculate economic outcomes, but also the FullCam or RothC model to evaluate the soil and tree carbon implications. Algorithms and activity data required to underpin improvements to the NGGI or a new ACCS method may require a meta-analysis or a systematic literature review published in the peer reviewed literature.

4.3.1 Specific skills of IMS project team leaders

Richard Eckard is a Professor of Sustainable Agriculture at the University of Melbourne and Director of the Primary Industries Climate Challenges Centre, a research centre addressing the impacts of a changing climate on agriculture. His research focuses on systems analysis of carbon neutral agriculture. Richard developed the first greenhouse gas accounting tools for agriculture with his research and expertise provided the science basis for the development of six carbon CFI/ ERF/ACCS methods in Australia.

Peter Grace is a Professor of Global Change, at Queensland University of Technology, specialising on nitrogen use efficiency and greenhouse gas emissions from agricultural and native ecosystems, soil carbon sequestration and mitigation strategies and simulation of agroecosystem productivity and its relationship to soil carbon and nitrogen management.

Warwick Badgery is a Research Leader, Rangelands and Tropical Pastures with NSW Department of Primary Industries and is a specialist in grazing systems and grazing management research, with more recent focus on soil carbon developing the first pilot trading scheme for soil carbon in Australia.

Annette Cowie is a Principal Research Scientist - Climate, in NSW Department of Primary Industries, specialising in sustainable resource management. Her current research focuses on sustainability assessment and greenhouse gas accounting for agriculture with particular focus on soil carbon dynamics, biochar and bioenergy; and development of emission reduction pathways for the primary industries sector.

4.4 The larger IMS project consortium

The IMS project team collaborated with a number of other similar projects and research teams, with the aim of avoiding duplication and to facilitate consistency in the approach taken to the various analysis. The IMS project team convened workshops, at least once per year, where all these aligned project teams can present their research in progress and share their innovations and approaches, with the aim of building national capability in low emissions agriculture systems analysis, consistent with the CN30 Plan on a Page (POAP) key work area. Apart from the IMS Project Team members, these workshops would include teams from related projects like the Nexus Project (e.g. Brendan Cullen, Matt Harrison, Di Mayberry), Methods 2 Markets project (Steve Bray, Maree Bowen, QDAF) and selected CSP, EAP, MERiL projects and other related project teams (e.g. Mandy Curnow, DPRID WA).

Depending on the tasks allocated by the STG, some of the more specialist roles can be sub-contracted directly additional teams with appropriate skills. For example, Dr Margaret Renouf, QUT Centre for Agriculture and the Bioeconomy, and Dr Stephen Wiedemann, Integrity Ag & Environment, both being specialists in lifecycle analysis, but focusing on post- versus pre-farm gate, respectively.

5. Results

5.1 STG Group meetings and IMS workshops

Milestone: Synthesis task group (STG) convened with priorities identified and allocated.

The Synthesis Task Group (STG) held meetings on:

- 2021: 8 September; 4 November and 2 December
- 2022: 29 March; 3 June and 22 November
- 2023: 15 February, 14 August and 7 December
- 2024: 29 April and 10 September

The minutes of STG meetings have been provided by MLA to the STG.

Milestone: IMS annual team workshop convened.

The IMS team met on the following occasions in person. However, getting the whole team together was not considered cost effective once relationships had been established and individual contact became the norm. For example, the University of Melbourne team would contact the NSW DPI team directly and individually.

- 14 July 2022 – inaugural project workshop North Sydney
- 14 March 2023 – project workshop in Canberra, connected to Monaro field day
- 8 August 2023 - IMS project team leaders meeting
- 2 February 2024 – IMS project team leaders meeting

5.2 Greenhouse Gas Accounting Frameworks

Milestone: Accounting frameworks for emissions reduction developed.

The Greenhouse Gas Accounting Framework calculators (e.g. SB-GAF) continue to be updated regularly, given significant feedback from commercial users of the tools. We now have produced a monthly time step version as well as a seasonal version of the sheep and beef calculator. These calculators have also been updated to the latest updates published in the March 2024 version of the national greenhouse gas inventory. This includes nitrogen fertiliser emission factor updates and crop residue factor updates.

The MLA carbon calculator has been further improved to include goats and feedlot cattle. This Update was the result of extensive collaboration between Maria Lopez, IMS research fellow University of Melbourne and Norbert Feron from Cognizant (formally Servian), MLA's developers. The MLA on-line version of the SB-GAF tool has now been tested by the University of Melbourne team in four farmer workshops with over 60 farmers providing feedback on the utility of the software. Overall, the farmers found it highly intuitive and user-friendly, with only minor suggestions for improvement.

Specific feedback included requests for features such as:

- The ability to reorder seasons in the calculator;
- The ability to name mobs (e.g. autumn and spring calving cows);
- Ability to enter wool weights with one decimal point;
- Improved tracking of calving/lambing percentages;
- Exclusion of lambing/calving rates where not relevant and
- More precise allocation of fractions for emissions and sinks at the farm scale.

The project team have also been actively working with AIA on the Environmental Accounting Platform, to create an engine for the calculation of red meat emission sources. The Technical Reference Group for the AIA online tool (Richard Eckard, Peter Grace, Annette Cowie and Dan Schwartz) now meets regularly to oversee key developments in these tools.

With the announcement by the Minister for Agriculture that government will "develop, publish and maintain voluntary emissions estimation and reporting 'standards' for industry", we have now formed a joint chaired industry reference and technical reference group, linking project 3.1 (Guidance for on-farm greenhouse gas (GHG) accounting) in the Zero Net Emissions Agriculture CRC with colleagues in DCCEW and DAFF.

5.3 Meta-analyses

Milestone: Allocated analyses completed and reported to stakeholders for review

Milestone: Livestock emissions framework developed for mitigation options.

The first step in the project was to develop an agreed protocol for conducting meta-analysis of potential methane mitigating feed supplements. This protocol included appropriate treatment of data, criteria for the selection of peer reviewed publications and appropriate statistical methodologies. A guideline document was produced, (attached in appendices) to assist subsequent groups in conducting similar analysis.

The project started with a comprehensive literature review of bromoform, 3-NOP, oils and essential oils. It was concluded fairly early in the project that there was insufficient data on bromoform concentrations across a number of rights of inclusion to conduct a statistically significant meta-analysis. This was agreed by Future Feed with an agreement to wait until the next round of MERIL projects have published their findings.

The project then focused on a meta-analysis of 3-NOP (Bovair ®) Including extensive engagement with the inventors of the product from DSM nutrition. A peer reviewed paper is now in review detailing equations for beef, dairy and all bovines combined (The paper is attached in the appendices).

The final meta-analysis then focused on oils and essential oils, with all the relevant data now extracted and perspective equations identified. A paper is in preparation for submission to a journal.

The project team also engaged with the Livestock Emissions Carbon Farming Working Group, contributing to the submission of an expression of interest to the ACCU scheme, proposing a "Reduction of enteric methane emissions in ruminant livestock from feed additives and forage". This was submitted in June 2024.

5.4 Case studies

Milestone: Allocated analyses completed and reported to stakeholders for review

Farm case studies were conducted on the Jigsaw farms, Dunkeld pastoral and Tipperary station. The purpose of these studies were as follows:

- Jigsaw Farms, Hamilton Vic: the main focus was to repeat the original audit conducted in 2011, given the change in property boundary and maturity of the tree plantings. The purpose was to show the temporary nature of opposites through soil and tree sequestration.
- Dunkeld pastoral, Dunkeld, Vic: This property was chosen given its proximity to the Jigsaw Farms case study, but with areas of much older vegetation (no offset value), versus new property areas purchased and converted from cropping to grazing.
- Tipperary station, Northern Territory: this property was chosen given a great diversity of farming operations, but with potential to confirm and feed cattle on cropping produce from the property.

The detailed case studies are provided in the appendices, with the Jigsaw Farms update now submitted as a paper for peer review.

5.5 QUT Tropical legumes and modelling soil carbon change

Milestone: Allocated analyses completed and reported to stakeholders for review

Tropical, summer dominate rainfall, pasture systems cover half of Australian continent and offer unique challenges re sustainable production in the long-term. Simulation models also play a key role in 'road testing' new management practices and their long-term impact. The Queensland University of Technology component of the IMS project included the following key deliverables:

- A review of tropical legumes and the methane mitigation potential (see Appendix 8.1.2)
- Modelling of soil carbon change and mitigation strategies in Queensland rangelands (see Appendix 8.1.4)
- Development of a robust soil carbon crediting system (see Appendix 8.1.3)
- Long-term soil carbon and modelling at tropical grassland sites (Brian Pastures and Wambiana) and Leucaena chronosequence (see Appendix 8.5.1)
- Long-term soil carbon and modelling at temperate DPIRD grassland sites (OAI, CAMBI and Monaro) (see Appendix 8.5.2)

5.6 DPIRD Soil carbon sequestration and farmer adoption pathways

Milestone: Allocated analyses completed and reported to stakeholders for review

Milestones: Research outcomes communicated to producers; consultation with producer groups and stakeholders via webinars/events.

Review of temperate legumes and herbs to reduce enteric methane

- A review was published to devise a framework to assess GHG reductions when introducing low methane yielding species, assess mechanisms of methane reduction in temperate legume and herb species for Australia, and provide a case study to demonstrate expected changes to system-level GHG emissions with the introduction of low methane yielding legumes.

Identify new and emerging mitigation and sequestration options that can deliver towards the CN30 target, evaluating these in a farming systems and supply-chain context

- Analysis and remeasurement of changes in soil carbon over 12 years in response to a range of stocking rates, rotational systems and days of rest between grazing events in a temperate climate (Orange Agricultural Institute long-term grazing trial).
- Analysis of archived soils collected from CSIRO long-term (20 years) soil fertility and stocking rate trial at the Ginninderra Research Station, ACT.
- Repeated measurement of long-term sites to determine the response to soil type, climate and pasture management on soil carbon in the cool temperate region of the Monaro region of southern NSW over a 15-year period.
- Remeasurement and analysis of the sites used for the soil carbon and market-based pilot study for the period 2012-2024 in the Central Tablelands regions of NSW.

Identify appropriate pathways for the adoption of new mitigation technologies by farmers, industry and policy

- Two producer groups were established
- Monaro region, SE NSW; primarily sheep and cattle grazing (16 enterprises)
- Central Tablelands region, central NSW; mixed farming (10 enterprises)
- Over 18-24 months, six workshop held for each producer group and determined their GHG emissions and the extent that these emissions could be mitigated using currently available technologies, changes in management (using GrassGro for a modelled farm appropriate for that region) and sequestering carbon.

- Using several potential scenarios, feedback from producers on the limitations, opportunities and other co-benefits that may occur from using a wide range of methods to reduce the emission intensity of their enterprises were explored and their feedback solicited.

5.7 Communications

Milestones:

- Policy briefing for DCCEW/DAFF/MLA.
- Papers submitted for publication.
- Research outcomes communicated to producers; consultation with producer groups and stakeholders via webinars/ events.

Significant communication has been conducted by the project team. This included industry conferences, field days, training events and webinars, reaching farmers and their consultants. Regular policy briefings were held with DCCEW and DAFF as reported in the Appendices.

6. Conclusion

Farm systems analysis is required to integrate component research to understand the whole of implications of various research developments. This is required to inform policy, avoid unanticipated outcomes from various best practise recommendations, and give farmers confidence to adopt new practices. It is also essential to advise MLA on pathways to achieve the goal of CN30.

A conclusion from this work is that it is essential to continue for the whole of agriculture which will now occur under the new Zero Net Emissions Agriculture CRC.

Specific conclusions from this research would include:

Dietary supplements:

There is currently insufficient data on bromoform to conduct a meta-analysis and develop a statistically significant predictive equation. Once the latest round of MERiL projects are peer reviewed it is like a this will provide sufficient data.

A statistically significant equation was developed for 3-NOP and for dietary oils. Equations can now be used to underpin a generic supplement method for all bovines.

Farm case studies:

Case studies were conducted on Jigsaw Farms, Dunkeld pastoral and Tipperary station, exploring relevant mitigation options and interventions.

Jigsaw Farms clearly showed the limitation of relying exclusively on soil and tree sequestration to achieve a net zero status, as 20 years later the trees have matured and no longer provide a complete offset. The conclusion here is that, unless a focus is on reducing methane, offsets are only a temporary solution.

Dunkeld pastoral provided a useful case study comparing older tree establishments with a greenfield cropping block, purchased with the view of planting trees with co-benefits in mind first;

Tipperary station allowed us to look at an integrated farm system where for example cotton seed, grown on the property could be fed to the cattle in the finishing feedlot not only providing them with Improved energy, but also reducing their emissions during the finishing phase.

Greenhouse gas accounting protocols

A conclusion from this project is that there will be an ongoing need to review and update appropriate accounting protocols for the red meat industry, as international reporting requirements continue to emerge over time and the national greenhouse gas inventory is updated periodically.

A project has been commissioned by the Zero Net Emissions Agriculture CRC to ensure that greenhouse gas accounting in Australia meets international requirements. Initially, this project will be jointly chaired between DCCEW and the CRC as they work towards an initial draft 'standard' for greenhouse gas accounting. Following this initial guideline document the CRC project will continue to work on guidelines for specific supply chain reporting requirements e.g. SBTI, GHG Protocol, TCFD.

Adoption by producers will be addressed through value chain reporting requirements i.e. Value chain each have their own nuanced reporting requirements and they will have the responsibility of gathering the appropriate scale of data. This might vary between the bank, processor, retailer etc.

Low methane pastures

The review suggested there are temperate legumes and herbs with anti-methanogenic properties, and/or high productivity that could reduce total methane emissions and emissions intensity of ruminant livestock production. Further, there is also great diversity in some plant genotypes that can be exploited, and this will be aided by more detailed understanding of plant secondary compounds associated with methane reduction.

Leucaena, Desmanthus, and Stylosanthes are not only effective at reducing CH_4 production but have also proven to be persistent and productive under Northern Australian conditions. Their persistence, marked by grazing tolerance, longevity, resistance to disease and pests, and the ability to flower and seed in short, variable wet seasons, makes them strong candidates for promotion in sustainable Northern grazing systems.

While these low methane pastures have potential to reduce commissions intensity, along with secondary compounds reducing absolute emissions, these may be nullified by the potential to increase stocking rate does increase total farm emissions.

Sequestration of carbon in soil

Soil carbon levels in both temperate and tropical grasslands are relatively static under contemporary management. Small increases may be possible but there is insufficient quality data on the longer-term impacts of rotational and regenerative practices, particularly to verify reported changes at depth.

Analysis of data from NSW DPIRD Orange Agricultural Institute and CSIRO long-term grazing studies both confirmed that provided a pasture system is not being overgrazed and degraded, stocking rate has little to no impact on soil C.

Pasture management strategies that increase plant productivity i.e., appropriate additions of superphosphate fertiliser and well-managed grazing strategies that ensure plants are able to recover post-grazing, not only increase the amount of carbon stored in soil but more importantly they help ensure that carbon is maintained in the soil during periods when it is more likely to be lost i.e., drought or periods of low-rainfall.

Data from the Monaro region of southern NSW suggest that effect of rainfall on soil C is strongly impacted by soil type and thus rainfall alone is not always a good short-term predictor of increases or decreases in soil carbon.

Longer periods of time (e.g. 5 years) are recommended between soil C measurements to account for annual rainfall variability and reduce the likelihood of over-estimating soil C gains. Reasonable bounds should also be established for expected long-term soil C gain due to management change, informed by the best available science.

An important finding, reported in our paper by Mitchell et al. 2024), found that of the ~250,000 carbon credits issued for SOC in 2023, these gains were primarily driven by above-average rainfall rather than by project interventions. Furthermore, when rainfall returned to average conditions, these large SOC gains did not persist, raising questions on whether the credits issued represent durable carbon sequestration in addition to what would have occurred without project intervention.

By calibrating and validating the internationally recognised DayCent model with both long-term soil C data and CO_2 exchange data from a network of eddy covariance flux towers located in Central and Southern Queensland, the validity of the simulation approach to successfully estimate and project soil C sequestration in response to management was confirmed for grasslands of north-eastern Australia.

Communications and engagement

Feedback from producers suggest that technologies to reduce emissions in grazing systems are currently of little advantage and are unlikely to be widely taken up due to a variety of limitations including, but not limited to, cost, lack of resources/labour and availability. They thought that the use of best management practices that improved the overall efficiency of their operation and thereby reduce their emission intensity (and increase gross margin) was practical and implementable. Moreover, these practices could be (continue to be) implemented relatively quickly (one to five years) with little change in most operations as most producers are already focused on improving efficiency in their business.

There is a significant asymmetry of information available to farmers on low emissions agriculture and carbon farming. The number of farmer engagements, field days, industry conferences online events that the project team were involved in demonstrate the high demand for independent accurate information.

6.1 Key findings

Meta-analyses

- The meta-analyses highlighted limitations in peer reviewed studies, particularly where the rate of active ingredient in Asparagopsis was not stated. This discounted the first half of all the peer reviewed studies with the bromoform content was not known.
- The meta-analyses also highlighted the need to shift from an absolute reduction to a relative mean difference, allowing pooling of datasets across species to provide a more rigorous equation. This is similar to what UC Davis discovered in their similar analysis.

Case studies

- The carbon audit on Jigsaw Farms has clearly demonstrated that carbon offsets in soils and trees are a short term solution only. This audit also demonstrated that the Co benefits should be the main focus, as the benefits of shade and shelter for animal welfare and the biodiversity benefits continue in perpetuity, while the carbon benefits show diminishing returns. This would fundamentally change the design of trees in agricultural landscapes, away from a block of trees on poor quality soils, to trees strategically placed throughout the grazing system.

Greenhouse gas accounting

- While significant effort is gone into the development of online tools for greenhouse gas accounting, the emergence of third party tools means that a national standard is required to ensure integrity in greenhouse gas accounting.
- The bottom up carbon accounts conducted continued to demonstrate the need to develop more farm specific accounting mechanisms, to ensure incentives for farmers to reduce emissions.
- The need for well managed long term reference sites to inform cost-effective modelling of soil carbon change to reduce the risk of over crediting.

Communications and engagement

- There is a significant asymmetry of information available to farmers on low emissions agriculture and carbon farming. The number of farmer engagements, field days, industry conferences online events that the project team were involved in demonstrate the high demand for independent factual information.

6.2 Benefits to industry

- The project has developed predictive equations that can be used to reward farmers for feeding dietary supplements to reduce methane;
- The project has updated the greenhouse gas accounting protocols for the red meat industry, which ensures that accounting for progress toward zero net emissions or carbon neutrality at a farm level meets international requirements;
- The project has provided clear information for farmers on the limitations of trees as an offset, but clearly demonstrated that the Co benefits on animal welfare, biodiversity and salinity management remain ongoing. This changes the approach to planting trees and where they are planted in landscapes.
- The project developed a significant body of practical information on dietary supplements, soil carbon change and legumes as potential mitigation strategies and highlighted the limitations of using offsets alone.
- The project has developed a practical source of independent and peer reviewed information that can now be communicated to farmers.

6.3 Future research and recommendations

- A generic supplement method should be supported using the meta-analysis equations developed in this project, so that farmers can get rewarded for their mitigation; this is currently prioritised by the Commonwealth, with a generic method already drafted;

- Future research is required ongoing to ensure greenhouse gas accounting protocols meet international reporting requirements. This priority has been captured in the Zero Net Emissions Agriculture CRC.
- Future research is required ongoing to capture component research and place this in a whole of systems context, to give farmers confidence in adoption, and policy more confidence in the viability of mitigation options. This priority has been captured in the Zero Net Emissions Agriculture CRC.
- Farm case studies are a useful way to place research in a context and demonstrate this to farmers for adoption. This priority has been captured in the demonstration sites under the Zero Net Emissions Agriculture CRC.

7. References

Milestone: At least 3 papers submitted for publication based on analyses.

Badgery, W, Li, G, Simmons, A, Wood, J, Smith, R, Peck, D, Ingram, L, Durmic, Z, Cowie, A, Humphries, A, Hutton, P, Winslow, E, Vercoe, P, Eckard, R (2023) Reducing enteric methane of ruminants in Australian grazing systems – a review of the role for temperate legumes and herbs. *Crop & Pasture Science* **74**, 661-679. https://doi.org/10.1071/CP22299

Grace P., de Rosa D., Shcherbak I., Strazzabosco A., Rowlings D., Scheer C., Barton L., Wang W., Schwenke G., Armstrong R., Porter I. Bell M. (2023) Revised Emission Factors for Estimating Direct Nitrous Oxide Emissions from Nitrogen Inputs in Australia's Agricultural Production Systems: A meta-analysis" *Soil Research* (accepted).

Macdonald A., Court J., Meyer R., Wooton M., Keenan R., Stewart H., Eckard R. (2024) Offsets required to reduce the carbon balance of sheep and beef farms through carbon sequestration in trees and soils: A decade on. *Animal Production Science* (in review)

Macdonald A., Hepworth G., Eckard R. (2024). Quantifying the effect of Bovaer® on methane emissions from confinement fed bovines: a meta-analysis. *Animal* (in review)

McDonald, SE, Badgery, W, Clarendon, S, Orgill, S, Sinclair, K, Meyer, R, Butchart, DB, Eckard, R, Rowlings, D, Grace, P, Doran-Browne, N, Harden, S, Macdonald, A, Wellington, M, Pachas, ANA, Eisner, R, Amidy, M, Harrison, MT (2023) Grazing management for soil carbon in Australia: A review. *Journal of Environmental Management* **347**, 119146. https://doi.org/10.1016/j.jenvman.2023.119146

Mitchell, E., Henry, B., Peck, G., Charmley, E., Grace, P., Eckard, R. (2024) Reducing enteric methane of ruminants in Australian grazing systems – a review of the role for tropical legumes (in review)

Mitchell, E., Takeda, N., Grace, L., Grace, P., Day, K., Ahmadi, S., … Rowlings, D. (2024). Making soil carbon credits work for climate change mitigation. *Carbon Management*, **15**(1). https://doi.org/10.1080/17583004.2024.2430780

Shephard, RJ Eckard, T Whittem, A Macdonald, G Hepworth (2024) A meta-analytical approach for estimating methane suppression from dietary additives in ruminants. *Frontiers in Animal Science* **5**:1451266. doi: 10.3389/fanim.2024.1451266

Simmons, A.T., Ingram, L., Badgery, W.B. Karl Andersson, K.O., Mitchell, E. Farming Carbon: The Risks faced by farmers relying on soil organic sequestration as a business strategy. Agriculture, Ecosystems and Environment (to be submitted).

Simmons, A.T., Ingram, L., McDonald, S., Kardailsky, I., Badgery, W.B. (2024) The impact of land use change and seasonal climate on soil organic carbon stocks are greater than those associated with grazing management. Agriculture, Ecosystems and Environment (in review).

Takeda, N, Parton, W., Grace, L., Rowlings, D., Day, K., Nguyen, T., Grace, P. (2024) Soil carbon sequestration in subtropical grasslands estimated by DayCent (in review)

8. Appendix

8.1 Publications

8.1.1 Low methane pastures review (published)

https://doi.org/10.1071/CP22299

CSIRO PUBLISHING

SPECIAL ISSUE | REVIEW
https://doi.org/10.1071/CP22299

CROP & PASTURE SCIENCE

Reducing enteric methane of ruminants in Australian grazing systems – a review of the role for temperate legumes and herbs

Warwick Badgery[A,*], Guangdi Li[B], Aaron Simmons[C], Jennifer Wood[D], Rowan Smith[E], David Peck[F], Lachlan Ingram[G], Zoey Durmic[H], Annette Cowie[I], Alan Humphries[F], Peter Hutton[H], Emma Winslow[J], Phil Vercoe[H] and Richard Eckard[K]

For full list of author affiliations and declarations see end of paper

***Correspondence to:**
Warwick Badgery
NSW Department of Primary Industries, Orange Agricultural Institute, 1447 Forest Road, Orange, NSW 2800, Australia
Email: Warwick.badgery@dpi.nsw.gov.au

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ABSTRACT

In Australia, 71% of agricultural greenhouse gas (GHG) emissions are enteric methane (CH_4), mostly produced by grazing sheep and cattle. Temperate low CH_4 yielding legumes and herbs can mitigate enteric CH_4 production, but system-level GHG emissions need to be considered. The aims of the study were to: (1) devise a framework to assess GHG reductions when introducing low CH_4 yielding species; (2) assess mechanisms of CH_4 reduction in temperate legume and herb species for Australia; (3) use a case study to demonstrate expected changes to system-level GHG emissions with the introduction of low CH_4 yielding legumes; and (4) identify knowledge gaps and research priorities. Results demonstrate lowering emissions intensity (kg CO_2-equivalent/kg product) is crucial to mitigate GHG emissions, but livestock productivity is also important. Several pasture species have anti-methanogenic properties, but responses often vary considerably. Of the species investigated biserrula (*Biserrula pelecinus*) has great potential to reduce enteric CH_4 emissions, but in a case study its emission intensity was similar to subterranean clover (*Trifolium subterraneum*) but higher than lucerne (*Medicago sativa*). We conclude that there are temperate legumes and herbs with anti-methanogenic properties, and/or high productivity that could reduce total CH_4 emissions and emissions intensity of ruminant livestock production. There is also great diversity in some plant genotypes that can be exploited, and this will be aided by more detailed understanding of plant secondary compounds associated with CH_4 reduction. This review suggests an opportunity to formulate pasture species mixtures to achieve reduced CH_4 emissions with greater or equal livestock production.

Keywords: bioactive plants, grazing systems, greenhouse gas reduction, herbs, legumes, livestock production, methane emissions, temperate pastures.

Introduction

Australia is a signatory to the Paris Agreement, which aims to limit global warming to no more than 2°C above pre-industrial levels. To meet this goal, there is an imperative to rapidly reduce global greenhouse gas (GHG) emissions. While reductions in GHG emissions are needed from most sectors, limiting global warming to below 2°C cannot be achieved without reducing emissions from the agricultural sector (Reisinger *et al.* 2021). In Australia, agriculture produces about 76.1 Mt carbon dioxide equivalents (CO_2-e) annually, which is about 15% of the national emissions (Commonwealth of Australia 2022). Approximately 71% of agricultural emissions are methane (CH_4) emitted from livestock, with enteric CH_4 emissions being the dominant source, equating to 48.2 Mt of CO_2-e emitted annually (DISER 2021). While there are other emissions sources in agricultural systems [e.g. nitrous oxide (N_2O) from soil], these sources make significantly lower contributions to the total GHG emissions of the agriculture sector. When the targets for GHG emissions reductions set by most multinational supply chain companies are considered, in conjunction with the fact that around 70% of Australian

8.1.3 Soil carbon credits paper (in press)

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Making soil carbon credits work for climate change mitigation

Elaine Mitchell[a], Naoya Takeda[a], Liam Grace[a], Peter Grace[a], Ken Day[a], Sahar Ahmadi[a], Warwick Badgery[b], Annette Cowie[b], Aaron Simmons[b], Richard Eckard[c], Matthew Tom Harrison[d], William Parton[a,e], Brian Wilson[f], Susan Orgill[g], Raphael A. Viscarra Rossel[h], David Pannell[i], Paige Stanley[j], Felicity Deane[k] and David Rowlings[a]

[a]Sustainable Agroecosystems, School of Biological and Environmental Science, Faculty of Science, Queensland University of Technology, Brisbane, QLD, Australia; [b]NSW Department of Primary Industries, Orange, University of New England, Armidale, NSW, Australia[c]School of Agriculture, Food, and Ecosystem Sciences, The University of Melbourne, Parkville, VIC, Australia; [d]Tasmanian Institute of Agriculture, University of Tasmania, Newnham, Launceston, TAS, Australia; [e]Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, USA; [f]School of Environmental and Rural Science, University of New England, Armidale, NSW, Australia; [g]Select Carbon, Brisbane, QLD, Australia; [h]Soil & Landscape Science, School of Molecular & Life Sciences, Faculty of Science & Engineering, Curtin University, Perth, WA, Australia; [i]Centre for Environmental Economics and Policy, University of Western Australia, Perth, WA, Australia; [j]Department of Soil and Crop Science, Colorado State University, CO, USA; [k]School of Law, Queensland University of Technology, Brisbane, QLD, Australia

ABSTRACT
In 2023, the Australian Government issued ~250,000 soil carbon credits following a measurement period characterised by high rainfall (Decile 10). The inferred soil organic carbon (SOC) sequestration rates during this period, ranging from ~2 to 8 t C ha^{-1} yr^{-1}, significantly exceed rates reported in Australian scientific studies (~0.1 to 1.2 t C ha^{-1} yr^{-1}). Our analysis, incorporating SOC and biomass measurements alongside remote sensing of NDVI, reveals that these SOC gains were largely attributable to above-average rainfall rather than project interventions. Moreover, these gains were not sustained when rainfall returned to average levels, raising concerns about the durability of credited sequestration and its additionality beyond natural climatic variability. Our findings demonstrate that current safeguards within the Soil Carbon Method—such as withholding 25% of credits during the first measurement period—are likely insufficient to account for climatic variability. To strengthen the integrity of the carbon crediting system, we recommend extending the minimum measurement period for credit issuance to at least five years. Additionally, governments should establish science-based 'reasonable bounds' for expected long-term SOC gains from management practices to sense-check reported outcomes. These measures will ensure that credited SOC sequestration is more closely tied to management-driven outcomes rather than short-term climate-driven fluctuations.

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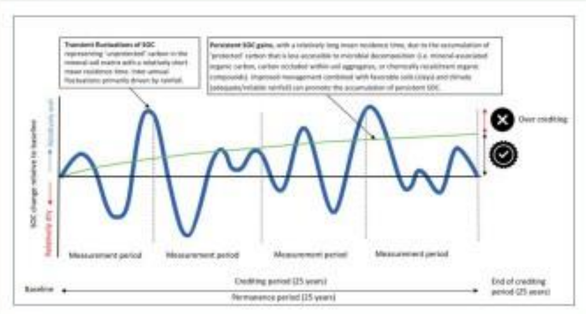
Policy; carbon market; carbon removals; soil carbon; greenhouse gas; climate change mitigation

GRAPHICAL ABSTRACT



A conceptual diagram of "new" carbon entering the soil system over a 25-year crediting period. Transient fluxes of SOC (blue) versus the accumulation of more persistent

8.1.4 Soil carbon modelling calibration and validation paper (in press)

Soil carbon sequestration potential under climate change in subtropical grasslands estimated by DayCent

Takeda, N., Rowlings, D., Parton, W., Grace, L., Day, K., Nguyen, T., & Grace, P. (2025). Soil carbon sequestration potential in subtropical grasslands estimated by DayCent-CABBI. *Soil Science Society of America Journal*, 89, e70003.

https://doi.org/10.1002/saj2.70003

8.1.5 Rumen additive estimation paper (published)

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Fred Provenza,
Utah State University, United States

REVIEWED BY
Ravikanth Reddy Poonooru,
University of Missouri, United States
Jihene Jabri,
National Veterinary School of Sidi Thabet, Tunisia

*CORRESPONDENCE
Richard Shephard
richard.shephard@unimelb.edu.au

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A meta-analytical approach for estimating methane suppression from dietary additives in ruminants

Richard Shephard[1,2*], Ted Whittem[3], Ainslie Macdonald[1], Graham Hepworth[4] and Richard Eckard[1]

[1]Food and Ecosystem Sciences, University of Melbourne, Melbourne, VIC, Australia, [2]Herd Health Pty Ltd, Maffra, VIC, Australia, [3]Djanowot Pty Ltd, Melbourne, VIC, Australia, [4]Statistical Consulting Centre, University of Melbourne, Melbourne, VIC, Australia

Introduction: Methane production inhibitors included in feed additives are increasingly used to suppress methane production in the rumen. Most products interact with the rumen microbiome and/or component biochemical pathways that scavenge free hydrogen ions (H+) to make methane (CH_4). The capacity of these agents to inhibit rumen methane production is determined by the ability of the chemical to block methane production pathways, the amount of agent delivered to the rumen (i.e. the dose) and the absorption, distribution, metabolism and excretion (i.e. the pharmacokinetic) characteristics of the chemical that contribute to removal from the site of action (the rumen). The intrinsic inhibitory capacity of an agent determines the maximum rate of methane suppression. This maximal rate may reduce according to pharmacokinetic effects arising from dose rate and frequency. Most studies of additive methane reduction efficacy use total mixed ration (TMR; with the additive included into the ration) feeding systems and estimate methane reduction (absolute or relative) across a 24-hour period. Few studies report critical pharmacokinetic parameters, making it difficult to extrapolate findings into non-TMR systems (such as grazing) where differing doses and dose frequencies apply.

Methods: We consider the likely behaviour of a rumen-acting oral additive to reduce methane production applying basic pharmacokinetic principles to propose an analytical approach to data from multiple field studies employing different dose rates and dose frequencies to estimate methane suppression responses. This is based upon a logistic transformation of relative efficacy (percentage reduction in methane comparing treatment with control groups) as the dependent variable and includes total dose, dose frequency, quadratic and interaction terms between total dose and dose frequency as independent variables that potentially capture any pharmacokinetic effects on performance. The model was tested using simulation and verified against real data (cattle 3-nitrooxypropanol (3-NOP) methane-reduction studies).

Results: Good fit between predicted and observed methane suppression was obtained.

8.1.6 Jigsaw farms paper (in press)

Macdonald, A, Court, J, Meyer, R, Wootton, M, Kantor, E, Keenan, R, Stewart, H, Eckard, R (2025) Can soil and tree carbon sequestration maintain zero net emissions grazing? Animal Production Science 65, -. https://doi.org/10.1071/AN24346

8.1.7 Bovaer® Meta-Analysis (in review)

Quantifying the effect of 3-Nitrooxypropanol on methane emissions from confinement-fed dairy and beef cattle: a meta-analysis *(paper in second round of peer review)*

Ainslie Macdonald[a]✉., Graham Hepworth[b]., Richard Eckard[a]

a School of Agriculture, Food and Ecosystem Sciences (SAFES), University of Melbourne, Melbourne, VIC 3010, Australia

b Statistical Consulting Centre, The University of Melbourne, Melbourne, VIC 3010, Australia

Funding: This work was completed with support from Meat and Livestock Australia and the Department of Climate Change, Energy, the Environment and Water as part of the Integrated Management Strategies project.

✉ Ainslie Macdonald ainslie@unimelb.edu.au

Abstract

Livestock industries are facing a challenge, they must reduce anthropogenic greenhouse gas emissions (GHGe) and mitigate climate change without reducing productivity or increasing global GHGe from livestock through leakage. This meta-analysis recognises that to achieve the significant and long-term reductions in GHGe, emissions need to be primarily avoided through innovations in technology such as 3-nitrooxypropanol (3-NOP), to sustainably produce low, or no-emission products. 3-NOP is a synthetic compound capable of reducing enteric methane by 11.49% to 63.01%, at the dosage of ≤60 mg 3-NOP/ kg DMI. Although 3-NOP supplementation has shown to have a strong relationship with methane reduction across all studies, regardless of animal type, breed or diet, there is significant heterogeneity within, and between studies. This meta-analysis utilises data from 21 *in vivo* studies of confinement fed dairy and beef cattle, to identify and quantify known and unknown causes of heterogeneity on the efficacy of 3-NOP. Previous studies identified dietary variables, including neutral detergent fibre (NDF), crude protein, and starch, as the primary contributors to variability after 3-NOP dosage. In this analysis, we expand upon existing knowledge by incorporating common components of Australian confinement diets; oil, monensin, and urea, to elucidate their impact on the heterogeneity observed, and included the outcomes of Australian studies previously not included in existing meta-analyses. Using the relative mean difference (RMD) in methane yield (g CH_4/ kg DMI). The meta-analysis employed mixed-effects meta-regression to develop equations capable of accurately quantifying the RMD in methane reduction from 3-NOP and identify causes of variability. This analysis revealed that the anti-methanogenic capacity of 3-NOP is influenced by dietary variables which change the rate of digestion, and thus the synchronicity of 3-NOP with digestion in the rumen. The most influential variable was 3-NOP dose, although dietary variables that changed the duration of time feed was in the rumen, also contributed substantially to the observed heterogeneity within and between studies. NDF, CP and urea were the dietary variables all identified as capable of influencing the relationship between 3-NOP and methane abatement, although they failed to explain all the heterogeneity between studies.

8.1.8 Meta-analysis of Australian grazing studies (published)

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Review

Grazing management for soil carbon in Australia: A review

Sarah E. McDonald[a,*], Warwick Badgery[b], Simon Clarendon[c], Susan Orgill[d], Katrina Sinclair[e], Rachelle Meyer[f], Dominique Bowen Butchart[g], Richard Eckard[f], David Rowlings[h], Peter Grace[h], Natalie Doran-Browne[i], Steven Harden[c], Ainslie Macdonald[f], Michael Wellington[j], Anibal Nahuel Alejandro Pachas[k], Rowan Eisner[g], Martin Amidy[j], Matthew Tom Harrison[g]

[a] NSW Department of Primary Industries, Trangie Agricultural Research Centre, Trangie, NSW, 2823, Australia
[b] NSW Department of Primary Industries, Orange Agricultural Institute, 1447 Forest Rd, Orange, NSW, 2800, Australia
[c] NSW Department of Primary Industries, Tamworth Agricultural Institute, Tamworth, NSW, 2340, Australia
[d] Select Carbon, 275 George St, Brisbane, Qld, 4000, Australia
[e] NSW Department of Primary Industries, Wollongbar Agricultural Institute, Wollongbar, NSW, 2477, Australia
[f] School of Agriculture and Food, The University of Melbourne, Parkville, VIC, 3010, Australia
[g] Tasmanian Institute of Agriculture, University of Tasmania, Newnham, Launceston, 7248, Australia
[h] Centre for Agriculture and the Bioeconomy, Queensland University of Technology, Brisbane, QLD, Australia
[i] The Mullion Group, Melbourne, VIC, 3000, Australia
[j] Centre for Entrepreneurial Agri-Technology, Australian National University, 116 Daley Rd, Acton, Australia
[k] QLD Department of Agriculture and Fisheries, 1 Cartwright Road, Gympie, QLD, 4570, Australia

A R T I C L E   I N F O

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A B S T R A C T

The livestock industry accounts for a considerable proportion of agricultural greenhouse gas emissions, and in response, the Australian red meat industry has committed to an aspirational target of net-zero emissions by 2030. Increasing soil carbon storage in grazing lands has been identified as one method to help achieve this, while also potentially improving production and provision of other ecosystem services. This review examined the effects of grazing management on soil carbon and factors that drive soil carbon sequestration in Australia. A systematic literature search and meta-analysis was used to compare effects of stocking intensity (stocking rate or utilisation) and stocking method (i.e. continuous, rotational or seasonal grazing systems) on soil organic carbon, pasture herbage mass, plant growth and ground cover. Impacts on below ground biomass, soil nitrogen and soil structure are also discussed.

Overall, no significant impact of stocking intensity or method on soil carbon sequestration in Australia was found, although lower stocking intensity and incorporating periods of rest into grazing systems (rotational grazing) had positive effects on herbage mass and ground cover compared with higher stocking intensity or continuous grazing. Minimal impact of grazing management on pasture growth rate and below-ground biomass has been reported in Australia. However, these factors improved with grazing intensity or rotational grazing in some circumstances.

While there is a lack of evidence in Australia that grazing management directly increases soil carbon, this meta-analysis indicated that grazing management practices have potential to benefit the drivers of soil carbon sequestration by increasing above and below-ground plant production, maintaining a higher residual biomass, and promoting productive perennial pasture species. Specific recommendations for future research and management are provided in the paper.

1. Introduction

Livestock production occurs on approximately 30% of global land and contributes to a significant proportion of agricultural output from developed (40%) and developing (20%) countries (Steinfeld et al., 2006; FAO, 2018). Globally, livestock contribute to around 34% of the food

* Corresponding author.
E-mail address: sarah.mcdonald@dpi.nsw.gov.au (S.E. McDonald).

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8.2 Documents

8.2.1 Guidelines for conducting a meta-analysis

Guidelines for conducting a meta-analysis on methane-mitigating diet supplements in ruminants under the Australian Livestock Emissions Framework

Ainslie Macdonald, Graham Hepworth, Richard Eckard

School of Agriculture, Food and Ecosystem Sciences (SAFES), University of Melbourne, Melbourne, VIC 3010, Australia

Purpose

The purpose of this protocol is to ensure that diet supplement technologies, proven to reduce enteric methane in ruminants, are evaluated for inclusion under the Livestock Emissions Framework, in a timely and unbiased approach, commensurate with the appropriate research and due diligence having been completed.

Background

Since the COP21 Paris Agreement set the world on a course towards net zero, many multinational supply-chain companies have set targets towards carbon neutrality by 2050. The red meat industry in Australia has also set the target of carbon neutrality by 2030 (CN30). These targets have created significant interest from livestock producers in methane mitigation technologies as a pathway towards lower emissions to meet future supply chain demands.

Enteric methane contributes about 68% of agricultural greenhouse gas emissions in Australia. Without significantly reducing enteric methane emissions, carbon neutrality cannot be achieved by the livestock industries. Several methane-mitigating technologies have been developed and many more are in development globally. Being able to account for the emissions reduction benefits of livestock methane reduction technologies is important to demonstrate the contributions of the agriculture sector towards meeting our Nationally Determined Contribution, under the Paris Climate Agreement, but also to incentivise the use of supplements through developing future Australian Carbon Crediting methodologies, and/or enabling supply chains to recognise and reward farmers for low emissions production. There is therefore a need to capture this mitigation both at a national inventory scale (e.g. through the National Greenhouse Gas Inventory (NGGI)) and at a local bottom-up scale to recognise and possibly reward farmers for specific mitigation action.

Livestock Emissions Framework for Feed Technologies

The Australian Government is developing a Livestock Emissions Framework (LEF) to provide a consistent approach to estimating enteric methane emissions reductions from the use of dietary supplements and methane inhibitor technologies. It is envisaged that the LEF will include a generic emissions response model and dose-response relationships for specific feed technologies. There is therefore a need for a common protocol to develop and update these dose-response relationships as technologies advance and additional research data becomes available.

The LEF has established a reference group of relevant livestock and policy experts, appointed by the Department of Climate Change, Energy, the Environment and Water (DCCEEW), to provide guidance in prioritising technologies and review the outputs of the meta-regression analysis process.

Protocol Steps

Meta-regression analysis provides the opportunity to create statistically robust, replicable and reliable response equations, by collating and utilising existing peer reviewed studies to quantify the impact of methane mitigation technologies on Australian livestock.

The protocol should cover the following steps:

- Transparent prioritisation of market-ready technologies;
- A meta-analysis literature review to determine if there is sufficient data[2] available to proceed to meta-regression analysis, in consultation with relevant commercial producers and accepted by a reference group appointed under the LEF;
- A meta-regression analysis to develop a series of empirical equations suitable for populating the LEF, and
- Peer review publication of the final meta-regression analysis and predictive equations.

Prioritising technologies

It is important that market-ready technologies are considered for inclusion in the LEF in a timely but also unbiased manner. This requires continual scanning of the literature and interaction with teams in Australia and globally to understand the new technologies emerging and when they are likely to be market ready. This scanning should avoid product-specific bias or lobbying by proponents. This may not be possible for single-suppler products like Bovaer®. However, fats, oils, essential oils or tannins would be more generic, given there are numerous suppliers (e.g. cotton seed; cold-pressed canola) and commercial products (e.g. Agolin, Mootral) already available.

This scanning and review is currently the task of the MERiL project "Delivering Integrated Management System (IMS) options for CN30" project, advising DCCEEW on emerging mitigation technologies through their Synthesis Task Group (STG) meetings. The DCCEEW, in consultation with the LEF reference group, would maintain a dynamic list of emerging technologies and prioritise those that should be subject to a meta-analysis literature review.

2. Pre-meta-analysis review

The DCCEEW, on advice from the LEF reference group, would then commission a critical literature review of each prioritised technology, by relevant but independent research experts. Currently this is the task of the IMS project team, but not exclusively. The review should cover the state of peer-reviewed evidence, the potential mitigation achievable, the availability of data on the rate and frequency of feeding responses (based on active ingredient(s) not product fed) and any evidence on potential adverse impacts or perverse outcomes.

A technology can be considered for full meta-regression analysis if:

- Data extracted from peer-reviewed papers are judged adequate[3] to deliver an empirical equation with a 95% confidence interval.
- Studies used in the development of the basic predictive equation must meet the following criteria:
    - Published in the peer reviewed literature;
    - Sourced from *in vivo* research (*in vitro* studies are not acceptable, due to limited correlation between *in vivo* and *in vitro* studies in absolute terms);

[2] Cochrane Handbook for Systematic Reviews of Interventions. Version 5.1.0. [updated March 2011]. Editors: Julian PT Higgins and Sally Green.
[3] https://www.meta-analysis.com/downloads/criticismsofmeta-analysis.pdf

  - Exclude studies where active ingredient is not quantified, the dose rate not defined or the dose frequency not clearly defined;
  - Exclude studies where base diet is not quantified, and the feeding system and frequency is undefined;
  - Grey literature or unpublished studies, provided by a technology developer, may be used to explore the power of the equation developed, but cannot be used to establish or invalidate the equation;
- Studies will be evaluated using the PICO framework (Problem; Intervention; Comparison; Outcome), as required within the PRIMSA checklist (see Appendix), to evaluate if studies are sufficiently similar and robust to allow combination (see Section 3 for the detailed data required).
- The meta-regression analysis should include all relevant studies from all countries, with countries included as a potential explanatory variable. If country effects are significant, a further analysis could seek to define if this is a team effect (i.e. a methodology bias by a single research group, as noted in this meta-regression analysis https://doi.org/10.1071/AN17832) or a genuine country effect; in the latter case the study may need to limit the studies to where the country effect is non-significant i.e. deemed to be part of the same population, or within country variance is greater than between countries.
- If there are limited technology providers, the company should be given a right of response to the pre-meta analysis review.
- This pre-meta-analysis review should then be submitted to the LEF reference group for consideration and decision to proceed to a meta-regression analysis.
- The review should clearly conclude if there is sufficient data to proceed to a full meta-regression analysis.

The meta-regression analysis

A meta-regression analysis on methane mitigation technologies must follow the PRISMA checklist (see Appendix) and the following guidelines:

1) Develop a search term based on inclusion criteria designed to identify as many relevant articles as possible and search these terms on at least three platforms (e.g. Google Scholar, SCOPUS and Web of Science);
    a. For example, to identify articles that studied the relationship between 3-NOP and enteric methane = *((3nop) OR (3-nitrooxypropanol) OR (3-nop)) AND ((*CH_4*) OR (methane) OR (enteric))*
2) Articles are initially screened based on the title and abstract, and then on the full article, to determine if they are suitable for the meta-regression analysis;
3) Determine the inclusion and exclusion criteria for studies to be included in the meta-regression analysis based on the PICO framework.
4) Document which studies were included in each stage of review and, for excluded studies, note the reason for exclusion. This process may change the inclusion and exclusion criteria.
5) Extract data from studies to populate a meta-regression analysis data file, including and considering the following:
    a. The meta-data of the study (i.e. full reference, DOI number, year of publication, country of origin, location of study);
    b. Statistical design of the study
        i. Must be randomised and replicated;
        ii. Must include a control treatment;
        iii. Duration of study (incl. adaptation vs measurement period);

   iv. Measures of variability.
  c. Experimental data available on:
   i. Method of methane measurement;
   ii. Number of replicates;
   iii. Number of animals per treatment (balance of breed, sex, age, mass);
   iv. Quantity, dose rate and frequency of active ingredient(s) fed (not total product fed) including any slow-release technology;
   v. Data on compounds likely to impact methane e.g. nitrates, fats, tannins, Monensin;
   vi. Feeding system, frequency and base diet description (incl. CP, NDF, ME etc)
  d. Methane data
   i. Control CH_4 measurements (g/day, g/kg DMI)
   ii. Treatment CH_4 measurements (g/day, g/kg DMI)
  e. Toxic effects, animal health.

6) Meta-regression analysis method
  a. While meta-regression statistical methods may vary, the procedure should weight observations inversely to their measures of variability. An observation would normally be a comparison of treatment vs control within a study.
  b. Where there are multiple observations within some studies, a mixed-effect meta-regression should be performed (e.g. R "metafor" package).
  c. The output should provide a series of predictive equations, from single predictor variables to a muti-variable equation. The statistical significance of each term in each equation and a measure of variability (standard error or 95% confidence interval) must be included.

The final product of the meta-regression analysis is several equations:

- A high-level equation suitable for the national inventory, using existing inventory data together with nationally aggregated data for the technology, e.g. amount of product fed and number of livestock fed;
- More detailed equations that can be utilised at a farm level (bottom-up) to estimate emission reductions, to underpin an Australian Carbon Crediting method or Climate Active calculation. The second equation must include all statistically significant predictors to ensure producers can obtain the most accurate mitigation values possible for their specific system.

4. Peer review publication of the predictive equations

For the predictive equations to be adopted in national inventory or to underpin a Climate Active claim or Australian Carbon Crediting methodology, the meta-regression analysis and associated equations must be published in a peer reviewed journal paper.

Appendix list of resources

- PRISMA guidelines

When writing a meta-analysis, PRISMA guidelines ensure that studies are clear and replicable. http://www.prisma-statement.org/

- Covidence

For screening articles, Covidence can be used to remove replicates of studies from different search engines and quickly remove irrelevant studies based on title, abstract and full article. https://www.covidence.org/

- GetData Graph Digitizer

A program for digitizing graphs and plots. It is often necessary to obtain original (x,y) data from graphs, e.g. from scanned scientific plots, when data values are not available. GetData Graph Digitizer allows researchers to easily get the numbers in such cases. http://getdata-graph-digitizer.com/

- Meta-Analysis Packages for R

    - The metafor package:

The metafor package is a free and open-source add-on for conducting meta-analyses with the statistical software environment R. The package consists of a collection of functions that allow the user to calculate various effect sizes or outcome measures, fit mixed-effects models to such data, carry out moderator and meta-regression analyses, and create various types of meta-analytical plots. https://www.metafor-project.org/doku.php/metafor

- clubSandwich: A Variance estimate Package for R

clubSandwich, is an R package developed by Pustejovsky., 2017 that includes functions for estimating the variance-covariance matrix and for testing single- and multiple-contrast hypotheses based on Wald test statistics.

Pustejovsky, J. E. clubSandwich: cluster-robust (sandwich) variance estimators with small-sample corrections (R package version 0.4.2) (2017)

- Elicit.org and artificial intelligence search engines

Search engines that utilise artificial intelligence may be soon useful to identify relevant articles and quickly extract information for meta-analyses. However, currently, due to the novel nature of the technology and the high rate of errors when extracting the information, they were not identified as suitable tools for meta-analyses at this stage. But the potential for this technology should be reviewed and included when this technology is more accurate. http://elicit.org

- Doing Meta-Analysis with R

This hands-on guide comprehensively outlines the stages and key considerations of undertaking a meta-analysis and pitfalls to avoid. https://www.protectlab.org/en/meta-analysis-in-r/

Harrer, M., Cuijpers, P., Furukawa, T.A., & Ebert, D.D. (2021). Doing Meta-Analysis with R: A Hands-On Guide. Boca Raton, FL and London: Chapman & Hall/CRC Press. ISBN 978-0-367-61007-4.

8.2.2 Carbon auditing guidelines

Guidelines for conducting a carbon audit on farm and farm products

Richard Eckard, Primary Industries Climate Challenges Centre, The University of Melbourne

Background

Since the COP21 Paris Agreement set the world on a course towards climate neutrality, many multinational supply-chain companies have set targets towards carbon neutrality by 2050. Many of these targets are informed by the Science Based Targets Initiative. These targets have created significant interest from farmers and supply chains in understanding their carbon position and a potential trajectory towards carbon neutrality to meet future supply chain demands. In response, a number of greenhouse gas accounting tools have started emerging, some producing different results.

There is therefore a need for a common agreed standard that has scientific integrity and fully consistent with IPCC -approved national greenhouse gas inventory methodology for Australia, but also compliant with international frameworks, like SBTI, GHG Protocol, and compliant with ISO lifecycle assessment standard, as per the Climate Active - National Carbon Offset Standard.

This short document aimed to provide a guide to ensure farm carbon audits have integrity and comply with international standards and frameworks. This then guides the choice of tool used, first ensuring this is 100% compliant with the guidelines below.

The basic concept

A whole farm carbon audit needs to comply with the following guidelines:

1) The methodology used should be consistent with the IPCC-approved, Australian National Greenhouse Gas Inventory (NGGI) methodology, only making adjustments where these are required to be more specific to the farm rather than a state or country (e.g. The NGGI uses the proportion of land area per state to determine indirect nitrous oxide from nitrate leaching, but at a farm boundary this is either property does or does not receive enough rainfall to leach);
2) The methodology used should align with:
    a. The Climate Active “Draft Guideline: Land and Agricultural Emissions”
    b. The GHG Protocol FLAG Guidance
    c. Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard
    d. ISO 14064 GHG emissions and removals
    e. ISO 14067/8 Carbon footprint of products
    f. The ISO 14040 Life Cycle Assessment framework and
    g. Farm Scope 3 emissions factors should be aligned with the Ecoinvent or AusLCI database.
3) The calculation should be conducted within a pre-farm to farm gate Life Cycle Assessment framework (ISO 14040), with the boundary representing the whole of farming enterprise (all activities within the ABN) e.g. if there are separate physical properties within the farm enterprise, movement of product between farms needs to be included as Scope 1 emissions. This applies to agistment properties if part of the business unit.
4) The greenhouse gas balance must be calculated on an annual timestep, but with the annual change in soil and tree carbon sequestration calculated based on a 10-year running mean, to minimise rainfall variability influences.

5) The audit should include:
   a. Scope 1 emissions: All direct greenhouse gas emissions (CO_2, CH_4, N_2O) from within the farming enterprise. The audit can also include the annual net change in soil and tree carbon, within the property boundary, but based on a 10-year rolling mean.
   b. Scope 2 emissions: This would mainly be electricity purchased from a fossil fuel origin onto the farm. This is included as the farmer now has choice to generate or buy renewable energy.
   c. Scope 3 emissions: Scope 3 emissions should be included in a carbon neutral product audit, as these emissions are essential to producing that product, but not all Scope 3 emissions are needed in carbon neutral property audit, only those that are essential to the management of the property. Scope 3 includes all pre-farm embedded emissions associated with the purchase of products onto the farm e.g. lime, steers, urea, herbicides. Some selected post-farm emissions are also included "where these are deemed to be under the control of the farmer's choice".

For a corporate company, ensure alignment with:

- GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard.
- ASRS 2 Climate-related Financial Disclosures including all 15 GHG Protocol scope 3 categories.

   d. Allocation: Where more than on product is produced, a protein-based allocation (livestock) or mass-based (lint vs seed) should be applied to apportion the emissions between the products
      i. Before applying allocation, ensure the proportion used is acknowledged between the industries. e.g. 15% of dairy farm emissions can be allocated to red-meat production, but only IF the bull calves are sold to a beef producer.
   e. **Carbon credits sold**: Carbon credits generated within but sold out of the boundaries of the audit, must be debited to the final balance. Likewise carbon credits generated and retained within the boundaries of the audit (i.e. an inset) are credited once off and retired. In other words, the final net emissions position should be increased by the number of carbon credits sold, or decreased by the number of carbon credits retained within the boundary. This is to avoid double counting of carbon offsets sold outside of the boundary, where clearly the intention of the new owner is to use these against their balance.

Tools

Greenhouse gas emissions: For the farm-based greenhouse gas emissions audit, any tool used must fully comply with the above standard.

Soil Carbon

For the purposes of a farm-based carbon audit, soil carbon should ideally be measured *in situ*, using the sampling methodology originally developed under The Soil Carbon Research Program (SCaRP) and prescribed under the Australian government method: Carbon Credits (Carbon Farming Initiative—Estimation of Soil Organic Carbon Sequestration Using Measurement and Models) Methodology Determination 2021.

Specifically:

- Soil organic carbon ideally needs to be measured in the top 30 cm (minimum) using the dry combustion method after removal of plant residues and root material carbonates (where present).
- Wet chemistry methods such as Walkley-Black are discouraged due to the high degree of variability in using this method.
- New laboratory methods using spectroscopic analysis can be considered if validated against the CSIRO or state department spectral libraries developed from SCaRP. *In situ* spectroscopic analysis or remote sensing are not valid as yet.
- Note that a single soil sampling event is insufficient to derive an annual time step change in soil organic carbon and would normally require a minimum of two soil sampling dates at least five years apart.
- If soil samples are not available, using a simulation model is potentially acceptable, on condition that this has been validated in the peer reviewed literature for this situation it is being used in e.g. FullCAM, SOCRATES, DayCent, Roth-C, SGS model. These models must be validated to the local soil and farming system, ideally including at least 20 years of *in situ* management history and run using climate data from the Bureau of Meteorology.
- Ideally, a combination of measurement and modelling (as per the ACCS method) is required to validate the history and trajectory of the change in soil organic carbon over time, with a detailed analysis of the soil profile providing associated chemical and physical properties used in the simulation. In this case, a time series of soil organic carbon analyses could be used if coupled with the above modelling protocol.

<u>Tree Carbon</u>

For the farm tree carbon audit, a very similar approach should be taken to soil sampling, where direct measurement by an accredited auditor would be the highest standard applied. This can be coupled with modelling using a peer reviewed tree growth model, demonstrated to be applicable to the Australian context e.g. FullCAM, 3PG, with the same validation and the review requirements as per the soil carbon method.

While the Greenhouse Accounting Framework (GAF) calculators provide a look up table version of the FullCAM model, it should be clearly noted that this was not to the integrity of having complied with the process above. These lookup tables can only provide a general indicator.

The final calculation

The net carbon position of the farm enterprise or product from the farm is then obviously a summation of the emissions minus the annual change in soil or tree carbon for that annual time-step.

A Carbon account/audit (CA) is the same as Net Emissions (NE = t CO_2e/ business unit) and includes:

- All GHG from boundary of the farm enterprise
- Annual change in soil and tree carbon
- Adjusted for carbon offsets bought or sold (note SBTI only allows purchased offsets for the intractable residual emissions).

The Carbon footprint (CF) or emissions intensity (EI = t CO_2e/t product) uses the same calculation as above, but the dominator is now the unit of product produced.

In this case also include all Scope 3 emissions (pre-farm GHG and some post farm), as these are essential for the product produced.

Net zero is then calculated as zero t CO_2e/ denominator (being either the business enterprise or the product).

8.3 Farm Case studies

8.3.1 Dunkeld Pastoral

A Greenhouse gas audit of Dunkeld Pastoral

Ainslie Macdonald, Hugh Stewart, Rachelle Meyer, Maria Lopez, Rodney Keenan, Richard Eckard

The University of Melbourne

Summary

The net balance of greenhouse gas (GHG) emissions on a farm is determined by emissions from livestock production (Scope 1 and 2) and carbon dioxide sequestration in vegetation and soil. Livestock and farm related GHG emissions vary with land use change, ruminant livestock, soils, fertilizer application and fossil fuels used for energy. Vegetation sequestration varies with site conditions, climate, type of vegetation, and the age of planted areas. Analysis indicated that Dunkeld Pastoral was a net emitter of 20,720 t CO_2-e/year (excluding Scope 3 emissions) from Jan 1st, 2021, to Dec 31st, 2021. With total farm emissions of 24,586 t CO_2-e per year (76% methane emissions) and sequestration in vegetation of 3,866 t CO_2-e per year. Insufficient data existed to reliably determine changes in soil carbon. Our analysis suggests that Dunkeld Pastoral can reduce on-farm emissions by 53.45% - 59.37% over the next 30 years (Table 3 & 5) without making any further changes. Strategies for further reducing GHG include increasing the area and growth rate of woody vegetation, increasing growth rates of livestock, reducing the amount of time animals are on Dunkeld, increasing animal fertility and using methane inhibitors to reduce livestock emissions.

Dunkeld GHGe Jan 1st, 2021 – Dec 31st 2021

Emissions/sequestration	t CO_2-e/year
Total scope 1 and 2 emissions	24,586
Total tree sequestration	-3,866
Net GHG balance	20,720

Introduction

Climate change is a major global policy issue with implications for all sectors of economy and society. Agriculture and food production are vital to human existence. Agriculture is also a significant source of GHGes that contribute to climate change, with emissions from land use change, ruminant livestock, soils, fertilizer application and fossil fuels used for energy. Within different agricultural systems significant opportunities exist to reduce these emissions through changing farm management practices and increasing carbon stocks in trees and other woody vegetation. Livestock emissions depend on the type of animal, stocking rates, diet, fertilisers, and energy use. Trees sequester carbon at varying rates depending on the area planted and the climate, soils, and tree species. Soil carbon can be increased with improved vegetation cover and input management. Rates of increase in tree and soil carbon (sequestration) slow over time as trees mature and begin to fully occupy planted areas and as the soil carbon capacity is reached.

Considerable research has been undertaken on these individual components of GHGs in farm systems and calculators and tools have been developed to provide guidance to farmers on their farm greenhouse balances. However, there have been relatively few in-depth studies to estimate GHG emissions and removals on a whole farm scale. This study provides a comprehensive assessment of GHG emissions and removals on the collection of properties belonging to Dunkeld Pastoral.

Dunkeld Pastoral is a beef and sheep grazing system with agroforestry for animal shelter, conservation, carbon sequestration and biodiversity conservation benefits. Dunkeld Pastoral are interested in understanding, and better managing, their farm's GHG balance. This analysis used livestock Fig.s, reconciled through the Grass Gro model, and the University of Melbourne SB-GAF modelling tool to estimate emissions from livestock and related farm management activities and revised estimates of carbon sequestration in trees using the latest calibration of the FullCAM model with adjustments based on field measurements of ecological plantings.

Aim

To provide a comprehensive assessment of the GHG emissions and removals on Dunkeld Pastoral.

Dunkeld Pastoral consists of 5 properties: Condah Hill, Mt Sturgeon, Devon Park, Corea South, and Blackwood. The total area is 12,700 ha. Pasture is an intensively managed combination of perennial ryegrass, Phalaris, and sub-clover. Trees planted provide shade, shelter, and biodiversity benefits.

Why net zero emissions was the outcome considered

There are three terms used when describing low or no emission enterprises that could be applicable to Dunkeld Pastoral: carbon neutral, climate neutral and net zero. Carbon neutral implies an enterprise does not contribute any additional GHGe through emissions avoidance and then, if necessary, utilizing carbon insets. Claiming to be carbon neutral would require Dunkeld to provide evidence that every option to reduce GHGe has been implemented and comes with scrutiny from the ACCC. Climate neutral considers the contribution of GHGe to global warming, by acknowledging that GHGe with different lifespans and GWP have different contributions to global warming. In the case of methane, climate neutral is beneficial as smaller, short-term reductions in methane can have the same impact as much larger long-term reductions in long lived greenhouse gas emissions such as carbon dioxide. The Methane Pledge aligns closely with climate neutral and has asked for 30% less methane by 2030 and 47% by 2050. Dunkeld Pastoral exceeds The Methane Pledge and could claim to be a climate neutral farm. However, this term does come with critiques of greenwashing and may not be applicable in the long term, as increased warming will result in supply chains and consumers ultimately demanding no or low emission productions well before 2050. Net zero emissions, is similar to carbon neutral, as it implies the enterprise does not contribute any additional GHGe, however unlike carbon neutral, it does not have stipulations regarding how that balance is achieved. For these reasons net zero emissions is the term used in this report. Dunkeld Pastoral could also claim to be climate neutral in the short-term, but this may put the brand at risk of greenwashing claims.

Results

1. Livestock and associated farm emissions

Total annual Scope 1 (direct) agricultural production emissions for 2021 were 24,453 t CO_2-e (Table 1), of which 20,333.86 t CO_2-e (76%) were enteric methane emissions from livestock. Scope 2 emissions (electricity) were very small (133 t CO_2-e per year), with total on farm emissions in 2021 being 24,586 t CO_2-e. Scope 3 emissions were estimated to be about 10% of the total emissions and should be included where reference is made to the product being produced, but not when reference is made to the carbon balance of the farm itself. Emissions are higher than expected due to the purchase of livestock and the retention of ewe lambs to build up flock numbers. This affects the emissions intensity estimates, as the total emissions are divided by less product than typical in a steadier state.

Table 1: Scope 1, 2 and 3 emissions of Dunkeld Pastoral for 2021. These values were taken from SB-GAFv2.3 and used the GWP methane conversion factor of 28 to be compliant with the National Greenhouse Gas Inventory. However, the IPCC 6th Assessment Report changed the methane GWP100 multiplier from 28 to 27. Once this is adopted by Australia's inventory Scope 1 emissions will reduce to 23,689 t CO_2-e.

Scope 1 Emissions by GHG	**t CO_2-e**
CO_2 – Fuel	275.27
CO_2 - Lime	193.35
CO_2 - Urea	99.07
CH_4 - Fuel	0.04
CH_4 - Enteric	20,333.86
CH_4 - Manure Management	1,060.85
N_2O - Fertiliser	83.25
N_2O - Urine and Dung	1,295.23
N_2O - Atmospheric Deposition	145.16
N_2O - Leaching and Runoff	964.74
N_2O - Fuel	1.85
Scope 1 Total	**24,453**
Scope 2 Emissions	
Electricity	133.00
Total on-farm emissions	**24,586**
Scope 3 Emissions	
Fertiliser	361.52
Purchased mineral supplementation	0.00
Purchased feed	449.75
Herbicides/pesticides	185.62
Electricity	10.95
Fuel	68.34
Lime	12.21
Purchased livestock	1349.47
Livestock on agistment	0.00
Scope 3 Total	**2,438**

Carbon sequestration in planted trees

We estimated sequestration in planted trees using the 2020 version of the FullCAM model. The standard calibration was used for environmental plantings. Model parameters were adjusted for agroforestry plantings based on field measurements (Model 4). Sequestration varies over time driven by the large areas planted from 2013 and the pattern of tree growth that peaks at an early age and then slows as the trees fully occupy the site (Table 2, Fig. 1). Carbon sequestration will peak in 2033 at 18,601 t CO_2-e/year.

Table 2: Annual carbon sequestration rates in existing trees and planned plantings (assuming no harvesting).

Year	t CO_2-e/year	Year	t CO_2-e/year
2013	2063	**2025**	6890
2014	1527	**2026**	8229
2015	1576	**2027**	9166
2016	1817	**2028**	10295
2017	1926	**2029**	11860
2018	2275	**2030**	14255
2019	2984	**2031**	16516
2020	3939	**2032**	18015
2021	3866	**2033**	18601
2022	4120	**2034**	18366
2023	4418	**2035**	17648
2024	5262	**2036**	16713

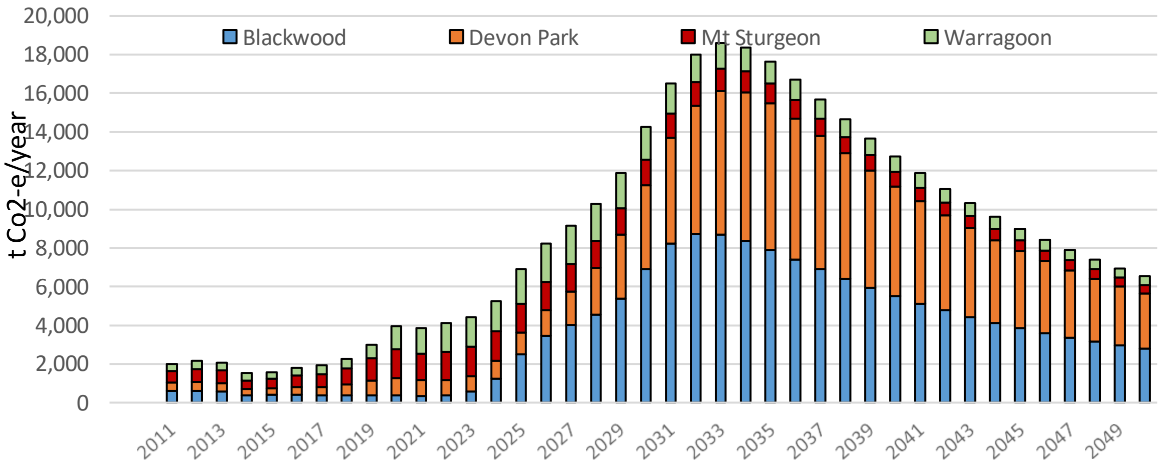

Fig. 1: Annual change in carbon sequestration existing trees and revegetation during 2022-2030 at Dunkeld Pastoral.

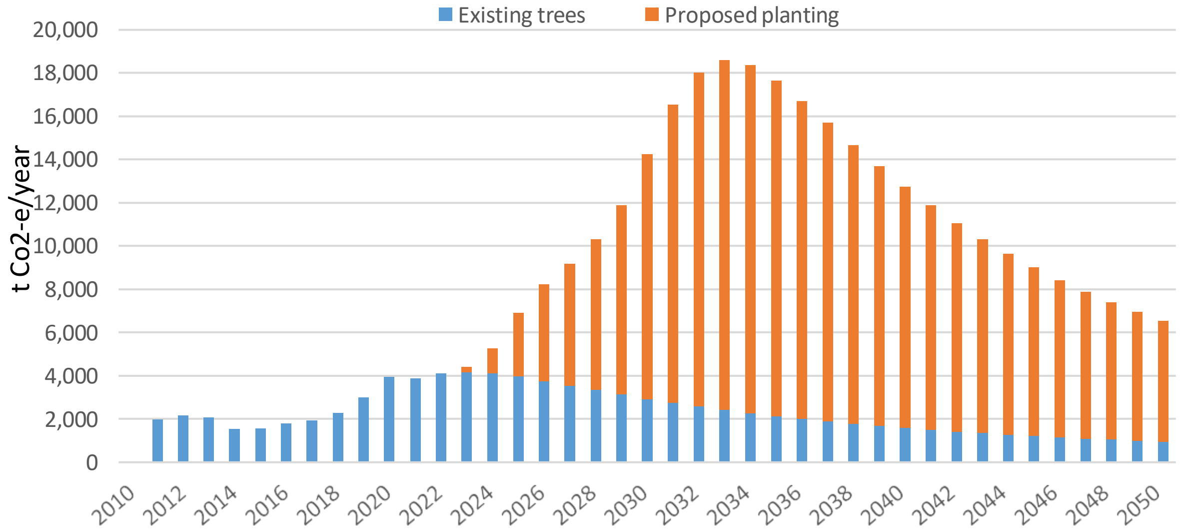

Fig. 2: Long-term carbon sequestration by existing trees and revegetation during 2022-2030 at Dunkeld Pastoral.

Summary of net GHG balance

The net GHGe for Dunkeld Pastoral was 20,720 t CO_2-e/year in 2021. Without intervention this number is already anticipated to be lower in future years. Due to the reduction of the methane emission factor from 28 to 27, which will reduce annual emissions by ~ 1,000 t CO_2-e once adopted by the National Inventory. Furthermore, emissions from 2021 were high due to the size of the flock increasing through the purchase of livestock and the greater retention of ewe lambs. If the current number of livestock is maintained, when the emission factor for methane is updated, gross on farm emissions are more likely to be ~22,000 t CO_2-e/year. The emission intensity and net emissions for both baseline scenarios are considered below:

Baseline 1

GHGe for Dunkeld pastoral remain steady, and the enterprises continue to produce 24,586 t CO_2-e/ year.

Table 3: The percentage of emissions offset at the peak of sequestration and on a 30-year average for baseline 1.

		Percentage of emissions offset	
	Total GHGe (t CO_2-e)	**Peak in 2023 (18,601 t CO_2-e)**	**30-year average (13,141 t CO_2-e)**
On Farm (Scope 1 & 2)	24,586	75.66%	53.45%
To farm gate (Scope 1, 2 & 3)	27,024	68.83%	48.63%

Table 4: Emissions intensity (EI) for sheep meat, wool, and beef with and without sequestration

		Emission intensity **kg CO_{2-e} / kg LW or wool**	Expected EI (exc seq)
Sheep meat	**excl seq**	12.2	6-10 kg CO_{2-e} / kg LW
	inc seq (peak)	2.1	
	inc seq (30-year avg)	5.1	
Wool	**excl seq**	44	20 – 35 kg CO_{2-e} / kg greasy
	inc seq (peak)	7.6	
	inc seq (30-year avg)	18.3	
Beef	**excl seq**	10	9-18 kg CO_{2-e} / kg LW
	inc seq (peak)	5.9	
	inc seq (30-year avg)	7.1	

Baseline 2:

GHGe for Dunkeld pastoral if animal numbers remain steady and produce 22,133 t CO_2-e/ year.

Table 5: The percentage of emissions offset at the peak of sequestration and on a 30-year average for baseline 2.

		Percentage of emissions offset	
	Total GHGe (t CO_2-e)	**Peak in 2023 (18,601 t CO_2-e)**	**30-year average (13,141 t CO_2-e)**
On Farm (Scope 1 & 2)	22,133	84.04%	59.37%
To farm gate (Scope 1, 2 & 3)	23,758	78.29%	55.31%

Table 6: Emissions intensity (EI) for sheep meat, wool, and beef with and without sequestration

		Emission intensity	Expected EI (exc seq)
Sheep meat	**excl seq**	8.7	6-10 kg CO_{2-e} / kg LW
	inc seq (peak)	0.1	
	inc seq (30-year avg)	2.6	
Wool	**excl seq**	31.1	20 – 35 kg CO_{2-e} / kg greasy
	inc seq (peak)	0.4	
	inc seq (30-year avg)	9.5	
Beef	**excl seq**	9.7	9-18 kg CO_{2-e} / kg LW
	inc seq (peak)	5.6	
	inc seq (30-year avg)	6.8	

Our analysis suggests that Dunkeld Pastoral can inset 48.63% - 55.31% of all GHGe produced over the next 30 years (Table 5) without making any further changes. This outcome exceeds the requirement of 47% less methane by 2050 set by The Methane Pledge and could further be increased through small, short-term changes to increase efficiency and using methane reduction technologies in the long-term.

Options to reduce net GHG emissions

Net GHG emissions could be reduced through a combination of the following:

- **Increase the tree area:** Increasing the area dedicated to trees, and staggering the growth rate would increase the volume of carbon sequestered and extend the period Dunkeld Pastoral could reduce GHGe.
- **Increasing productivity:** Increasing fertility and livestock growth rates to reduce the number and amount of time animals are on the property producing methane, which also reduces the emissions intensity of the product.
- **Use methane inhibitors**: If commercially available Bovaer® (3-NOP) was fed a 30% reduction in all enteric methane could realistically be achieved, with an immediate effect on scope 1 emissions. If fed to confinement fed animals, achieving an almost 80% reduction in methane from this source, it would reduce overall livestock emissions from 21,949 to 16,433 t CO_2-e/year. By 2025, slow-release technologies could be available that could be fed to grazing livestock. This could reduce enteric methane emissions by 45-50% from all livestock and allow Dunkeld Pastoral to reach net zero, with less tree planting.

8.3.2 Tipperary Station

Greenhouse Gas audit of Tipperary Station

Ainslie Macdonald, Jane Court, Richard Eckard

The University of Melbourne

Summary

The net balance of greenhouse gas emissions (GHGe) on a northern farm system is determined by the sum of annual carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2) emissions from agricultural enterprises, as well as deducting the annual sequestration of carbon in vegetation and soils, and the GHGe avoided from savannah fire burning management. Agricultural enterprises' GHGe vary with land use change, ruminant livestock numbers, soils, fertilizer application and fossil fuels used for energy. Vegetation sequestration varies with site conditions, climate, type of vegetation, and the age of planted areas. Avoided emissions from savanna fire management is dependent on the size of the area burnt, rainfall, timing and frequency of burn, vegetation type and fuel loads.

Our analysis indicates that Tipperary Station produced **19,427 t $CO_{2\text{-}e}$** during the 2021 calendar year, from Jan 1st – Dec 31st (excluding Scope 3 emissions). The primary source of emissions during this period was enteric methane from the trade and breed cattle enterprises. Emissions avoided through savannah fire management could reduce net emissions to **8,724 t $CO_{2\text{-}e}$ / year**, if these ACCUs were retired. If emissions avoided through the capture and removal of feral ruminants were also considered, the net emissions for Tipperary Station would further reduce to **7,602 t $CO_{2\text{-}e}$ / year**; however, it remains unclear if this can be claimed. If Tipperary continued to produce the same volume of GHGe over the next 30 years, Tipperary could inset 61.26% of total emissions without making any further changes.

Strategies to further reduce GHG_e were modelled to create agricultural products with the lowest environmental impact possible. These strategies are 1) supplementing livestock with cotton seed grown at Tipperary; 2) planting sterile Leucaena into selected pastures, and 3) reducing the amount of time animals are at Tipperary through productivity gains. Other options to reduce GHGe in future may include the purchasing of carbon neutral or low emission steers for the trade cattle enterprise, capturing and removing more feral ruminants, and increasing carbon sequestration in organic matter burnt during savannah burning.

Table 1: Net GHG summary of Tipperary enterprises Scope 1 emissions for 2021 (t $CO_{2\text{-}e}$)

Sources of GHGe (+)					
Enterprise	**Methane**	**Nitrous oxide**	**Carbon Dioxide**	**Total**	**Tool**
Trade stock	+12,375	+425	+67	+12,853	SB-GAFv2.3
Breeder cattle	+2,509	+105	+13	+2,628	SB-GAFv2.3
Cotton	+17	+1,536	+3,076	+3,145	H-GAFv1.46
Jarrah grass	+4	+275	+426	+443	G-GAFv10.8
Rhodes grass	+2	+140	+262	+292	G-GAFv10.8
Lemons	+0.01	+44.38	+21.17	+65.57	H-GAFv1.46
Total GHGe	**+14,787**	**+2,521**	**+3,865**	**+19,427**	
Sources of GHGe avoidance (-)					
Enterprise	**Methane**	**Nitrous oxide**	**Carbon Dioxide**	**Total**	**Tool**
Feral Buffalo	-532	-56	0	-588	B-GAF v1.5
Feral cattle	-511	-22	-1	-534	SB-GAFv2.3
Savannah Burning	n/a	n/a	- 10,703*	-10,703	ACCS data
Total GHGe avoided	**-1,043**	**-78**	**-10,704**	**-11,825**	
Enterprise	**Methane**	**Nitrous oxide**	**Carbon Dioxide**	**Total net GHGe (2021)**	
Net enterprise GHGe	**+13,744**	**+2,443**	**-6,839**	**+7,602**	

** Savannah Burning data were not disaggregated by gas, but typically 64% as methane and 36% nitrous oxide*

Table 2: Projected net GHG summary of Tipperary enterprises Scope 1 emissions for 2025 (t $CO_{2\text{-}e}$)

Sources of GHGe (+)					
Enterprise	**Methane**	**Nitrous oxide**	**Carbon Dioxide**	**Total**	**Tool**
Trade stock	+12,375	+425	+67	+12,853	SB-GAFv2.3
Breeder cattle	+2,936	+128	+13	+3,077	SB-GAFv2.3
Cotton	+43	+3,838	+7,688	+7,859	H-GAFv1.46
Jarrah grass	+4	+275	+426	+443	G-GAFv10.8
Rhodes grass	+2	+140	+262	+292	G-GAFv10.8
Lemons	+0.01	+138.88	+21.18	+160.06	H-GAFv1.46
Total GHGe	**+15,360**	**+4,945**	**+8,477**	**+24,684**	
Sources of GHGe avoidance (-)					
Enterprise	**Methane**	**Nitrous oxide**	**Carbon Dioxide**	**Total**	**Tool**
Feral Buffalo	-532	-56	0	-588	B-GAF v1.5
Feral cattle	-511	-22	-1	-534	SB-GAFv2.3
Savannah Burning	n/a	n/a	- 10,703*	-10,703 to -6,109	ACCS data
Total GHGe avoided	**-1,043**	**-78**	**-10,704**	**-9,528**	
Enterprise	**Methane**	**Nitrous oxide**	**Carbon Dioxide**	**Total net GHGe (2025)**	
Net enterprise GHGe	**+14,317**	**+4,867**	**-2,227**	**+15,156**	

Table 3: Past and projected emissions intensity (EI) for Tipperary enterprises excluding sequestration, assuming no further changes

		Emission intensity	Unit
Trade Cattle (exc seq)	**2021**	11.3	kg CO_{2-e} / kg LW
	2025	11.3	
Breeder cattle (exc seq)	**2021**	N/A*	kg CO_{2-e} / kg LW
	2025	10.9	
Cotton (exc seq)	**2021**	1.0	t CO_{2-e} /t cotton
	2025	1.0	
Jarrah Grass (exc seq)	**2021**	1.41	t CO_{2-e} /t grass
	2025	1.41	
Rhodes grass (exc seq)	**2021**	2.06	t CO_{2-e} /t grass
	2025	2.06	
Lemons (exc seq)	**2021**	N/A*	t CO_{2-e} /t crop
	2025	0.16	

* Emissions intensity could not be determined for the breeder enterprise and the lemon enterprise in 2021 as no products were sold, and emissions intensity is the division of total emissions (Scope 1 and 3) by the volume of product produced and sold (i.e., kg LW or t crop).

Introduction

Greenhouse gas emission reduction is a major global policy issue with implications for all sectors of economy and society, including agriculture and food production which are vital to human existence. Agriculture however is also a significant source of GHGs that contribute to climate change, with emissions from land use change, ruminant livestock, soils, fertilizer application and fossil fuels used for energy. Within different agricultural systems significant opportunities exist to reduce these emissions through changing farm management practices and increasing carbon stocks in trees and other woody vegetation. Livestock emissions depend on the type of animal, stocking rates, diet, fertilisers and energy use. Trees sequester carbon at varying rates depending on the area planted and the climate, soils, tree species and management. Soil carbon can be increased with improved vegetation cover, plant growth, reduced soil disturbance, and input management. Rates of increase in tree and soil carbon (sequestration) slow over time as trees mature and begin to fully occupy planted areas and as the soil carbon capacity is reached.

Considerable research has been undertaken on these individual components of GHGs in farm systems and calculators and tools have been developed to provide guidance to farmers on their farm greenhouse balances. However, there have been relatively few in-depth studies to estimate GHG emissions and removals on a whole farm scale, especially in Northern Australia. This study provides a comprehensive assessment of GHG emissions and removals on the collection of properties that form Tipperary Station, belonging to the Booloomani Corporation and Branir Pty Ltd.

Tipperary Station is comprised of 3 properties (Tipperary East & West: 209,842ha; Litchfield: 133,859ha, and Douglas West: 42,300ha). Purchased after 2003 by Allen Myers QC, as of 2015 Tipperary has a range of enterprises including livestock, horticulture, cropping, and tourism under the management of David Connolly. While carbon neutrality is not an objective for livestock management or changes in land use, strategies to diversify income, improve efficiency and productivity in livestock systems have benefited Tipperary Station's carbon account. Understanding how decisions have impacted the emissions and emissions intensity of Tipperary can best inform future efforts to reduce, avoid and inset emissions. This analysis used livestock Fig.s provided by Tipperary and together with

University of Melbourne's Greenhouse Gas Accounting Framework (GAF) modelling tools to estimate emissions from agriculture and related farm management activities.

Aim

To provide a comprehensive assessment of the GHG emissions and removals on Tipperary Station during the 2021 calendar year.

The primary enterprises at Tipperary Station include cotton, hay, lemons, and trade cattle. Additional income is generated from mango harvesting, feral buffalo and Shorthorn cattle harvesting, savannah fire management, ecotourism, crocodile egg harvesting and cattle breeding. Enterprises have been separated into two categories: sources of GHGe and sources of GHGe avoidance.

Results (GHGe emissions)

Trade cattle (+12,853 t CO2-e / year)

The largest source of GHGe from Tipperary Station is the trade cattle enterprise. Cattle are purchased at 240kg from Queensland and sold when they reach 350kg. The number of cattle purchased each year largely depending on availability. In 2021, approximately 15,000 head of cattle were purchased from April to November and sold from December to February. However, as the number of cattle each year could range from 5,000 to 25,000 and given the number of cattle on Tipperary has the largest influence on GHGe, scenarios for the maximum and minimum number of cattle were also run to show the influence of cattle numbers on GHGe.

Table 4: GHGe from SB-GAF v2.3 for trade cattle enterprise at different herd sizes

Outputs	beef t CO_2e/farm 5,000 cattle sold at 350 kg	beef t CO_2e/farm 15,000 cattle sold at 350 kg	beef t CO_2e/farm 25,000 cattle sold at 350 kg
Scope 1 Emissions			
CO_2 - Fuel	4.50	13.49	22.48
CO_2 - Lime	0.00	0.00	0.00
CO_2 - Urea	13.23	39.69	66.15
CH_4 – Fuel	0.00	0.00	0.00
CH_4 - Enteric	3,193.16	9,883.96	15,622.70
CH_4 - Manure Management	807.36	2,490.90	3,959.20
CH_4 - Savannah Burning	0.00	0.00	0.00
N_2O - Fertiliser	0.00	0.00	0.00
N_2O - Urine and Dung	76.44	240.64	369.51
N_2O - Atmospheric Deposition	8.03	25.27	38.80
N_2O - Leaching and Runoff	50.45	158.82	243.88
N_2O - Savannah Burning	0.00	0.00	0.00
N_2O - Fuel	0.03	0.10	0.16
Scope 1 Total	**4,153**	**12,853**	**20,323**

Scope 3 Emissions			
Fertiliser	0.00	13.49	0.00
Purchased mineral supplementation	4.84	0.00	24.21
Purchased feed	0.00	39.69	0.00
Herbicides/pesticides	0.00	0.00	0.00
Electricity	0.00	9,883.96	0.00
Fuel	1.11	2,490.90	5.56
Lime	0.00	0.00	0.00
Purchased livestock	15293.42	45880.00	76466.58
Livestock on agistment			
Scope 3 Total	**15,299**	**45,898**	**76,496**
Net Farm Emissions	**19,453**	**58,751**	**96,819**
Emissions intensity			
Beef excl. sequestration (kg $CO_{2\text{-}e}$ / kg LW)	11.2	11.3	11.2
Beef inc. sequestration (kg $CO_{2\text{-}e}$ / kg LW)	11.2	11.3	11.2

Total GHGe for Scope 1 and 3 emissions ranged from **19,453 – 96,819 t $CO_{2\text{-}e}$** for different scenarios, with 5,000 cattle roughly equating to 19,500 t $CO_{2\text{-}e}$. The largest source of GHGe was the purchase of livestock from Queensland (78%). Emissions from the purchase of livestock are the emissions the cattle produced over their life prior to their purchase by Tipperary. These values are based on existing emission factors. If the GHGe from the cattle were known by the seller, and they accounted for these emissions through management or carbon insets, this number could significantly reduce or be eliminated in future. The second largest source of emissions, and the largest source of Scope 1 emissions was the production of enteric methane (17%).

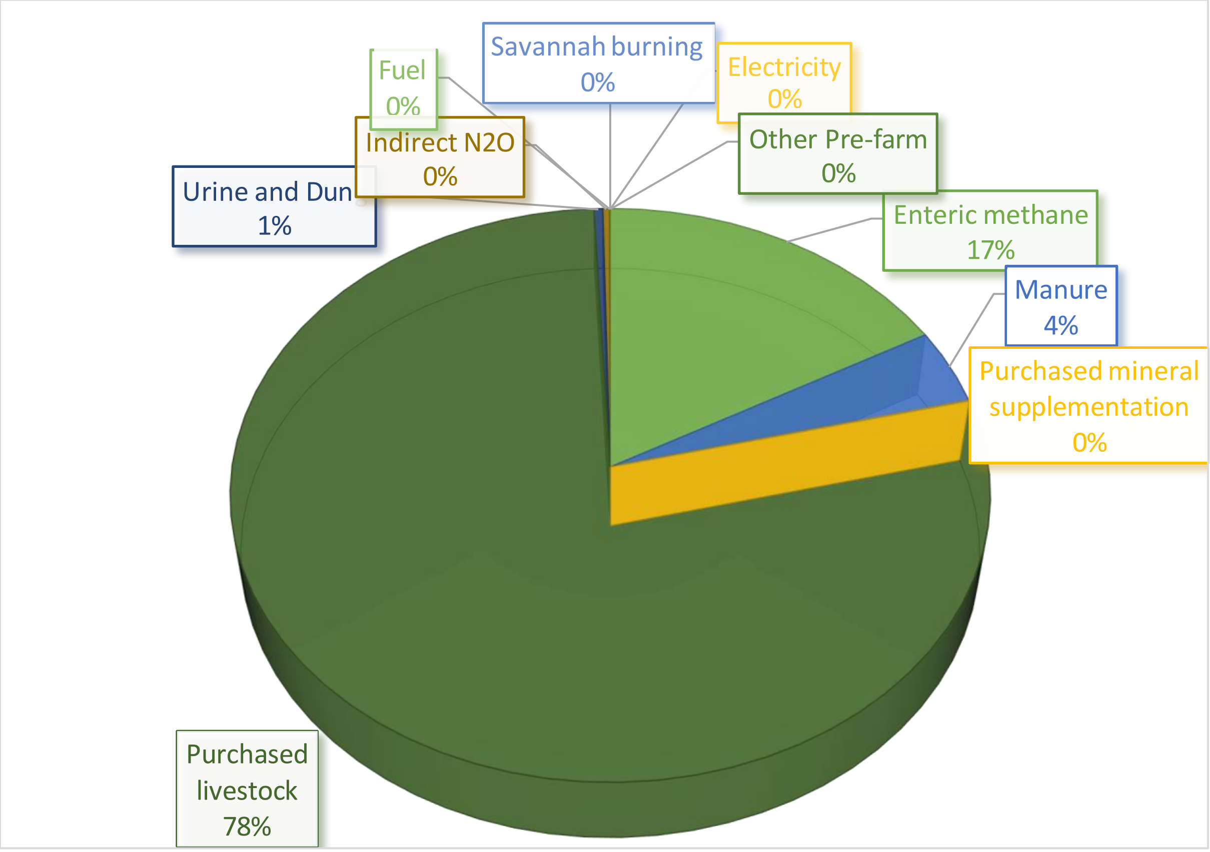

Fig. 1: Hotspot analysis of Tipperary's trade cattle enterprise in 2021, identifies the largest sources of GHGe.

Breeding cattle (+2,628 t CO2-e / year)

The third largest source of GHGe from Tipperary station is the breeding cattle enterprise. 1,000 Breeding cattle from Queensland and 100 Bulls from Katherine are purchased annually. 75% of the cows calf in either April or September, and calves are sold once they reach 350 kg (at approximately 18 months). This enterprise is new and did not sell any calves in 2021; Table 5 shows both the actual GHG_e produced in 2021, and the predicted GHGe from the enterprise once it is fully established.

Table 5: GHGe from SB-GAF v2.3 for the observed (2021) and projected (2025) cattle breeding enterprise

Outputs	beef t CO_2e/farm 2021 emissions	beef t CO_2e/farm 2025 emissions
Scope 1 Emissions		
CO_2 - Fuel	13.49	13.49
CO_2 - Lime	0.00	0.00
CO_2 - Urea	0.00	0.00
CH_4 - Fuel	0.00	0.00
CH_4 - Enteric	2,007.89	2,347.43
CH_4 - Manure Management	501.46	588.10
CH_4 - Savannah Burning	0.00	0.00
N_2O - Fertiliser	0.00	0.00
N_2O - Urine and Dung	59.29	72.58
N_2O - Atmospheric Deposition	6.23	7.62
N_2O - Leaching and Runoff	39.13	47.90
N_2O - Savannah Burning	0.00	0.00
N_2O - Fuel	0.10	0.10
Scope 1 Total	**2,628**	**3,077**
Scope 3 Emissions		
Fertiliser	0.00	0.00
Purchased mineral supplementation	0.00	0.00
Purchased feed	0.00	0.00
Herbicides/pesticides	0.00	0.00
Electricity	0.00	0.00
Fuel	3.34	3.34
Lime	0.00	0.00
Purchased livestock	4898.00	4898.00
Livestock on agistment		
Scope 3 Total	**4901**	**4901**
Net Farm Emissions	**7,529**	**7,979**
Emissions intensity		
Beef excl. sequestration	**N/A**	**10.9**
Beef inc. sequestration	**N/A**	**10.9**

Like the trade cattle enterprise, the largest sources of GHGe were the purchase of livestock and enteric methane respectively. Mitigation options for the breeding enterprise are similar to the trade enterprise, with the purchase of low or no emission cattle capable of significantly reducing the emissions and emissions intensity of the enterprise. On farm changes to reduce emissions primarily relate to management methods capable of increasing efficiency and reducing the number of animals and the duration of time they spend on the farm to produce the same volume of product. This could include increasing fertility rates, purchasing pregnant livestock to ensure high fertility rates or reducing the length of time between calves for cows would also further emissions. However, an emissions intensity of 10.9 t CO_{2-e} / t LW already demonstrates high efficiency (typical ranges are 10 to 18 t CO_{2-e} / t LW).

<u>Cotton (+3,145 t CO2-e/ year)</u>

In 2021, Tipperary station grew 4,000ha of GM cotton and 200 ha of non-GM cotton. With plans to increase production to 10,000 ha of GM-cotton and 500 ha of non-GM cotton. This enterprise produces both cotton and cotton seed for cattle. The emissions from both the enterprise in 2021 (Table 6) and future emissions from the anticipated 10,000 ha (Table 7) were calculated. The emissions intensity in Table 6 and 7, is based on a yield of 5 bales per ha (1,135kg /ha). This emissions intensity is significantly lower than the NSW average emissions intensity of 1.2 t CO_{2-e}/ t cotton. This emissions intensity could further be reduced by feeding cotton seed to cattle. This allocates 15% of the cotton emissions away from the lint to the cattle, but also reduces enteric methane from the cattle by up to 20% per day fed at 7% maximum oil in the diet.

Table 6: Scope 1 and 3 GHGe from H-GAF v1.46 for the cotton enterprise based on inputs used in 2021 for 4,000 ha of GM cotton

	GM Cotton	**Non -GM Cotton**
Outputs	**t CO_2e/farm**	**t CO_2e/farm**
Scope 1 Emissions (on-farm)		
CO_2 - Fuel	1,349.1	134.9
CO_2 - Lime	0.0	0.0
CO_2 - Urea	246.7	0.0
CH_4 - Field burning	0.0	0.0
CH_4 - Fuel	1.930	0.193
N_2O - Fertiliser	646.3	0.0
N_2O - Atmospheric Deposition	71.1	0.0
N_2O - Field Burning	0.0	0.0
N_2O - Crop Residues	420.3	0.0
N_2O - Leaching and Runoff	266.9	0.0
N_2O - Fuel	6.8	0.7
Scope 1 Total	**3,009**	**136**
Scope 3 Emissions (pre-farm)		
Fertiliser	830.6	0.0
Herbicides/pesticides	636.2	17.8
Electricity	0.0	0.0
Fuel	69.5	6.9
Lime	0.0	0.0
Scope 3 Total	**1536**	**25**
Net Farm Emissions	**4,545**	**161**
Emissions intensity (t CO_{2-e}/t crop)	**1.00**	**N/A***

*Non-GM cotton is not sold, and therefore does not have an emissions intensity.

Table 7: Scope 1 and 3 GHGe from H-GAF v1.46 for the cotton enterprise based estimated inputs for 2025 for 10,000 ha of GM cotton

Crop	GM Cotton	Non -GM Cotton
Outputs	**t CO_2e/farm**	**t CO_2e/farm**
Scope 1 Emissions (on-farm)		
CO_2 - Fuel	3,372.7	337.3
CO_2 - Lime	0.0	0.0
CO_2 - Urea	616.0	0.0
CH_4 - Field burning	0.0	0.0
CH_4 - Fuel	4.825	0.483
N_2O - Fertiliser	1,614.3	0.0
N_2O - Atmospheric Deposition	177.6	0.0
N_2O - Field Burning	0.0	0.0
N_2O - Crop Residues	1,050.7	0.0
N_2O - Leaching and Runoff	667.0	0.0
N_2O - Fuel	16.9	1.7
Scope 1 Total	**7,520**	**339**
Scope 3 Emissions (pre-farm)		
Fertiliser	2074.9	0.0
Herbicides/pesticides	1590.5	44.6
Electricity	0.0	0.0
Fuel	173.7	17.4
Lime	0.0	0.0
Scope 3 Total	**3839**	**62**
Net Farm Emissions	**11,359**	**401**
Emissions intensity (t CO_{2-e}/t crop)	**1.00**	**N/A**

Citrus (+65.57 t CO2-e/ year)

Between 2020 and 2023, 40 ha of citrus was planted at Tipperary station. Currently, trees do not produce fruit, with profitable yields anticipated by 2025. Given the enterprise does not currently produce yields, the emissions from the enterprise were calculated without (Table 8) and with the estimated yield of 30 t fruit/ ha (Table 9).

Table 8: Scope 1 and 3 GHGe from H-GAF v1.46 for the citrus enterprise based on inputs used in 2021

Outputs	t CO_2e/farm
Scope 1 Emissions (on-farm)	
CO_2 - Fuel	9.44
CO_2 - Lime	0.00
CO_2 - Urea	11.73
CH_4 - Field burning	0.00
CH_4 - Fuel	0.01
N_2O - Fertiliser	31.21
N_2O - Atmospheric Deposition	3.43
N_2O - Field Burning	0.00
N_2O - Crop Residues	0.00
N_2O - Leaching and Runoff	9.69
N_2O - Fuel	0.05
HFCs - Refrigerant Leakage	0.00
Scope 1 Total	**66**
Scope 3 Emissions (pre-farm)	
Fertiliser	24.69
Herbicides/pesticides	4.71
Electricity	0.00
Fuel	2.34
Lime	0
Scope 3 Total	**32**
Net Farm Emissions	**97**

Table 9: Projected scope 1 and 3 GHGe from H-GAF v1.46 for the citrus enterprise based on estimated inputs for 2025

Outputs	t CO_2e/farm
Scope 1 Emissions (on-farm)	
CO_2 - Fuel	9.44
CO_2 - Lime	0.00
CO_2 - Urea	11.73
CH_4 - Field burning	0.00
CH_4 - Fuel	0.01
N_2O - Fertiliser	31.21
N_2O - Atmospheric Deposition	3.43
N_2O - Field Burning	0.00
N_2O - Crop Residues	74.76
N_2O - Leaching and Runoff	29.43
N_2O - Fuel	0.05
HFCs - Refrigerant Leakage	0.00
Scope 1 Total	**160**
Scope 3 Emissions (pre-farm)	
Fertiliser	24.69
Herbicides/pesticides	3.96
Electricity	0.00
Fuel	2.34
Lime	0
Scope 3 Total	**31**
Net Farm Emissions	**191**
Emissions intensity (t CO2-e/t crop)	**0.16**

Long term, emissions for the citrus enterprise are anticipated to be **191 t CO_{2-e}/ year**, and assuming a yield of 30 t/ ha, this enterprise will have an emissions intensity of 0.16 t CO_2 / t of fruit. If trees are maintained over a long period, this enterprise could also sequester carbon, with each tree sequestering approximately 5.5 kg of carbon. However, to include this in the audit, the entire life cycle of the trees would need to be considered as the trees could not be removed for 10+ years if they are to truly remove carbon from the carbon cycle for a significant period. Although a valid carbon sequestration, it is still unclear if the carbon in the lemon trees can be counted towards a farm sequestration.

Grass (+735 t CO2-e/ year)

In 2021, Tipperary station produced 20,000 t of Jarrah grass on 2,000 ha and 200 t of Rhodes grass on 50 ha. This produced **735 t CO_{2-e}/ year.**

Table 10: Scope 1 and 3 GHGe from H-GAF v1.46 for the grass enterprise based on inputs used in 2021

Crop	Jarrah grass	Rhodes grass
Outputs	**t CO_2e/farm**	**t CO_2e/farm**
Scope 1 Emissions (on-farm)		
CO_2 - Fuel	134.9	134.9
CO_2 - Lime	0.0	0.0
CO_2 - Urea	65.8	32.9
CH_4 - Field burning	0.0	0.0
CH_4 - Fuel	0.193	0.193
N_2O - Fertiliser	172.4	86.2
N_2O - Atmospheric Deposition	19.0	9.5
N_2O - Field Burning	0.0	0.0
N_2O - Crop Residues	8.6	0.7
N_2O - Leaching and Runoff	41.6	26.8
N_2O - Fuel	0.7	0.7
Scope 1 Total	**443**	**292**
Scope 2 Emissions (off-farm)		
Electricity	0.0	0.0
Scope 2 Total	**0.0**	**0.0**
Scope 3 Emissions (pre-farm)		
Fertiliser	221.5	110.8
Herbicides/pesticides	40.5	1.8
Electricity	0.0	0.0
Fuel	6.9	6.9
Lime	0.0	0.0
Scope 3 Total	**269**	**120**
Net Farm Emissions	**712**	**411**
Emissions intensity (t $CO_{2\text{-}e}$/t crop)	**1.41**	**2.06**

Mangos (0 t CO2-e/ year)

Mangos have no inputs and thus no associated emissions, beyond the emissions caused by decay from termites, which is not recognized by the Australian GHG inventory and were not included in the audit. Carbon sequestered by the trees was also not included in the audit, as the trees are already fully grown and are no longer net sequestering large amounts of carbon to increase their mass.

Results (GHGe avoidance)

Buffalo (-585.67 t CO2-e/ year)

Feral buffalo are an invasive species, classified by the Australian government as an environmental disaster in the wetlands of the Northern Territory. They cause soil erosion, increased spread of weeds, intrusion of saltwater into freshwater habitats, the trampling of native flora and fauna, and destruction of fauna, reduced vegetation for native species and the loss of ground cover. Feral buffalo are responsible for reducing the numbers of crocodiles, barramundi, freshwater turtles, and many native water birds in the wetlands of the Northern Territory. Tipperary Station captures and removes an average of 400 feral Buffalo each year. There is currently no evidence to suggest that their removal has the capacity to reduce feral populations long-term without consistently increasing removal rates. However, the annual removal of feral buffalo would benefit native species and reduce the negative ecological impacts of buffalo in the short-term. Furthermore, the removal of buffalo would result in a short-term reduction in enteric methane (numbers naturally rebuild so the reduction in methane is short term only). As a pest, feral Buffalo are not acknowledged in the National GHG Inventory and cannot be captured in return for carbon credits. However, reducing the number of feral buffalo producing enteric methane would reduce the volume of methane that is seen by the atmosphere. To consider the potential that capturing and selling feral buffalo could potentially inset in Tipperary's carbon accounts, the impact of the removal of 400 adult buffalo for one year was included in this audit.

In 2021, Tipperary captured 400 feral buffalo in December and sold them the following April. Although GHGe from feral Buffalo are not included in the National inventory, emissions from Buffalo captured and maintained from December to April would be considered in the inventory.

The emissions and emissions intensity from the capture and retention of the feral buffalo are below in Table 11.

Table 11: GHGe from B-GAF v1.5 for the Buffalo enterprise based on inputs used in 2021

Scope 1 Emissions (t $CO_{2\text{-}e}$)	
CO_2 - Fuel	1.35
CH_4 - Enteric	319.20
CH_4 - Manure Management	12.06
N_2O - Urine and Dung	9.87
N_2O - Atmospheric Deposition	1.09
Scope 1 Total	344
Scope 3 (t $CO_{2\text{-}e}$)	
Fuel	0.33
Total (t $CO_{2\text{-}e}$)	**344.33**
Buffalo meat (exc seq)	0.0018 kg $CO_{2\text{-}e}$ / kg LW

If the capture and sale of the buffalo reduced the population of feral buffalo by 400 for a year, 930 t $CO_{2\text{-}e}$ would be avoided. This would result in a net avoidance of **585.67 t $CO_{2\text{-}e}$/** year, which could be inset to against the Tipperary station total, as well as improve biodiversity on Tipperary Station.

Shorthorn cattle (-532.31 t CO2-e)

Like buffaloes, feral cattle have a negative ecological impact in the Northern Territory. Feral cattle are responsible for land degradation, soil compaction, soil erosion, increased nutrient loading, the increased spread of weeds and sedimentation in waterways. In addition to harming native species in ecosystems, feral cattle also pose a higher risk of carrying and spreading diseases present. The National GHG inventory does not consider wild Shorthorn cattle, as they are feral. However, like buffalo, their removal reduces the volume of enteric methane produced on Tipperary until their population recovers. This short-term reduction in enteric methane could be considered in the balance of GHGe produced by Tipperary.

In 2021, 250 wild Shorthorn cattle were captured and sold. The emissions avoided from the capture and sale of the Shorthorn cattle in below in Table 6 and the emissions produced by the capture and sale of Shorthorn in Table 12.

Table 12: SB-GAF GAF v2.3 emissions avoided

Scope 1 Emissions (t $CO_{2\text{-}e}$)	
CO_2 - Fuel	1.35
CH_4 - Enteric	408.57
CH_4 - Manure Management	102.49
N_2O - Urine and Dung	12.45
N_2O - Atmospheric Deposition	1.31
N_2O - Leaching and Runoff	8.22
Total (t $CO_{2\text{-}e}$)	**534**

Table 13: SB-GAF G \F v2.3 Emissions from capture of Shorthorn

Scope 1 Emissions (t $CO_{2\text{-}e}$)	
CO_2 - Fuel	1.35
N_2O - Fuel	0.01
Scope 3 (t $CO_{2\text{-}e}$)	
Fuel	0.33
Total (t $CO_{2\text{-}e}$)	**1.69**

The capture and removal of 250 feral Shorthorn cattle, produce 1.69 t $CO_{2\text{-}e}$ from the use of fuel to capture the cattle, and avoided approximately **532.31 t $CO_{2\text{-}e}$** from being produced in 2021, assuming the removal of wild Shorthorn reduced feral population for approximately 12 months.

Savanna Burning (-10,703 to -6,109 t CO2-e)

In 2021/2022, Tippary's Savanah Burning Project changed the burning time for approximately 20,000 ha and were allocated 10,703 ACCUs. The following year 6,109 ACCUs were allocated. The emissions avoided through savannah burning could not formally inset emissions produced on Tipperary Station in 2021 as they were sold. This data does suggest that future savannah burning could reduce the GHGe from Tipperary by **10,703 - 6,109 t $CO_{2\text{-}e}$** / year if ACCUs were inset and not sold.

Avoided clearing (-285,000 to -335,000 t CO2-e)

5,000 ha of land on Tipperary was approved for clearing but management chose not to clear the area. Recent changes to the Australia's Carbon Crediting Mechanism no longer award ACCUs for avoided deforestation. However, avoided emissions could be inset to reduce the net emissions produced by Tipperary Station. The Looc-C model estimates 57- 67 t $CO_{2\text{-}e}$ is potentially sequestered for each ha of land, as defined on Tipperary, that was not cleared. The retention of this woodland could result in a one-off total of **285,000 – 335,000 t $CO_{2\text{-}e}$** of avoided emissions. Part of this reduction can be attributed to reducing the net emissions of Tipperary Station in 2021. Note that the official policy position on this is no longer clear now that the avoided deforestation methodology is cancelled, so this would be more up to the supply chain buyer to judge if this falls under their SBTI target criteria.

Further mitigation

Emissions could be reduced or avoided through a combination of:

1. **Purchase of low emission livestock:** The largest source of GHGe across all enterprises was the purchase of livestock which produced 50,788 t $CO_{2\text{-}e}$ in 2021. If Tipperary Station wanted to produce, market, and sell low or no emission livestock, choosing to purchase low or no emission livestock from suppliers who know their emissions would have the largest impact on reducing the emissions intensity of the trade and breed enterprises.
2. **Cotton seed:** Feeding of cotton seed produced at Tipperary has the capacity to reduce enteric methane from livestock, add a rate of about 3.5% less methane per each 1% oil added to the diet. Due to the low inputs required by the cotton seed, and the potency of methane, feeding cotton seed could reduce emissions from cotton (15% transferred to the livestock) and reduce methane emissions from the livestock. Tipperary Station currently produces 5kg of cotton seed per ha, with the potential to produce up to 50 t cotton seed / year. The mean DM/head/day on Tipperary was 5.89 kg, based on 15,000 cattle on average trade cattle consume 88,350 kg DM/herd/day. Including cotton seed in trade cattle diets at approximately 5% of DM would reduce enteric methane by 17.5% for each day fed. This would reduce enteric methane by 579.45 t $CO_{2\text{-}e}$, the equivalent of removing 465 trade cattle for a year. This would reduce 15% of emissions from the cotton enterprise and could reduce the emissions of the trade cattle (although further analysis would be required of a specific case study to explore the net outcome of this strategy). Furthermore, increased consumption of fat would increase cattle's weight gain and reduce the amount of time trade cattle are on Tipperary, further reducing their emissions intensity.
3. **Avoided deforestation:** The avoided clearing action involves retaining areas of native forest that would otherwise be permitted to be cleared in the normal course of events. The land must have existing native forest cover, must have been cleared at least in the past, the management history per Carbon Estimation Area (CEA) must be uniform, and there must be valid unrestricted clearing consent. Avoided deforestation of vegetation no longer generate ACCUs as the required methodology has now been discontinued under the Australian Carbon Crediting Mechanism, but could be used as a carbon inset for the property (note this would be subject to the requirements of the purchaser of products from Tipperary, also noting that this may not be recognised by the Science Based Targets Initiative and GHG Protocol, which many supply chain companies now adhere to). Abatement is calculated as the difference between a modelled baseline scenario (in which the land continues to be cleared) and a project scenario (in which the land is no longer cleared). Abatement estimates in LOOC-C assume a baseline clearing interval of 15 years.
4. **Wild harvest Shorthorn and water buffalo**: Feral animals are not included in the national GHG inventory, but their capture and sale does reduce the volume of GHG_e produced. Although reductions are temporary, lasting only until populations return to their carrying capacity (the 'sink' effect), and could not be used to generate ACCUs, reductions are cumulative and unlike sequestration, they are permanent. Removing feral species could also have further benefits for biodiversity and their removal would benefit Tipperary in a shift towards biodiversity credits. Again the counting of this credit depends on the supply chain requirements and their adherence to the Science Based Targets Initiative and GHG Protocol.

8.3.3 Jigsaw farms

Jigsaw Farms Emissions balance summary

Emissions

In 2021, a carbon audit conducted on Jigsaw Farms determined that the combined sheep and beef enterprise produced **9,543 t $CO_{2\text{-}e}$** of on farm emissions (Table 1). The largest source of emissions was enteric methane, which produced 7,367 t $CO_{2\text{-}e}$. Emissions were calculated utilising animal numbers taken from Jigsaw farms and validated with Grass Grow models, before being inputted to the SB-GAF tool.

Excluding sequestration, the emissions intensity was **8.3 kg $CO_{2\text{-}e}$**/ kg LW for sheep meat, **30 kg $CO_{2\text{-}e}$** /kg greasy wool and **11.3 kg $CO_{2\text{-}e}$** for beef.

Sequestration ranged between **6,704 t $CO_{2\text{-}e}$** to **7,936 t $CO_{2\text{-}e}$** in 2021 (Fig. 1, Table 3). This means that during the 2021 calendar Jigsaw farms inset a minimum of **70.3%** of GHG_e and a maximum of **83.2%** of GHG_e. If carbon sequestration can be averaged over 10 years (2012-2021), this increases to **88.8%** and **105.8%** respectively (Table 3).

Table 1: Jigsaw Farms emissions in the 2021 calendar year, determined by SB-GAFv2.3, not including sequestration and assuming the GWP for CH_4 is 27.

Outputs	beef t CO_2e/farm	sheep t CO2e/farm	total t CO2e/farm
Scope 1 Emissions			
CO_2 - Fuel	23.85	95.41	119.26
CO_2 - Lime	142.96	571.82	714.78
CO_2 - Urea	5.09	20.36	25.45
CH_4 - Fuel	0.00	0.02	0.02
CH_4 - Enteric	1,225.43	6,141.34	7,366.77
CH_4 - Manure Management	55.70	331.63	387.33
CH_4 - Savannah Burning	0.00		0.00
N_2O - Fertiliser	4.49	17.96	22.46
N_2O - Urine and Dung	94.51	364.50	459.01
N_2O - Atmospheric Deposition	10.42	40.25	50.67
N_2O - Leaching and Runoff	68.31	264.28	332.59
N_2O - Savannah Burning	0.00		0.00
N_2O - Fuel	0.15	0.61	0.76
Scope 1 Total	**1,631**	**7,848**	**9,479**
Scope 2 Emissions			
Electricity	12.75	51.00	64
Scope 2 Total	**13**	**51**	**64**
Scope 3 Emissions			
Fertiliser	31.90	112.12	144.02

Purchased mineral supplementation	0.00	0.00	0.00
Purchased feed	151.18	604.70	755.88
Herbicides/pesticides	3.25	6.88	10.13
Electricity	1.05	4.20	5.25
Fuel	5.94	23.75	29.69
Lime	9.03	36.10	45.13
Purchased livestock	25.27	24.41	49.68
Livestock on agistment			
Scope 3 Total	**228**	**812**	**1040**
Net Farm Emissions	**1,871**	**8,711**	**10,583**
Emissions intensity			
Sheep meat (breeding herd) excl. sequestration	**8.3**		kg CO2-e / kg LW
Sheep meat (breeding herd) inc. sequestration	**8.3**		kg CO2-e / kg LW
Wool excl. sequestration	**30.0**		kg CO2-e / kg greasy
Wool inc. sequestration	**30.0**		kg CO2-e / kg greasy
Beef excl. sequestration	**11.3**		kg CO2-e / kg LW
Beef inc. sequestration	**11.3**		kg CO2-e / kg LW

Sequestration

The trees on farm team ran 5 models to determine the sequestration of environmental and agroforestry plantings on Jigsaw farms (Fig. 1) detailed below.

Modelling of carbon sequestration

We estimated carbon sequestration in the agroforestry and permanent revegetation plantings using the predictions from the FullCAM model (2020 Public release version). FullCAM has various calibrations to estimate forest growth and hence carbon sequestration to cater for different species, planting densities and planting configurations. The default calibration of 'Mixed species environmental planting temperate – Block planting' provides the most conservative estimate of forest growth. If a plantation species is planted, as in the case of agroforestry plantings at Jigsaw Farms, calibrations specific to these species can be applied which will result in a higher rate of carbon sequestration. We set up five models using different calibrations (Table 1).

Table 2: Models used to estimate carbon sequestration by trees planted at Jigsaw Farms.

Model	Tree planting type	Tree growth calibration
1	Permanent revegetation Agroforestry	'Mixed species environmental planting temperate – Block planting' for all CEAs (the default).
2	Permanent revegetation Agroforestry	As for Model 1, except that 'Mixed species environmental planting temperate – Belt plantings <1500 sph' was applied to eligible CEAs in permanent revegetation.
3	Permanent revegetation Agroforestry	As for Model 2. 'Plantation' calibration after Paul et al. (2022).
4	Permanent revegetation Agroforestry	As for Model 2. 'Plantation' calibration after Paul et al. (2022) adjusted using measurements of site-specific growth collected at Jigsaw Farms.
5	Permanent revegetation Agroforestry	Estimates from Model 2 adjusted using measurements of site-specific growth collected at Jigsaw Farms. As for Model 4.

All plantings were modelled with a start date of 1 July in the year the plantings were established. The model for each CEA was run from the planting date until 2046, using a modelling point that was in the approximate centre of the CEA. The details of the five models are provided below.

Model 1

Under the Methodology Determination we followed we initially modelled the permanent revegetation and agroforestry as 'Mixed-species environmental planting temperate – Block configuration'[4].

Model 2

Under the Methodology Determination, a 'belt' planting means a planting that is established in a belt configuration, follows landscape contours, or is arranged in a straight line, and is no more than 40 m wide. Plantings that do not meet these requirements are 'block' plantings. FullCAM has calibrations for belt plantings with <1500 stems per ha and belt plantings with >1500 stems per ha. There are further calibrations for different establishment methods (the use of weed control and application of fertiliser). For Jigsaw Farms for Model 2, we used 'Mixed-species environmental planting temperate – Belt configuration, <1500 stems per ha (sph)' for those permanent plantings that met the requirements of a belt configuration.

In applying the calibration for the belt configuration, we applied the test for 'material competition' from adjacent trees specified in the Methodology Determination and adjusted where necessary the length of the belt to which we could apply the calibration. At Jigsaw Farms most of the material competition was caused by remnant River Red Gum trees.

At both Hensley Park and Melville Forest, 34 per cent of the area of permanent revegetation plantings were modelled using the calibration for belt configurations.

Model 3

For the Jigsaw Farms location, FullCAM had calibrations for three eucalypt plantation species but not for species established in the agroforestry plantings. We discussed this with a FullCAM expert[5] and

[4] Carbon Credits (Carbon Farming Initiative) (Reforestation by Environmental or Mallee Plantings—FullCAM) Methodology Determination 2014, Compilation No. 2, 2018, Authorised Version F2018C00118 registered 26/02/2018.

[5] Geoff Roberts, Mullion Group, 5 August 2022.

developed an approach to model abatement in the agroforestry plantings, which led to the use of a user-defined calibration in FullCAM. This was based on recently published information that is being used in the recalibration of FullCAM for a new version expected to be released in 2023 (Appendix 1).

Model 4

We collected tree inventory data from the agroforestry plantings at Jigsaw Farms to improve the user-defined calibration we used in FullCAM. We did this by adjusting the tree growth calibration in FullCAM after comparing measured tree growth with growth predicted by FullCAM. Details of the method are provided at Appendix 2.

Model 5

In our analysis of carbon sequestration by permanent revegetation plantings at Jigsaw Farms, we considered the possibility that FullCAM underpredicted the actual rate of carbon sequestration. To test this, in April 2023 we collected field measurements of the growth of the permanent revegetation plantings including those that were direct seeded with high plant densities. The aim was to measure carbon stocks in the live aboveground biomass and compare the results with those predicted using the FullCAM model.

From a sample of permanent revegetation tree plantings 13 to 31 years of age at Jigsaw Farms, we found that FullCAM (2020 Public Release version) consistently predicted lower carbon stocks in the live above-ground biomass relative to estimates derived from field measurements. The results indicated that the measured carbon stocks were in the order of two times to four times those predicted by FullCAM – equivalent to 100% to 300% higher (Appendix 3).

Based on these findings, we applied a multiplier of two to the FullCAM carbon predictions for the permanent revegetation plantings that we assessed as being closed forest (i.e., having a crown cover >80%). For plantings established between 1987 and 2017 we did this from Google Earth imagery with ground-truthing in April 2023 of some plantings close to the lower bounds of the crown cover class of closed forest. We assumed that plantings established since 2017 would become closed forest.

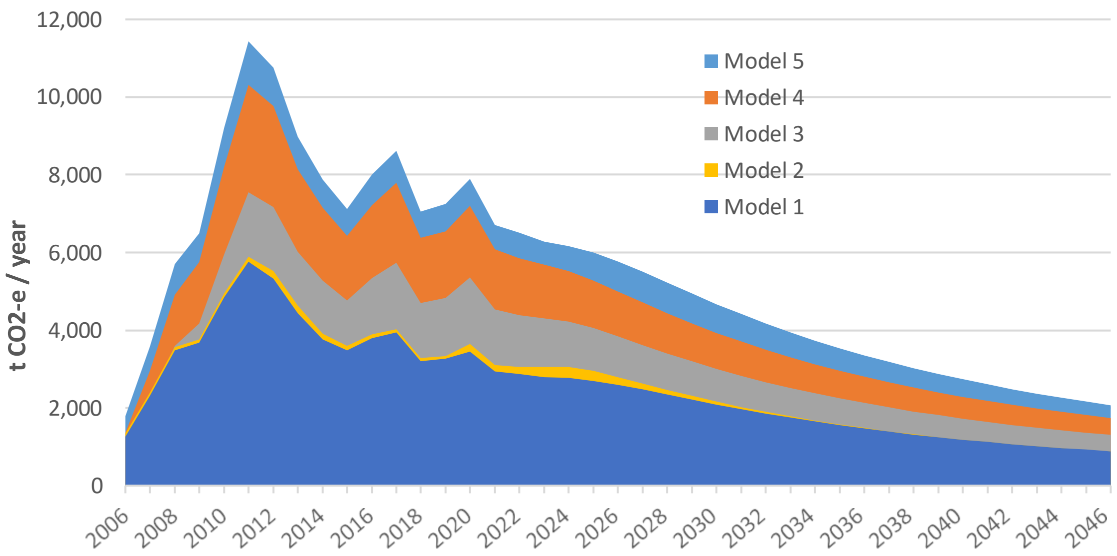

Fig. 1: Annual sequestration of carbon in trees planted on Jigsaw farms from 2006 to 2046.

These models determined that Jigsaw farms sequestered a minimum of **6,704 t CO_{2-e},** and a maximum to **7,936 t CO_{2-e}** during the 2021 calendar year. The range of sequestration is due to model 5, which adjust for FullCAM's underestimation of carbon sequestered in environmental plantings by incorrectly determining the ratio of eucalyptus to acacias. **6,704 t CO_{2-e}** is the conservative estimate which doubled carbon stocks in environmental plantings (Fig. 1, Model 5) and **7,936 t CO_{2-e}** assumed carbon stocks in environmental plantings were four times higher than FullCAM initially estimated. Both values are provided, for transparency and to show that although the conservative number is favoured by modellers, likely the impact of trees on Jigsaw farms as seen by the atmosphere was higher.

Table 3: The minimum and maximum sequestration t of CO_2 sequestered by Jigsaw farms between 2012 – 2031 based on Models 1-5.

Last 10 years			Next 10 years		
Year	**Min**	**Max**	**Year**	**Min**	**Max**
2012	11,434	13,674	**2022**	6,236	7,625
2013	9,717	11,615	**2023**	6,236	7,625
2014	9,717	11,615	**2024**	6,236	7,625
2015	9,717	11,615	**2025**	6,236	7,625
2016	8,000	9,556	**2026**	5,768	7,314
2017	7,352	8,746	**2027**	5,092	6,575
2018	7,352	8,746	**2028**	5,092	6,575
2019	7,352	8,746	**2029**	5,092	6,575
2020	7,352	8,746	**2030**	5,092	6,575
2021	6,704	7,936	**2031**	4,416	5,836
10-year avg	**8,469.7**	**10,100**	**10-year avg**	**5,549.6**	**6,995**

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8.4.2 Soil carbon in the Monaro region

The role of soil type (parent material), pasture and climate on soil carbon in the Monaro region of southern NSW

Background

It is well acknowledged that soil carbon is highly variable over both time and space and that this is driven primarily by rainfall and soil type, respectively. Soil type is derived from the underlying geological parent material. However, it is less well known the extent that productivity of different pastures (and the role they in turn play in driving carbon sequestration) present on these differing soil types will be impacted by rainfall. As part of a long-term study investigating the role of soil type, vegetation community and how they are impacted by climate, we have continued the repeated sampling of multiple sites across the Monaro region of southern NSW (Orgill et al. 2014).

Materials and Methods

Soils for this study are all based in the Monaro region of southern NSW. Some 31 generally paired (e.g., basalt soil / native grass vs basalt soil / introduced grass) sites were sampled that encompassed a number of different vegetation types; remnant vegetation (trees), native grasses and introduced pastures that were present on a range of soil types (parent material) basalt, deep granite and shallow granite soils. These sites have been sampled approximately every three years; 2009, 2012, 2015, 2018 and 2022. Soils were sampled at depth increments of 0-5, 5-10, 10-20, 20-30, 30-40 and 50-70 cm with the exception of the shallow granite soils that could only be sampled to a maximum depth of 40-50 cm depth. To allow comparisons to be made across all soil types only soils to a depth of 50 cm depth has been analysed.

Results & Discussion

As expected, there were substantial differences between the different soil types and soil depth (Fig. 1). In general, the same trend was observed across depths as for the shallower soil depths (0-5 cm) however for the granite soil there was little change over time at depths greater than 5cm for the shallow granite sites and greater than 10 cm for the deep granite soils. In contrast, depths down to the 20-30cm layer paralleled the 0-5cm depth. On average the basalt soils had TC values that were about 50% greater than the deep granite soils which in turn were about twice that of the shallow granite soils (Fig. 1). For all soils most of the year-to-year variation was observed in the 0-5 & 5-10cm soil depth with increasing less variation occurring in the deeper depths. This is important as it is has been stated that large amounts of soil C can be stored at depth, however this data indicates that there is little change in TC at depth despite a wide variation in climatic conditions including both the worst drought and wettest period recorded during the time over which this study has occurred (Fig. 2).

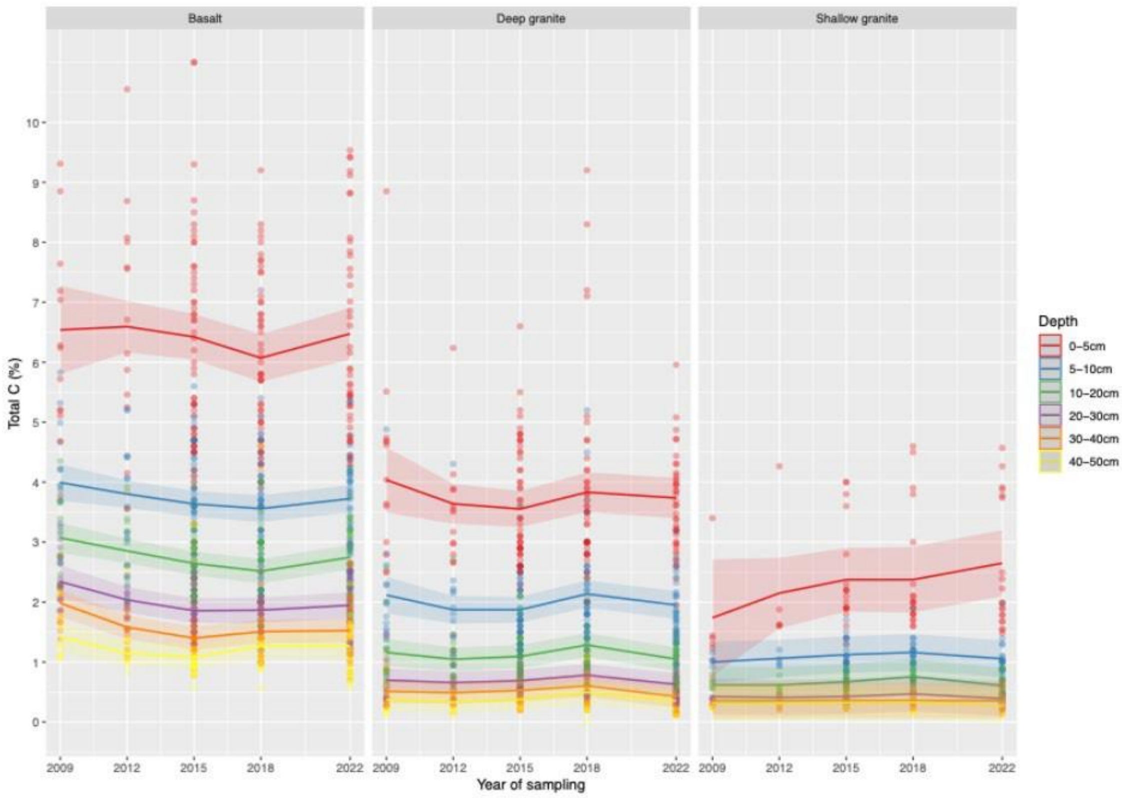

Fig. 1 Total C by depth across different sampling years and soil/parent material.

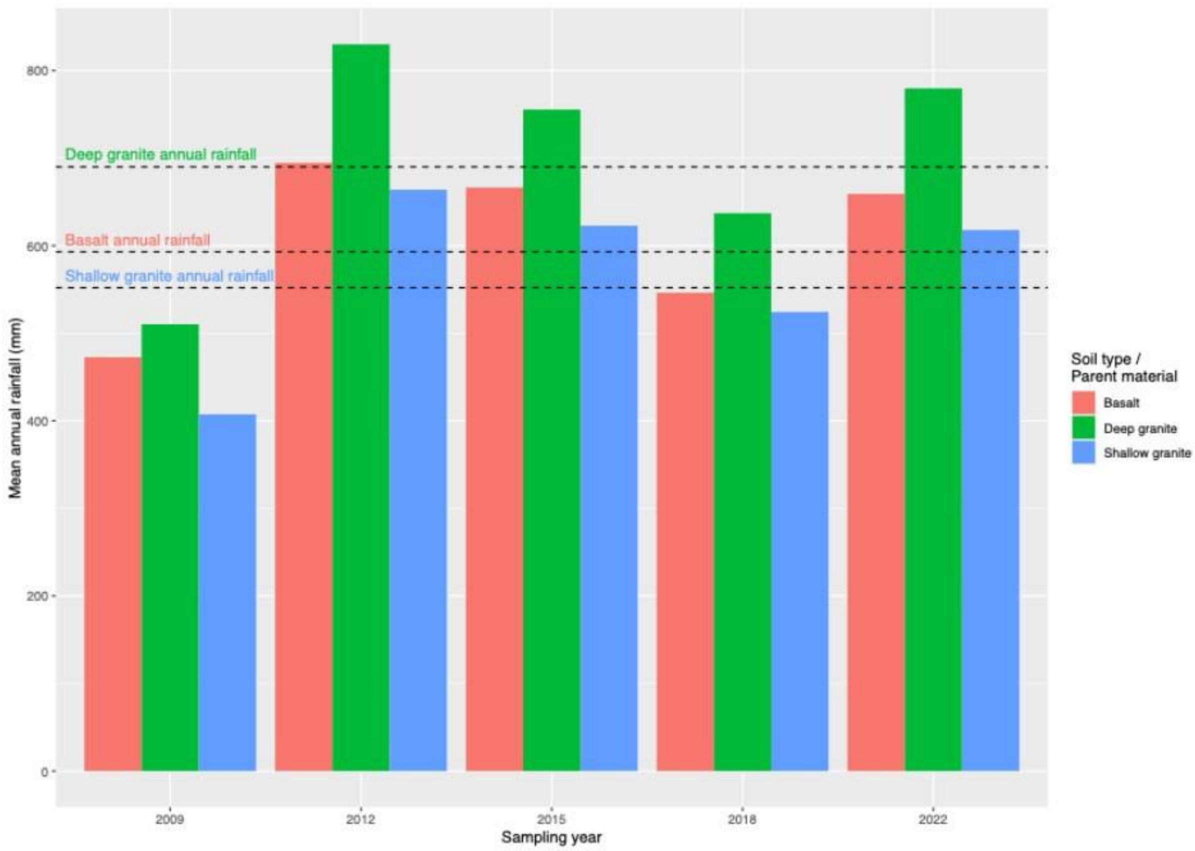

Fig. 2. Mean rainfall that occurred for each of the soil types/parent material between sampling dates or in the case of sampling year 2009, the mean rainfall that fell in the three years prior to

sampling. The mean annual rainfall for each of the soil types/parent material (basalt, 593 mm; deep granite, 690 mm and shallow granite, 552 mm) is indicated by the dashed line).

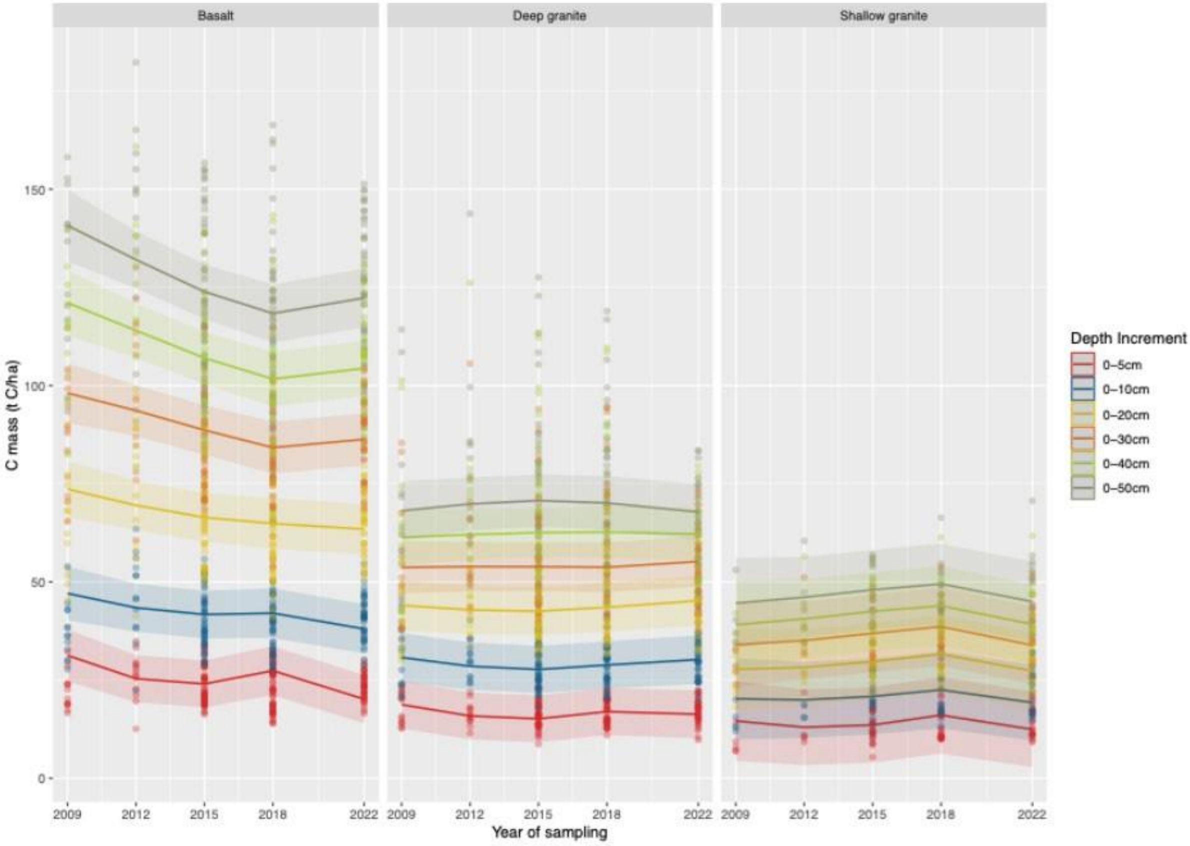

Fig. 3 Total mass of C by depth across different sampling years and soil/parent material

The total mass of C followed a generally similar trend as for TC (Fig. 3). Basalt soil generally declined from 2009 (end of a drought period in the Monaro) until 2018 (middle of a drought) (Fig. 2) before increasing after a period of sustained well above average rainfall in 2022. In contrast, both the granite soils, shallow and deep, while exhibiting a slight increase from 2009 to 2015 thereafter changed very little. Due to the much higher concentration of total C, the amount of C sequestered to a depth of 50 cm exhibited the same trend as the that for TC, with shallow granites sequestering ~47 t C/ha, deep granites ~69 t C/ha and the basalt soils, ~117 t C/ha. Of interest is that the mass of SOC present in the 0-50 cm of the shallow granite soils is comparable to that found in the 0-20 cm of the deep granite soils and the 0-10 cm of the basalt soils.

Across all soil types, there was no significant difference in the mass of C (0-50 cm) between vegetation types; with introduced pasture having 85.2 t C/ha for the 0-50cm soil depth; native grasslands, 86.3 t C/ha; and remnant vegetation, 63.5 t C/ha.

The basalt soils exhibited stronger relationships to rainfall with every additional 100 mm resulting in an increase of 5 t C/ha which was significantly greater than the 1 t C/ha that was observed in either the shallow or deep granite soils (data not shown). It is likely that is a result of the increased clay content of basalt soils, which results in a greater water-holding capacity combined with greater soil fertility and leading to increased pasture productivity and subsequent increase in root production and turnover, leading to increased SOC. As can be observed that pattern of C increase/decrease in the basalt soils (Fig. 2) strongly follows that of the rainfall patterns (Fig. 3) observed on these sites whereas in contrast, both the granite sites exhibit a relatively flat response to rainfall (Fig. 3). As granite soils are substantially lower in; 1) Total N, shallow granite, 0.19%, deep granites, 0.33% than basalt soils 0.56%; 2) P, shallow granites 33 mg P /kg soil (Colwell P), deep granites 36 mg P/kg soil compared to basalt soils (77 mg P/ kg soil), and to a lesser degree, S; shallow granites 5.1 mg S / kg soil (KCL40), deep granites 11.0 mg S/kg soil compared to basalt soils, 12.0 mg S/kg soil, it is likely that plant productivity is constrained by lower soil fertility reducing its ability to be as productive and reducing plant inputs, via root growth and turnover of C into the soil.

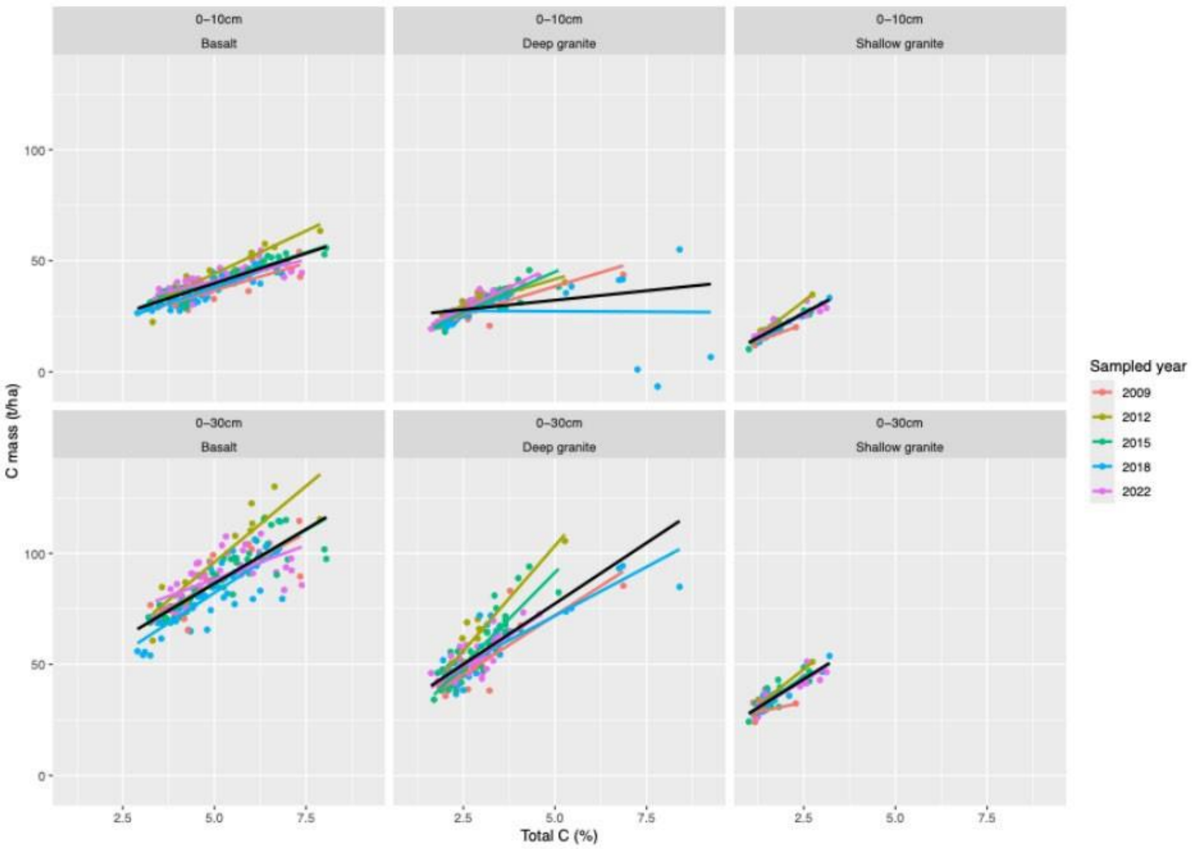

Fig 4. Regression relationship between total carbon (% for the 0-10 cm soil depth and carbon mass (0-10 and 0-30 cm depth intervals) for different soil types by different years of sampling. The average relationship across all years is shown by the black line.

There is increasing interest from producers to inset their on-farm emissions, however a major sticking point is that to undertake a comprehensive on-farm soil programming may cost many tens of thousands of dollars which dissuades many producers from considering the process. However, soil fertility testing of the 0-10 cm depth is a common practice in pastoral systems and commercial soil and pant testing laboratories are readily able and cheaply determine soil C at the same time as other soil characteristics are being determined. As such it would be of great value to most producers if a simple relationship between TC% and the C mass for either the same depth interval (0-10cm) or for the 0-30cm depth, which is of more interest in C sequestration. To that end we determined that despite a variety of different prior climatic conditions and sampling times (Autumn, Winter, Spring) and variations in measured bulk density that the relationship between TC and C mass was reasonably strong across all years (Fig. 4, Table 3).

Table 3: Relationship b/w Total carbon (%) for the 0-10cm depth and C mass (0-10 & 0-30 cm)

Soil type	Relationship between TC% and C mass (0-10 / 0-30 cm)
Basalt	$Cmass_{0\text{-}10cm} = 5.40 \times TC_{0\text{-}10cm} + 12.85$, adjusted r2 = 0.73
	$Cmass_{0\text{-}30cm} = 9.79 \times TC_{0\text{-}10cm} + 37.48$, adjusted r2 = 0.63
Deep granite	$Cmass_{0\text{-}10cm} = 5.37 \times TC_{0\text{-}10cm} + 13.89$, adjusted r2 = 0.71
	$Cmass_{0\text{-}30cm} = 12.19 \times TC_{0\text{-}10cm} + 19.28$, adjusted r2 = 0.70
Shallow granite	$Cmass_{0\text{-}10cm} = 8.81 \times TC_{0\text{-}10cm} + 4.37$, adjusted r2 = 0.88
	$Cmass_{0\text{-}30cm} = 10.30 \times TC_{0\text{-}10cm} + 17.64$, adjusted r2 = 0.75

In summary, the extent that soils can sequester C is greatly impacted by a large number of variables that for the most part producers have little control over. These are primarily the soil type which is wholly dependent on the underlying geological material from which it was derived and rainfall. On most extensively grazed systems, the primary areas that farmers do control are, soil fertility, the pastures present on the farm, and the management of those animals. The results of this study showed that as long as pasture are a perennial grass, be they native or introduced, that the amount of C stored has little to no impact. However, as our previous research has shown at the long-term soil P grazing trial undertaken by CSIRO at the Ginninderra Experiment Station (8.4.1 Optimal soil phosphorus increases and maintains soil carbon – a multidecadal study - this report) as well as the grazing trial undertaken at the Orange Agricultural Institute (8.1.9 Effect of grazing on soil C - of this report) found, that provided pastures are not being overgrazed, that stocking rate has minimal impact on soil C sequestration. Finally, from fertility trial undertaken by CSIRO (8.4.1 Optimal soil phosphorus increases and maintains soil carbon – a multidecadal study - this report) that optimising soil fertility can not only increase soil C in a relatively short period of time but can also maintain that increase in SOC under conditions of highly variable rainfall and this is something that producers can control. In addition, this also has economic benefits to producer in terms of the additional animal production that is gained as well as in-setting additional C and thereby reducing the emission intensity of the system.

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8.4.3 Producer pathways to adoption of new mitigation

Delivering integrated management system (IMS) options for CN30: training and adoption component

Introduction

The Australian red meat industry makes a significant economic contribution nationally (Mayberry et al., 2019). In addition to the economic benefits, the industry, as a major exporter, contributes to meeting the increasing global demand for the consumption of red meat (Herrero et al., 2016). At the same time, national and international governments and multinational livestock supply chains are setting targets to be carbon neutral by 2050 (UNFCC 2015). As a response, the Australian red meat industry has set an aspirational target to achieve carbon neutrality by 2030 together with an enabling program of supporting activities (MLA 2020). However, approximately 71% of agricultural greenhouse gas emissions (GHG) are from methane (CH_4), primarily as enteric emissions from cattle and sheep (Australian Government 2024).

To reach the industry 2030 target producers will need to make reductions in their total farm emissions and the emission intensity (EI) of their product. This will require the widespread adoption of management options to reduce emissions in a whole of farm approach. At the same time, producers need to ensure their farm business maintains its resilience. That is, the production system must be productive, profitable and sustainable in a changing climate. In addition, the various mitigation technologies and practices must be socially acceptable if the red meat industry is to maintain and retain its social licence to operate.

One of the first tasks for producers is to quantify their farm carbon footprint and their product EI. This enables producers to baseline and then year-on-year calculate their total farm emissions and product EI providing the capacity to assess trends over time. It also allows producers to benchmark their emissions against other producers. In Australia there are several calculators including the Greenhouse Gas Accounting Framework (SB-GAF tool) and the MLA farm calculator available to producers. The tools should give the same outputs as they are both operating under the same underlying equations that come from the SB-GAF tool, though the MLA tool has a cleaner interface and appears to be simpler to use.

Strategies to reduce enteric methane (CH_4) emissions include manipulating the rumen, diet and the animal with a range of technology and practice mitigation options varying in abatement efficacy and cost-effectiveness (Beauchemin et al., 2020; Eckard et al., 2010). Options include feed additives [3-nitooxypropanal (3-NOP), marine algae (*Asparagopsis taxiformis* and *Asparagopsis armata)*, dietary oils and lipids, nitrates, ionophores) and improved feed digestibility (supplementary grain, forages with increased concentrations of condensed tannins and saponins, high digestibility forages) in order to reduce enteric CH_4 emissions (Almeida et al., 2021; Badgery et al., 2023). These strategies can reduce enteric emissions either directly by inhibiting production of enteric CH_4 or indirectly as target weights are achieved faster and thereby avoiding emissions relative to slower growing animals. Practices improving the productivity and health of animals including genetic selection for production and low CH_4, improved reproduction performance, removing unproductive animals and reduced herd mortality are effective in reducing emissions per unit of product (Almeida et al., 2023; Herrero et al., 2016).

While a substantial number of options are available or will be available in the near-term, producers will need to take a whole-farm systems approach in evaluating these options. Producers will need to explore and understand the co-benefits and trade-offs (economic, environmental and social dimensions) when implementing mitigation options (Mayberry et al., 2019). In assessing 54 emission abatement options Harrison et al (2021) found that only 16 had a medium to high mitigation potential but may also have economic, environmental and social co-benefits. With most individual mitigation options likely to be low to medium impact (i.e. 10-30%) on reducing emissions combining strategies will be necessary in the short-term (Beauchemin et al., 2020; Harrison et al., 2021)

Within the Australian agricultural adoption literature, a useful conceptual framework has been advanced by Pannell et al. (2006). Typically, four key sets of factors have influenced a producer's decision to adopt a new technology or practice: their personal characteristics and circumstances, their wider social context, the attributes of the practice, and the support they receive through the adoption process. Exploring the adoptability of the different mitigation and sequestration options with producers is essential in understanding their perspectives about the acceptability of the different options, the technical feasibility of implementing these options on-farm and the policy mechanisms required to support adoption of different option. Currently, there are few quality studies exploring producer decision-making to understand the enablers and constraints to the uptake of mitigation/sequestration practices and the support producers require to implement those practices. This component of the IMS project attempts to address this knowledge gap by directly engaging with producers at a farm scale.

An intensive program of informing and consulting with producers was undertaken over a period of 18 months. The focus of the program was to build producer's capacity to enable them to transition (i.e., change in practice and structure) their business toward carbon neutrality. Specifically, the program aimed to build producers knowledge, skills, and confidence in the use of the carbon accounting framework and identified abatement/sequestration strategies. The program also focussed on understanding the perspectives and information needs of producers, and constraints and incentives to implementing current and future abatement/sequestration strategies.

Method

Producer groups

Two producer groups were formed following an EOI process inviting producers to participate in a series of participatory "Carbon-ready farm business" workshops. The two groups represented red meat production systems operating in cool temperate environments. One group was in the Monaro region of southern NSW with a focus on livestock grazing native and improved pastures. The other group was located on the Central Tablelands of NSW with a focus on livestock grazing improved pastures and forage crops together with a cropping operation.

Training program

Six sessions were held with each group following the same session plans as outlined in Table 1. Within the sessions a process of presenting to, interactive discussion and consulting with producers was followed.

Table 1: Outline of session program

Session	Program outline
Session 1	Foundational knowledge session to ensure all participants had a basic knowledge. A broad overview of the current situation with regards to emission reductions was presented with an emphasis on an interactive discussion with producers. Topics included GHG emissions from livestock enterprises on-farm, definitions and terminology, the measuring of on-farm emissions and an introduction to the SB-GAF tool.
Session 2	Intensive session on producers using their own farm data and the SB-GAF tool to obtain their farm emission intensity (EI) per kg product and total on-farm emissions. This was followed by a presentation on methane (CH_4) reduction supplements including their mode of action, efficacy and expected cost with an interactive discussion with the presenter.
Session 3	Develop an agreed farm model with producers for each location. Parameters included farm location, soil and pasture types and proportion of each type on the farm, enterprise types and management and abatement strategies. GrassGro used to model the farm system incorporating the agreed parameters to develop scenarios.
Session 4	Presentation of the GrassGro modelling scenarios for the enterprises/abatement strategies to be tested including the impact on production, emissions intensity, and gross margin.
Session 5	The focus of this session was on the opportunities for C sequestration in soil and vegetation. This was an information session presented as a webinar.
Session 6	In this final session producers were asked to respond to two scenarios requiring a reduction in emission intensity. Scenario 1 required action within a 12-month period to make a reduction in emission intensity while Scenario 2 gave producers until 2030 to achieve changes in EI. The session also provided the opportunity for clarification and an update of the most current information including government policy and pledges, international and domestic markets and supply chain commitments.

Findings

Session 1: Building foundational knowledge and understanding of GHG emissions and the implications for livestock production

Producers in this first session were highly engaged. The questions posed by producers were wide-ranging. This capacity building session was very important as it enabled the information presented later to be covered in depth as well as enabling high level of discussion.

In general, producers believed they were already implementing 'best practice' management on their farm. However, they were prepared to make minor adjustments to improve their management which would also have the benefit of reducing their on-farm emissions. They remain strongly focussed on the productivity and the profitability of their farm business. They also needed to know "*at a minimum their on-farm emissions*" before considering any abatement option that may impede achieving their current business goals. They were also aware of the need to measure their emissions year-on years as they do with their financials as it is likely that data will be required in the near term, for example, when engaging with the banks and the buyers of their product

Following the presentations and discussion, producers were asked to respond to the following question:

"Given what you have heard today, what do you think you could do within your business to reduce emissions or offset your emissions?"

At the time of this first session in late 2022, producers were only willing to make changes that would continue improve the efficiency of their business operation. Producers also recognised the need to be prepared for when they want to sell their product they can provide EI figures. The following quotes represent typical producer responses:

> *"There looks to be an opportunity to intensify production and get rewarded for it. … We could definitely increase our efficiency per unit of product. … Maybe…tinkering with the enterprises you could do. But, I mean, I don't think it's going to* [be] *break through stuff. I mean until you know how much your emissions are and … whether your supplier sets some sort of benchmark. … Until you work out where you sit – influence what practice you employ. So, you sort of need to know where you sit where everyone else is, but to improve, I think you can definitely improve."*

> *"I just think it's really important that we all get on the front foot. And have all that data ready to go so that as things are changing, as things evolve, we can say, this is what we do, and we've got figures around it. That's probably one of the main things I'd be looking at. So, just have that history of emissions, to do it every year."*

Session 2: Quantifying total farm emission and emission intensity and methane abatement supplements

Using the SB-GAF tool to conduct an audit

Conducting the SB-GAF tool session was very intense for the project team to enable the producers to determine total farm emissions and the EI of their product. Producers had different levels of proficiency in using the tool. They were also running slightly different enterprises and imposing different management strategies. This meant some producers required one-on-one support to determine their farm emissions and EI. The emission intensity per unit of product for 14 Monaro farms is shown in Table 2.

Table 2: Emission intensity per unit of product for beef, sheep meat and wool enterprises on the Monaro in southern NSW.

Farm	Beef (excl. C seq.) ($kgCO_2$-e/kg LW)	Sheep (excl. C seq.) ($kgCO_2$-e/kg LW)	Wool (excl. C seq.) ($kgCO_2$-e/kg GW)
Farm 1	11.3	6.5	25.2
Farm 2	14.3	11.9	43.5
Farm 3	9.1	7.2	26.1
Farm 4	11.6	8.0	31.4
Farm 5		8.0	21.6
Farm 6	15.7	9.6	40.0
Farm 7	-	5.6	20.8
Farm 8	-	6.9	25.6
Farm 9	-	13.3	34.3
Farm 10	-	6.6	25.7
Farm 11	14.0	9.1	31.6
Farm 12	-	10.1	-
Farm 13	9.8	-	
Farm 14	10.7	12.1	
Average	**12.1**	**8.8**	**29.6**
Industry average	**9-18**	**6-10**	**20-35**

LW=liveweight, GW= greasy wool

In presenting the above data producers were able to compare their emission intensity outputs against the other workshop producers as well as against industry. Producers were then asked to respond to the following question:

"Do people feel that they are capable of conducting an audit themselves?"

As one producer explained:

> *"I think I can get a rough blunt assessment. What I don't know is how much I really look at my pasture content and what the digestibility would be. How accurate I've got that. I don't think I've spent any time on that and whether that would actually have any material difference to emissions. That's the curiosity to me, because that's the stuff you can change quite quickly or at least get some accuracy. "*

In using the SB-Gaff tool producers had stock inventory numbers readily available. However, they were concerned about the lack of actual liveweight data rather than estimated weights as this parameter was critical in estimating the emission intensity of their product and where they ranked against the industry benchmark.

As one producer commented:

> *"I don't know how everyone else feels but to get the best out of the tool - we're putting a lot of estimated figures in there. I can give you an inventory of stock in every season. That's not an issue. But you nearly need to be weighing stock four times a year to have an accurate idea on growth rates on anything, and then build that data set over a couple of years. Because, if you're just assuming you use 60 kilograms in winter and 65 kilograms in spring … I assume that can throw the numbers out massively unless you've got…"*

While the GAF tool can estimate emissions for a particular beef and sheep system it is unable to do two different enterprises for the same type of livestock. As one producer explained:

> *"I thought the fact that it only had one sheep – could only have one sheep enterprise is really limiting and too hard to dissect out a sheep meat enterprise from wool. It makes it not very useful. I would have thought one of the useful things about the spreadsheet – if you change your production system, how that affects your emissions. But when … you're trying to average cross-bred lambs with merino lambs it just confounds it all. I think it's a bit useless."*

Methane reducing supplements

Following a comprehensive presentation about CH_4 reducing supplements producers were asked to respond to the following question:

"Given what you have heard in the presentation about CH_4 supplements, would you consider using them?"

At this point in time, almost all producers indicated they were not prepared to consider the use of CH_4 reducing supplements on the grounds of their cost and delivery mechanism. They believed that the available information was insufficient: *"premature"*. *"I don't think we know enough about them"*, *"more information on efficiency"*, *"cost"*, *"what the pay-off is"*, *"cost to effort ratio"*. "*The issue is around how you deliver it in an extensive grazing system … that's the biggest problem."*

As one producer summed up early in the discussion:

> *"Yeah, very much the same as everyone else. You'd certainly consider it, but it needs to stack up and it needs to be in an easy way to deliver and be dollars and cents as well. It needs to be a smart business decision too."*

However, as the discussion about CH_4 supplements proceeded one of the producers raised the issue of compliance in the future:

"We're all talking about the financial benefit to us. There's a potential that it's just going to be a big bloody stick and we're going to have to do it. So, it's all well and good for us to sit here and go, I'm not going to do it unless I make money out of it. There's potential that we have an obligation to do it. And that, from a sheep breeders' perspective, we're miles away from it I would have thought looking at what that presentation said."

3.3 Session3 and 4: GrassGro modelling farm methane abatement options

Each group provided input into the development of a model farm to represent the soil and pasture types expected for their location. Producers also selected the enterprises to be examined together with mitigation options to be explored for each enterprise focused on efficiency. The mitigation options put forward by the producers were considered as being viable or would be compatible with their farming system.

Monaro farm modelling

A description of the enterprises selected and their proposed mitigation options for the model farm is provided in Table 3. In addition, the impact from increasing the area of improved pasture in the model on the base farm enterprises is explored.

Table 3: Monaro selected enterprises and proposed mitigation options for the model farm.

Enterprise	Mitigation options
1. Merino breeding with self-replacing wether component	1. Change in wether proportion in flock. 2. Increased lamb survival rate.
2. Prime lambs with purchased replacements	1. Production feeding to reach 55 kg. 2. Joining ewes as lambs. 3. Smaller maternal weight ewes.
3. Self-replacing beef cattle	1. Later calving and sell yearlings. 2. European cross breeding.

1. Merino breeding with self-replacing wether component

i.) Scenario: c*hange in wether proportion*

A base herd flock consisted of 2200 breeding age ewes and 600 wethers was proposed with 6.59 DSE/ha. The number of breeding age ewes and wethers were adjusted while maintaining flock size and DSE rating. The combinations of breeding ewes and wether numbers tested are shown in Table 4.

Table 4: Change in wether proportion in flock with DSE/ha maintained.

Practice	No. of breeding age ewes	No. of mixed age wethers	DSE/ha
Base (21% wethers)	2200	600	6.59
T1 (42% wethers)	1880	1200	6.68
T2 (64% wethers)	1570	1795	6.68
T3 (84% wethers)	1250	2350	6.57

The changes in meat and wool production (kg/ha), EI (kgCO2-e/kg product) and gross margin ($/ha) with increasing the proportion of wethers in the flock from 21% to 84% is shown in Figs 1, 2 and 3, respectively. Increasing the flock wether % decreased meat production by around one-third with only a small increase in wool production. As the wether % increased the EI for meat increased slightly and to a greater extent for wool. The highest gross margin was achieved at the lowest wether%, falling slightly as the wether% increased to 64% with a substantial decrease at the highest wether %.

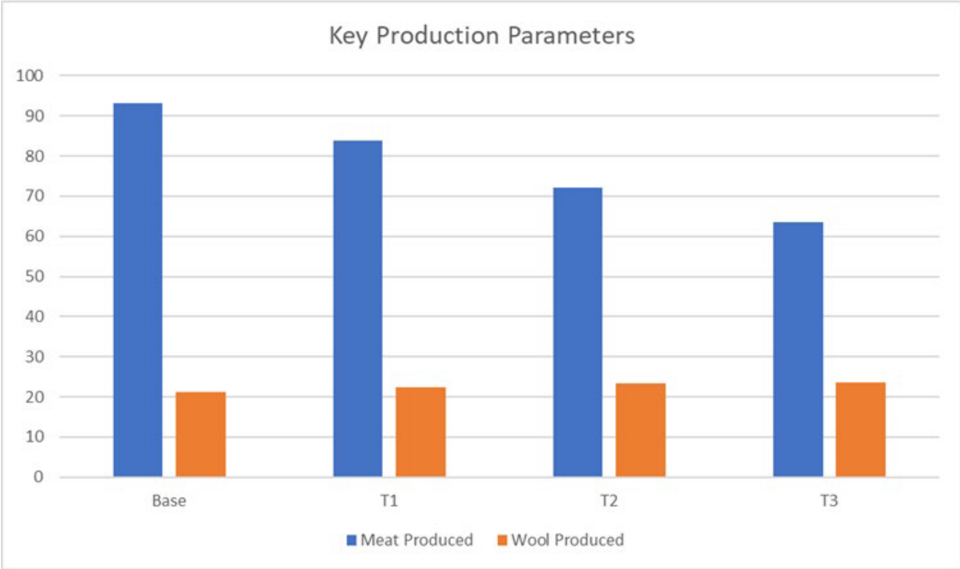

Figure 1: Change in meat and wool production (kg/ha) with increasing proportion of wethers in the flock from 21% (Base) to 42% (T1) to 64% (T2) to 84% (T3).

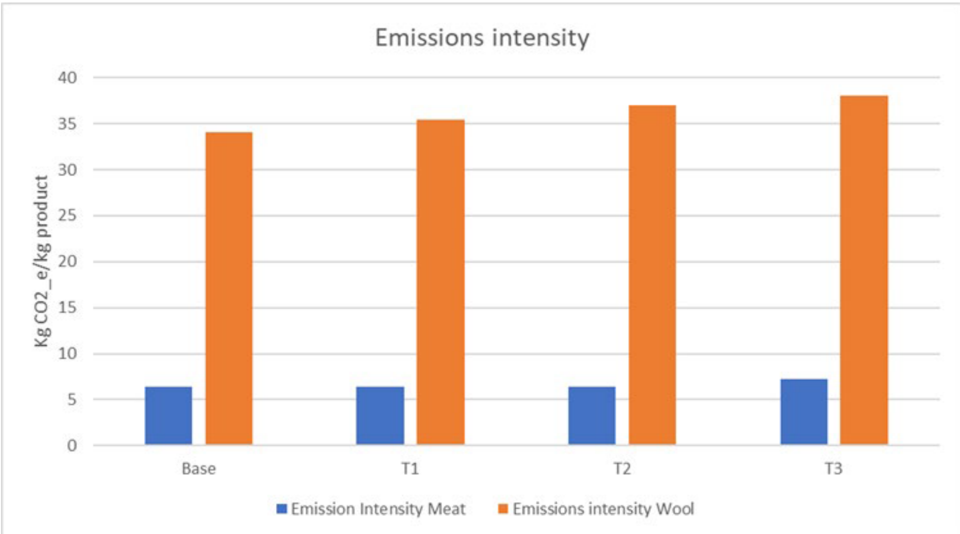

Figure 2: Change in emission intensity (kgCO2-e/kg product) for meat and wool with increasing proportion of wethers in the flock from 21% (Base) to 42% (T1) to 64% (T2) to 84% (T3).

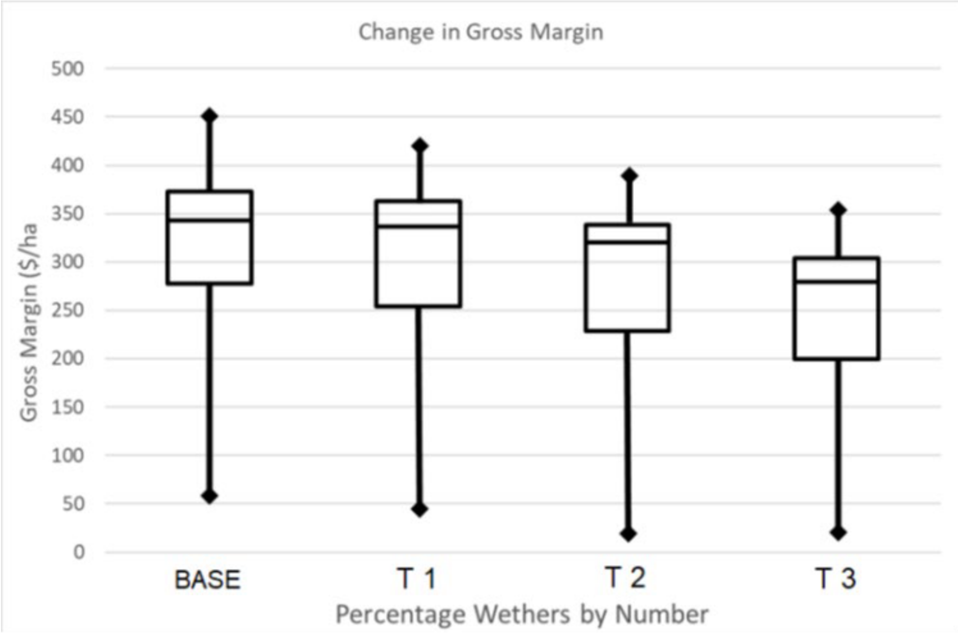

Figure 3: Change in gross margin ($/ha) with increasing proportion of wethers in the flock from 21% (Base) to 42% (T1) to 64% (T2) to 84% (T3).

ii.) Scenario: c*hange in lamb survival rates*

For the farm model the stocking rates of ewes was adjusted to ensure the same minimum levels of ground cover were achieved. Lamb marking rates of 90% (Base), 95% (T1), 100% (T2), 105% (T3) were explored for changes in meat and wool production (kg/ha), EI (kgCO2-e/kg product) and gross margin ($/ha) as shown in Figs 4, 5 and 6, respectively. Increasing the lamb marking rate slightly increased meat production with wool produced largely unchanged. Increasing the lamb marking rate to 105% decreased the meat EI only slightly whereas increasing the lamb marking rate to 100% decreased the EI for wool with little change in wool EI above a 100%. With increasing lamb marking rate the gross margin continued to increase.

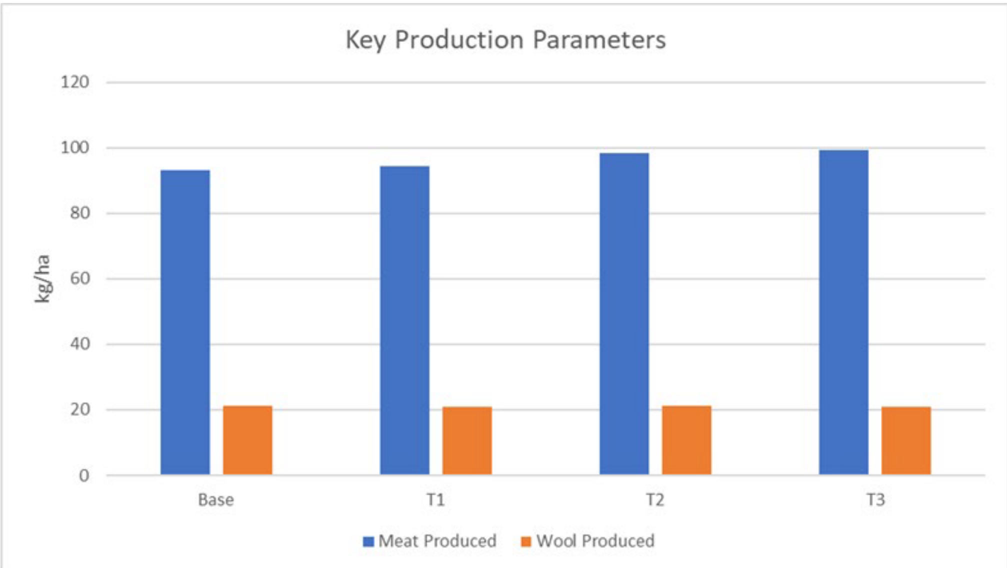

Figure 4: Change in meat and wool production (kg/ha) with a lamb marking rate at 90% (Base), 95% (T1), 100%(T2) and 105% (T3).

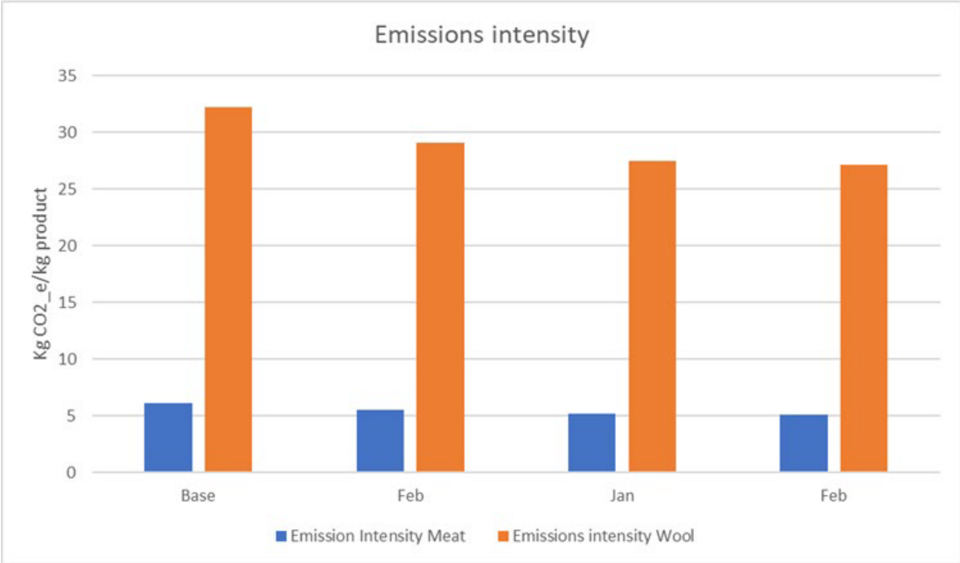

Figure 5: Change in meat and wool EI (kg CO_2-e/kg product) with a lamb marking rate at 90% (Base), 95% (T1), 100%(T2) and 105% (T3).

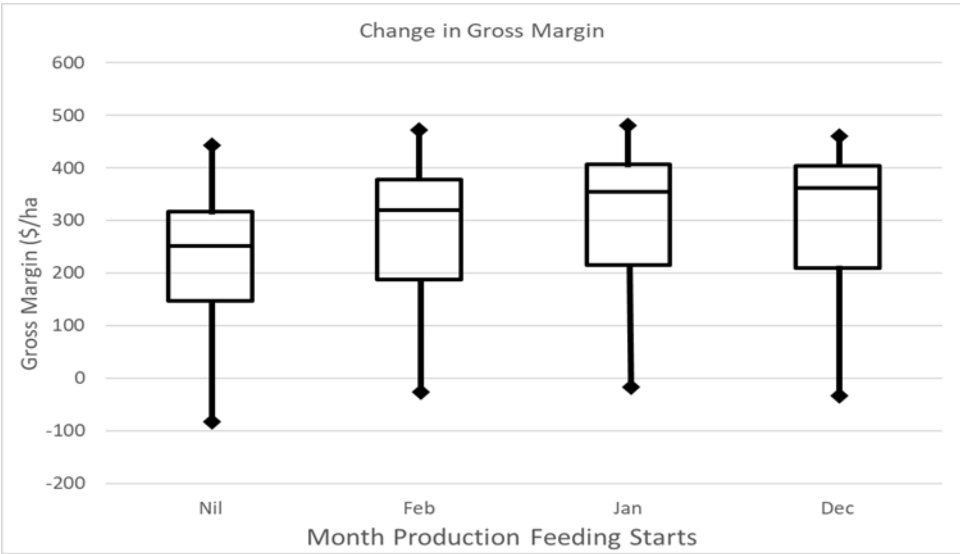

Figure 6: Change in gross margin ($/ha) with lamb marking rate at 90% (Base), 95% (T1), 100%(T2) and 105% (T3).

In summary, it appears there is no benefit from increasing the wether % in the flock from a base level of 21% in terms of improving productivity, reducing the EI and increasing profitability. As would be expected, there appears to be a substantial benefit from increasing the lambing marking rate from 90% to 100% in terms of productivity, EI and profitability.

2. Prime lamb enterprise with purchased replacements

i.) Scenario: production feeding to increase weight at sale

Changes in the length of supplement feeding (barley at 13.7 Mj/kg DM) with no feeding (nil) or commencing in late summer (February), mid-summer (January) or early summer (December) for prime lamb production for animals with an intended sale date of mid-March were also explored with the changes in production (kg/animal and kg/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) shown in Table 5, Figs 8, 9, and 10, respectively. As expected, increasing the length of supplement feeding increased median sale weight for both wether and ewe lambs by 34%. Production/ha was highest when lambs were fed from December or January and this was associated with a lower EI and higher gross margin.

Table 5: Median finish weight (kg) for wether and ewe lambs with changes in supplement feeding, no feeding (nil) or commencing in late summer (February), mid-summer (January) or early summer (December).

Feeding commencement	Wether lambs Median weight (kg)	Ewe lambs Median weight (kg)
Nil	47	41
February (6 weeks)	57	50
January (10 weeks)	62	54
December (14 weeks)	63	55

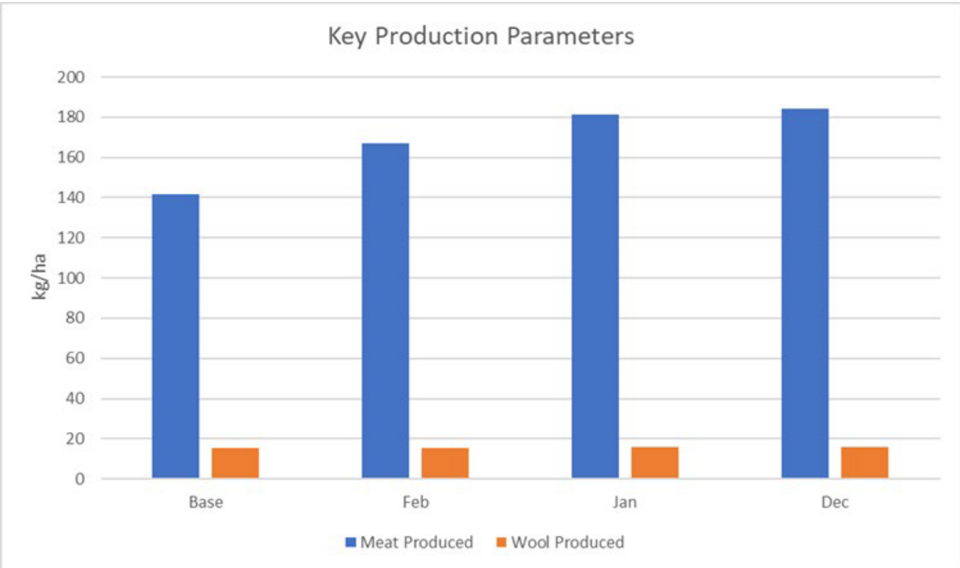

Figure 8: Change in meat and wool production (kg/ha) with no feeding (nil) or commencing in late summer (February), mid-summer (January) or early summer (December).

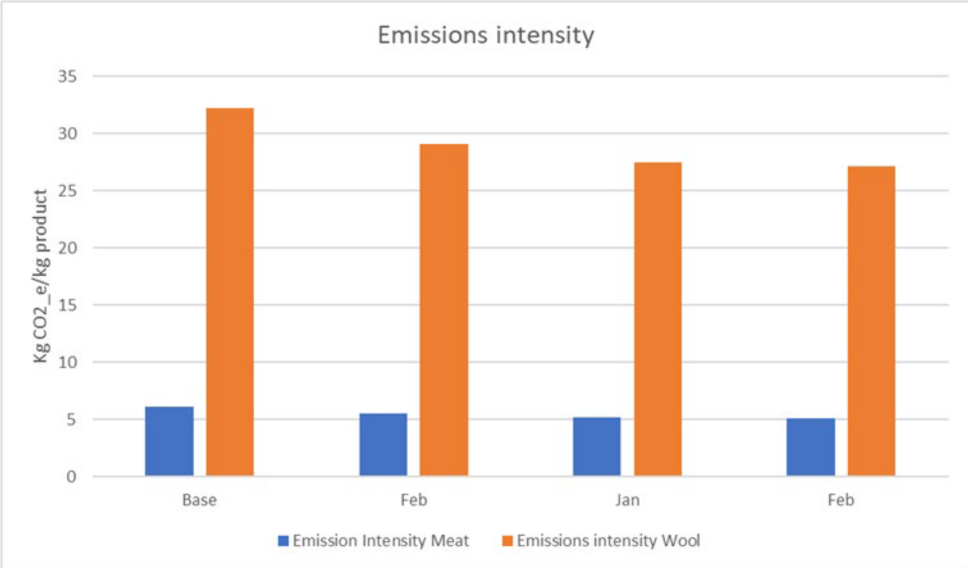

Figure 9: Change in meat and wool EI (kg CO_2-e/kg product) with no feeding (nil) or commencing in late summer (February), mid-summer (January) or early summer (December).

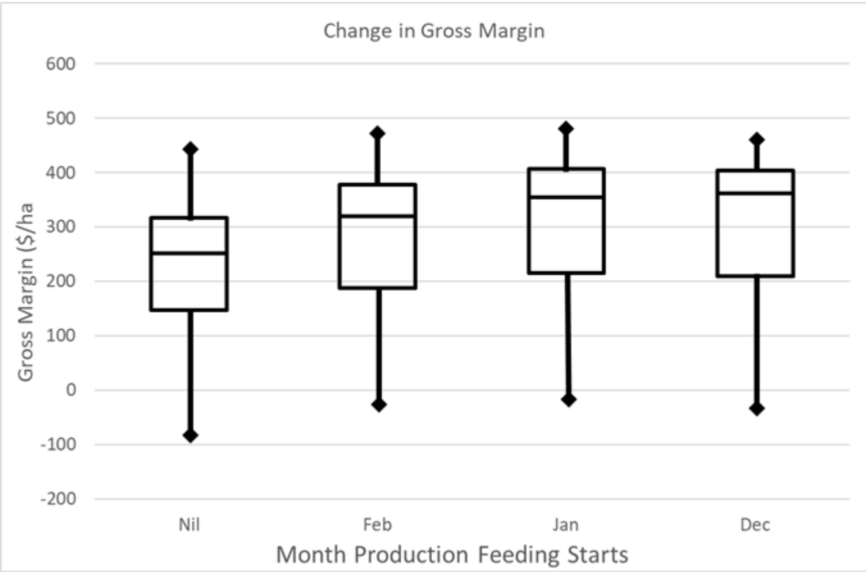

Figure 10: Change in gross margin ($/ha) with no feeding (nil) or commencing in late summer (February), mid-summer (January) or early summer (December).

ii.) Scenario: joining ewes as lambs

The aim of joining as lambs than hoggets is to remove non-productive cohort from the age structure. The weight of wether and ewe lambs when joined as hoggets or lambs is shown in Table 6. The changes in meat and wool production (kg/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) with change in joining as lambs or hoggets is shown in Figs 11, 12 and 13, respectively. Joining as lambs slightly decreased both production and gross margin while slightly increasing the wool EI compared to joining as hoggets.

Table 6: Median weight (kg) of wether and ewe lambs at joining either as lambs or hoggets.

Joining	Wether lambs Median weight (kg)	Ewe lambs Median weight (kg)
Lamb joining	47.0	41.8
Hogget joining	46.7	41.1

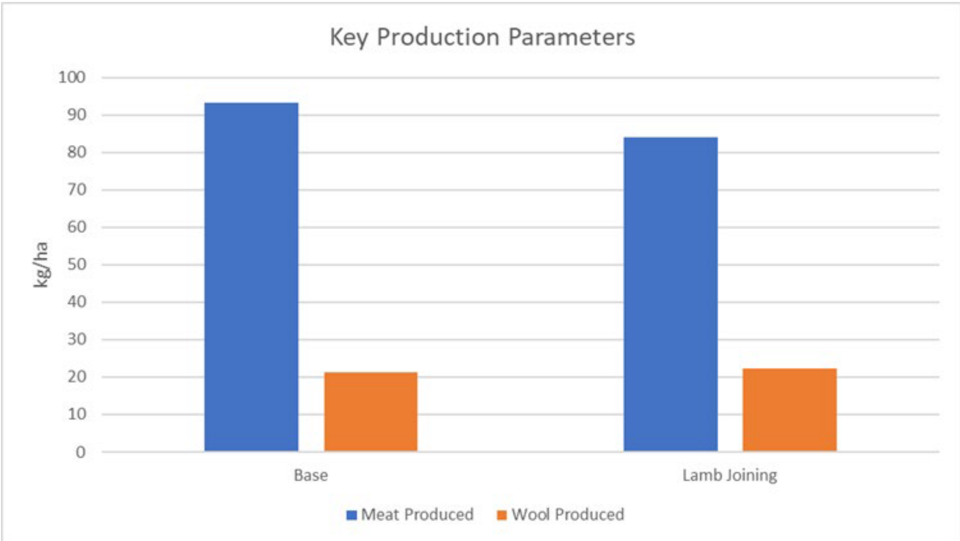

Figure 11: Change in production (kg/ha) when joining as hoggets or lambs.

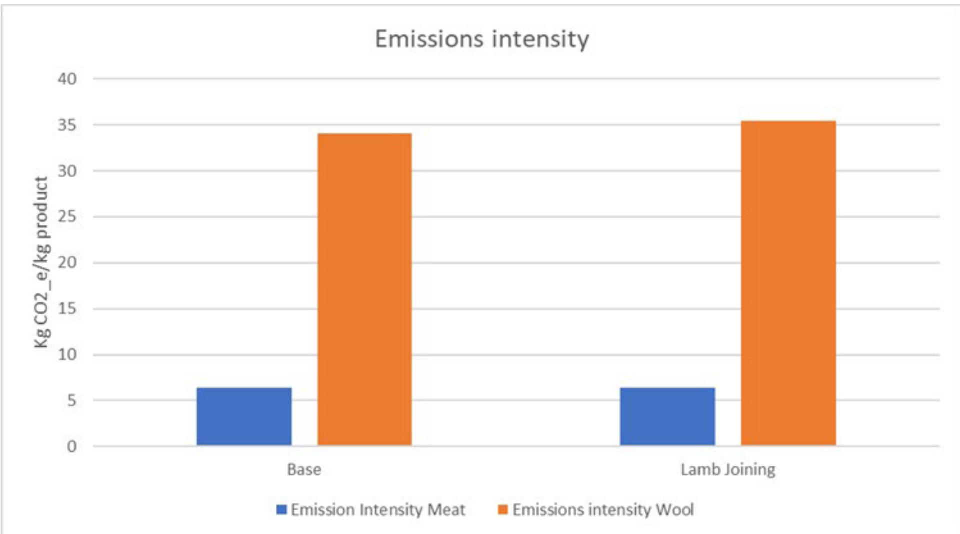

Figure 12: Change in EI (kg CO_2-e/kg product) when joining as hoggets or lambs.

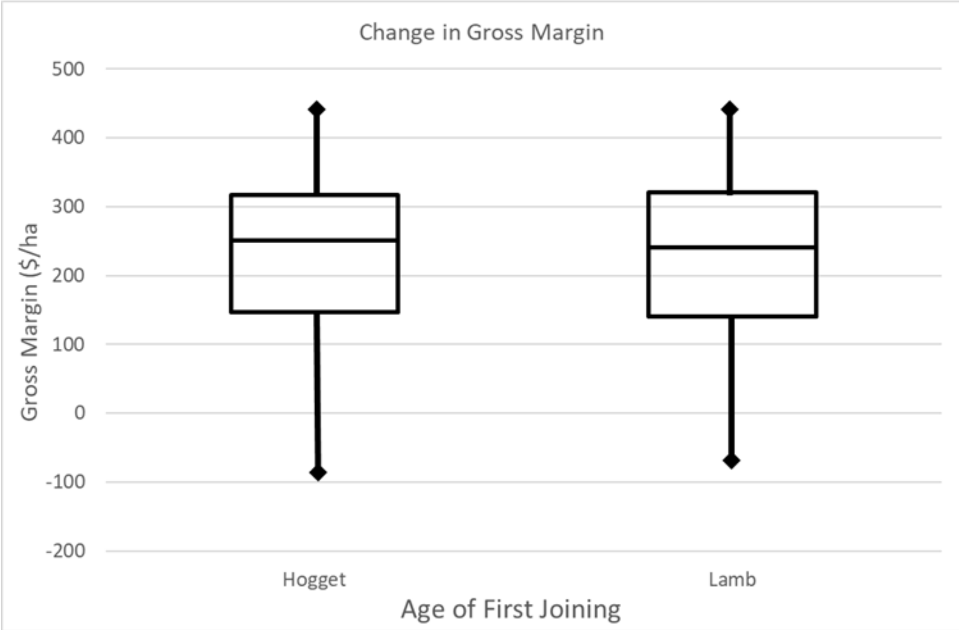

Figure 13: Change in gross margin ($/ha) when joining as hoggets or lambs.

iii.) Scenario: smaller maternal weight

Lower mature weights in breeding ewes should reduce the amount of feed required for maintenance. However, if pasture utilisation/profit are to remain the same or better then stocking rate will need to be adjusted upwards as shown in Table 7. The changes in meat and wool production (kg/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) are shown in Figs 14, 15 and 16, respectively. Decreasing the mature ewe weight slightly increased productivity, slightly decreased EI with a small decrease in the gross margin.

Table 7: Mature ewe weight, stocking rate/ha, DSE/ha, median sale weight lambs and ewes (kg) and total liveweight production/ha.

Mature ewe weight (kg)	Ewes/ha	DSE/ha	Wether lamb median sale weight (kg)	Ewe lamb median sale weight (kg)	Total liveweight produced (kg/ha)
70	3.0	7.07	46.7	41.1	141.85
65	3.2	7.13	44.6	39.7	145.07
60	3.4	7.11	43.2	38.4	147.71
55	3.6	7.08	41.5	36.4	150.41

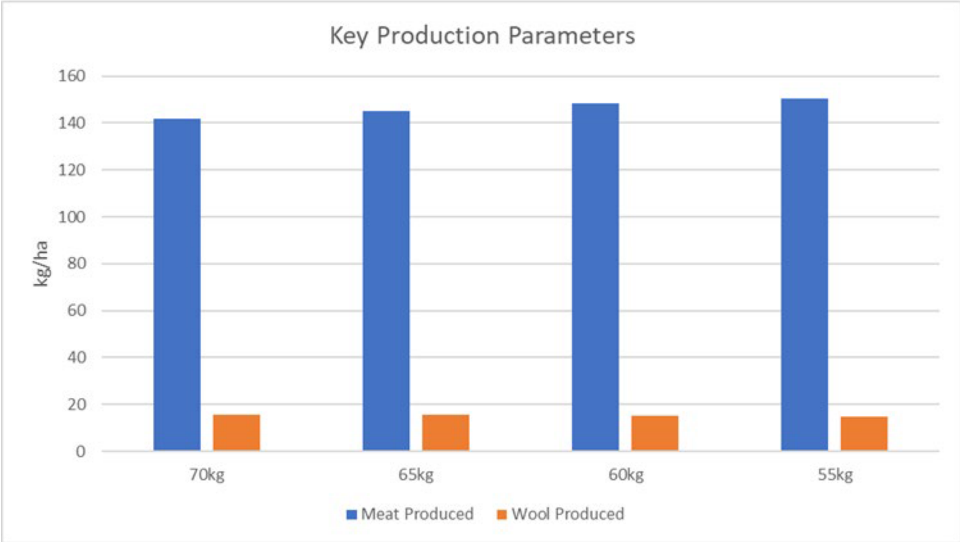

Figure 14: Change in production (kg/ha) with decreasing mature ewe weight from 70 kg to 55 kg.

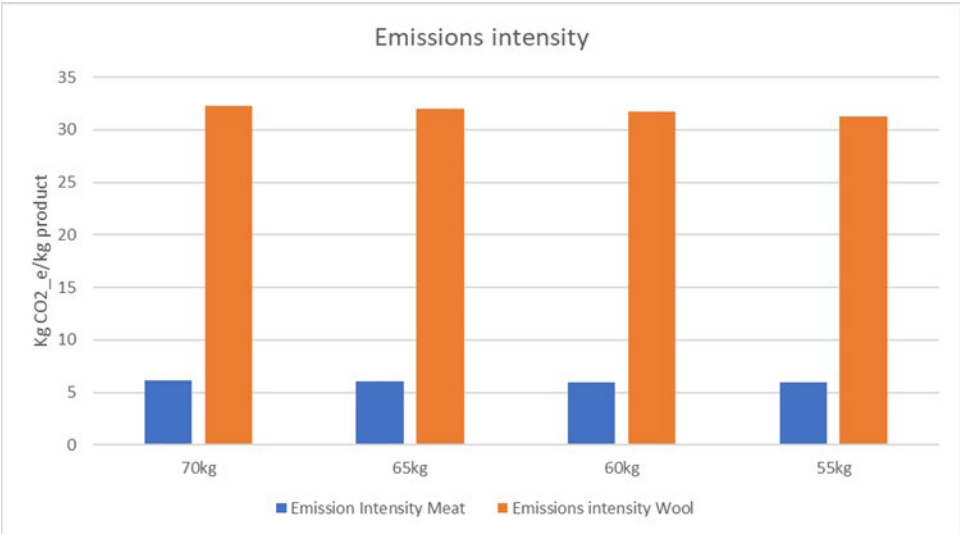

Figure 15: Change in EI (kg CO_2-e/kg product) with decreasing ewe weight from 70 kg to 55 kg.

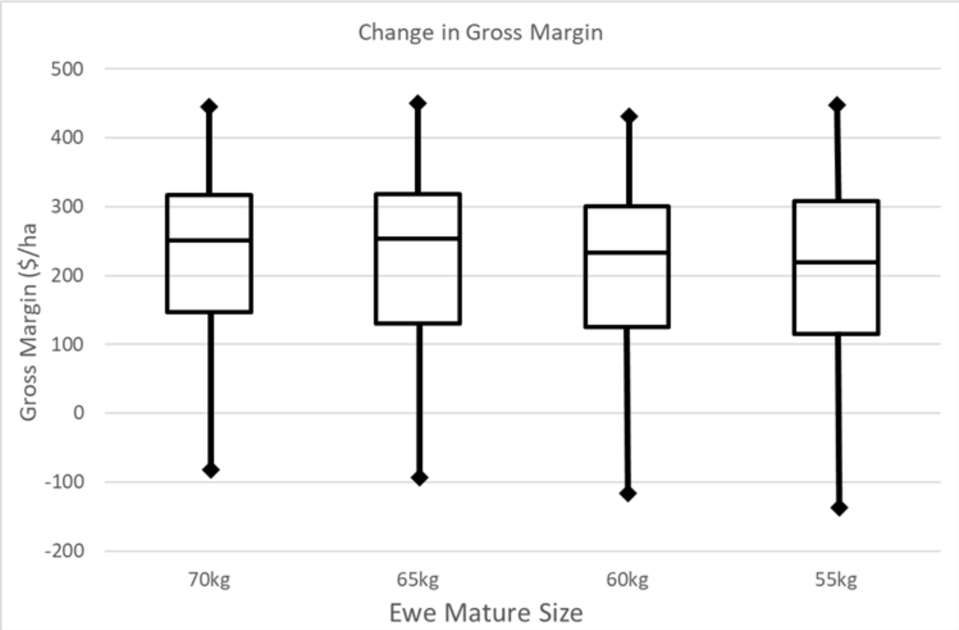

Figure 16: Change in gross margin ($/ha) with decreasing ewe weight from 70 kg to 55 kg.

3. Beef cattle enterprise as a self-replacing herd

i.) Scenario: later calving and sell yearlings, Angus or European X

The median sale weight of steers and heifer by breed, calving date and sale date is shown in Table 8.

Table 8: Median sale weight of steers and heifers by breed x calving date.

Breed x calving date x sale date	Calving start month	Sale date/age	Median steer sale liveweight (kg)	Median heifer sale liveweight (kg)
Base (Angus)	August	Sell as weaners in April at 33 weeks	264	246
Angus, late calving, sell later	September	Sell January at 15 months	417	355
Angus, late calving, sell earlier	September	Sell December at 14 months	397	340
Angus, same calving, sell later	August	Sell January at 16 months	426	363
Angus, same calving, sell earlier	August	Sell December at 15 months	409	349
European X, same calving, sell earlier	August	Sell December at 15 months	465	397

The comparison for all changes in calving and selling date was an Angus calf born in August and sold in April at a median weight of 246 kg (heifer) or 264 kg (steer). As all changes in management were proposed by producers and modelled in GrassGro all resulted in a later selling date regardless of when calving occurred, sale weights were all greater. The sale weight for an August calving of Angus calves, sold at 15 months (January) had similar productivity, EI and gross margin compared to European cross bred calving over the same period, sold one month earlier (December. These combinations of breed x calving x sale date were the most productive of the combinations examined. The changes in production (kg/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) are shown in Figs 17, 18 and 19 respectively.

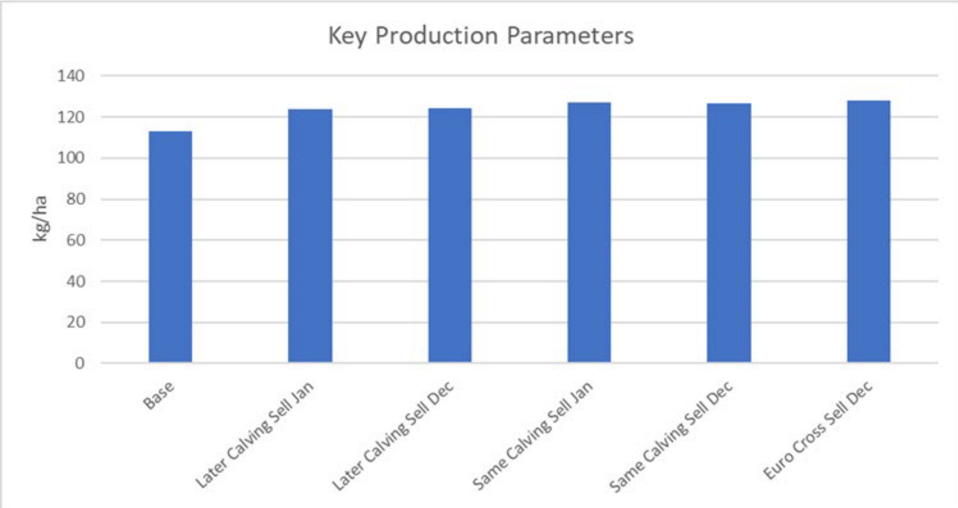

Figure 17: Change in production (kg/ha) with calving and sale date, and breed type.

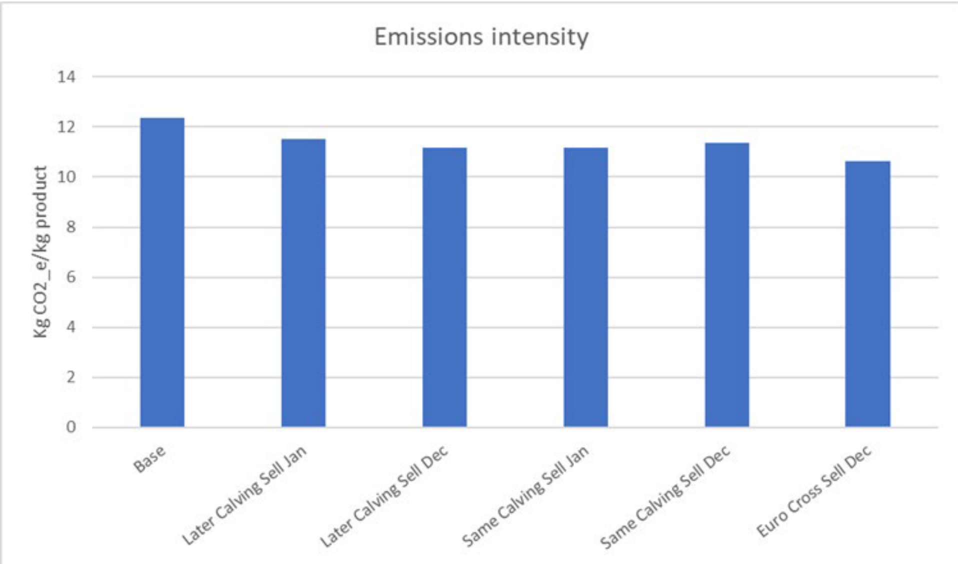

Figure 18: Change in EI (kg CO_2-e/kg product) with calving and sale date, and breed.

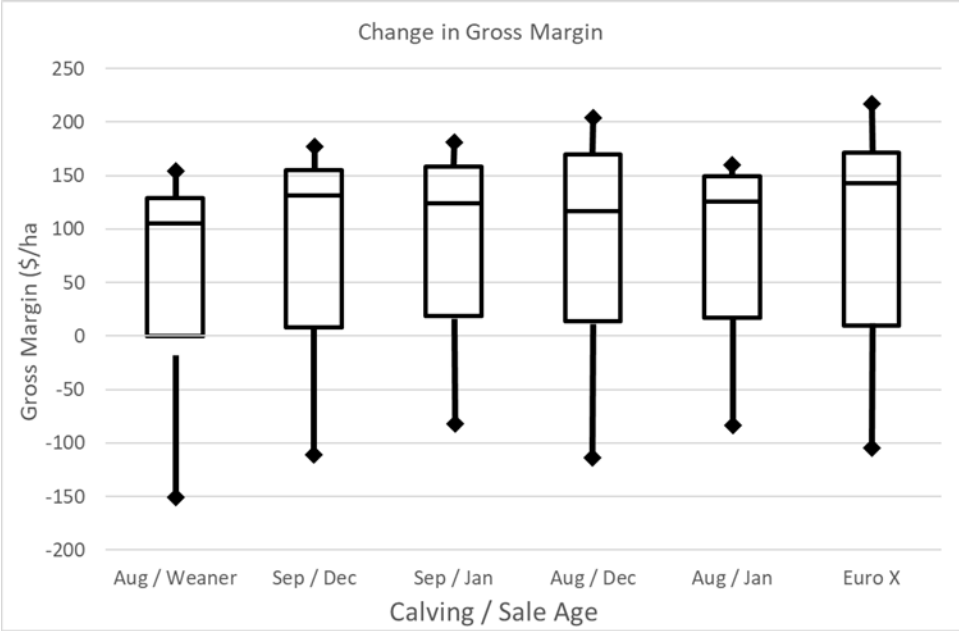

Figure 19: Change in gross margin ($/ha) with calving and sale date, and breed.

4. Scenario: increase the area to improved pasture for a Merino, prime lamb and beef cattle enterprise

In the base farm model, the area sown to improved pasture was 62% and for the purposes of this exercise was increased to 76% (i.e. around 22% on the base farm). The change in production (kg/ha) and emission intensity (kg CO_2-e/kg product) for a Merino, prime lamb and beef weaner enterprise were explored and are shown in Figs 20, 21 and 22, respectively. Increasing the area to improved pasture increased the productivity of all three enterprises, but and more so for the prime lamb enterprise. Increasing the area to improved pasture had little impact on the EI of the enterprises. The gross margin improved for the two sheep enterprises with an increase in the area to improved pasture, although this was not the case for the beef enterprise where there was little change in the gross margin (Fig. 23).

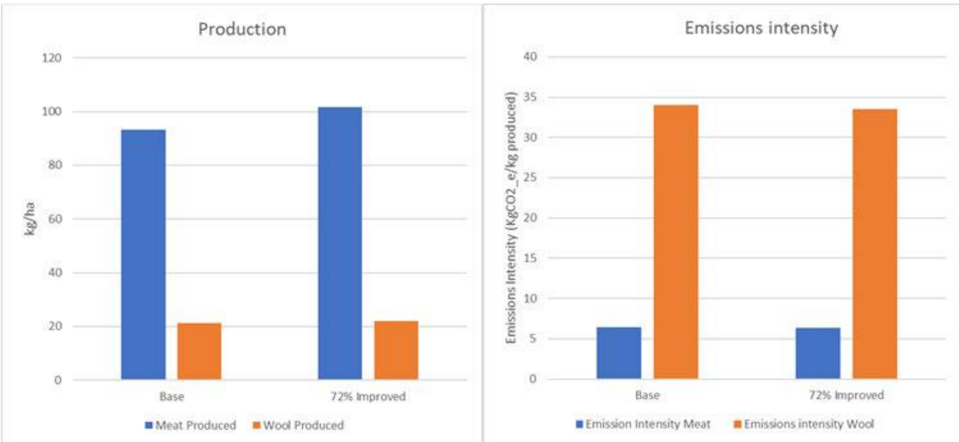

Figure 20: Changes in meat and wool production (kg/ha) and emission intensity (kgCO_2-e/kg product) of a Merino enterprise when the area of improved pasture is increased from 62% to 76%.

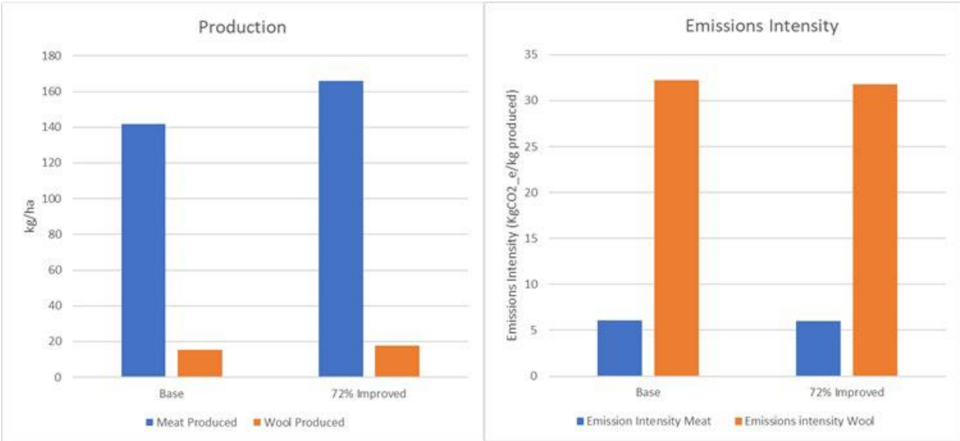

Figure 21: Changes in meat and wool production (kg/ha) and emission intensity (kg CO_2-e/kg product) for a prime lamb enterprise when the area of improved pasture is increased from 62% to 76%.

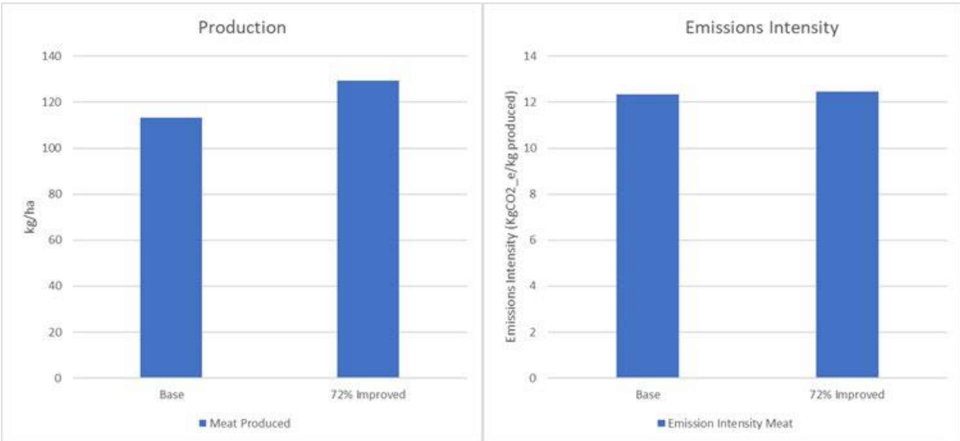

Figure 22: Changes in meat production (kg/ha) and emission intensity (kg CO_2-e/kg product) for a beef weaner enterprise when the area of improved pasture of the base model farm is increased from 62% to 76%.

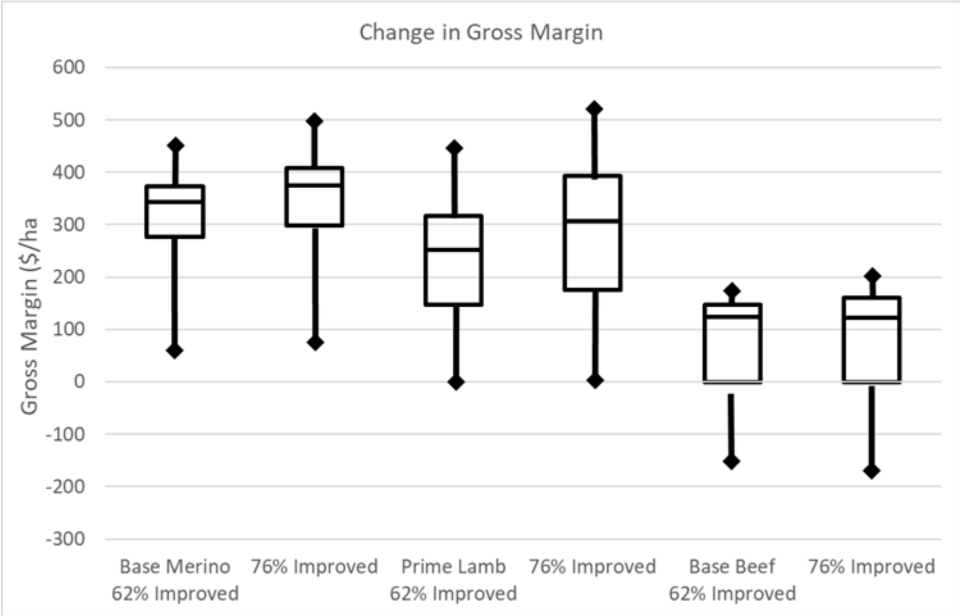

Figure 23: Changes in gross margin ($/ha) when the area of improved pasture of the base model farm is increased from 62% to 76% for a Merino, prime lamb or beef weaner enterprise.

3.3.2 Monaro group responses to the modelling

The Monaro farm modelling outputs demonstrated that the change in EI from a single change in management could be small. However, combining or stacking multiple small management changes could make a more substantial reduction. Making these multiple changes will improve the efficiency of the farm operation with an associated increase in gross margin and accumulate the benefits in reducing emissions.

As one producer concluded:

> *"Looks like what you have to change when it comes to the gross margin is really going to help intensity as we kind of knew. … So no, it's not really going to make a big difference. You're going to do what you would have done anyway. … Probably just clarified. … Not big game changes. …They're all increments."*

From the groups perspective change will be market driven either by access to markets or the supply chain buying their product.

As one producer explained the buyer will prefer their product as they will have their EI figures compared to those producers who have not calculated their product's EI:

> *"They can insist on it [EI] anyway. … So, they will say, 'we're only going to buy from you because you've got your emissions recorded'*

3.2 Canowindra farm modelling

A description of the enterprises selected and the proposed mitigation options to be explored for the Central Tablelands is provided in Table 9.

Table 9: Central Tablelands selected enterprises and proposed mitigation options for the model farm.

Enterprise	Mitigation options
Prime lambs with purchased replacements	1. Supplement strategy to improve efficiency. 2. Retain lambs to achieve heavier weight. 3. Turn lambs off earlier (improve pasture with more legumes). 4. Improved animal genetics (faster growth but not larger mature size). 5. Higher fecundity. 6. Lambing time
Self-replacing beef cattle	1. Increase stocking rate (more pasture crops, improved soil fertility). 2. Compare with trading steers (buy in April at 300 kg, sell in November at 470 kg). 3. Sell as weaners. 4. Increase pregnancy rates.

a.) Prime lambs with purchased replacements

i.) Scenario: supplement strategy to improve efficiency

The proposed selling rules to be implemented include 1st sale date is 15 August, sell at 48 kg, sell if average weight gain is below 50 g/head/day over 14 days, sell by 15 September irrespective of weight or conditions. The supplement feeding strategies to be explored are shown in Table 10. The changes in meat and wool production (kg/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) for the different feeding strategies are shown in Figs 24, 25 and 26, respectively. Ad lib feeding post weaning and sold under the proposed selling rules achieved the highest production and the lowest EI, although the production and EI of the other feeding strategies were marginally lower and higher, respectively. There was little difference in gross margin between the different feeding strategies. Including the no supplement strategy.

Table 10: Supplement feeding strategy and selling rules implemented.

Supplement feeding strategy	Selling rules
Base, 0.5 kg/head/day post weaning	As proposed
Base, no supplement	As proposed
Ad lib supplement post weaning	As proposed
Ad lib supplement post weaning	1st sale date 15 July, one month earlier
Targeted supplement, fed as required from 20 June	Aim to reach 48 kg by 1 August
Targeted supplement, fed as required from 20 June	Aim to reach 48 kg by 15 July

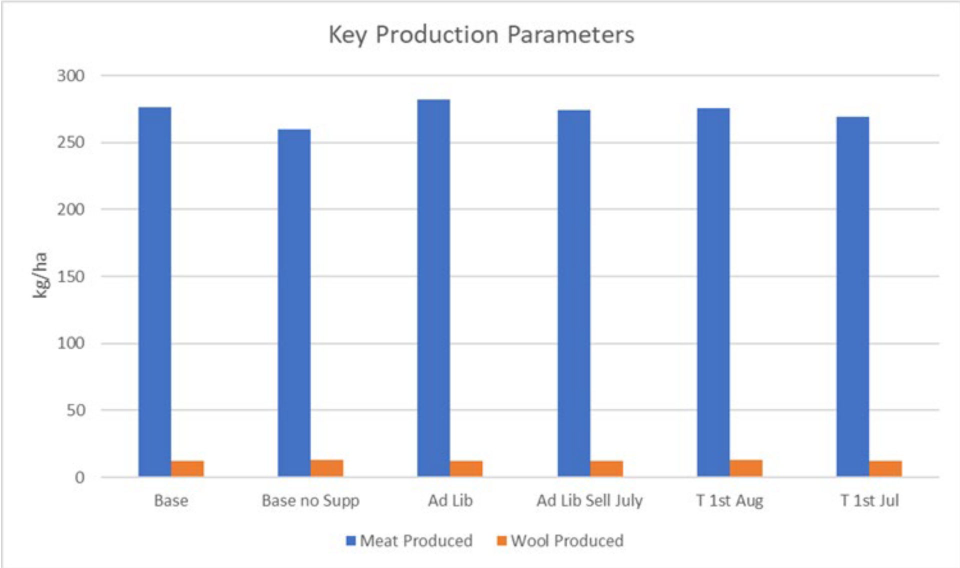

Figure 24: Changes in meat and wool production (kg/ha) with different supplement strategies.

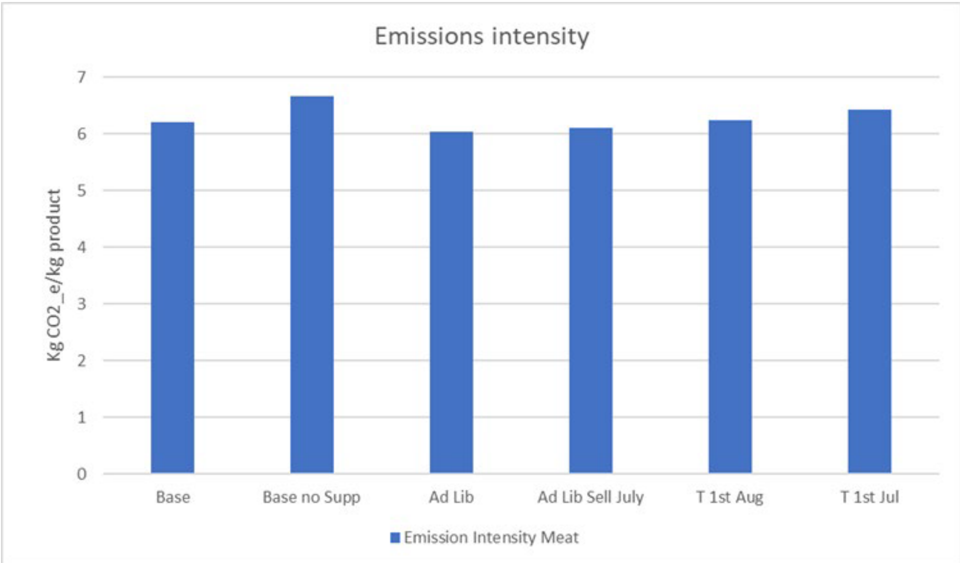

Figure 25: Changes in EI (kg CO_2-e/kg product) with different supplement strategies.

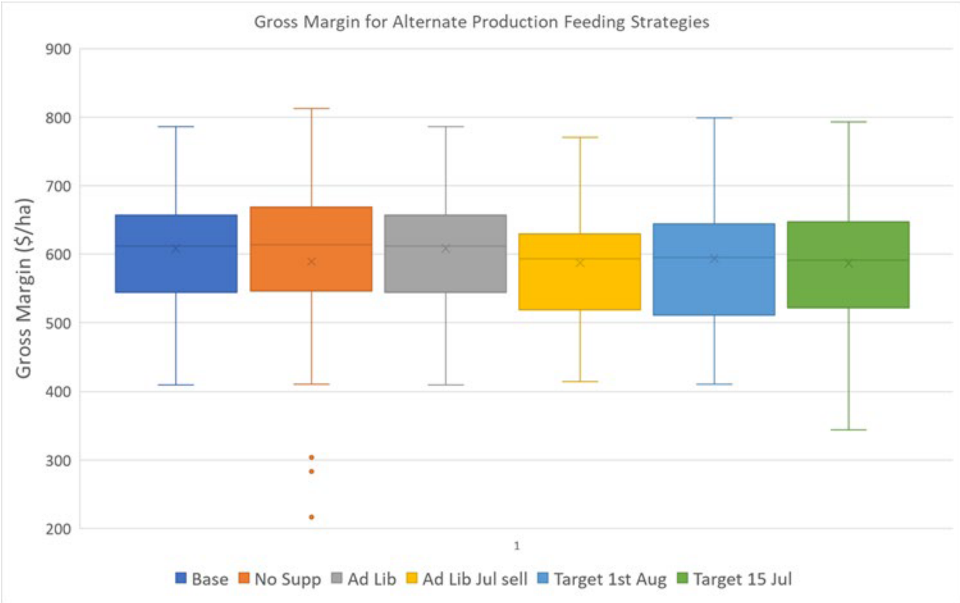

Figure 26: Changes in gross margin ($/ha) with different supplement strategies.

ii.) Scenario: retaining lambs with different feeding and selling strategies to achieve heavier weights

This strategy explored retaining lambs longer to sell at 55 kg with different feeding strategies to achieve the target weight. The different strategies employed are described in Table 11. The changes in meat and wool production (kg/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) for the different feeding strategies are shown in Figs 26, 27 and 28, respectively. The highest production and lowest EI were achieved when lambs were retained for either 1 or 2 months and targeted fed for 10 weeks to achieve 55 kg sale weight. There was little difference in the gross margin between the supplement feeding strategies to target 55 kg and later sale dates. Selling lambs at 48 kg and earlier in August resulted in the lowest production and gross margin and the highest EI compared to retaining lambs for longer and selling heavier.

Table 11: Supplement feed strategy and selling rules implemented.

Supplement strategy	Selling rules
Base, 0.5 kg/head/day post weaning	1st sale date 15 August, as described in full above
Retain 2 months, no supplements	Sell by 15 November
Retain 2 months, target supplement feeding after 1 August	Sell by 15 November
Retain 1 month, no supplements	Sell by 15 October
Retain 1 month, target supplement feeding after 1 July	Sell by 15 October

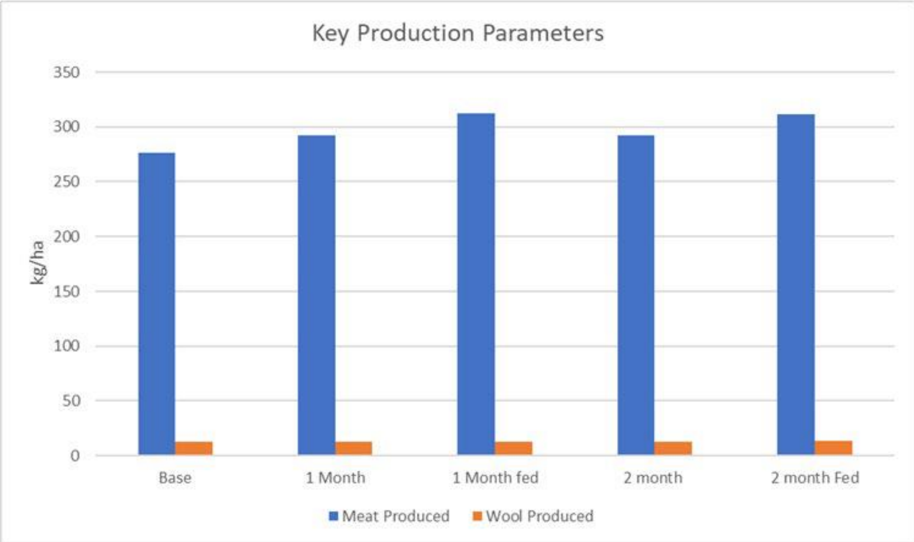

Figure 27: Changes in meat and wool production (kg/ha) with retaining stock using different supplement strategies.

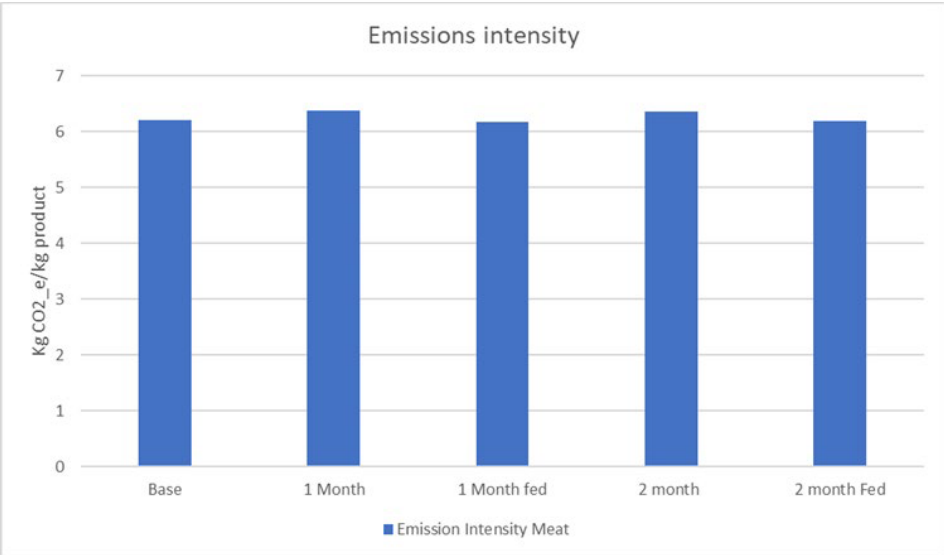

Figure 28: Changes in EI (kg CO_2-e/kg product) with retaining stock using different supplement strategies.

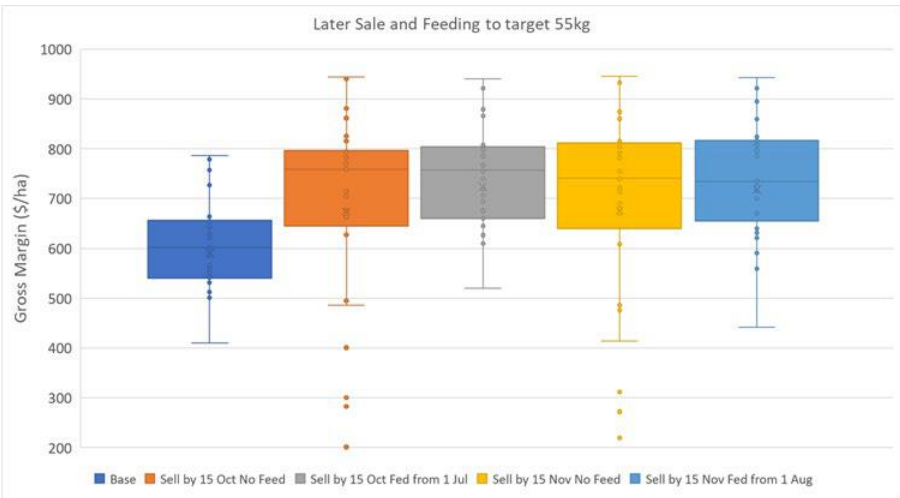

Figure 29: Changes in gross margin ($/ha) with retaining stock using different supplement strategies.

iii.) Scenario: lambing later with different feeding strategies

Lambing on 1 June with four different feeding strategies to reach specified target weight and month were explored and compared with the base model. The different feeding strategies employed are described in Table 12. The changes in meat and wool production (kg/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) are shown in Figs 30, 31 and 32, respectively. Of the strategies employed a later lambing on 1 June with no supplementary feeding and lambs sold at 55 kg or by 15 December achieved the highest production, lowest EI and a substantially higher gross margin. The base scenario had the lowest production and gross margin and the highest EI.

Table 12: Later lambing date with different supplementary feeding strategies, and sale weight and time.

Lambing date and supplement strategy	Weight at sale
Base, 0.5 kg/head/day post weaning	1st sale date 15 August, as described in full above
Lamb 1 June, no supplements	Reach 48 kg
Lamb 1 June, supplements fed from 1 September	Reach 48 kg by 1 November
Lamb 1 June, supplements fed from 1 September	Reach 48 kg by 1 October
Lamb 1 June, no supplements	Sell at 55 kg or by 15 December

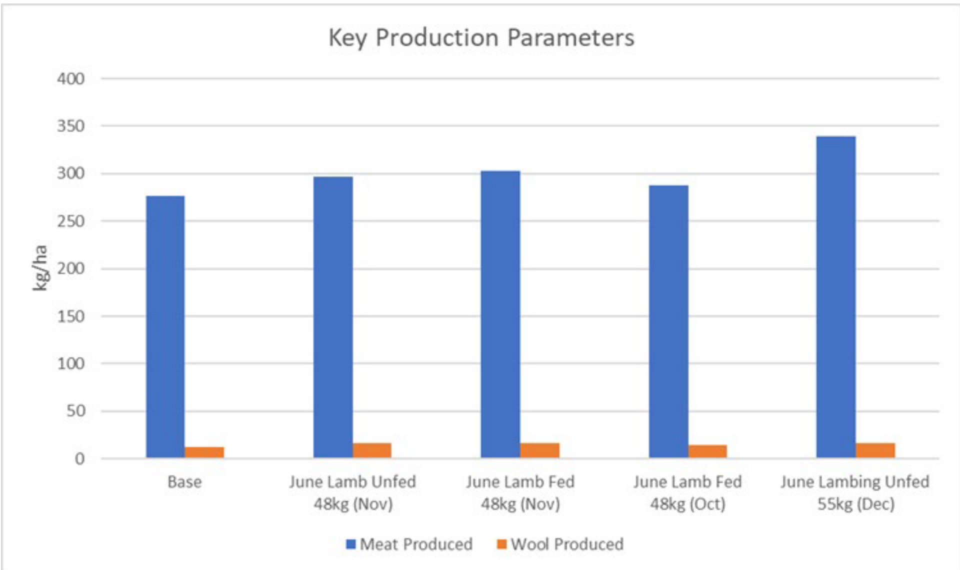

Figure 30: Changes in meat and wool production (kg/ha) with a later lambing, different supplementary feeding strategies, and sale weight and time.

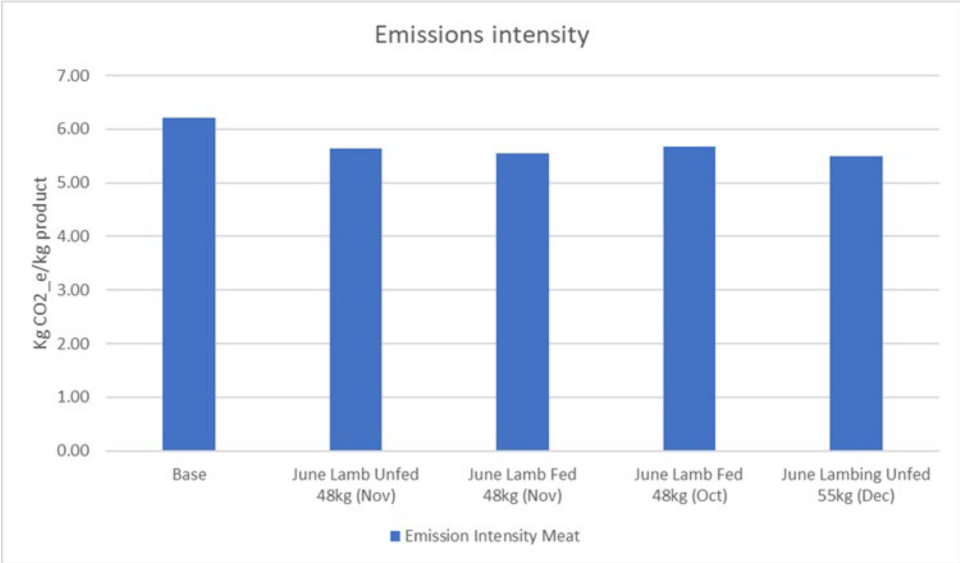

Figure 31: Changes in EI (kg CO_2-e/kg product) with a later lambing, different supplementary feeding strategies, and sale weight and time.

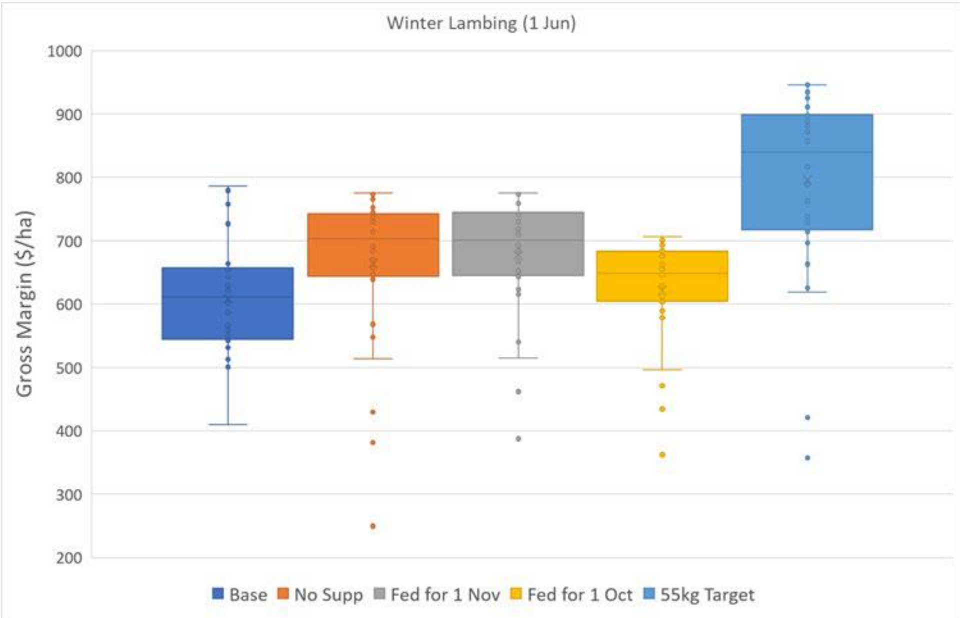

Figure 32: Changes in gross margin ($/ha) with a later lambing, different supplementary feeding strategies, and sale weight and time.

iv.) Scenario: later lambing date with change in lucerne area

The scenarios lambing on 1 June with no supplements to achieve a 48 kg or 55 kg target to sell after 15 November and by 15 December with or without an extra 100 ha of lucerne. Figs 33, 34 and 35, respectively, show the changes in meat and wool production (kg/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) with increased area to lucerne. All the combinations had similar production apart from the June lambing 48 kg sale weight without the extra lucerne. There was little difference in EI amongst the different combinations. The June lambing 48 kg sale weight without extra lucerne combination had substantially lower gross margin.

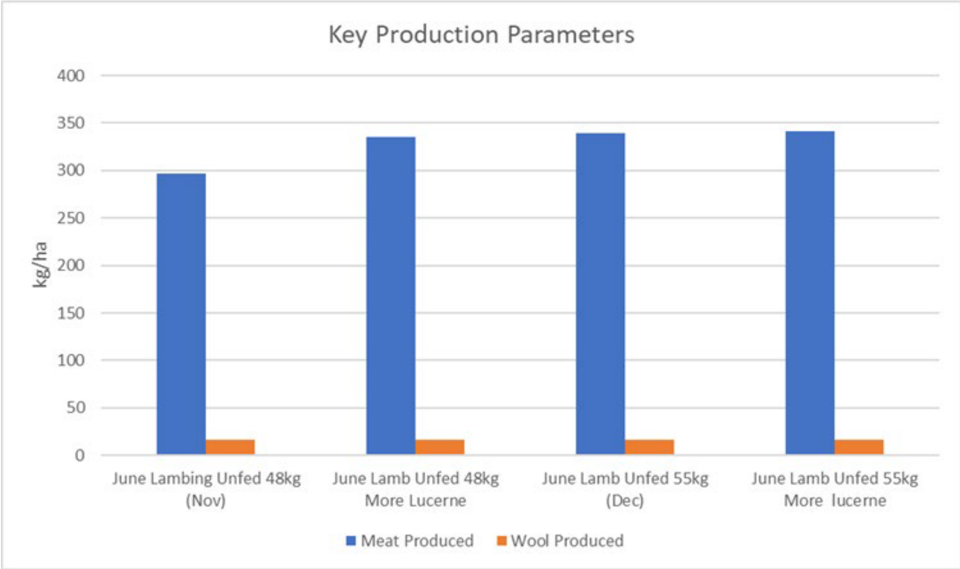

Figure 33: Changes in meat and wool production (kg/ha) with a later lambing, different sale weight and time and with or without an extra 100 ha lucerne.

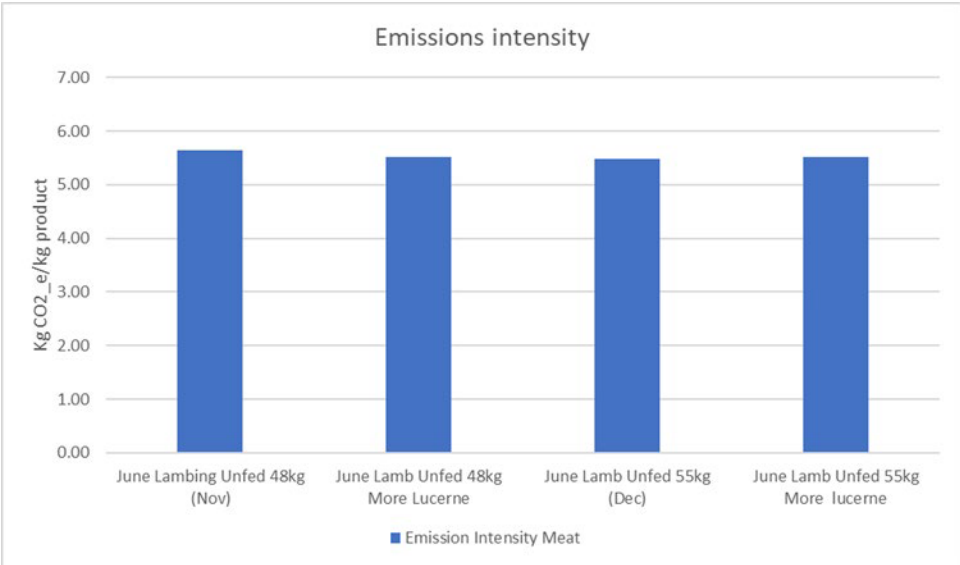

Figure 34: Changes in EI (kg CO_2-e/kg product) with a later lambing, different sale weight and time and with or without an extra 100 ha lucerne.

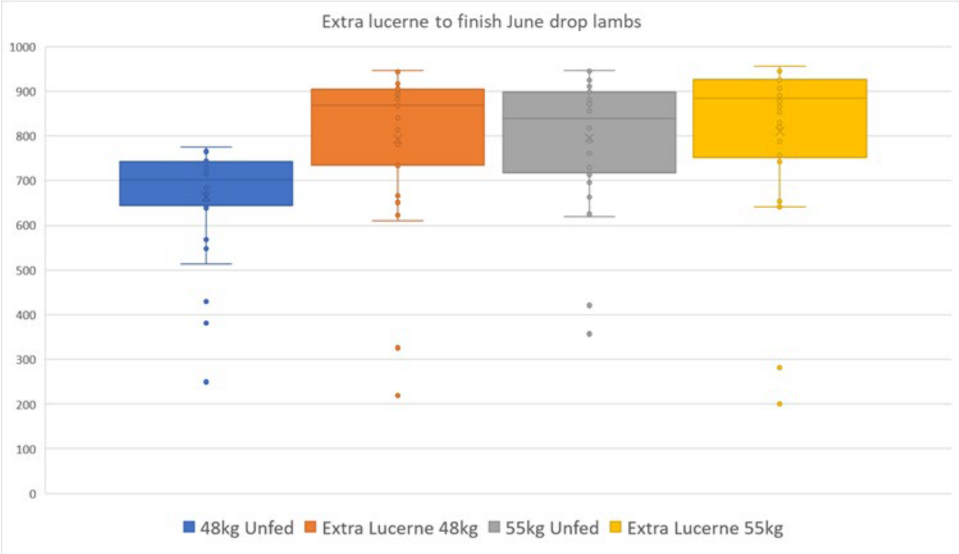

Figure 35: Changes in gross margin ($/ha) with a later lambing, sale weight and time and with or without an extra 100 ha lucerne.

v.) Scenario: change in animal genetics

Selecting animals with traits for faster early growth with no change in weight at maturity or animals with traits for a 10% increase in feed use efficiency for maintenance and growth. Overlaying these traits is an autumn base lambing (15 March) or winter base lambing (15 June). Figs 36, 37 and 38, respectively show the changes in meat and wool production (kg/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) for the faster early growth with no change in mature weight or with a 10% increase in feed use efficiency. Selection for winter fast early growth or winter feed use efficiency achieved the highest production and gross margin with the lowest EI. The increase in gross margin and reduction in EI for either of these winter traits was substantial.

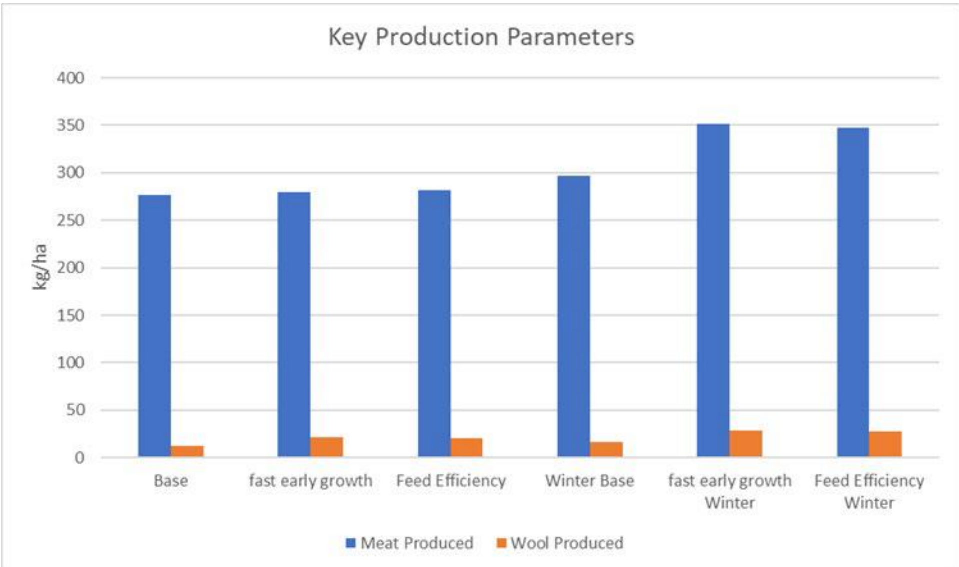

Figure 36: Changes in meat and wool production (kg/ha) with selection for faster early growth with no change in mature weight or selection for a 10% increase in feed use efficiency for maintenance and growth with either an autumn base lambing or winter base lambing.

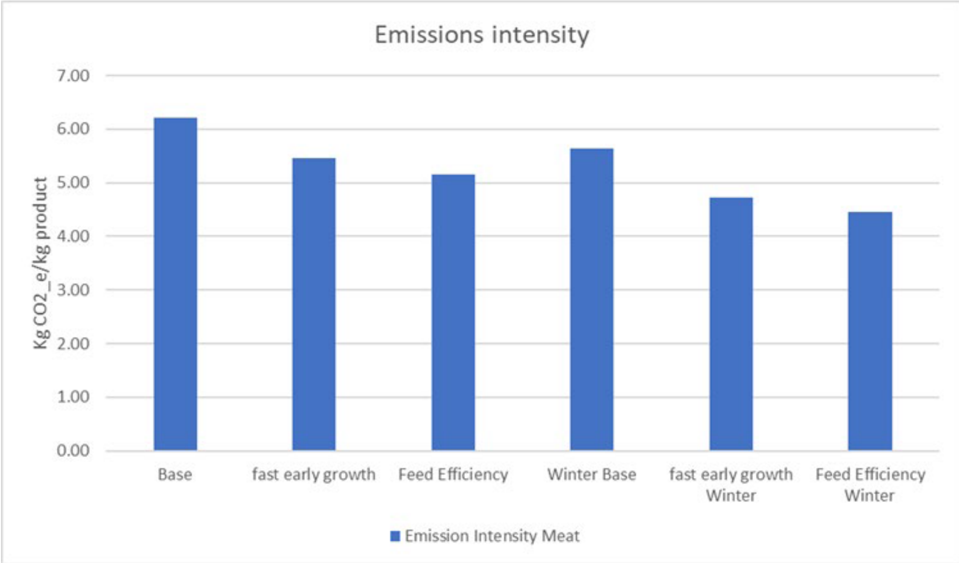

Figure 37: Changes in EI (kg CO_2-e/kg product) with selection for faster early growth with no change in mature weight or selection for a 10% increase in feed use efficiency for maintenance and growth with either an autumn base lambing or winter base lambing.

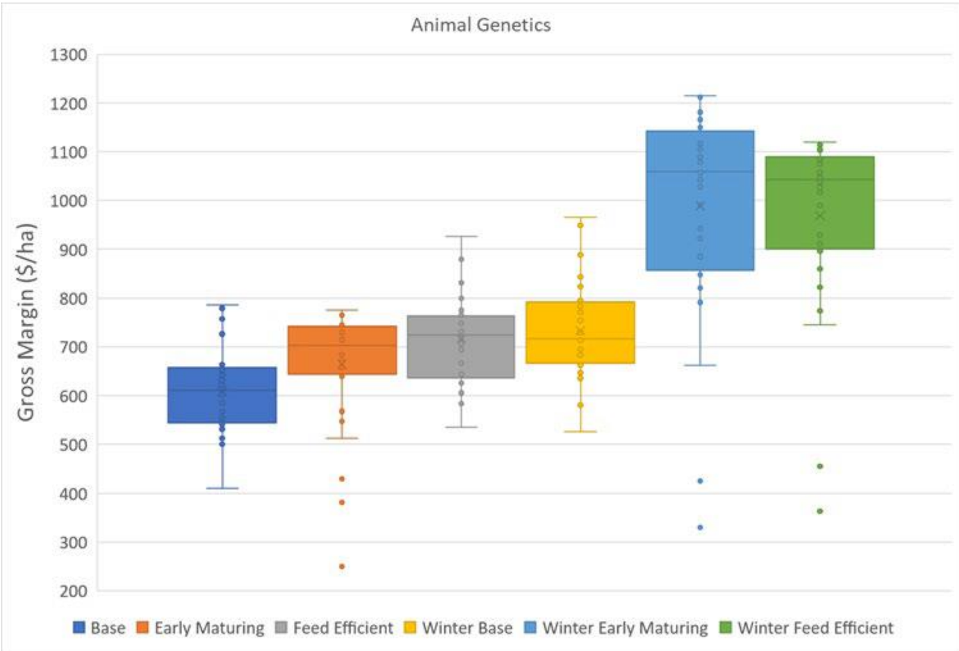

Figure 38: Changes in gross margin ($/ha) with selection for faster early growth with no change in mature weight or selection for a 10% increase in feed use efficiency for maintenance and growth with either an autumn base lambing or winter base lambing.

vi.) Scenario: improved fecundity

Overlaying an autumn lambing (15 March) or a winter lambing (15 June) with a change in lambing composition from the base consisting of 30% singles, 69% twins and no triplets to 20% singles, 69% twins and 10% triplets. The changes in meat and wool production (kg/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) for the different combinations is shown in Figs 39, 40 and 41, respectively. Increasing the reproductive performance increased production and gross margins with reduced EI and this was more so for a winter base. Increasing the fecundity increased the production and gross margin and reduced the EI and more so with a winter lambing.

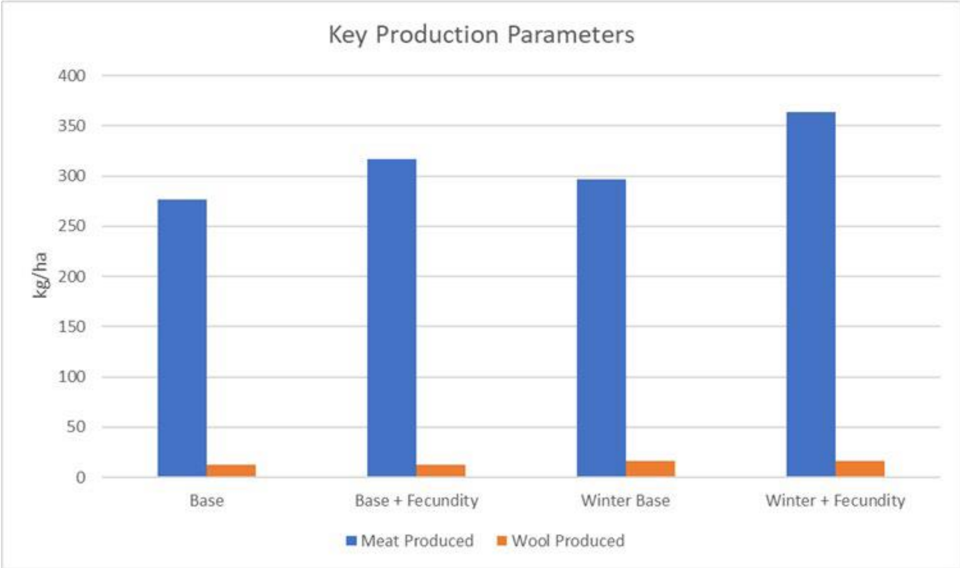

Figure 39: Changes in meat and wool production (kg/ha) with change in fecundity and with an autumn base lambing or a winter base lambing.

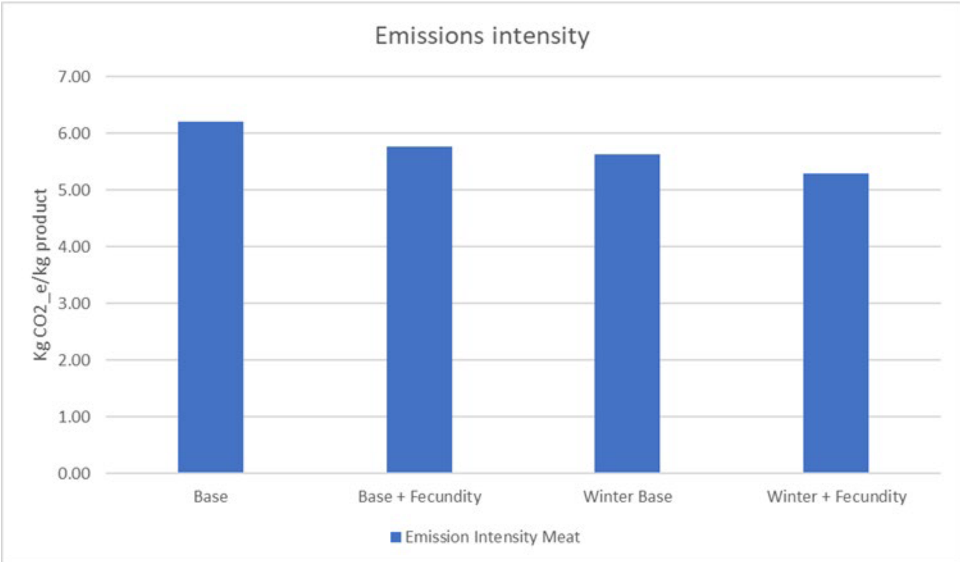

Figure 40: Changes in EI (kg CO_2-e/kg product) with change in fecundity and with an autumn base lambing or a winter base lambing.

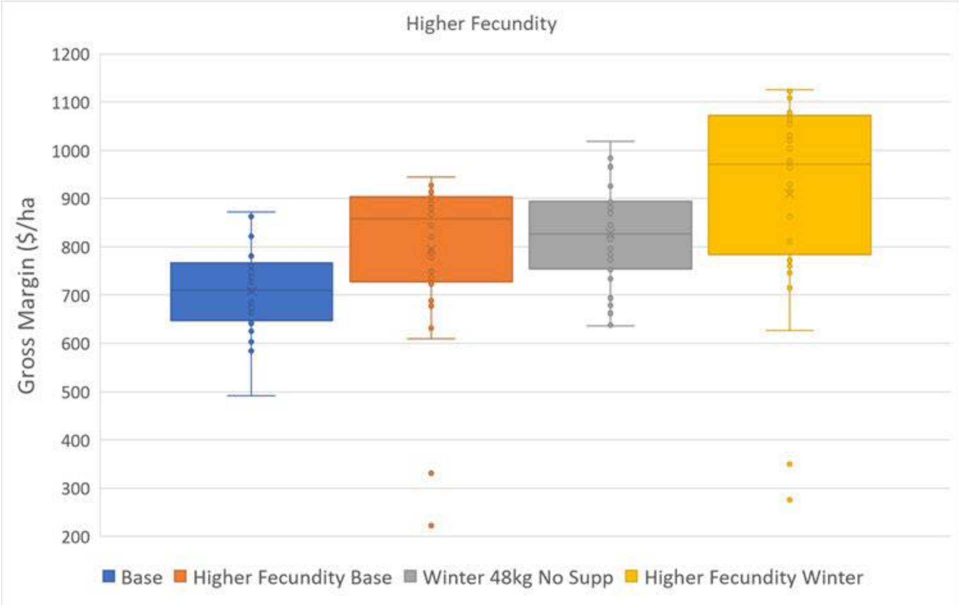

Figure 41: Changes in gross margin ($/ha) with change in fecundity and with an autumn base lambing or a winter base lambing.

b.) Angus beef enterprise

i.) Scenario: increase stocking rate by increasing lucerne, winter forage crop or soil fertility, market weight and fertility

The stocking rate and utilisation assumptions are described in Table 13. The changes in meat production (kg liveweight/ha), EI (kg CO_2-e/kg product) and gross margin ($/ha) are shown in Figs 42, 43 and 44, respectively. Trading steers achieved the highest production and this was substantially above the all the other strategies explored. Trading steers also had the lowest EI and was well below the other strategies. However, scope 3 emissions were not accounted for with trade steers. While trading steers had the highest gross margin, the other strategies had similar gross margins apart from selling as weaners which had the lowest.

Table 13: Stocking rate (head/ha, DSE/ha) and utilisation (%) assumptions.

	Stocking rate No. of head/ha	Stocking rate DSE/ha	Utilisation (%)
Base yearling	0.65	10.9	31
Increase winter forage crop	0.60	10.8	33
Increase lucerne	0.65	11.1	32
Soil fertility non-limiting	0.80	13.4	35
Selling as weaners	0.80	10.6	32
Trading steers	1.90	12.3	38
90% conception rate	0.63	10.9	32
95% conception rate	0.61	10.7	32

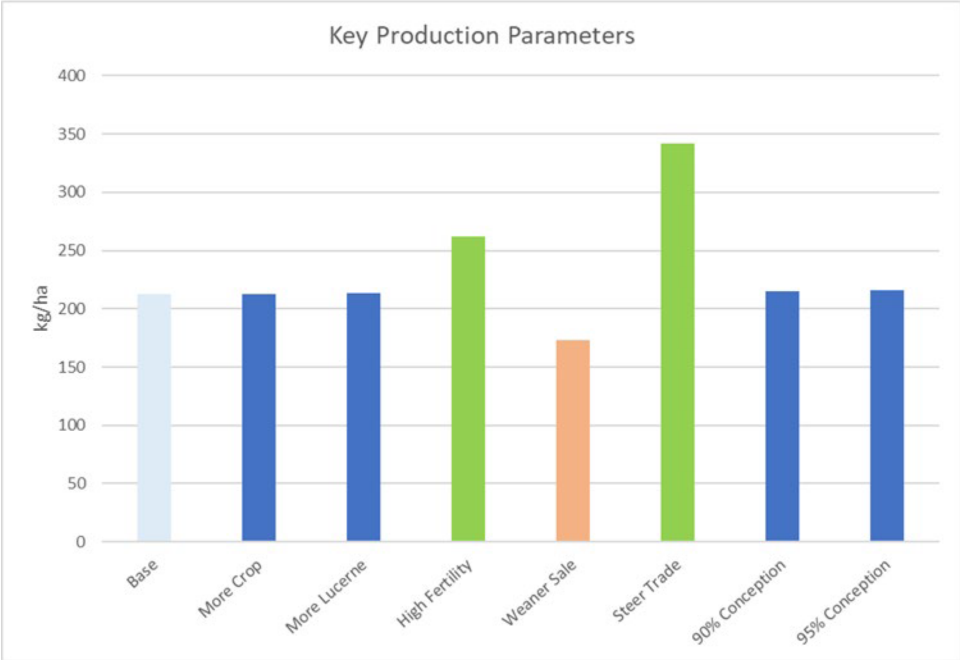

Figure 42: Changes in production (kg liveweight/ha) with increasing lucerne, winter forage crop or soil fertility, market weight and fertility.

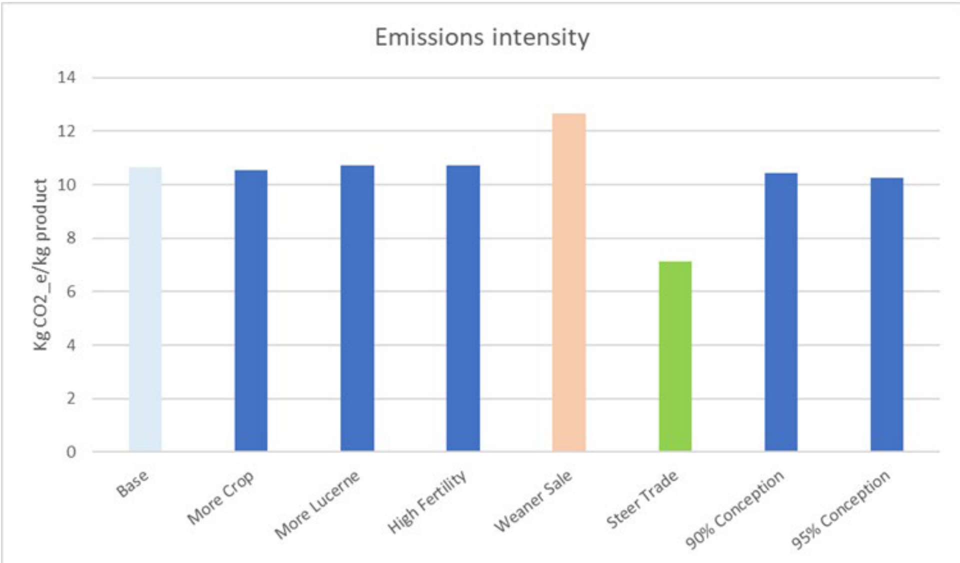

Figure 43: Changes in EI (kg CO_2-e/kg product) with increasing lucerne, winter forage crop or soil fertility, market weight and fertility.

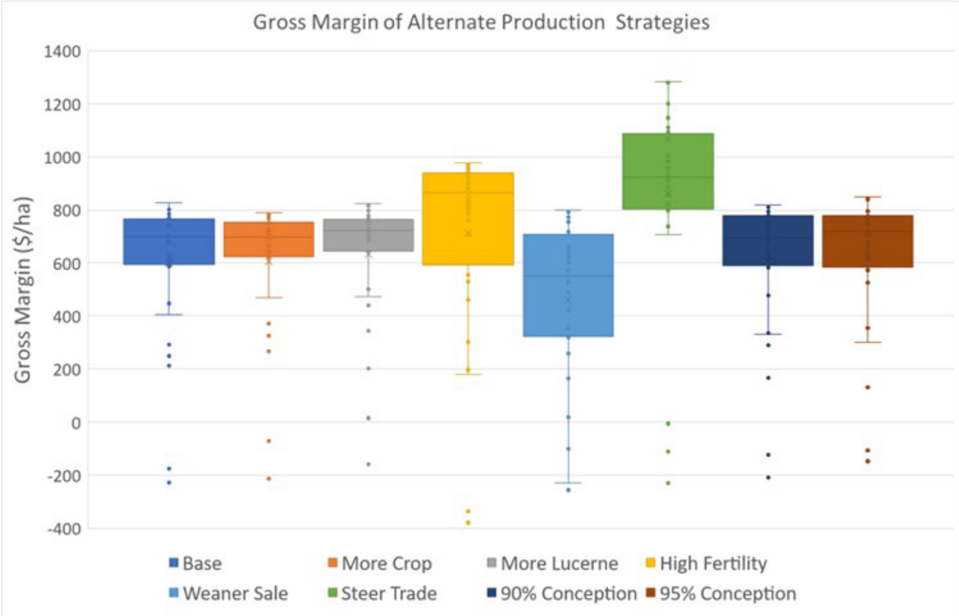

Figure 44: Changes in gross margin ($/ha) with increasing lucerne, winter forage crop or soil fertility, market weight and fertility.

3.2.1 Canowindra group responses to the modelling

The group focussed on the options that were of interest to improving farm productivity and reducing emission per unit of product. As one producer explained they are already investing in higher cost rams to improve feed use efficiency using improved genetics to turn-off high quality *"fine"* lambs:

> *"The most interesting thing for me was where prime lamb production on our farm basically talking about how genetics in the animal affect emission intensity. So, if we are to improve our genetics in our sheep by up to 10% on feed use efficiency it could lead to a 12-17% lowering in emission intensity. I thought this was a real take home message for me. … Because when you are comparing … the different scenarios of supplementary feeding or not there wasn't that much difference but when you come to this [genetics] the was a big change in the whole emissions. High fecundity was a good thing as well. … But I think we will certainly be looking at the genetics a lot harder I'd say. We have been using a higher cost ram."*

Another producer explained that they would focus on intensifying the business rather than de-intensifying:

> *"My sort of thinking is probably fairly straight forward. The fact that we can try, probably already tried it on our farm, to do a better job – improve fertility, have more feed available, pasture improvement – whatever it might be. It seems to be that if we can do better … the outcome as far as the emissions side is not an issue. … That is something I see as quite exciting. Rather than having to wind things back a bit. … Just keep on doing what we have been trying to do for a long time to improve things rather than having to perhaps wind things back a bit. … Just keep on doing what we have been trying to do for a long time. Keep improving things. Like the opportunity to buy in as trade stock, fatten lambs, the more feed we can have there, the better job we can do of that to get stock off. Improve the overall property, business. … We are probably in a position if we needed to, we might back off a bit (with the cost of carbon) on lime, gypsum or pasture improvement. It doesn't seem like you have to, or for a better word 'go full hog' as we pretty much do."*

For another producer their focus was on high fertility to produce more kg of product.

> *"I agree with the fertility side of things. My take home from that is that higher fertility, lower intensity emissions, higher turn off. High fertility then lower emissions per kg product. Similar to cropping."*

3.4 Session 6: Short-term and longer-term market scenarios

In this final workshop we captured the management strategies the two producer groups would consider if they had to reduce their on-farm greenhouse gas emissions. Two scenarios were presented, one in which an emission reduction was required within the next 12-months and the other scenario required a more substantial reduction over a 5-year period. Suggested emission reduction strategies included improving herd efficiency, improved pasture management, use of methane inhibitors and feed supplements, sequestering carbon in trees and soil and using technology.

3.4.1 Short term scenario: 2025 (12 months)

JBS announce that come 1 July 2025 they will require all producers supplying livestock will need to provide their EI numbers and they will be selecting suppliers whose EI are in the ***bottom 50%*** for any given enterprise. Using industry accepted tools that allow you to calculate your EI, you determine that for your given enterprise that you are sitting above the 50% mark. On the assumption that you have minimal time/capital/resources to make substantial changes which of the suggested strategies (outlined in the first paragraph) would you consider may be able to reduce your EI below the 50% mark by 1 July 2025 deadline.

3.4.1.1 Produces' response

The management strategies to immediately reduce methane emission proposed by the Monaro and Central Tablelands groups related to improving the production efficiency and for livestock to reach sale weight earlier.

1. Introduce supplementary feeding

As one Monaro producer explained:

> *"Wouldn't supplementary feeding probably be the quickest way around that? … you're getting your stock off first … like you could actually do that pretty quickly."*

2. Improving livestock productivity

One Central Tablelands producer explained how they were deliberately turning stock off earlier and increasing shearing.

> *"So, we're not looking to produce fat lambs, as such in a six-month period. We're turning off currently a Merino lamb at 12 to 14, 15 months. We've made a move to move that back to a 10-month, 11-month sort of window to turn them off.*
>
> *Probably shearing them [the Merinos] twice to achieve that which is probably not going to help our carbon emissions. Having more wool come off them, I don't know but I suppose it should be the same overall quality. … We're increasing our fleece by shearing twice."*

3.. Use technology to improve herd efficiency

a.) Use Optiweigh which measures individual animal liveweights in the paddock in real-time to check cattle growth rates and link this with the DNA testing of progeny. As one of the producers with Wagyu cross cattle explained his strategy:

"So, anything that marble scores low and average daily gain low would be in my sale … So, what I'm actually saying is that I need a combination of marble score [which gives a price premium] and the actual average daily growth. … We also want to be putting a kilo a day on so there's your growth. So, tying those in together. … Anything that's a poor performer I'll sell off as a weaner."

For a prime lamb enterprise selecting ewes for twinning and selling ewes lambing singles or joining at 8 months has the potential to reduce EI. *"It's all about your weaning percentages."* Reproductive rate and growth rate are the critical drivers. Another option is an 8-month lambing cycle at 100% to give 150% per year.

b.) Use of electronic identification (eIDs) as a management tool to identify and focus on twinning ewes as the standard. One producer described how he was using eIDs:

"We're already using eIDs. Anything over 18 months has to scan to a twin every eight months. Otherwise, it's out the door."

4. Boost pasture production

Favourable rainfall and temperatures are required when nitrogen is applied to boost growth. The winter climate on the Monaro limits the responsiveness of nitrogen but it is potentially useful as an option for the Central Tablelands. However, there is the complication that if you have a pasture with 30% legume then *"you are going to make your legume lazy"*.

While applying nitrogen will give an immediate boost to production, particularly with annual ryegrass, there is a crossover point between the increase production/improved feed quality and emitted emissions. Applying extra nitrogen has a cascading effect in managing the production system. As this producer explained the consequences from boosting pasture applying nitrogen:

"Where you add extra application of your nitrogen that increases your pasture growth. Mean you need more stock to do that. But then you've got to be able finish that stock. So, you can run into your production risk. So, I'd say there is a crossing over of all those points becomes the optimum."

5. Improve feedbase quality

Although the grazing of dual-purpose crops and highly productive annual temperate grasses is common on the Central Tablelands, it is less so on the Monaro. However, one of the Monaro producers explained how they have increased their winter production:

"We've done a lot in our system to improve winter feed base through fodder cropping. So having wheats and annual rye grasses which do get winter production. Not huge but more than anything else to increase our cattle production."

The Monaro producers as graziers were more limited in their options to reduce emissions compared with the Central Tablelands producers as mixed farmers. The Central Tablelands group had the option to sow forage crops and to increase the cropping area or even sow longer season crops.

A discussion among Monaro producers took place around negotiating current market complexities and with the expectation to reduce EI is this will only further complicate market access. The following quotes exemplify the discussion:

"… we've talked about grain and supplementary feeding, but for JBS particularly, if you're targeting a grassfed market you're hamstrung…"

"This market led I think will come but it's going to be fickle. Because sometimes they're going to want…grassfed."

"Then if they're desperate they don't care."

"It'll wax and wane. When there's an oversupply of cattle they can pick and choose."

"Then so, this is where this market led thing, I think is going to hard to navigate."

3.4.2 longer-term scenario:2030 (5 years)

JBS announce that come 1 January 2030 they will only be selecting their suppliers whose EI are in the bottom 25% for any given enterprise. Again, based on the industry accepted tools that allow you to calculate your EI, you determine that for you given livestock enterprise that you are sitting above the 25% mark. Which of the suggested strategies (outlined in the first paragraph) would you consider implementing to reduce your EI below the 25% mark by 1 July 2030.

3.4.1.1 Response by producers

1. Sequestering carbon in trees

Planting trees lines is viewed favourably as it provides shelter for stock. However, producers recognise to have an impact on carbon footprint it would need to be at scale. As one producer explained to offset their average emissions, they would need to plant 300 ha or 25% of the property.

There is interest in establishing timber plantations in the region because of a government initiative to increase timber supply. It would be a good business decision to establish a plantation as it would bring economic and sequestration benefits. One suggestion was to use existing less productive land on the property for timber. Another suggestion was to purchase lower productive land specifically for timber.

One producer proposed a novel concept of establishing a collective timber planation rather than private industry or investors purchasing the land for timber only and impacting social fabric of communities. This producer explained the concept:

"The model that I've sort of mud mapped on the back of an envelope, is there's a collective of land holders that operate with a timber production enterprise that you give your land or under whatever circumstances, for plantation timber, lower production, which gets collective emissions to then distribute. … Because some people have land that's probably better suited entirety for its agriculture, some people don't. So, you try and balance it on a bigger scale and just the individual land holders that you get an economy of scale. … But the landholders have got to have it rather than private firms coming in … potential synergies between agriculture and production and emissions abatement."

2. Sequestering carbon in soil

Monaro producers indicated that soil carbon sequestration would not have a role in offsetting their emissions. For some they already had naturally high levels of soil carbon with little opportunity to increase soil carbon levels under current practice. These producers understood that carbon in soil fluctuated over time with rain as the main driver of soil carbon levels. They also recognised they were being exposed misinformation that was not based on science. One producer explained their position:

"Well, I've written off, even for 2030, I've written off soil carbon. I just don't see it as an avenue. But then I was at an event there a couple of months ago and these people reckon they've, I don't how many acres they were operating on, but a 300 head cattle breeding program that they reckon was fully offset by the soil. … they reckon it was heavily degraded soil but I didn't think that would be … enough then to offset."

Monaro producers has a strong focus on managing soil fertility, and, most notably, soil phosphorous levels. Their view is that by maintaining high levels of soil fertility, they have the potential to produce high quality feed and to maintain the carbon levels in the soil. They have little *"impetus"* to test soil carbon per say as *"I'm not a carbon farmer"* (i.e. they are not interested in measuring soil carbon per se and particularly using an ACCU based methodology). However, since *"0 to 10 cm soil testing is part of my system"* (i.e. has a regular 0-10 cm depth soil testing program) then there is no additional effort to obtain a carbon value for that depth. This would allow them to measure the trend in soil carbon and the effect of management/climate leading to an increase/decrease. This was of interest to these producers as potentially they could take an estimated soil carbon value to inset some of their on-farm emissions.

3. Use of genetics

The role of EBVs will be important with breeding objectives to target animal for high growth and low mature cow weight. Improving animal performance requires using both genetics and longer-term management objectives as this producer explained:

"I think it links to your genetics and combining it with a few other strategies that take a bit longer to implement … so it's really for your sheep enterprise it's pushing your scanning rates and lambing percentages out. Isn't it?"

4. Herd efficiency

One producer summed the need to pay attention to improving efficiency across the whole production system:

"But I think your herd efficiencies is pulling all those levers to maximise fertility, maximise growth through genetic improvements, grazing management of your joining. Weaning, all those things, you've just got to become really efficient for all of that."

5. Increase lambing rate

A Central Tablelands producer suggested lambing every eight months explaining how it would work:

"You're not in a winter summer cycle … [Lambing] March, July and November."

However, it requires good quality feed following lambing to ensure ewes recover and are pregnant by the due time. Those ewes who get out sync they are culled as pregnant ewes. As one mixed farmers pointed out that November is when crops are being harvested so the idea to lamb every eight months is not suitable.

6. Use of methane inhibitors

While the role of methane inhibitors on-farm was viewed by producers as neither cost-effective nor practical, they could have a role in finishing their livestock in a feedlot. One producer suggested if you could reduce the time on-farm by entering a feedlot earlier at a lower weight and then use a methane inhibitor in the feedlot then on-farm and supply chain emissions should be lower.

Early life programming involving the feeding calves with the methane inhibitor 3-NOP from around 6 to 14 weeks was an appealing option to producers if they had to substantially reduce the EI of their product.

"It just comes down to executing everything that you possibly can. But in the end, it sounds like the story is that you can't do it without sequestration. We need to have ways to deliver supplements to animals that's efficient and cost effective. I don't think that's there."

Discussion

Producer's use of the SB-GAF tool

(a.) Producers found the SB-GAF tool to be too coarse/blunt to obtain outputs that were meaningful for their business. For example, current estimated changes in liveweight gain did not closely reflect their actual figures. The tool does not allow for the running of two different sheep enterprises in the one business.

(b.) Producers require a tool that will allow them to better understand their products' EI. This will enable producers to understand the impact of making operational changes on their carbon footprint.

(c.) Producers require the collection of EI data to be automated through incorporation in farm software. This will facilitate the collection of data and encourage widespread use by producers.

(d.) Producers understand the need to measure their carbon footprint at least annually to enable them to build an emissions profile for when future market/governments interventions are imposed.

4.2 Extensive livestock producers' position

Drawing on from what we have learnt from producers, we can distinguish between those mitigation options that are 'probable' (i.e. likely to be implemented by producers, win-win, low hanging fruit) and those considered 'possible' (i.e. technically feasible, unlikely to be implemented by producers, not cost effective or difficult to implement, may require regulatory pressure) (Anastasiadis et al.2012). Producers participating in this study focussed on the 'probable' practices as these practices were associated with improving production efficiency with any emission reduction viewed as a co-benefit. Producers paid less attention to the 'possible' mitigation options even though some of these practices could substantially contribute to emission reductions. Methane inhibitors, sequestering soil carbon and tree planting were assessed as either too costly, too uncertain, impractical to deliver, scale required or timeframe limiting.

As one producer summed up their current position:

> *"It just comes down to executing everything that you possibly can. But in the end, it sounds like the story is that you can't do it without sequestration. We need to have ways to deliver supplements to animals that's efficient and cost effective. I don't think that's there."*

It is likely policy mechanisms will be required to promote 'possible' mitigation options including regulation and compliance, incentives (i.e. cash grants, tax offsets and low interest loans), and delivery of training and information (Feliciano et al., 2014).

At present time, producers are only likely to implement those options that had a production benefit or something they intended to do as this producer explained:

> *"It's just increasing our production efficiency really. That's the only thing you'd ever consider. Wouldn't it, realistically. Just like claiming on your tree lots that you're putting in anyway."*

Producers' hold the view that being more productive is the best way to reduce the emission intensity of their product. *"You look at the calculator and how it works. It's just about productivity at the end of the day. The more you can get off for the same amount of emissions."*

Producers acknowledge implementing multiple changes across their farm system is required, although the changes stacked together will not achieve carbon neutrality. As these two producers explained:

> *"It's all going to help your intensity. You're not going to get yourself neutral with it but if you can just nudge yourself closer it all helps. Doesn't it?"*

> *"I don't think carbon neutral is achievable in my system. Not unless there's a breakthrough in technology … From everything we've looked at, it's just about being more efficient."*

Most producers were clear in their desire to maintain 'business as usual' as the status quo with reducing emissions to align with their business goals. One of producers explained their perspective:

> *"But I'm not making business decisions on emission intensity … my goal is not to produce the lowest emissions. It should be to produce what I want at the lowest emissions. Or produce what's profitable at the lowest emissions."*

However, not all producers held the same position as this producer explained:

> *"So, I think for our business the big focus in to try and get that balance. Like we've got to have production, we've got to be making money. But we want to do the right thing by the environment … try and get it somewhere in the middle."*

Producers expressed the concern that they would bear the costs of reducing emissions in the supply chain as the power lies with the other sectors (i.e. meat processors and supermarkets). As one producer explained:

> *"We know this stick is coming … because we all have a responsibility. But big business is going to pass it down to us."*

Producers also expressed their concern about their ability to be competitive in the international markets. The requirement to implementing practices that substantially reduce the EI of their product will substantially increase their production costs. *"Australia is at the higher end of the production system." "We do not have subsidies and all the rest of it." "It's got to have a premium. Something to offset the costs in an export majority market."*

Conclusion

Producers do accept they will need to make changes as they recognise livestock emissions are the most significant contributors to agricultural emissions. They also understand their on-farm emissions are significant and will not be simply offset by insetting from carbon sequestration. Producers are focussed foremost on efficiency gains in their production system that would benefit their business with emission reductions viewed as a co-benefit.

Using the SB-GAF tool to estimate on-farm emissions and product EI needs to be further refined to be meaningful to the individual producer. Ideally, estimating emissions needs to be incorporated into farm software to enable the data to be captured as standard practice.

Producers are only likely to reduce emissions by 20-25% with technology in the foreseeable future and sequestration will have to be part of the solution. There is no incentive for producers to move from a 'business as usual' model to one that encompasses transformational change. The transition to a 'transformative' model will require a substantial change in farm structure, farm practices and producer mindset to enable a significant reduction in on-farm emissions.

Finally, while the red meat industry and governments are seeking to reduce emissions there is no clear driver (signal, pathway, value proposition) to make change, producers will continue to make changes that are in their interests. For changes to go beyond those that have a favourable business outcome, they will require incentive with an embedded carbon price.

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8.5 Long term soil organic carbon data and modelling

Soil organic carbon (SOC) data from pastures is presented for long-term trials at Brian Pastures, Wambiana and a leucaena chronosequence in tropical Qld and for the Orange Agricultural Institute (OAI) and the CAMBI trials in temperate NSW.

Simulating changes in pasture production and SOC change in response to management using predictive models is a cost-effective alternative to having to run long term trials and provides graziers with site specific options to optimise management for the best economic and environmental outcomes. The DayCent model was used to simulate changes under different grazing management at Brian Pastures, Moura, OAI and the CAMBI trial.

DayCent is a biogeochemical process model that simulates the C and N cycling across the soil–plant-atmosphere interface on a daily basis (Del Grosso et al., 2012; Parton et al., 2001). The Integrated Management Systems projects used a modified version of DayCent (DayCent-CABBI) that was developed by the Centre for Advanced Bioenergy and Bioproducts Innovation (Berardi et al., 2020; Moore et al., 2020) based on the DayCent-Photo model version (Straube et al., 2018) which simulates the seasonally variable photosynthetic capacity in the calculation of gross primary production (GPP).

Model inputs and configuration

Soil inputs (bulk density, soil texture and pH) (0-1.0 m) for the DayCent-CABBI model were calculated from the soil sampling event at each site where available. For the CAMBI sites, these soil inputs were measured at one site down to 1.0 m and the 0–0.1 data at the other sites was adapted from (Badgery et al., 2021). The historic climate data were retrieved from Scientific Information for Land Owners (SILO) climate stations and interpolated gridded database (Jeffrey et al., 2001). For future projections, the historic weather data was repeated.

Initialisation of the DayCent-CABBI model followed the approach in Takeda et al. (2024). The measured baseline SOC stock (0-0.3 m) and the measured ratio of organic C in MAOM (and PyOM) to total SOC were used to calculate the "passive" C pool in the model. The measured ratio of the passive C pool to total SOC was 70% and 87% at the Brian Pastures and Orange sites, respectively, while it was set at 80% and 75% at the CAMBI and Hewitts sites where the fraction data was missing. These estimated values were within the range of 72%–87% (on average 80%) reported across the Brigalow Belt region (Takeda et al., 2024). Then the model was spun up by simulating a long-term grassland history (~2000 years at the Brian Pastures sites) or an approximate cropping history after land clearing (typically since 1950's to 70's for the other sites), following the farmer's record at each site to reproduce the current masses of labile ("active" and "slow" in the model) soil C.

Calibration of DayCent-CABBI

The DayCent-CABBI model was calibrated for the subtropical pasture systems in the Brigalow Belt region in Takeda et al. (2024), characterised typically by cracking clay soils with Buffel grass. At the Orange and CAMBI sites, the calibrated DayCent-CABBI was applied and the grass parameters (potential production and temperature response of photosynthesis) were updated by fitting the biomass measurements to represent the template grass. At the Brian Pastures sites, both soil (maximum organic matter decomposition rates) and grass (potential production) parameters were updated by fitting the SOC data and ~40 years of grass biomass data. At the Hewitts site, the soil and grass parameters remained the same as Takeda et al. (2024), while the Leucaena tree parameters were calibrated to follow the growth patterns reported in the literature (Mullen et al., 2003; Radrizzani et al., 2016; Rengsirikul et al., 2011).

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8.5.1 Tropical pasture systems

Brian Pastures

Introduction

A long-term (39-year) experiment has been conducted at the Brian Pasture Research Facility near Gayndah southeastern Queensland. The continuous series of pasture growth data at Brian Pastures is almost double the length of what is believed to be the next longest series in the Southern Hemisphere (15-19 years at four sites in Zimbabwe; Dye and Spear, 1982). The long time- series of growth measurements at Brian Pastures, across different soil types, provides an ideal test for models in terms of capturing both site (soil x species) differences, year differences (rainfall and climate), and carry-over effects from one year to the next (grass basal cover, composition, nitrogen etc). For example, potential nitrogen uptake, and the capacity for plant species to dilute that nitrogen, is a key determinant of pasture growth. This is well demonstrated by having several sites on different soil types at the one location. Simulation modelling, based on DayCent (Appendix 8.1.4) has shown how such biogeochemical and biophysiological processes can be better incorporated into GRASP.

The Brian Pastures exclosures were originally part of a network of 16 sites established across Queensland in that year with the aim of obtaining a minimum data set to calibrate the GRASP (GRASs Production) model (McKeon et al., 1982) for a specific pasture type (soil x species combinations). Originally the study was known as 'GUNSYND' (Grass Under Nutritional Stability – Yield, Nitrogen and (phenological) Development; McKeon and Johnston, 1990). The GUNSYND methodology was soon replaced by the less onerous 'SWIFTSYND' methodology (Day and Philp, 1997) – the main difference being site layout and frequency of measurements.

Study site

The facility encompasses eight native pasture enclosure sites: THEM, LEND, LENS, RON, P55, LMA, LMB, and BAMN (Figure 1). These enclosures, each measuring 40 m x 40 m, on a wide range of soil types and depths, varying from high clay soils to sandy textures. Four of the original sites (RON, LMA, THEM, and P55) were established in 1986. In subsequent years, additional sites (BAMN, LENS, LEND, and LMB) were added to evaluate the effects of soil depth and species composition on pasture dynamics. The site characteristics are presented in Table 1.

At the THEM site, kangaroo grass (*Themeda triandra*) dominates, reflecting the pre-European settlement vegetation before tree clearing and cattle grazing altered the landscape in the late 1800s. The RON site, in contrast, is dominated by black speargrass (*Heteropogon contortus*), which became the dominant species in the region following this period of disturbance. Similar vegetation patterns are observed across the other sites, with varying species dominance. The LEND site, initially dominated by *Themeda triandra*, experienced a significant shift in species composition after 2007. Sites like LMA and LMB saw rapid transitions toward black speargrass dominance, while the change was more gradual at others, particularly at THEM. This shift, driven by long-term exclosure and burning, continues to shape the ecological dynamics and productivity of the sites. Over time, the species composition of these sites evolved, with native grasses such as *Heteropogon contortus* and *Themeda triandra* eventually being supplemented or replaced by *Bothriochloa pertusa* (Indian couch) in some areas, notably at RON and THEM. These shifts in species balance have significantly altered pasture productivity across the study area.

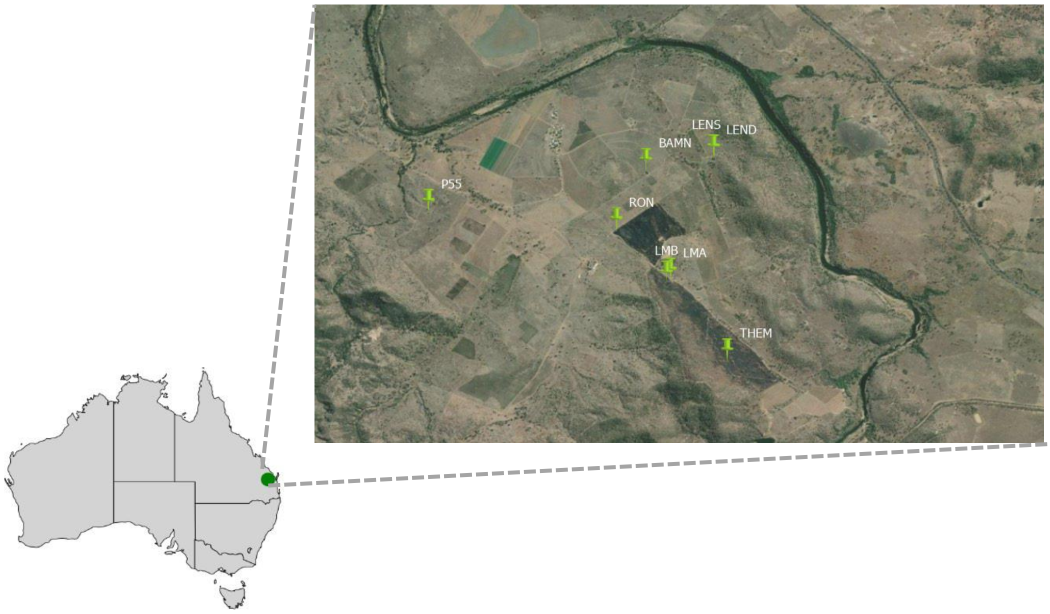

Figure 1: The study sites located in Brian Pasture research facility, Queensland, Australia

Table 1. Site and soil characteristics for Brian Pastures in Queensland.

ID	Est.	Soil type	PPF	Parent	Soil depth (mm)	Orig. Spp.	Current Spp.	BD (g/cm^3)	Sand (%)	Clay (%)	pH
LMA	1986	Loam	Uf6.31	Andesite	~1000	*Arram*	*Hecon, Boper*	1.37	58	26	6.4
LMB	1989	Loam	Uf6.31	Andesite	~1000	*Arram*	*Hecon, Boper*	1.37	62	26	6.4
LENS	1989	Sand	Uc2.21	Granite	~500	*Merep*	*Hecon*	1.4	86	7	6.1
LEND	1989	Sand	Uc4.21	Granite	~1000	*Merep*	*Hecon*	1.4	86	7	6.1
BAMN	1993	Brown clay	Ug5.12	Basalt	>1000	*Bobla*	*Hecon, Boper*	1.12	30	45	6.8
RON	1986	Black earth	Ug5.12	Basalt	~500	*Bobla, Diser*	*Hecon, Boper*	1.04	29	46	6.5
THEM	1986	Loam	Uf6.31	Andesite	~1000	*Thtri*	*Hecon, Boper*	1.33	42	47	6.7
P55	1986	Grey clay	Ug5.22	Andesite	~900	*Bobla*	*Hecon, Bobla*	1.31	37	42	7.1

Field measurements

The experimental sites at Brian Pastures adhere to the SWIFTSYND protocol, a standardized approach to pasture and soil data collection that ensures consistent, repeatable measurements across long-term studies. Sampling is typically conducted annually in late May or early June, a period that coincides with the end of the growing season and provides an accurate estimate of total pasture growth. In certain years, additional sampling at approximately three-week intervals has been undertaken to monitor regrowth dynamics, enabling a more detailed understanding of seasonal growth patterns.

Pasture samples are collected from designated quadrats (1m x 0.5 m) within each exclosure. These quadrats are sampled on a rotational basis, ensuring that areas previously sampled are given adequate time for recovery. The centre of each quadrat is marked with galvanized pickets to maintain systematic sampling consistency across years. This system allows for both spatial and temporal monitoring of pasture conditions, minimizing disturbance to the ecosystem. The plant samples are harvested based on species composition. Once harvested, they are sorted into their constituent components—leaf, stem, and inflorescence—before being dried on-site for biomass estimation. Subsamples are then taken to the laboratory for further chemical analysis, focusing particularly on nitrogen and phosphorus content. This analysis provides valuable insights into the nutrient dynamics of the pasture ecosystem and its potential productivity.

Fire management is a critical component of the experiment, with controlled burns being conducted annually during the spring or summer months, following significant rainfall events of 25 to 50 mm. These burns are designed to mimic natural grazing effects and clear dead plant material, promoting regrowth and maintaining the ecological balance. Firebreaks are created around the exclosures by slashing vegetation, while efforts are made to minimize slashing within the sites themselves to prevent the spread of invasive species, such as *Bothriochloa pertusa* (Indian couch), which has become prevalent in some areas.

Observed soil carbon stocks

The observed SOC stock varied widely across the paddock in Brian Pastures, ranging from 24.5 to 95.9 t C/ha (Table 2). No consistent impacts of the exclosure or burning on SOC were observed across the paddocks.

Table 2. Observed SOC at Brian Pastures in Southern Qld.

Paddock name	Treatment	Date sampled	SOC mean ± se (t C/ha)	TON mean ± se (t N/ha)
BAMN	Paddock	7/07/2021	87.9 ± 6.1	5.8 ± 0.3
BAMN	Exclosure	7/07/2021	87.7 ± 5.8	5.6 ± 0.3
Desmanthus	Desmanthus	7/07/2021	86.6 ± 3.7	6.3 ± 0.3
Desmanthus	Non-Desmanthus	7/07/2021	72.6 ± 6.4	5 ± 0.4
LEND	Paddock	7/07/2021	29.8 ± 3.7	2.3 ± 0.3
LEND	Exclosure	7/07/2021	24.5 ± 2.1	1.8 ± 0.1
LMB	Paddock	7/07/2021	95.9 ± 2.3	6.2 ± 0.1
LMB	Exclosure	7/07/2021	86.2 ± 1.8	5.1 ± 0.1
LMB	Paddock	7/07/2021	95.9 ± 2.3	6.2 ± 0.1
P55	Paddock	7/07/2021	59.2 ± 3.5	4 ± 0.2
P55	Exclosure	7/07/2021	62.2 ± 3.7	4 ± 0.3
RON	Paddock	7/07/2021	76.6 ± 5.2	4.8 ± 0.5
RON	Exclosure	7/07/2021	92.6 ± 4	5.5 ± 0.2
RON	Exclosure	20/03/2024	81.4 ± 3.3	4.2 ± 0.4
RON	Exclosure_unburned	20/03/2024	81.1 ± 2.7	4.7 ± 0.1
THEM	Paddock	20/03/2024	62.8 ± 1.7	4.3 ± 0.1
THEM	Exclosure	20/03/2024	73.6 ± 3.2	4.3 ± 0.2
LMA	Exclosure	20/03/2024	60 ± 3.1	3.8 ± 0.2
LMA	Exclosure_unburned	20/03/2024	67 ± 2.8	4.7 ± 0.2

Modelling SOC change

The DayCent biogeochemical ecosystem model was calibrated and validated for northern Australian pasture systems (Takeda et al. 2024) (Appendix 8.1.4) and its accuracy was further tested using the observed SOC data from the Brian Pastures long-term trial (Table 1) and associated biomass data.

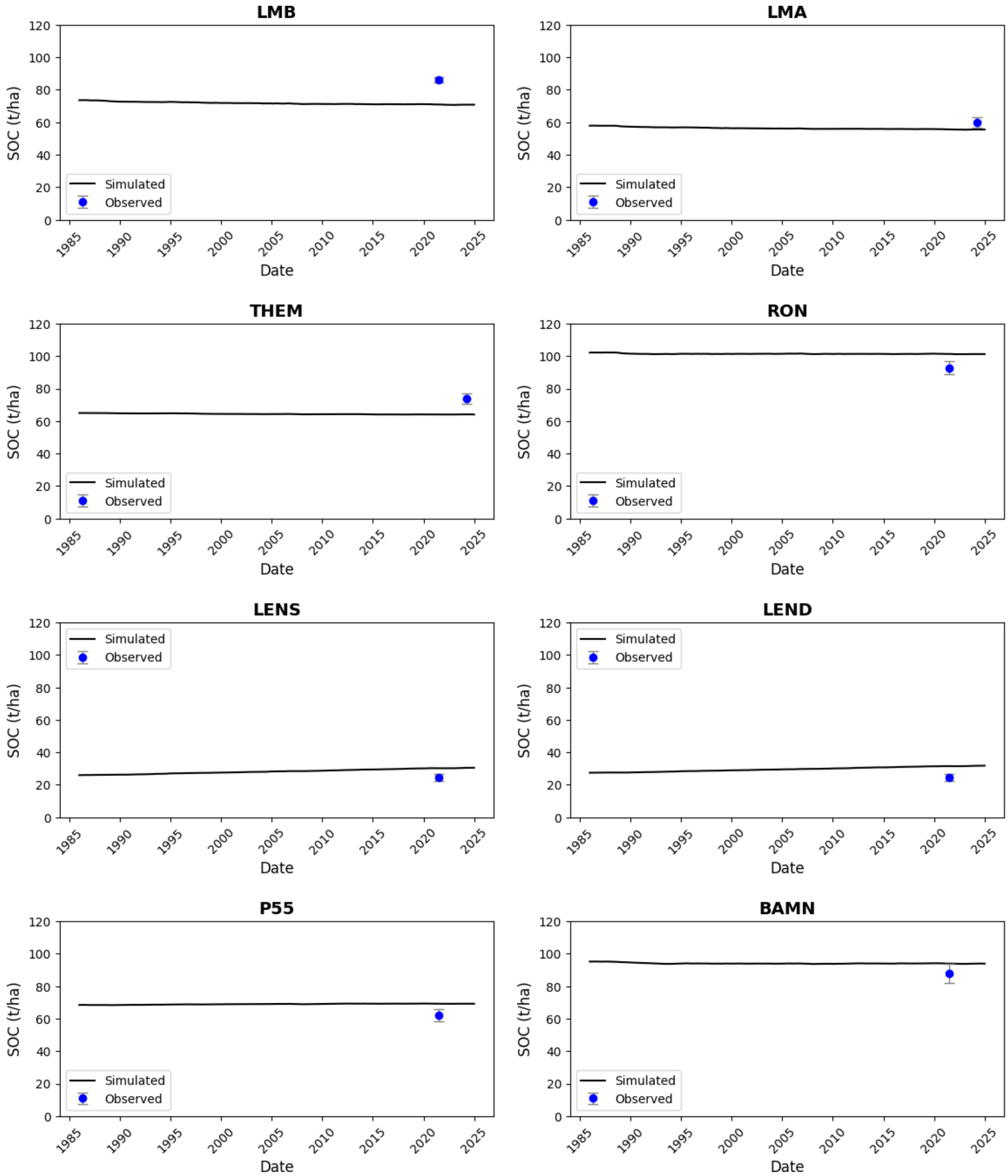

Figure 1: Long-term trends in SOC at Brian Pastures, Queensland as simulated by DayCent.

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8.5.2 Wambiana

Introduction

Research from different locations in Queensland, as well as overseas shows that stocking rate is the most important management factor affecting pasture condition and animal production. A number of grazing management strategies that focus on stocking rate are accordingly recommended to manage for rainfall variability. For example, moderate stocking at long-term carrying capacity reduces exposure to drought. Alternatively, variable stocking in line with available pasture should avoid overgrazing in dry years but allow the manager to take advantage of good rainfall years. Strategies involving wet season spelling are also recommended as are variable strategies that use seasonal climate forecasts such as the Southern Oscillation Index (SOI) to make stocking rate adjustments

Study site

The Wambiana grazing experiment is a long-term research site which commenced in 1997. It is situated ~70 km south-west of Charters Towers, Queensland on a commercial beef property. Long-term (1905–2012) average annual summer dominant rainfall for the site is 640 mm but is highly variable (207–1409 mm) (O'Reagain et al. 2011). As changes in SOC are heavily dependent on both rainfall (for determining biomass inputs) and soil type, the advantage of Wambiana is there are three main soil types each associated with distinct types of savanna woodland: (1) moderately fertile brown sodosols and chromosols dominated by Reid River box (*Eucalyptus brownii*), (2) more fertile grey earths and vertosols dominated by brigalow (*Acacia harpophylla*) and (3) well drained, low fertility yellow/red kandosols dominated by silver-leaf ironbark (*E. melanophloia*) (O'Reagain et al. 2009). Cattle are free to selectively graze on any of these soil types within each paddock. The site is dominated by native C4 grasses with all soils having species defined as perennial, productive and palatable. The pasture biomass data has been measured annually from 1998 to 2012 at the end of the wet season (May), which is close to the annual peak of pasture mass.

Five different stocking strategies (with 2 replicates) have been applied at the Wambiana trial (Figure 1). All reflect an underlying management philosophy and approach to climate variability. These strategies and their approximate stocking rates are as follows:

- Moderate stocking (MSR)—relatively constant stocking at the calculated LTCC of the site of approximately 8–10 ha per adult equivalent (AE). (AE defined as a 450 kg steer). Management philosophy: conservative stocking rates reduce exposure to drought, minimise years in which a feed deficit will occur and maintain land condition.
- Heavy stocking (HSR)—relatively constant stocking at twice the LTCC, that is, approximately 4–5 ha/AE. However, in May 2005, the HSR stocking rate had to be reduced to 6 ha/AE due to ongoing feed shortages in the treatment. The full stocking rate was restored in May 2009. Management philosophy: high stocking rates are required for profitability with the increased drought risk to be managed with drought feeding; the effects of heavy grazing in drought years are presumed to be short term with recovery occurring in better seasons.
- Variable stocking (VAR)—stock numbers adjusted annually at the end of the wet season (May) according to total standing dry matter (TSDM) of the pasture (range: 3–12 ha/AE). Management philosophy: annual adjustment of stocking rates to match feed availability minimises the risk of overgrazing and feed deficits in dry years, but also allows the full economic benefits of good rainfall years to be captured.
- Southern Oscillation Index (SOI)—variable strategy with stock numbers adjusted annually at the end of the dry season (November) according to pasture TSDM and SOI-based climate forecasts

for the next wet season (range: 3–12 ha/AE). Management philosophy: as for the VAR strategy but the use of the SOI should allow proactive rather than just reactive adjustment of stocking rates.

- Rotational wet season spelling (R/Spell)—relatively constant stocking rate at about 50% above LTCC with a third of the area spelled annually during the wet season, from approximately November to May, on a rotational basis. Initially stocked at 7–8 ha/AE but reduced to 10 ha/AE in November 2003 due to the combined effects of fire in 2001 and low follow-up rainfall. Management philosophy: spelling buffers the effects of rainfall variability on fodder availability and could allow increased rates of pasture utilisation without causing pasture degradation. Spelling also allows the use of fire for woodland and pasture management.

Further details of the Wambiana long-term experiment are detailed in O’Reagain et al. (2011).

Adjacent to the main Wambiana trial is a 9 year *Desmanthus* treatment under heavy grazing.

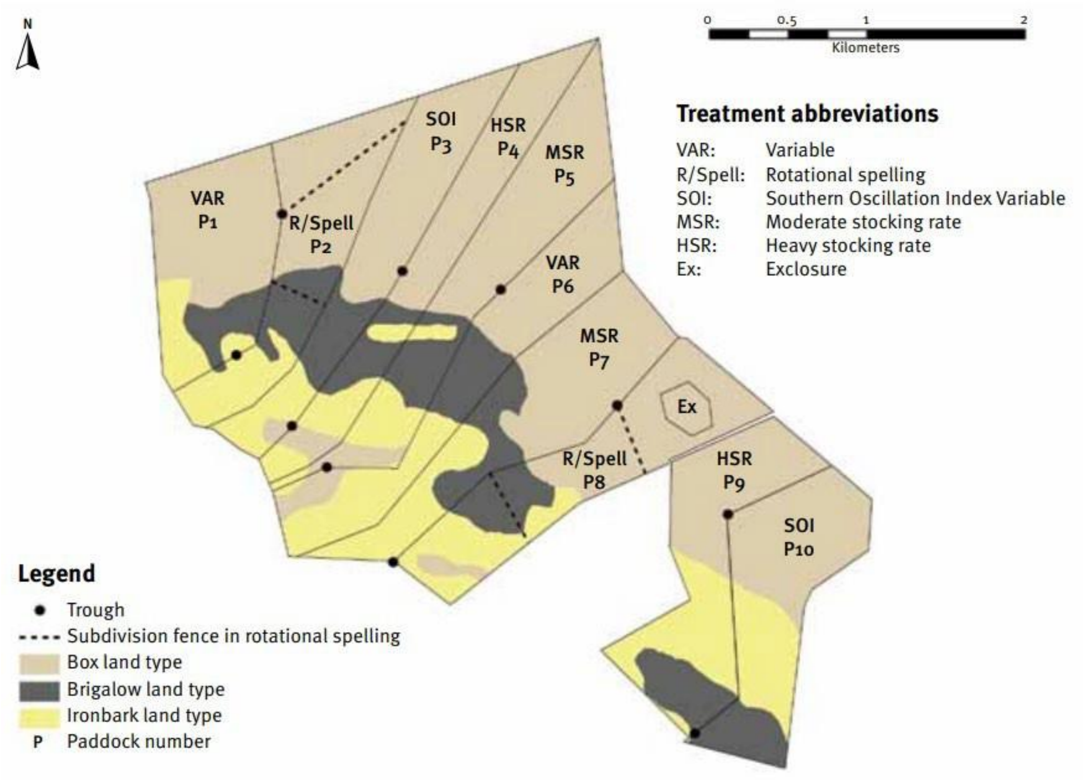

Figure 1: Layout of paddocks, associated grazing strategies and water points across the three major soil and vegetation associations at the Wambiana grazing trial.

Field measurements

The main data collected at the Wambiana trial includes cattle weight changes, condition score, frame growth; diet quality via faecal near infra-red spectroscopy (NIRS); supplementation and drought feeding costs; carcass grades and meatworks price; pasture mass, species composition and ground cover; rainfall, run-off and soil loss; fire effects on woody plant survival; pasture growth and rainfall relationships; land type selection and grazing distributions. In frequent data collection has included nutrient inputs via tree litter; decomposition rates of tree and grass litter; soil health and rainfall infiltration rates (CSIRO); faunal biodiversity (CSIRO); grazing effects on soil carbon (QDES).

Soil samples were collected in 2008, 2009 and 2010 by the Queensland Government (Pringle and in mid-2023 by QUT and analysed for SOC and bulk density (BD) (Table 1). In the latter campaign, a total of 39 soil cores were collected to an average depth of 48 cm. Data was also collected at the adjacent *Desmanthus* trial and analysed for SOC and BD. Both of these datasets will support future modelling exercises.

Observed soil carbon stocks

Table 1. Soil organic carbon data (mean and standard deviation) collected at Wambiana in mid-2023.

Paddock ID	Samples (#)	Mean Depth (cm)	BD (g/cm^3)	OC (%)	SOC (t C/ha)
2	4	0-50	1.64 (0.19)	0.19 (0.05)	15.0 (2.1)
4	10	0-47	1.68 (0.10)	0.33 (0.07)	26.0 (4.5)
5	9	0-52	1.55 (0.20)	0.33 (0.10)	25.7 (6.0)
7	6	0-46	1.71 (0.08)	0.34 (0.11)	25.0 (3.7)
8	4	0-51	1.53 (0.24)	0.36 (0.12)	27.0 (7.7)
9	6	0-41	1.61 (0.06)	0.30 (0.09)	19.2 (4.7)

Table 2. Cumulative soil organic carbon stocks (mean and standard deviation) to 100 cm at Wambiana after 9 years of *Desmanthus*.

Depth (cm)	Control SOC (t/ha)	Desmanthus
10	16.6 (6.3)	12.7 (2.3)
30	37.7 (16.5)	28.0 (5.1)
50	51.8 (20.4)	42.7 (8.9)
70	68.3 (28.6)	55.8 (9.8)
100	74.0 (25.9)	65.7 (10.8)

Whilst there was an increase in SOC at all depths under *Desmanthus* when compared to the control, the differential was statistically non-significant. The SOC stock in the top 30 cm was (on average) 46% of the total SOC stock to 100 cm which is a typical distribution. The very high spatial variation in SOC under *Desmanthus* compared to the control across the field sites is consistent with any mixed pasture species.

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8.5.3 Leuceana chronosequence

Introduction

Leucaena leucocephala (leucaena) is a perennial legume shrub of subtropical regions that has forage characteristics favourable for livestock production, often delivering ruminant liveweight gains that are superior to most other forage systems (McSweeney et al. 2011). Recent work suggests that leucaena mitigates ruminant enteric methane emissions (Kennedy & Charmley, 2012), implying that the shrub may also reduce greenhouse gas (GHG) emissions at the whole farm level. Around 84% of leucaena pastures in these areas are grown on brigalow clay soils (Vertisols), with mixed leucaena-grass pastures consisting of Buffel grass (*Cenchrus ciliaris*) and Rhodes grasses. Enterprises with leucaena that had equivalent stocking rates or total liveweight production to comparable grass enterprises had lower net farm emissions, resulting in carbon offset income (Harrison et al. 2015).

Radrizzani et al. (2011) reported that leucaena pastures accumulated an extra 3.0 to 5.3 t/ha of soil organic carbon (SOC) in the upper 15 cm of a Vertisol, compared with an adjacent buffel grass pasture over 20 to 38 years. Conrad et al. (2017) reported increases in SOC 17–30% over 40 years in the top 30 cm of leucaena pasture systems, equating to a sequestration rate of 280 kg/ha/yr. In contrast, Carter et al. (1998) found a decrease in SOC in the surface horizon but a net accretion below 20 cm in a leucaena-grass pasture on a Vertisol. Compared with buffel pasture, leucaena stored an extra 5 t ha to a depth of 80 cm over 10 years. There is minimal data to clarify the observed trends on GHG storage and provide information for comprehensive GHG accounting of leucaena systems.

Study site

A leucaena chronosequence was identified on an organic grass-fed beef and fattening operation (Hewitt's) located near Moura, in the northern Brigalow belt of Queensland. The 22,000 ha property had a mix of landuse history with large areas historically summer-fallowed for winter oats production and the remainder dominated by sub-tropical buffel grass. Since 2016 the Hewitt property has embarked on a major leucaena planting program with approximately 1000 ha planted annually. Strips of pasture are sprayed in out with glyphosate in 3-4m strips 8-10 m apart, long-fallowed (12-18 months) and sown on double rows.

Field measurements

Soils were sampled (0-30 cm) were sampled for SOC and total organic nitrogen (TON) on two chronosequences covering the two land-use histories including a zero (unplanted), 1-3, 3-5 and 5-7 years after planting. Soils were collected to a depth of 1 m along 4 transects for each land-use history age with 12 cores each in pasture interrow and row.

Observed soil carbon stocks

After an initial loss in SOC on establishment of the leucaena there is evidence of a gradual increase in SOC after 3 years (Table 1). Total organic nitrogen levels however tended to stabilise but the soil C/N < 10 is indicative of nitrogen accumulation as a result of the introduction of the legume.

Table 1. Soil organic carbon and nitrogen (0-30 cm) in a leucaena chronosequence in southern Queensland.

Leucaena age	SOC mean ± se (t/C ha)	TON mean ± se (t N/ha)	CN mean ± se
0	54.2 ± 1.3	5.1 ± 0.2	11.1 ± 0.3
1-3	38.9 ± 1.6	5.1 ± 0.2	7.7 ± 0.2
3-5	34.8 ± 0.8	4.9 ± 0.1	7.0 ± 0.1
5-7	39.0 ± 1.1	4.5 ± 0.1	8.9 ± 0.1

Modelling SOC change

The DayCent ecosystem model, calibrated and validated for north-eastern Australia (Takeda et al. 2024) was able to replicate the change in SOC in response to the establishment of leucaena (Figure 1) and indicated a slow accumulation in SOC (0-30 cm) equivalent to 0.4 t C/annum over the next 25 years.

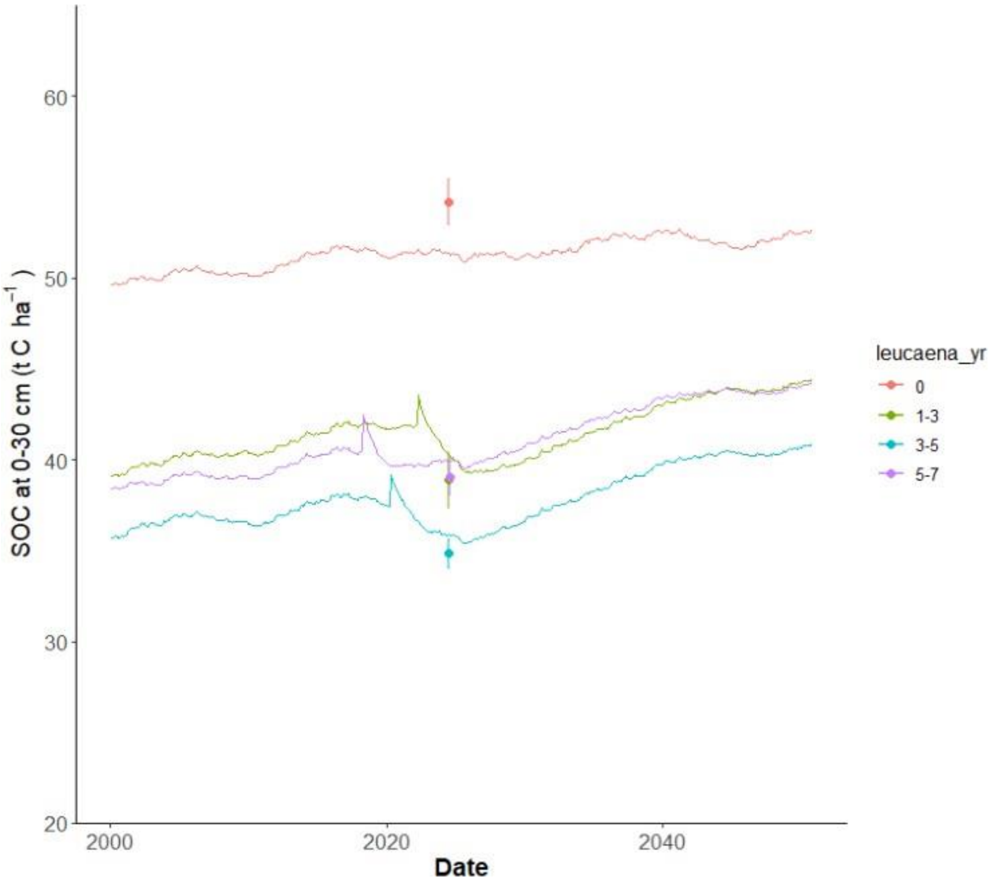

Figure 1: Simulated v observed SOC (0-30 cm) in a leucaena chronosequence in central Qld.

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8.6 Communication events

Date	Title of activity	Topic/information presented	Who	Attendees	Link
26-Oct-21	Leucaena Carbon Forum	Carbon Markets, Carbon Farming, Leucaena and Carbon	Eckard	45	
9-Nov-21	Podcast farmingahead.com.au	Soil Carbon	Eckard	?	
23-Nov-21	Webinar to AgLink Australia	Carbon neutral agriculture: Drivers, options and risks	Eckard	13 consultants	
25-Nov-21	Carbon Neutral Grazier Network webinar	Emissions, soil carbon sequestration potential and progress toward methane abatement options	Eckard	?	
26-Nov-21	Livestock Advisor Update (Brisbane) MLA	Carbon Farming – Opportunities and Risks	Eckard	50	
26-Nov-21	Livestock Advisor Update (Brisbane) MLA	Carbon Farming - eyes wide open	Grace	50	https://www.youtube.com/watch?v=uT70xZpOkeE
28-Nov-21	Rabobank regional managers	Carbon Neutral Agriculture Training	Eckard	20	
1-Dec-21	Marcus Oldham podcast	Soil carbon under grazing systems	Eckard	National podcast	
6-Dec-21	Field day presentation on 'Greenhouse gas mitigation in grazing systems'	Role of soil C in mitigating GHG	Badgery	85	

		from livestock systems			
7-Dec-21	SALRC Meeting	Carbon neutral grazing	Eckard	15	
2-Feb-22	ABC Landline Interview	Carbon neutral agriculture	Eckard	National	
4-Feb-22	Ag Institute Australia	Carbon neutral agriculture	Eckard	13	
10-Feb-22	Vic independent consultants group	Carbon neutral agriculture	Eckard	12	
10-Feb-22	Corangamite Catchment Management Authority board	Carbon and Emissions	Eckard	15	
15-Feb-22	Gippsland Red Meat Conference	Carbon neutral livestock	Eckard	120	
3-Mar-22	NAB Agri-bankers training	Carbon neutral agriculture	Eckard	25	
10-Mar-22	Presentation to farmers in Bairnsdale	Carbon neutral agriculture	Eckard	27	
16-Mar-22	The Riverina Cooperative Society	Carbon farming - sorting fact from fiction	Eckard	60+	
17-Mar-22	NAB Agri-bankers	Carbon Neutral Agriculture Training	Eckard	22	
18-Mar-22	ORM Farm Business Champions forum	Carbon neutral agriculture	Eckard	12	
18-Mar-22	Field day presentation (Central Tablelands LLS): 'Soil C and grazing management'	Central Tablelands LLS	Badgery	12	
18-Mar-22	Field day presentation on 'Soil C and grazing management'	Presented the result of soil C from	Badgery	12	

		grazing management study			
22-Mar-22	Webinar – DIPRID staff and consultant network, WA	Introduction to carbon neutral agriculture	Eckard	45	
22-Mar-22	Webinar - DIPRID staff WA	Carbon and nitrogen cycle in agriculture	Eckard	15	
23-Mar-22	Rabobank, WA Breakfast presentation	Carbon neutral agriculture	Eckard	15	
28-Mar-22	SA Beef & Sheep Industry Blueprints Working Group	The opportunities, risks and common pitfalls for livestock producers	Badgery	35	
29-Mar-22	Dinner presentation SAI Platform meeting	Carbon neutral agriculture	Eckard	15	
5-Apr-22	MLA Livestock Genetics Forum, Adelaide	Implications for breeding	Eckard	60	
11-Apr-22	Field day presentation (NSW DPI and Central Tablelands LLS): 'Soil C and grazing management' as part of the Carbon conference.	Carbon Forum	Badgery	100	
12-Apr-22	Presentation: ‘Livestock emissions and herd management: The science’	Carbon Forum	Eckard	100	
27-Apr-22	Carbon neutral agriculture training	Holbrook Landcare Group	Eckard	22	
3-May-22	Presentation to SALRC council 2022	Mitigation and CN30	Eckard	30	
9-May-22	South Gippsland Landcare group	Methane	Eckard	15	

10-May-22	Carbon Neutral Agriculture course Melb	Mitigation and accounting	Eckard	30	
16-May-22	CPC Board	Carbon + grazing systems	Eckard	11	
17-May-22	Building soil C in grazing systems	Soil C and GHG information for grazing systems	Badgery, Simmons	100	
23-May-22	PAS conference presentation	Soil C and GHG information for grazing systems	Badgery	80	
14-Jun-22	JBS Leadership team	Mitigation and accounting	Eckard	15	
21-Jun-22	Grain & Graze Conference 2022	Carbon Neutrality in Agriculture	Eckard	140	
23-Jun-22	Australian and New Zealand College of Veterinary Scientists Conference	Cows, climate and carbon	Eckard	50	
5-Jul-22	NSW Farmers carbon meeting	Carbon Neutrality in Agriculture	Badgery	50?	
5-Jul-22	NFF Sustainable development and climate change committee 2022	Carbon Neutrality in Agriculture	Eckard	15	
5-Jul-22	NSW Farmers Briefing	Soil C and GHG information for grazing systems	Badgery	10	
15-Jul-22	Sheep Sustainability Framework Launch 2022	CN30	Eckard	80	
27-Jul-22	Carbon Neutral Agriculture course - Alice Springs	Mitigation and accounting	Eckard		
2-Aug-22	Carbon Neutral Agriculture course – Perth	Mitigation and accounting	Eckard		

2-Aug-22	Carbon Neutral Agriculture course – Perth	Mitigation and accounting	Eckard		
16-Aug-22	Agriculture Victoria's nutrition group	Methane Supplements	McDonald	25	
16-Aug-22	Agriculture Victoria's nutrition group – A. McDonald, UoM	Methane Supplements	McDonald		
23-Aug-22	Carbon Neutral Graziers Network– A. McDonald, UoM	Methane Supplements	McDonald	35	
23-Aug-22	Carbon Neutral Graziers Network – A. McDonald, UoM	Methane Supplements	McDonald		
30-Aug-22	Nutrien workshop 2022	Carbon Accounting	Eckard	15	
14-Sep-22	Monaro Farming Systems (MFS) – field day	Presentation of information on workshop and participant sign-up.	Ingram	50	
20-Sep-22	Australian Agronomy Conference, Key note presentation – Cowie, NSW DPI	The role of the land sector in meeting the net zero challenge	Cowie	200	
23-Sep-22	Grazing systems and soil C - advisor update	Soil C and GHG information for grazing systems	Badgery	10	
23-Sep-22	Grazing systems and soil C - field day	Soil C and GHG information for grazing systems	Badgery	70	
5-Oct-22	Ag Vic Community of Practice Webinar 2022	Are you providing On-Farm Emissions Advice?	Eckard	100+	

5-Oct-22	Tallangatta Better Beef producer group - field day	Mitigation of on-farm GHG and C sequestration	Ingram	25	
5-Oct-22	Better Beef group in Tallangatta, Vic	Carbon Neutral Agriculture	Badgery		
10-Oct-22	1 Tonne of CO_2 is equivalent to diagram	GHG emissions	McDonald		
13-Oct-22	Beef from dairy Roundtable 2022	Carbon accounting	Eckard	120	
14-Oct-22	Victorian Farmers Federation Conf 2022	Net Zero Ag	Eckard	180	
18-Oct-22	Agriculture Victoria Sheep Notes article	Methane Supplements and sheep	McDonald		
20-Oct-22	Tamworth Carbon Neutral field day	Mitigation of on-farm GHG and C sequestration	Simmons		
20-Oct-22	Field day, Tamworth	Carbon Neutral Agriculture	Badgery		
25-Oct-22	FVAS Research Conference Poster Presentation	3-NOP Meta-Analysis	McDonald		
9-Nov-22	QDAF - Charters Towers	Soil C & grazing	Badgery	40	
10-Nov-22	QDAF - Charters Towers	GAF tool	Ingram	40	
8-Feb-23	Pastures for Carbon Neutrality - Gundagai	Options for mitigating GHG emissions - Integrated Management Systems	Ingram	30	
10-Feb-23	Pastures for Carbon Neutrality - Cowra	Options for mitigating GHG emissions - Integrated	Ingram	40	

		Management Systems			
2-Mar-23	Field day, Cudal	Pasture Update	Badgery	75	
14-Mar-23	Field day presentation (Monaro Farming Systems): 'Greenhouse gas mitigation in grazing systems'	Monaro Faming Systems	Eckard,Badgery, Cowie	85	
28-Mar-23	Presentation	Soil C & grazing	Badgery	15	
4-Apr-23	Field day	Grazing towrds 2030	Badgery	40	
20-Jun-23	Queensland Investment Corporation	Cost effective natural capital assessment	Grace	6	
23-Jun-23	On-farm GHG emissions and mitigation options	Towamba Valley Landcare Group	Ingram	30	
13-Oct-23	AgVic Ruminant Community Meeting	Carbon Neutral Agriculture	Eckard	65	
19-Oct-23	AusFine Learning Lunch	The Future of Dairy and Meat in a changing environment	Eckard	175	
26-Oct-23	Marcus Oldham	Carbon Neutral Agriculture and carbon accounting training course	Eckard	46	
27-Oct-23	Filming AusMedia	How to make carbon work for a livestock business	Eckard	?	https://www.farmonline.com.au/story/8388585/fiona-conroy-on-carbon-livestock-and-methane/
9-Nov-23	Farmers for Climate Action	Methane and global warming	Eckard	?	https://youtu.be/fHKVT2evv-c?si=8RjiordZ071gqxEn

15-Nov-23	ABC radio	Zero-emissions food not possible with current technology, says agriculture industry	Eckard	?	https://www.abc.net.au/news/rural/2023-11-30/agriculture-on-the-agenda-cop28-climate-change/103167496
22-Nov-23	DLF Seeds Consultant Update	Low methane pasture presentation	Badgery	25	
5-Dec-23	Landcare Australia Webinar	Carbon in the Landscape	Badgery/Eckard	85	https://www.youtube.com/watch?v=4s41UAjjmgM
5-Dec-23	SB-GAF Tutorial	How to fill in the SB-GAF	Macdonald	149 (views)	https://www.youtube.com/watch?v=o9k_Hg8evlU&ab_channel=ThePrimaryIndustriesClimateChallengesCentre
7-Dec-23	Carbon Storage Partnership Webinar	Can grazing management increase soil carbon?	Badgery/Sarah McDonald	73	https://www.youtube.com/watch?v=ywoywqNzdUA
12-Dec-23	Ararat wool group	Carbon Neutral Agriculture and carbon accounting training	Eckard	15	
12-Dec-23	Article in The Land	Gained then lost: researchers highlight variability in soil carbon	Badgery/Sarah McDonald	?	
3-Feb-24	RRR Interview on soil C	Soil C	Badgery	?	
13-Feb-24	Central Tablelands LLS Webinar	CAMBI soil carbon project	Badgery/Aaron Simmons	80	
14-Feb-24	Ag Vic COP	What has changed over 2023, looking ahead to 2024	Eckard	65	

14-Feb-24	GRDC Update - Wagga	The science behind a GHG footprint	Badgery	224	
18-Feb-24	GRDC Update - Baradine	The science behind a GHG footprint	Badgery	73	
19-Feb-24	Woolworth board	Scope 3 – Supply Chain Agricultural Emissions	Eckard	12	
20-Feb-24	Evoke conference	Quantifying your farm GHG emissions	Eckard	750	
20-Feb-24	Evoke Conference 2024	Quantifying your farm GHG emissions	Eckard	800	
20-Feb-24	Evoke Conference 2024	Quantifying your farm GHG emissions	Eckard	800	
29-Feb-24	GRDC Update - Dubbo	The science behind a GHG footprint	Badgery	163	
5-Mar-24	The Australian Association of Ruminant Nutrition	Mitigating greenhouse gas emissions from ruminants current and future potential	Eckard	85	
12-Mar-24	Pasture Update - Wagga	Preparing livestock industries for a low carbon economy	Badgery	60	
13-Mar-24	Agribusiness Summit, Goondiwindi	Carbon neutral farming	Eckard	150	
13-Mar-24	Pastures Update - Binya	Preparing livestock industries for a low carbon economy	Badgery	25	
14-Mar-24	MFS Seasonal Field Day	Update on Carbon Neutral Workshops	Ingram	70	
15-Mar-24	Pastures Update - Meadow Flat	Grazing management & soil carbon in Australia	Badgery	63	

19-Mar-24	Farmlink Breakfast	The science behind a GHG footprint	Badgery	42	
20-Mar-24	WA government Carbon Farming team	On the road to carbon neutral farming	Eckard	25	
20-Mar-24	MLA Board presentation	CN30 - Carbon Neutral, Climate Neutral or Net Zero	Eckard	15	
22-Mar-24	Landcare emissions workshop	Methane Supplement technologies	Macdonald	?	
22-Mar-24	'Food Futures: Nourishing a Nation' 2024 Australian Academy of Science	Climate change resilience in agriculture: Impacts of science, technology and policy	Eckard	140	https://youtu.be/ONIsyrVwxDs?si=7CoMuTVYdvH2KCW0
22-Mar-24	'Food Futures: Nourishing a Nation' 2024 Australian Academy of Science	Climate change resilience in agriculture: Impacts of science, technology and policy	Eckard	140	
11-Apr-24	Wagyu conference	Impacts of science, technology and policy	Eckard	300?	
8-May-24	Beef Week	Beef24 Seminar - Sem #5 Carbon Neutral Beef - Where to focus what to do	Eckard	140	

9-May-24	DCCEEW Integrated Farm and Land Management workshop	Soil carbon sequestration methodology	Grace	60	
29-May-24	Soil science SoC, Friends of parliament briefing, Canberra	Parliamentary Friends of Soil - SSA Soil Carbon Information Session at Parliament House	Eckard	15	
31-May-24	Soil science SoC forum Canberra SSSA CanberraEckard 2024	A scientific approach to policy development: Standards for carbon accounting	Eckard	75	
3-Jun-24	Pilot group online presentation	Carbon sequestration in soils and trees workshop	Ingram	12	
5-Jun-24	MerinoLink Conference	Carbon in grazing systems	Badgery	120	
12-Jun-24	Climate and Agriculture Webinar, all NAB regional managers	Climate change and the Australian Agricultural sector	Eckard	75	
12-Jun-24	ABC radio	Nitrogen use and greenhouse gases	Grace		https://www.abc.net.au/news/science/2024-06-12/nitrous-oxide-the-forgotten-greenhouse-gas-is-on-the-rise-study/103959392
13-Jun-24	AgForce Winter Webinar Series	Carbon farming: Accounting towards GHG targets	Eckard	450	
20-Jun-24	NSW DPI Soil Network of Knowledge (SNoK)	Nitrogen use and greenhouse gases	Grace	322	

20-Jun-24	Ballarat BetterBeef Conference, Bendigo	*Reducing emissions in the supply chain - what it means for producers*	Eckard	300	
27-Jun-24	Canadian Agri-Food Policy Institute (CAPI)	Quantifying farm GHG emissions in Australia: Challenges and opportunities	Eckard	?	
10-Jul-24	Country hour interview	Capacity to store soil C	Badgery	?	Country Hour (NSW) at 12:25 noon - Isentia (mediaportal.com)
10-Jul-24	ABC Online story	Capacity to store soil C	Badgery	?	https://www.abc.net.au/news/2024-07-10/australian-agriculture-to-play-key-role-in-net-zero-emissions/103995436
17-Jul-24	Grassland SoC of southern Australia conference 2024	Carbon Neutral livestock production: Is it possible?	Eckard	250	
23-Jul-24	Pilot group final wrap up meeting - Canowindra	Determining GHG emission reduction strategies will implement	Ingram, Badgery	10	
30-Jul-24	Pilot group final wrap up meeting - Monaro	Determining GHG emission reduction strategies will implement	Ingram, Badgery	8	
5-Aug-24	SheepVension, Hamilton Victoria	Peter Schroder Memorial Lecture, SheepVension	Eckard	140	
7-Aug-24	Northern Cattle Sustainability Workshop, Sustainability manages	*Accounting towards Carbon Neutral (low) Livestock Production*	Eckard	8	

	from the large pastoral companies				
8-Aug-24	Presentation to rural financial councilors	Carbon in grazing systems	Badgery	20	
9-Aug-24	CN30 pathways carbon accounting workshop	Carbon Accounting Workshop Dookie 2024	Eckard	35	
13-Aug-24	MERiL Annual Livestock Emissions Reduction Forum	report on the project Integrated Management Systems for CN30	Eckard	75	
21-Aug-24	Southern Australian Livestock Research Council annual conference 2024	Carbon Opportunities – Inset is the new offset	Eckard	220	
13-Sep-24	Field day presentation	Carbon accounting	Badgery	80	

8.7 Policy Briefings

Meetings and briefings with policy				
Date	**Stakeholder**	**Audience**	**Who**	**Topic**
11/02/2022	DCCEW, CCA	Richard Eckard, Ben Holt, Alex Brown	Richard Eckard	Market readiness & adoption of feed additives
7/03/2022	DCCEW	Richard Eckard, Ben Docker, Ben Holt, Daniela Croce, Penny Reyenga, Mark Newnham	Richard Eckard	Pre-Meta-Analysis paper discussion
15/03/2022	Chief Scientist	Alan Finkel, Richard Eckard etc	Richard Eckard	LETS 2022 Expert Focus Group on Livestock Feed Supplements
22/03/2022	Policy briefing to DIPIRD corporate executive in Perth	Terry Hill – Director General, Carl Binning – Deputy Director General, Cecilia (Cec) McConnell – Soil and Land Commissioner, Heather Brayford – Deputy Director General, Sustainability and Biosecurity, Liam O'Connell – Deputy Director General, Industry and Economic Development, Kerrine Blenkinsop, Lead, Climate Resilience, the Low Carbon Economy Taskforce, DPIRD	Richard Eckard	
14/04/2022	Livestock feed tech stretch goal	Richard Eckard, Daniela Croce, Ben Docker, DISER	Richard Eckard	
4/11/2022	DISER Livestock Emission Framework	Margaret Jewel, Ben Docker, Daniela Croce, Penny Reyenga, Mark Newnham, Alex Brown	Richard Eckard	
30/05/2023	Climate Change Authority	Ben Holt; Zoe Sinclair; Alexandra Larkin; Joanne Halliday; Haley Lambert; George Spyrou, Richard Eckard	Richard Eckard	Land sector decarbonisation and ACCU supply

13/07/2023	Senators and advisors	Senators: Janet Rice + Victoria Taylor (adviser); Linda White + Ben Armstrong (adviser); Raff Ciccone; Andrew McLachlan + Jack Manning (adviser); Perin Davey MPs: Brian Mitchell; Meryl Swanson + James Bartlett (adviser); Dan Tehan; Skye Laris (Adviser Bowen MP) DAFF: Cate McElroy (DAFF) Australian Forest Products Association: Joel Fitzgibbon CEO, Natasa Sikman, Joe Prevedello, Sara Bray NFF: David Jochinke VP, Warwick Ragg, Tonami Deed Presenters: Richard Eckard and Mark Wooten	Richard Eckard	Briefing and farm visit to Jigsaw farms, IMS case study on carbon neutral livestock
3/08/2023	Briefing with DAFF	Nadia Bouhafs, Heather McGilvray, Claire Boyle, Susanne Busch, Stefan Hasenohr, Penny Reyenga, James Fell, Zoe Bucher-Edwards, Richard Eckard	Richard Eckard	Sectoral decarbonisation plan for Agriculture and Land.
11/10/2023	Briefing with DCCEEW	Naidu Bodapati, Daniela Croce, Penny Reyenga, Richard Eckard, Ainslie Macdonald	Richard Eckard	Progress on the Meta-analysis of 3-NOP and Asparagopsis
12/10/2023	Briefing with Minister Murray Watt	Min Murray Watt, Ben Antenucci, Richard Eckard	Richard Eckard	Carbon farming and Carbon Offsets
13/12/2023	Integrity Committee ACCS	Prof Karen Hussey, Chair, Integrity Committee ACCS, Richard Eckard	Richard Eckard	carbon offsets versus carbon insets
1/02/2024	DCCEEW/DAFF	Heather McGillivray, Daniela Croce, Richard Eckard	Richard Eckard	Agriculture and Land Sectoral Plan
29/02/2024	Climate change authority	George Spyrou, Paul Mattiazzi, Ben Holt, Brad Archer, Eliza Murray, Matt Searson, Richard Eckard	Richard Eckard	Briefing on carbon neutral agriculture