Final Project Summary
P1d – Kikuyu: Carbon on NSW dairy farms

May 2026

A path to carbon-neutral dairy

Reducing greenhouse gas emissions from dairy farming requires a better understanding of where emissions come from, how they vary between farming systems, and which management practices can reduce emissions while maintaining productive and profitable farms.

The purpose of this project was to provide practical, region-specific evidence to support lower-emissions dairy farming under Australian conditions. It was designed to inform practical, whole-farm approaches to reducing greenhouse gas emissions. It also aimed to support evidence-based decision-making by farmers, industry and policymakers working toward carbon-neutral dairy systems.

Why carbon research?

The Australian dairy industry is working to reduce greenhouse gas emissions while maintaining productive and profitable farming systems. Dairy Australia has pledged to reduce the emissions intensity of Australian dairy production to 30 per cent below 2015 levels by 2030, contributing to Australia's broader net zero commitments under the Paris Agreement.

Multipronged approach

This Dairy UP project investigated multiple aspects of carbon and greenhouse gas emissions on NSW dairy farms, including:

- Whole-farm greenhouse gas emissions
- Feeding strategies and methane monitoring
- Soil carbon and nutrient management
- Digital soil mapping
- Pasture carbon dynamics.

Key findings

Our findings show there is no single pathway to carbon-neutral dairy production. Effective emissions reduction requires integrated, system-specific strategies combining methane reduction, feeding, fertiliser and manure management, and soil stewardship. One-size-fits-all approaches are unlikely to deliver optimal outcomes.

Carbon on NSW Dairy Farms

Unlocking the potential of Kikuyu

Dairy UP's P1 project aimed to unlock the potential of Kikuyu pastures used by NSW dairy farmers. P1 was a suite of five projects that collectively explored new management options to grow and utilise more Kikuyu over summer and increase the productivity of Kikuyu-based pastures.

P1a – Kikuyu: Remote monitoring

P1b – Kikuyu Investigating toxicity

P1c – Kikuyu: Developing new varieties

P1d – Kikuyu: Carbon on NSW dairy farms

P1e – Kikuyu: Nutritional value

This document is the final update on P1d – Kikuyu: Carbon on dairy farms.

Whole-farm emissions

- Emissions intensity was similar between pasture-based and confinement (housed) systems, but the main emission sources differed between systems.
- Methane produced by cows during digestion (enteric methane) was the largest source of emissions in both systems, accounting for more than half of total farm emissions.
- Confinement systems produced higher manure-related emissions, while pasture-based systems produced higher fertiliser-related and off-farm input emissions.

Feeding and methane monitoring

- Feeding 2–3 t DM/cow/year concentrate increased milk production and reduced emissions intensity by about 12%. However, the impact on profitability depends on each farm's management and market conditions.
- Low-cost methane sensors showed promise for future on-farm methane monitoring but require further development before commercial adoption.

Soil carbon and nutrient management

- Pasture-based systems stored substantially more soil organic carbon and nitrogen than confinement systems, especially under permanent pasture and tree cover. However, confinement farms were in lower rainfall zones than pasture-based farms.
- Confinement systems accumulated much higher soil phosphorus levels, reinforcing the need for targeted nutrient management.
- The Soil and Landscape Grid of Australia (SLGA) was useful for broad whole-farm assessments but not accurate enough for paddock-scale management or carbon crediting.

Pasture carbon dynamics

- At the study site, ryegrass pastures acted as a carbon sink during regrowth. In contrast, kikuyu pastures became a net greenhouse gas source when surplus pasture required slashing and a net sink after the litter decomposed.

More info

P1d Final report

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Research and results

Research aims

1. Quantify greenhouse gas emissions from pasture-based and confinement (housed) dairy systems and identify the main emission sources.
2. Assess the effect of concentrate feeding on milk production, emissions intensity and farm profitability.
3. Evaluate low-cost methane sensors for practical, on-farm methane monitoring.
4. Measure soil carbon and nutrient status across different dairy land-uses and farming systems.
5. Assess the accuracy of the Soil and Landscape Grid of Australia (SLGA) for dairy farm soils.
6. Measure greenhouse gas fluxes from ryegrass and kikuyu pastures and assess how management influences carbon dynamics.

1. Whole-farm GHG emissions

Dairy Australia's Australian Dairy Carbon Calculator was used to analyse greenhouse gas emissions from 10 commercial NSW dairy farms: five pasture-based and five confinement (housed) systems.

Key findings

Pasture-based and confinement (housed) dairy systems in NSW produced similar greenhouse gas emissions intensity — meaning a similar amount of emissions per kilogram of milk produced:

- pasture-based: 1.07 kg CO_2-eq/kg fat- and protein-corrected milk.
- confinement: 1.02 kg CO_2-eq/kg fat- and protein-corrected milk.

However, the main sources of emissions differed between systems, highlighting different opportunities to reduce emissions (see graph over page).

In both systems, enteric methane (produced by cows during digestion) was the largest source of emissions accounting for more than half of total farm emissions.

Manure emissions were substantially higher in confinement systems (31% of total emissions compared with 13% in pasture-based systems), largely due to stored manure under low-oxygen conditions.

Fertiliser and pre-farm emissions were higher in pasture-based systems, reflecting greater reliance on nitrogen fertiliser.

Tree cover provided modest carbon offsets:

- Pasture-based systems: about 6% of total emissions.
- Confinement systems: about 1%

Implications for farmers

While both systems require methane reduction strategies, the priority for emissions reduction differs between systems:

- Pasture-based: improve fertiliser efficiency and reduce reliance on external inputs.
- Confinement: improve manure management.

2. Feeding strategies

This study examined how concentrate feeding affects milk production, greenhouse gas emissions intensity and farm profitability in pasture-based dairy systems.

The analysis used Dairy Australia's Dairy Farm Monitor Project data from 120 commercial pasture-based dairy farms across New South Wales, Victoria, Tasmania and South Australia. Farms were grouped according to annual concentrate feeding rate:

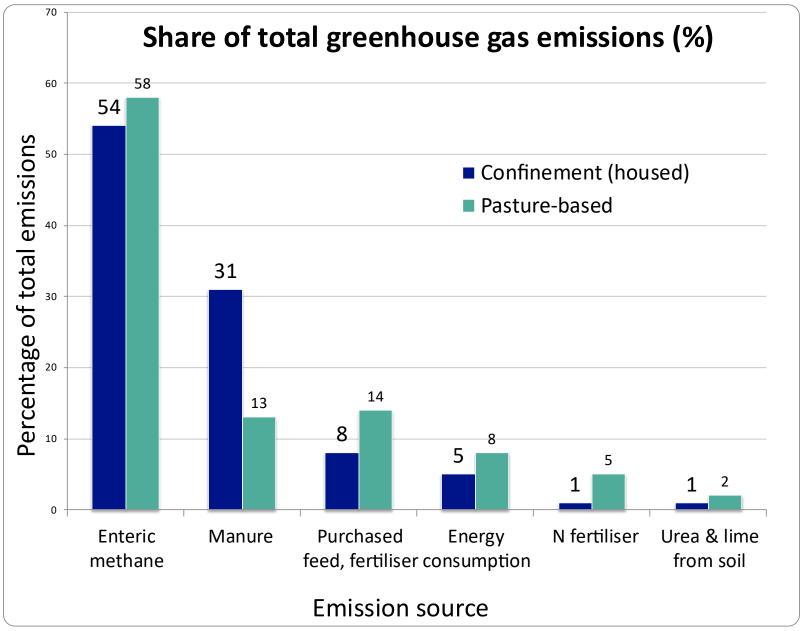
- low: less than 1 t DM/cow/year.
- moderate: 1–2 t DM/cow/year.
- high: 2–3 t DM/cow/year.
- very high: more than 3 t DM/cow/year.

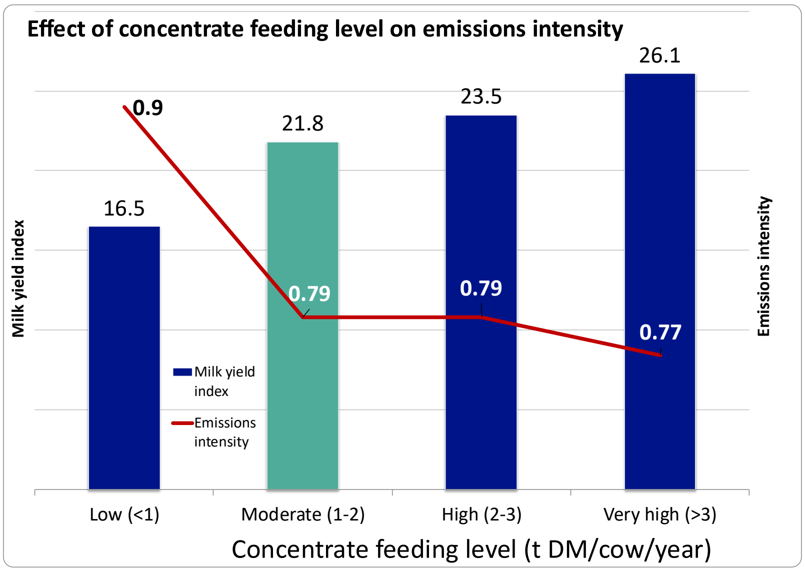
Greenhouse gas emissions were estimated using Dairy Australia's Australian Dairy Carbon Calculator. Economic performance was assessed using gross margin and Earnings Before Interest and Tax (EBIT).

Key findings

Farms feeding concentrates at 2–3 t DM/cow/year generally achieved the strongest balance between productivity, emissions efficiency and profitability. Productivity gains were the main driver of lower emissions intensity.

Feeding 2–3 t DM/cow/year of concentrate increased milk production and reduced greenhouse gas emissions intensity by about 12% compared with farms feeding less than 1 t DM/cow/year (see graph above).





Feeding more than 3 t DM/cow/year delivered diminishing returns, with higher feed costs and increased manure-related emissions reducing the overall benefit.

Table: Profitability of concentrate feeding levels

	Low	Moderate	High	Very high
EBIT $/cow/year	347	371	532	282
Net income $/cow/yr	58.5	135	222	-44.5
EBIT $/kg milk solids	1.07	0.77	1.05	0.54
Net income $/kg ms	0.03	0.23	0.43	-0.12

Implications for farmers

The findings suggest feeding 2–3 t DM concentrates/cow/year can be a practical strategy to improve milk production while reducing emissions intensity in pasture-based dairy systems. However, higher feeding rates do not necessarily improve profitability or emissions outcomes because of the trade-off associated with manure emissions. Feeding strategies should be balanced with feed costs, manure management and overall farm system efficiency.

3. Methane monitoring

This study evaluated whether low-cost methane sensors could provide a practical alternative to expensive methane monitoring systems currently used in research.

A 45-day trial involving 28 heifers compared a low-cost methane sensor with the established GreenFeed methane monitoring system. Researchers assessed how accurately the low-cost sensor measured methane patterns and how consistently it performed under commercial field conditions.

Key findings

While the sensor is not yet suitable as a replacement for established methane monitoring systems, the results demonstrated potential for future development of low-cost methane monitoring technologies for dairy farms.

The low-cost sensor showed moderate agreement with the GreenFeed system, meaning it was able to detect general methane emission patterns but was less accurate for precise measurement.

The low-cost sensor was also less consistent than the GreenFeed system, showing greater variability in measurements.

Implications for farmers

Affordable methane monitoring technologies could eventually help farmers:

- track methane trends within herds for applications such as animal breeding for low emissions
- assess the impact of feeding or management changes
- support emissions benchmarking and reporting.

Further development and validation are still required before low-cost methane sensors are ready for widespread commercial use.

4. Soil carbon and nutrient status

This study measured soil carbon and nutrient status across different dairy farming systems and land uses in NSW.

More than 800 soil samples were collected from nine dairy farms representing pasture-based and confinement (housed) systems. Soil samples were taken from a range of land uses including natural pasture, improved pasture, mixed pasture/forage cropping paddocks and tree-covered areas.

Soil organic carbon, nitrogen, phosphorus and other soil physicochemical properties were analysed to better understand how dairy farming systems and land management practices influence soil nutrient reserves and carbon storage.

Key findings

Pasture-based dairy systems stored substantially more soil carbon and nitrogen than confinement systems, particularly under permanent pasture and tree-covered areas (see table). However, pasture-based farms in this study were located in drier regions.

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Table: Soil organic carbon, nitrogen and phosphorus status		
	Pasture-based systems	Confinement systems
	(Mg ha^{-1})	
Soil organic carbon	105	60
Total nitrogen	8.73	5.3
Total phosphorus	0.15	0.56

In the pasture-based systems, cropping paddocks generally had lower soil carbon levels than permanent pastures. This highlights the importance of long-term ground cover and pasture systems for maintaining soil carbon reserves in high rainfall zones.

Confinement systems had much higher phosphorus levels, reflecting gcumulative (legacy) phosphorus from historical inputs and/or inherent differences in parent material and mineralogy, rather than contemporary annual applications alone.

The study also showed substantial variation in soil carbon and nutrient status within farms, reinforcing the importance of direct soil measurement rather than relying solely on regional averages or maps.

Implications for farmers

The findings suggest pasture management, land use and nutrient management practices can strongly influence soil carbon storage and nutrient accumulation on dairy farms.

Maintaining permanent pasture and tree cover may help support soil carbon reserves, while regular soil testing can help identify nutrient imbalances and guide fertiliser management.

5. Digital soil mapping

This study evaluated how accurately the Soil and Landscape Grid of Australia (SLGA) predicts soil carbon and nutrient levels on dairy farms.

The SLGA predictions were compared with laboratory analysis of 810 soil samples collected across nine NSW dairy farms. The study assessed how well the SLGA estimated soil carbon, nitrogen and phosphorus at both whole-farm and paddock scale.

Key findings

The findings suggest digital soil mapping tools can provide useful broad-scale insights for dairy farms where direct sampling is limited. However, the SLGA was not accurate enough for paddock-scale management or carbon crediting, despite being useful for broad whole-farm assessments of soil carbon and nitrogen

The digital mapping system showed moderate accuracy for soil carbon and nitrogen, capturing broad differences between farming systems. However, it was not accurate for phosphorus and was unable to reliably detect fine-scale variation between paddocks.

The findings highlight the importance of validating digital soil maps with direct soil sampling, particularly where farmers are making nutrient management or carbon accounting decisions.

Implications for farmers

Digital soil mapping tools such as the SLGA can be a useful starting point for understanding soil carbon and nutrient status. However, it is not accurate for paddock-level management decisions and accurate carbon accounting.

6. Pasture and carbon dynamics

This study investigated how pasture species and management practices influence greenhouse gas emissions and carbon cycling in dairy systems.

It was conducted at the University of Sydney's Corstorphine research farm at Camden.

Greenhouse gas chambers and gas analysers measured daily greenhouse gas fluxes from ryegrass and kikuyu pastures before, during and after grazing.

The study assessed how grazing, pasture regrowth, slashing and nitrogen fertiliser application influenced short-term carbon exchange between the pasture and atmosphere.

Key findings

The study showed well-utilised pastures can potentially act as a net carbon sink by capturing more carbon dioxide through photosynthesis than they release through greenhouse gas emissions under the conditions measured.

At the study site, ryegrass pastures acted as a carbon sink during active regrowth. Kikuyu pastures also captured carbon during active growth. However, when surplus pasture required slashing, emissions from decomposing plant material reduced the overall carbon benefit. Under the conditions measured, this sometimes shifted the pasture system from a net carbon sink to a net greenhouse gas emitter.

Pasture growth stage, grazing management, and seasonal conditions all influenced greenhouse gas fluxes. Dry conditions reduced photosynthesis and limited the ability of pastures to capture carbon.

The study also highlighted the importance of measurement timing and methodology when assessing pasture greenhouse gas emissions and carbon sequestration.

Implications for farmers

The findings suggest pasture management practices can influence the greenhouse gas balance of dairy systems over short timeframes. Maintaining actively growing pastures and grazing management to avoid the need to slash excessive surplus pasture may help improve carbon capture and reduce emissions from pasture systems.

Limitations

The findings were based on measurements from a single research site and specific seasonal conditions, highlighting the need for further research across multiple environments and years.

PhD student

Mulisa Dida, University of Sydney

Collaborators

The scope of this Dairy UP project was expanded thanks to additional funding from the NSW Environmental Protection Authority (EPA).

Journal articles

Dida et al., 2026 Environmental impacts of dairy farming intensification and land use on soil organic carbon stocks and physicochemical properties. Environmental Impact Assessment Review, Vol 120.

Carbon terminology

Carbon calculator: a tool for farmers to measure their farm's carbon footprint and understand the sources of emissions and explore options for reducing emissions.

Carbon credit (carbon offset): permits the owner to emit a certain amount of carbon dioxide or other greenhouse gases.

Carbon dioxide equivalents: a measure used to compare emissions from various greenhouse gasses on the basis of their global warming potential by converting amounts of other gasses to the equivalent amount of carbon dioxide with the same global warming potential.

Carbon sequestration: the process of capturing and storing carbon dioxide from the atmosphere.

Fat and protein corrected milk **emissions intensity**: kilograms of carbon dioxide equivalents per kilogram of fat and protein corrected milk.

Enteric methane: produced by cows during digestion.

Fluxes: the kilograms of greenhouse gas emissions or uptake per hectare per day.

Dida et al., 2025 Potential applications of a low cost gas sensor to monitor enteric methane emission from ruminant animals. Smart Agricultural Technology, Volume 10.

Dida et al., 2025 Greenhouse gas emissions of confinement and pasture-based dairy farms: Implications for mitigation. Journal of Dairy Science, 2025; 108, 11026-11040

Dida M. F., et al (2024), Dietary Concentrate Supplementation Increases Milk Production and Reduces Predicted Greenhouse Gas Emissions Intensity in Pasture-based Commercial Dairy Farms. Journal of Dairy Science March 22, 2024

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Delivery organisations

The University of Sydney Dairy Research Foundation | NSW Government Department of Primary Industries and Regional Development | Scibus | Dairy Australia

Partner organisations

NSW Farmers Growing the best | eastAUSmilk | Dairy NSW | Dairy Australia | AFMH | Leppington Pastoral Company Pty Ltd | NSW Government Local Land Services | Norco

Additional program supporters, collaborations or partnerships

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