Bioeconomy Science Institute
AGRESEARCH GROUP

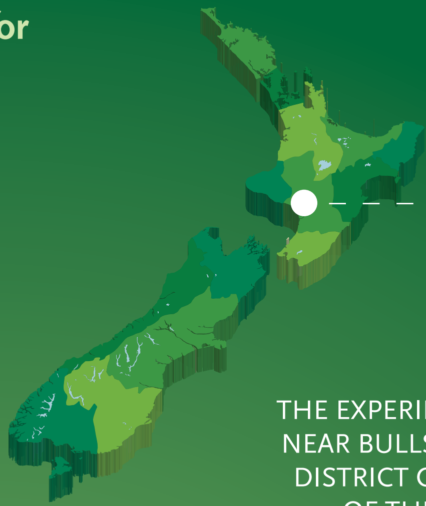
IMPACT CASE STUDY

Preparing Pastoral Systems for a Higher CO_2 Future

Impact of the New Zealand Free Air Carbon Dioxide Enrichment Experiment

AgResearch ran the NZ FACE experiment for 25-years from 1997 through to 2022.

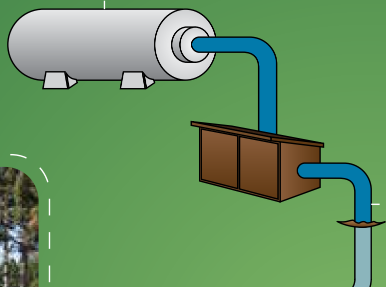
3 ambient (control) and 3 elevated-CO_2 grazing rings were monitored for the duration of the experiment.

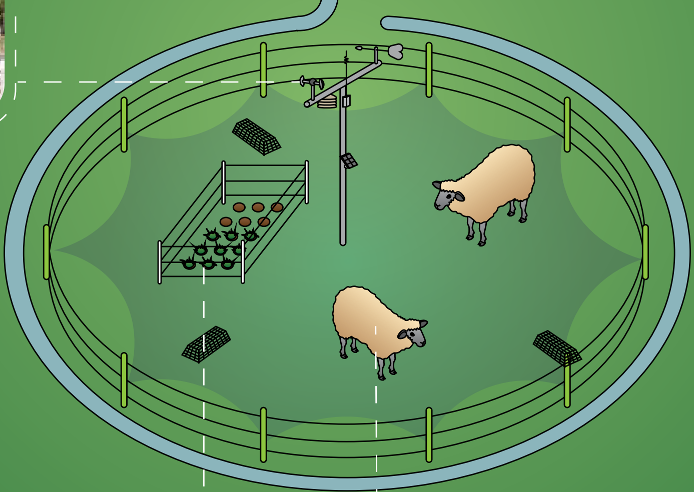


THE EXPERIMENT WAS LOCATED NEAR BULLS IN THE RANGITIKEI DISTRICT ON THE WEST COAST OF THE NORTH ISLAND OF AOTEAROA NEW ZEALAND.

CARBON DIOXIDE

CO_2 was delivered to the research site and then stored in a pressurised tank.



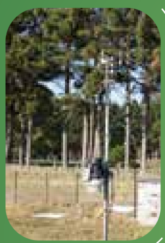


STAND PIPES

CO_2 was transported via underground pipes to standpipes on the edge of each elevated-CO_2 grazing ring.

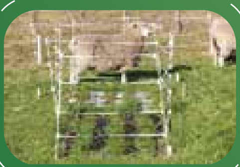
The standpipes delivered CO_2 to elevate atmospheric CO_2 within the grazing ring by 25% (+100 p.p.m, the level of atmospheric CO_2 expected circa 2050)

A computer system controlled which standpipes CO_2 was emitted from – usually those in the upwind direction.



MONITORING

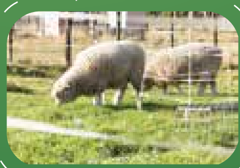
Levels of CO_2, windspeed and wind direction were monitored.



SOIL AND PASTURE TESTS

Soil tests and pasture growth monitoring throughout the experiment found that elevated CO_2 resulted in:

- 3% average increase in pasture growth per decade
- Decrease in phosphorus available to plants, partly offset by increase in the ability of plants to extract phosphorous from the soil
- 50% decrease in the efficacy of phosphorus fertiliser
- Decrease in nitrogen fixation
- Decrease in forage quality and animal intake



GRAZING

NZ FACE experiment was the only CO_2 enrichment experiment in the world that included grazing animals. The three grazing rings were grazed an average of 8 times per year.

ACADEMIC ACHIEVEMENTS INCLUDE

7 book chapters 6 major reports 57 academic papers
Over 70 conference presentations (46 internationally)
Collectively >7000 citations of the project in publications

The New Zealand Free Air Carbon Dioxide Enrichment experiment (NZ FACE) collected data over 25-years to provide answers to how pastoral agriculture will perform under a future environment. It is an excellent example of fundamental research of major importance to farm investment, agri-environmental policy, and further applied research.

The AgResearch team designed an outdoor experiment which included grazing animals, and which added carbon dioxide (CO_2) to the air to create a CO_2 enriched atmosphere. From 1997 to 2022, the experiment provided data on pasture response to elevated CO_2 levels, demonstrating the practical implications of our changing atmosphere for pastoral agriculture.

The inclusion of animals was significant: it made the experiment highly relevant to pastoral agriculture globally, since approximately 40% of the world's land is grassland, the majority of which is grazed (Bai, 2022). Importantly, the NZ FACE experiment was the only experiment in the world to study the impacts of elevated CO_2 on grazed grassland. Its results therefore made a very significant contribution to global research on climate change.

The NZ FACE experiment gained the support of many stakeholders, particularly the Ministry of Agriculture and Forestry (now the Ministry for Primary Industries (MPI)) and research priorities were determined in consultation with MPI over two decades. The experiment was determined to be of national importance and received secure, strategic science investment funding.

Importantly, many of the NZ FACE experiment's most important findings were made in the second decade of CO_2 enrichment: ending measurements earlier would have generated very different conclusions. This reinforces a broader pattern seen in ecosystems research, that responses to environmental change often involve slow-developing feedback mechanisms over long timescales, underscoring the essential role of sustained, foundational research.

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We acknowledge funding from the Ministry for Business Innovation and Employment, the Ministry for Primary Industries and the Ag Emissions Centre (and their respective predecessor organisations). We also acknowledge funding and support from the Lottery Board, the Ministry for the Environment, and BOC Gases.

HISTORY

Projecting the effects of climate change on pastoral agriculture relies heavily on modelling, but modelling is only reliable if it is underpinned by good understanding of biological responses to changes in temperature, rainfall, and atmospheric CO_2 concentration.

In the 1980s and 90s, AgResearch scientists recognised that the greatest uncertainty regarding the effects of climate change was in ecosystem responses to increasing atmospheric CO_2. At the time, research from controlled-environment chambers had established that elevated CO_2 had positive effects on plant photosynthesis in the short term, becoming known as CO_2 fertilisation. Meanwhile, the long-term consequences of increased atmospheric CO_2 on pasture ecology, soils and animals largely remained matters of theoretical speculation.

Consequently, AgResearch scientists designed the New Zealand Free Air Carbon Dioxide Enrichment experiment to study the effects of future atmospheric CO_2 levels in a real livestock production environment using grazing rings managed according to industry guidelines for grazing and fertiliser application.

Enrichment of the grazing rings with CO_2 began in October 1997 and continued until June 2022. The chosen enrichment level (+25% or +100 parts per million) represented the expected atmospheric CO_2 concentration circa 2050. Over the 25 year period, monitoring of plant, soil and animal responses was nearly continuous.

In early 2022, the cost of CO_2 escalated rapidly due to shortages in bulk CO_2 supply (associated with the simultaneous closure of the Marsden point oil refinery, disruptions at the Kapuni gas plant, and COVID-19 supply chain issues). As a result, a reluctant decision was made to end the CO_2 enrichment element of the project.

IMPACT OVERVIEW

Data from the ambitious and globally significant 25-year NZ FACE experiment is shaping decisions that will influence the sustainability and productivity of Aotearoa New Zealand's pastoral agricultural sector for decades to come.

The NZ FACE experiment provided unique insights into the real-world response of grazed grassland to a future environment that have improved farm systems modelling. The experiment is a flagship example of fundamental research that has generated practical information of major importance for people making farm investment decisions, those setting agri-environmental policy, and applied researchers nationally and internationally.

THE NZ FACE EXPERIMENT HAS:

- Improved the **accuracy of economic planning** for pastoral agriculture, Aotearoa New Zealand's most valuable export industry.
- Updated farm productivity knowledge and models, **informing agricultural land-use decisions and reducing financial uncertainty and risk**.
- Highlighted the effect of elevated CO_2 on agri-environmental processes, **enabling optimisation of farm systems for productivity and economic and environmental benefits**.
- Positioned pastoral agriculture for a **sustainable future** under projected climate scenarios.
- Informed emissions and climate change projections, **allowing adaptation and mitigation strategies** to be targeted most effectively.
- **Informed policy development**, providing accurate global assessments of climate change impacts.
- **Raised the profile** of ecological and climate change experiments
- **Provided a foundation for future research** to optimise research investment and accelerate the development of solutions to the critical issues agriculture is facing.
- **Enhanced Aotearoa New Zealand's international research reputation** and commitment to addressing climate change.
- Provided an exemplar of the **importance and value of long-term trials**.

The NZ FACE experiment has fed accurate, ground-truthed information into the models that help us plan for future climate scenarios. It has informed emissions and climate change projections, allowing adaptation and mitigation strategies to be targeted most effectively.

Data on pasture response to elevated CO_2 from the NZ FACE experiment continues to provide information for evidence based policy making and provides a solid foundation for future researchers to accelerate the development of adaptation solutions.

IMPACT STORIES

Essential information for international climate change impact assessments

As the only CO_2 enrichment experiment in the world to include grazing, the NZ FACE experiment offers unique insight into the likely response to future environments of the world's largest biome (grasslands) and the world's largest agricultural system (grazing).

Data from the NZ FACE experiment is therefore essential to producing accurate global assessments of climate change impacts. Data from the experiment have been included in research summaries (Godde et al., 2021; Izaurralde et al., 2011; Polley et al., 2013) and meta-analyses (Terrer et al., 2019) that form the basis for international and national climate change impact studies, which in turn inform policy decisions.

Accurate farm productivity forecasting

The NZ FACE experiment's findings enable more accurate economic planning for Aotearoa New Zealand's most valuable export industry by refining our understanding of CO_2 fertilisation effect on pasture growth.

CO_2 fertilisation, where plants photosynthesise more and therefore grow more due to elevated atmospheric CO_2, is a major uncertainty factor in modelling future climate scenarios, determining whether projected productivity changes are positive or negative (Clark et. al., 2012).

Modelling had suggested a strong, near-proportional increase in pasture production due to CO_2 fertilisation, corresponding to the approximate 6.5% rise in atmospheric CO_2 every decade. The NZ FACE experiment found, however, that over 25 years the increase in pasture growth was only 3% per decade.

This finding has important economic implications. If CO_2 fertilisation is incorporated into economic modelling it is expected to contribute to an increase in farm productivity. Projections for the value of this contribution are more accurate when applying findings from the NZ FACE experiment. In 2023 around $18.6 billion was contributed to Aotearoa New Zealand's GDP by pasture-based dairy and meat production and processing (Stats NZ Infoshare). Using NZ FACE experiment data reduces the expected increase in productivity value due to the CO_2 fertilisation effect by 2050 from $3 billion to $1.2 billion. More accurate projections of potential financial returns can provide clarity and inform government decision-making and economic planning.

Reduction in white clover nitrogen fixation under climate change

The NZ FACE experiment has shown that white clover fixes less nitrogen under elevated CO_2. This is a significant and serious finding since pastoral agriculture relies on nitrogen for productive pasture growth.

In Aotearoa New Zealand, white clover fixes 1.3 million tonnes of nitrogen every year, equivalent to $2.25 billion in fertiliser. If biological nitrogen fixation is reduced, agriculture will become more reliant on fertilisers, which are economically and environmentally costly.

Ongoing biological nitrogen fixation by plants under a changed climate is crucial for sustainable agriculture. Further research is essential to learn how and why biological nitrogen fixation is reduced under elevated CO_2 and how to maintain biological nitrogen fixation.

Understanding changes in pastoral productivity

Findings from the NZ FACE experiment show that the fertilisation effect of elevated CO_2 that is apparent in glasshouses where conditions can be optimised for plant growth is not as strong in a field situation. The increase in pasture production in the NZ FACE experiment was 3% per decade, about half that projected by models. This is due to changes in soil nutrient availability under elevated CO_2 conditions. Furthermore, a reduction in the nutritional value of the plants grown under elevated CO_2 meant that sheep ate less of them: lower nutritional intake by animals could lead to lower productivity.

These findings highlight the need for further research into the underlying causes of these changes to understand and address the apparent stagnation in pastoral productivity observed over the past 20 years. Future research may enable the pastoral sector to ameliorate the negative effects of climate change and take advantage of any positive effects. (Chapman et. al., 2024)

Clarifying future land investment decisions

Accurate productivity models and tools, incorporating NZ FACE experiment results, can inform landholder decisions about the future of their land. The benefits of these better-informed decisions will be felt over decades.

To understand the value of making well-informed choices based on potential productivity we can consider investments in land-use change. For example, farmers need to decide whether to retain or renew pasture, or whether to transition marginal land to forestry production. These are difficult investment decisions, where long-term changes in productivity over multiple decades determine whether the returns justify the initial investment cost.

Expectations of productivity and long-term returns, guided by fundamental research such as the NZ FACE experiment, inform and influence these large investments. Increased certainty about potential financial returns reduces the risk associated with the major upfront investment in land-use change. Projections which indicate increasing productivity and returns can justify land-use change decisions, while projections which indicate decreasing productivity and returns can help landowners avoid poor investment decisions and redirect capital to other opportunities.

Demonstrating environmental feedback loops

The NZ FACE experiment provides a valuable demonstration of how environmental feedback loops can occur in response to the atmospheric CO_2 levels projected in future climate scenarios. Data showed that soil sequestration of additional CO_2 is unlikely, while nitrous oxide emissions from grazed pasture are likely to increase, both of which have the potential to contribute to further climate change.

These findings inform future projections of greenhouse gas emissions and can assist the development of effective policies and strategies for climate change adaptation and mitigation.

Optimising the efficiency of agricultural research

Optimising Aotearoa New Zealand's $286 million research investment in animal production and primary products (StatsNZ, 2022) could generate millions in benefits.

Aotearoa New Zealand's pastoral agriculture is highly efficient and productive as a result of research and farm practices that have focussed on optimising productivity under current conditions. As these conditions change, practice also needs to change.

The NZ FACE experiment provides the empirical data needed to model the effect of increased atmospheric CO_2 and inform farm practice guidance to mitigate its negative effects. Farming practices cannot necessarily be changed quickly or easily and the rationale for any recommended change will rely on information and projections from research.

For example, an unexpected finding from the NZ FACE experiment was that under elevated CO_2, phosphorus fertiliser was only half as effective at raising soil phosphorus availability. This finding can focus future research efforts on developing a solution to this challenge. This targeted approach will increase the efficiency of research funding and accelerate the development of adaptive strategies.

Questions raised about soil phosphorus availability tests under climate change

A major finding of the NZ FACE experiment relates to soil phosphorus.

Phosphorus is a key fertiliser for pastures, particularly for the growth of legumes which supply nitrogen through nitrogen fixation.

Under elevated CO_2 phosphorus fertiliser was only half as effective at raising the soil Olsen P score – the measurement used to determine the amount of phosphorus available to plants.

The negative effects of this were, however, partly offset by a greater ability of plants under elevated CO_2 to extract phosphorus from the soil.

An important consequence of this finding is that the current soil test used to determine fertiliser requirements will need to be recalibrated for a higher CO_2 world.

RESEARCH TEAM AND COLLABORATORS

SCIENTIFIC TEAM

Paul Newton (Project Leader) Paul initiated the NZ FACE experiment and led the subsequent research. He has gained an international reputation for his research on the impacts of climate change. His work on the NZ FACE experiment contributed to him winning a Science New Zealand lifetime achievement award in 2022.

Harry Clark Harry was heavily involved in the design and construction of the NZ FACE experiment and in the scientific research that followed. He has since focussed on greenhouse gas emissions research, being the original Director and then Chief Scientist of the Aotearoa New Zealand's Ag Emissions Centre. He was appointed a Member of the New Zealand Order of Merit for services to environmental science in 2014.

Mark Lieffering Mark worked on the Japanese rice FACE experiment before joining the NZ FACE experiment team. His research in the NZ FACE experiment focussed on botanical composition and plant nutritive value. He has been a central figure in transferring the knowledge gained in the NZ FACE experiment into ecological models that can be used for climate impact projections.

Saman Bowatte Saman specialises in the impacts of climate change on plant-soil-microbe interactions in pastoral agricultural systems. His research as part of the NZ FACE experiment significantly advanced understanding of how elevated atmospheric CO_2 affects soil nitrification, nitrous oxide emissions, biological nitrogen fixation and the soil microbiome.

Zac Beechey-Gradwell Zac made a significant contribution to the NZ FACE experiment in the latter stages of the project. His work on soil phosphate and legumes was critical in bringing attention to the long-term impacts of elevated CO_2 and the adaptations to farming systems this will require.

As well as **Andrew Carran, Coby Hoogendoorn, Grace Chibuike.**

TECHNICAL TEAM

Chris Hunt Chris is the electronics and control system expert who designed the software and hardware for the NZ FACE experiment and kept the facility operating.

Shona Brock Shona worked on the NZ FACE experiment for over 20 years. She was responsible for a range of technical tasks but, critically, she was the person responsible for all the botanical measurements including plant dissections for botanical composition assessments.

Phil Theobald Phil also worked on the NZ FACE experiment for over 20 years, specialising in soil sampling and chemical analyses of soil and plant samples.

As well as **Colin Bell, Yvonne Gray, Elaine Glasgow, Jocelyn Tilbrook, Danica Thompson**.

AOTEAROA NEW ZEALAND COLLABORATORS

Bioeconomy Science Institute (Manaaki Whenua – Landcare Research and Plant and Food Research (previously HortResearch) groups)

Earth Sciences New Zealand (previously GNS Science and NIWA)

He Kupenga Hao I Te Reo

Lincoln University

Massey University (Te Putahi-a-Toi School of Māori Studies, Agronomy Department, Soil Science Department)

PGG Wrightsons

Waikato University

INTERNATIONAL COLLABORATIONS

INTERNATIONAL RESEARCHERS

10 Sabbatical Visitors

7 French Interns

EARLY CAREER RESEARCHERS

5 Postdoctoral Researchers

9 PhD Researchers

3 Bachelor's Students

6 Bachelor of Technology Students

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