Final report

The potential of biomineral fertiliser to increase soil carbon sequestration

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Abstract

This project aimed to assess the ability of a biomineral fertiliser to increase soil carbon sequestration, while at least maintaining productivity and profitability in relation to best practice conventional fertiliser use. The project was conducted over 3 years across five sites in the Southwest of Western Australia, made up of the main trial site, the small plot trial, and three producer demonstration sites. The project was designed to explore the objectives through an Integrated Research & Development Producer Demonstration Site (PDS) model. Project findings are relevant to all livestock producers currently implementing a fertiliser regime.

It was proposed that biomineral fertilisers will reduce carbon emission through two pathways, firstly by increasing the formation and stability of soil organic matter compounds, and secondly by improving soil biological fertility and subsequent plant nutrition, reducing carbon emissions by increasing nutrient density of pastures and increasing weight gain efficiency of livestock.

The primary or main trial site (MTS) experiment was designed to apply the best practice fertiliser regime of both fertilisers (biomineral and synthetic) and measure under each system the impact on carbon emissions that relate to soil carbon sequestration and the methanogenic properties of the pasture and cattle production. The trial was conducted over a 3-year period.

The small plot trial contained within the main trial site paddock assessed applying equivalent nutrient application rates of the biomineral fertiliser and the synthetic fertilisers. The objective of the small plot trial, by applying equivalent nutrient rates, was to assess the impact of the microbe blend applied to the bio mineral fertiliser and how it impacts soil micro-biology and pasture production. This trial within the whole the project allowed assessment of the impact of biology above the effect of different nutrient application regimes has production and carbon sequestration.

The three producer demonstration sites were implemented to complement the research component of this project as a comprehensive adoption pathway. The producer demonstration sites involved 3 commercial demonstration sites as a vehicle to enable producers in the Southwest, South Coast and Great Southern regions to build knowledge, awareness and skills.

For the analyses of the change in total soil carbon and nitrogen from 2022 to 2025 for the MTS at each of the five soil depths, there were no significant differences for Biomineral or Synthetic fertiliser treatments. Soil nitrogen and carbon tended to increase at all depths over time and for both fertiliser treatments, but the changes were not significant. At the Main Trial Site, no treatment effect was evident and so the hypotheses that the Biomineral treatment would increase soil carbon sequestration ahead of the synthetic fertiliser treatment was rejected.

The results showed that biomineral fertilisers were able to maintain pasture and livestock productivity at levels similar to synthetic fertilisers. However, feed quality was generally higher under synthetic fertiliser regimes. Whole-farm greenhouse gas modelling indicated modest reductions in emissions when using biominerals. Biomineral fertilisers were however significantly more expensive. This higher cost of the biomineral fertiliser reduced farm profitability, despite equivalent production outcomes.

The project measured what is required to offset the GHG emissions from the Bridgetown property in terms of increasing soil organic carbon for each fertiliser system:

- 0.017% soil carbon sequestration is required in year one for carbon neutrality using synthetic fertiliser. (Edward T, 2021)
- 0.016% soil carbon sequestration is required in year one for carbon neutrality using biomineral fertiliser. (Edward T, 2021)

The findings confirm that biomineral fertilisers are a viable option in terms of production for livestock systems, though cost remains a barrier to adoption. Future research should focus on long-term monitoring of soil carbon, testing reduced fertiliser application rates to lower costs and exploring integration with a wider range of alternative practices.

The project drew considerable interest from producers and the general industry, especially from growers wanting to better understand and reduce their carbon footprint. Key adoption outcomes include 61 of 74 or 82.43% of the participants increased their knowledge rating between the start and the end of the project however the increase in understanding of soil carbon only improved by 28.1% or from 5.62 to 7.20 as rated by core and observer producers.

An increase of 4.91% to 41.67% of participants now believe it is extremely important to work towards carbon neutrality. The survey results demonstrated a minor increase of 2% in alternative fertiliser used to 39.95%. However, the high portion of alternative fertilisers was not due to the outcomes of the project but demonstrates producers' willingness to use or try alternative types of fertiliser away from synthetic fertilisers despite the lack of proven outcomes.

Finally, the exit survey results covered the extension objective for producers considering a production system change. From the exit surveys 86.77% demonstrated a willingness to change fertiliser practices and 64.29% are considering a change in fertiliser practices. The difference between a *willingness to change* and *considering a change* is in the likelihood of change. A producer who is willing to change will change when the right product is demonstrated while a producer who is considering change will take more time to change and potentially watch the new product for a period before changing. The average of these two results is 75.53%, demonstrating the project has achieved the second primary extension objective of over 75%.

1. Executive summary

Background

The primary question being assessed in this project is the ability of a biomineral fertiliser to increase soil carbon sequestration, while at least maintaining productivity and profitability in relation to best practice conventional fertiliser use.

The project is important for the industry as it assists producers address the increasing demand from consumers and supply chains for low-emission, environmentally responsible production systems. Project results will inform potential management practices and assessment of alternative products by producers, when considering climate-related sustainability targets. It also supports best practice fertiliser use in general, beyond the considerations of emissions and soil carbon.

The primary target audience is livestock producers in the South-West region of Western Australia, before extending to livestock producers across Australia. The results of the project can be used by livestock producers and industry as independent research to inform considerations producers are now facing around soil carbon sequestration, reducing emission, productivity and climate-related sustainability targets.

Objectives

The objectives for the project as detailed in the research agreement are:

1. Assess the potential of biomineral fertilisers to increase soil carbon, above that of conventional fertilisers.
2. Assess the carbon emissions of a biomineral and conventional fertiliser regime in a pasture fed beef system typical of South-West WA.
3. Assess the ability of biomineral fertilisers to maintain or exceed productivity and profitability of conventional fertiliser regimes, including a cost benefit analysis.
4. 70% of all core and observer producers increase their knowledge around biomineral fertilisers, soil carbon, strategies to increase it and carbon accounting by 60%.
5. 75% of livestock producers to consider the importance of implementing production systems changes to reduce operational greenhouse gas emissions within their operation.
6. 75% of core producers (minimum 10) to have trialled or started the process to implement a new fertiliser regime.
7. 40% of observer producers (minimum 60) to have trialled or started the process to implement a new fertiliser regime.

Methodology

The project comprises of 5 trials, the main trial site, the small plot trial and 3 x producer demonstration sites which were all contained within the South-Western region of Western Australia.

The main trial site and the 3 x producer demonstration sites were designed to apply the best practice fertiliser regime of both fertilisers (biomineral and synthetic), with the small plot trial designed to match nutrient input (nitrogen and phosphorus) and assess biological action. The outputs measured under each system included the change on net carbon emissions by measuring soil carbon and soil microbe levels every 10cm to 50cm and productivity through measuring pasture quality, DM production and cattle production. The benefit cost analysis and cost of production for

each fertiliser system was then calculated with the net carbon emissions position then overlayed to give the final output.

The project was conducted over a 3-year period to understand and measure the potential impact on carbon sequestration, production and profitability.

Results/key findings

Overall, the project was unable to measure an increase in soil carbon in from the use of biomineral fertilisers, that exceeded that of synthetic fertilisers. At the MTS there were no significant changes from 2022 to 2025 or differences between treatments for total soil carbon (surface soil range 5.31 to 7.77%), total soil nitrogen (surface soil range 0.42 to 0.62%), Microbial Biomass Carbon (MBC) (surface soil range 617 to 724 mg/Kg of soil), Microbial Biomass Nitrogen (MBN) (surface soil range 48 to 53 mg/Kg of soil) or Dissolved Organic Carbon (DOC) (surface soil range 70 to 90 mg/Kg of soil).

Additional key findings include:

- For the SPT, at soil depth of 0-10 cm MBC and MBN increased for Biomineral but decreased for Synthetic from 2022 to 2025 ($P<0.05$). At depth 30-50 cm, DOC increased for Synthetic, but decreased for Biomineral ($P<0.05$).
- The lack of treatment effect at the MTS may be due to pre-existing high levels of total soil carbon, resulting from effective carbon sequestration from long-term and well-managed perennial pasture.
- At the MTS, there were no significant differences in fermentability or methane formation (anti-methanogenic properties) between treatments in any year. The fermentability correlated strongly with pasture digestibility, which was also found to be similar between treatments and seasons.
- Results from the exit survey show 61 of 74 or 82.43% of the participants increased their knowledge rating between the start and the end of the project however the increase in understanding of soil carbon only improved by 28.1% or from 5.62 to 7.20 as rated by core and observer producers.
- 75.53% of livestock producers are considering the importance of implementing production systems changes to reduce scope 1 and 2 greenhouse gas emissions within their business.
- 70% of the core producers have now trialled or have started the process to implement a new fertiliser regime.
- Pasture and cattle growth across the main trial site, and producer demonstration sites showed that biomineral fertilisers can maintain production levels equivalent to synthetic fertilisers, despite drastically less nutrient levels being applied within the biomineral fertiliser regime
- Feed quality results were more variable. Synthetic fertilisers generally produced higher crude protein and metabolisable energy values across the main trial site and small plot trial.
- The greatest limitation of Biomineral fertilisers identified is cost. They were consistently more expensive than synthetic fertilisers across all sites. This eroded profitability, even though productivity was maintained.
- The results demonstrate that biomineral fertilisers are a viable alternative to synthetic fertilisers for pasture-based livestock systems. They maintained productivity and supported

equivalent animal performance, while offering modest greenhouse gas reductions through more efficient fertiliser use.

Benefits to industry

The project has delivered many key benefits to industry including:

- The results informed producers that to increase soil carbon and to reduce emissions the required strategy is more complex than simply changing to an alternative fertiliser.

- The project upskilled producers in their ability to understand whole of farm carbon accounting and emissions produced, plus how to generate the benefit cost analysis to measure the impact of alternative fertiliser decisions.

- The project benefited industry by upskilling producers to implement data driven informed fertiliser purchasing decisions around the viability of alternative fertilisers covering both changes in production and the commercial returns of these decisions.

Future research and recommendations

Based on the results of the project, recommendations for future research or development include the following areas:

- Long-term carbon monitoring by extending trials beyond three years to capture delayed soil carbon responses to biomineral fertiliser use, particularly under variable rainfall and seasonal conditions.

- Optimising fertiliser application rates by conducting trials on based on the reduced biomineral nutrient application rates to test whether productivity can be sustained while lowering costs.

- Integration with other practices to study synergistic effects of biominerals combined with organic amendments (e.g., compost, manure, biochar) and improved grazing practices.

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2. Background

1.1 Project Overview

The project aimed to assess the ability of a biomineral fertiliser to increase soil carbon sequestration, while at least maintaining productivity and profitability in relation to best practice conventional fertiliser use.

The project aimed to address the issue of long-term soil carbon depletion and assess whether biomineral can increase soil carbon levels compared to synthetic fertilisers. A secondary question to this is whether there is an impact on production should producers shift to a biomineral fertiliser strategy.

The project has been designed to explore the objectives through an Integrated R&D PDS model and is relevant to all livestock producers currently implementing a fertiliser regime.
It is proposed that bio-mineral fertilisers will reduce carbon emission through two pathways:

By increasing the formation of permanent humus compounds and through an increase in the soil organic matter stability. Consequently, the contribution of the organic matter fractions that are more resistant to decomposition are crucial for increasing soil carbon sequestration. This is achieved by:

- microbes in biomineral fertiliser colonise roots and drain more carbon to the rhizosphere soil to increase soil carbon pool
- biomineral fertiliser increases root biomass which are a source of carbon locked up in the soil over time.

- Bio-mineral fertilisers were hypothesised to improve soil biological fertility, plant nutrition and reduce carbon emissions by increasing nutrient density of pastures and subsequently increasing weight gain efficiency of livestock. Anti-methanogenic impacts were also assessed in the trial methodology.

The carbon footprint of a biomineral and conventional fertiliser regime were calculated to determine the ability of biomineral fertilisers to be a tool for reducing net GHG emissions from an improved pasture system.

1.2 Project Background

The biomineral fertiliser used in the project was a mineral based fertiliser which consists of a proprietary combination of fine mineral ores, such as micas, alkali feldspars, soft rock phosphate, dolomite, basalt, granite and crystalline silica, that are blended with various sulphates (ammonium, potassium, manganese, copper and zinc). This combination is then blended with a suite of microbes (fungi and bacteria) including phosphate solubilising bacteria and mycorrhizal fungi. The granular form of the above blend in a diameter of 2 - 4mm is then coated in a controlled release compound which is a polymer composed of modified wax, natural additives and trace elements. The controlled release polymer creates the targeted slow release rate of the fertiliser. The microbe blend applied to the bio mineral fertiliser is a balanced blend of beneficial soil microbes.

The project was built on knowledge taken from previous MLA funded northern WA research at Gillingarra (Gillingarra Perennial Pastures Project, P.PSH.0977) and translated components of this information to be relevant for the South Western regions. This work primarily examined the use of irrigation to fertigate, produce perennial pastures and background cattle. The project also undertook split fertiliser trials to compare bio mineral based products, which promote soil biology, compared to traditional chemical fertilisers. The results of this work indicated increased soil carbon on the bio mineral based fertiliser applications and similar plant production.

3. Objectives

3.1 Project Objectives

The objectives for the project as detailed in the research agreement are:

1. Assess the potential of biomineral fertilisers to increase soil carbon, above that of conventional fertilisers.
2. Assess the carbon emissions of a biomineral and conventional fertiliser regime in a pasture fed beef system typical of South-West WA.
3. Assess the ability of biomineral fertilisers to maintain or exceed productivity and profitability of conventional fertiliser regimes, including a cost benefit analysis.
4. 70% of all core and observer producers increase their knowledge around biomineral fertilisers, soil carbon, strategies to increase it and carbon accounting by 60%.
5. 75% of livestock producers to consider the importance of implementing production systems changes to reduce operational greenhouse gas emissions within their operation.
6. 75% of core producers (minimum 10) to have trialled or started the process to implement a new fertiliser regime.
7. 40% of observer producers (minimum 60) to have trialled or started the process to implement a new fertiliser regime.

3.2 Project Value Proposition Objectives

The key value outcome from the overall project for the Australian livestock industry, is the potential for greater soil C sequestration rates. At the time of project development, it was identified that through adoption of biomineral fertilisers producers could expect the following increases in soil carbon (pers coms Dr Zakaria Solaiman, UWA Institute of Agriculture):

- SW Western Australia, rainfall <450mm soil carbon to increase from ~1.0% to 2.2% in 3 years and to 3 - 3.5% in 10 years
- SW Western Australia, rainfall >600mm soil carbon to increase from ~2.2% to 3.6% in 3 years and to 4.2 - 4.8% in 10 years

The 72 core and observer producers engaged in this project represented 290,572 Ha’s being managed. Under the above potential impacts (5-10t/ha additional C sequestered, using 7.5t/ha for this calculation) and the anticipated adoption rate within this project (31 producers), this project forecast a potential of 872,000 t of Carbon to be sequestered above what would occur under a conventional fertiliser regime.

3.3 Success of Achieving Project Objectives

The project was successful in achieving all the objectives from the research agreement methodology.

1. Assess the potential of biomineral fertilisers to increase soil carbon, above that of conventional fertilisers.

Over the three years of the project across 5 trial and demonstration sites, utilising a comprehensive soil testing regime to a depth of 50cm, the objective of assessing the ability of biomineral fertiliser to increase soil carbon, above that of conventional fertilisers, was achieved. While the results, that there is no difference between the fertiliser types to change soil carbon, weren't in line with the projects hypothesis the project confidently and comprehensively achieved the objective.

2. Assess the carbon emissions of a biomineral and conventional fertiliser regime in a pasture fed beef system typical of South West WA.

The project successfully met the objective of assessing the carbon emissions of a biomineral and conventional fertiliser regime in a pasture fed beef system typical of South West WA. The project was held on a commercial cattle breeding operation under which the primary source of emissions comes from the cattle, with the fertiliser input only being a minor contributor to emissions. The project successfully demonstrated that a pasture fed beef system using biomineral fertilisers does have reduced carbon emissions compared to that of a synthetic based system.

3. Assess the ability of biomineral fertilisers to maintain or exceed productivity and profitability of conventional fertiliser regimes, including a cost benefit analysis.

The project successfully met the objective of assessing ability of biomineral fertilisers to maintain or exceed productivity and profitability of conventional fertiliser regimes, including a cost benefit analysis. The productivity of the biomineral fertiliser program was shown to be equivalent to the synthetic fertilisers and this trend was seen across all 5 of the trials.

While productivity was maintained by the biomineral fertiliser the synthetic fertilisers were more profitable than the biomineral fertiliser regimes even when the best practice (lower) application rates of the biomineral fertilisers were applied, primarily due to the much higher cost of the biomineral fertilisers.

Benefit cost analysis was carried out across the project at two levels, at the operational or cattle production commercial business level and secondly by overlaying the net change in CO2 emissions which included operating emissions and the change in soil carbon, both calculated back to an ACCU for accounting practicality.

The project was successful in reaching large numbers of producers in the Southwestern region of Western Australia and throughout the greater agricultural region. Extension throughout the project period was conducted by the Future Food Network. The Future Food Network's is a producer driven group with the primary role being to drive a progressive, connected, and resilient food and beverage industry in Western Australia by connecting producers, manufacturers, and other stakeholders to foster innovation and value-add opportunities.
Extension through the Future Food Network of Facebook posts, E-news articles, LinkedIn posts, direct electronic mail reached nearly 1,200 recipients, primarily comprised of producers in the South-West of WA.

The success of achieving the 4 extension objectives of the project are detailed below:

4. 70% of all core and observer producers increase their knowledge around biomineral fertilisers, soil carbon, strategies to increase it and carbon accounting by 60%.

Through the extension component of the project considerable work was conducted to increase producer knowledge. Results from the exit survey show 61 of 74 or 82.43% of the participants increased their knowledge rating between the start and the end of the project. The increase in understanding of soil carbon only improved by 28.1% or from 5.62 to 7.20 as rated by core and observer producers.

5. 75% of livestock producers to consider the importance of implementing production systems changes to reduce operational greenhouse gas emissions within their operation.

The survey covered a series of questions around the extension objective for producers considering the production system changes. From the results 86.77% have demonstrated a willingness to shift in fertiliser practices as means of managing enterprise emissions.

6. 75% of core producers (minimum 10) to have trialled or started the process to implement a new fertiliser regime.

There were 10 core producers involved in the project who assisted in structuring the best practice fertiliser regimes across the main trial site and the 3 Producer Demonstration Sites. Of the 10 core producers 7 have trialled the process of implementing a new fertiliser regime using biomineral fertilisers over selected areas of their property during the 3-year timeframe of the project.

The project was unable to achieve the 3rd extension outcome of over 75% of the core producers trialling or to be in the process of implementing a new fertilise regime.

7. 40% of observer producers (minimum 60) to have trialled or started the process to implement a new fertiliser regime.

There were 62 observer producers for the project again with the majority located across the South-West of Western Australia and throughout the greater agricultural region of WA. From the exit survey results there is a strong willingness to move away from synthetic fertilisers with biomineral fertilisers being one of the key alternatives for the change. 39.95% of producers use alternative fertilisers often. This very nearly achieves the 40% implementation rate targeted in this objective.

3.4 Success of Achieving Value Proposition Objectives

The project was unsuccessful in achieving the targeted value proposition objectives of increasing soil carbon by 1.4% in 3 years in the SW Western Australia >600mm rainfall region. There was no change in soil carbon levels between the two fertiliser regimes across the three years of the project.

4. Methodology

4.1 Project Aim

This project aimed to assess the ability of a biomineral fertiliser, to increase soil carbon sequestration, while at least maintaining productivity and profitability in relation to best practice conventional fertiliser use. The project was structured through an Integrated R&D PDS model and is relevant to all livestock producers currently implementing a fertiliser regime.

It was proposed that biomineral fertilisers will reduce carbon emission through two pathways:

• By increasing the formation of permanent humus compounds and through an increase in the soil organic matter stability. Consequently, the contribution of the organic matter fractions that are more resistant to decomposition are crucial for increasing soil carbon sequestration. This is achieved by:

- microbes in biomineral fertiliser colonise roots and drain more carbon to the rhizosphere soil to increase soil carbon pool
- biomineral fertiliser increases root biomass which area source of carbon locked up in the soil over time.

• Bio-mineral fertilisers will improve soil biological fertility, plant nutrition and reduce carbon emissions by increasing nutrient density of pastures and subsequently increasing weight gain efficiency of livestock. Possible anti-methanogenic impacts will also be assessed.

The carbon footprint of both biomineral and synthetic fertiliser regimes were calculated to determine the ability of biomineral fertilisers to be a tool for reducing net GHG emissions from an improved pasture system.

4.2 Methodology Summary

The primary or main trial site (MTS) experiment was designed to apply the best practice fertiliser regime of both fertilisers (biomineral and synthetic) and measure under each system the impact on carbon emissions that relate to soil carbon sequestration, the methanogenic properties of the pasture and cattle production. The trial was conducted over a 3-year period. The paddock selected was a long-term pasture paddock (+40 years) containing a mixture of perennial grasses and annual legumes and grasses. The site has surface irrigation to provide green feed over the summer. The paddock had been selected to minimise the impact of building soil carbon through establishing perennial pastures and enabled the change in soil carbon to be directly related to each of the fertiliser regimes. It has also been selected for the irrigation as this may bring forward the impacts of each fertiliser system as pasture is grown 12 months of the year.

The trial paddock, 30 Ha in size, is in Bridgetown WA, 255 km South, Southeast of Perth in the Southwest region of WA. The long term (125 years) rainfall is 823 mm though this has been declining over recent decades, and the length of growing season has also been contracting. The paddock was divided into 6 x 5 Ha cells to generate 3 replications for each of the fertiliser treatments under cattle production. Within each cell 4 x 25m quadrants were selected for soil testing (5 depths; 0-10, 10-20, 20-30, 30-40 and 40-50 cm) to conform with the Australian standards for carbon sampling.

The trial design was developed in conjunction with Professor Phil Vercoe, Associate Director, The UWA Institute of Agriculture and Dr Zakaria Solaiman, Research Assistant Professor, The UWA Institute of Agriculture.

4.3 Methodology Outputs

Project outputs assessed under each fertiliser regime, with relevant data captured, include:

- Carbon emissions budget, following the National Greenhouse Gas Inventory methodology

- Soil Carbon measurements
  - Soil synthetic carbon, organic carbon, total carbon and total N.
  - Measure and compare the change in soil biology in the formation of organic matter fractions that are more resistant to decomposition for increasing soil carbon sequestration.

- Soil Carbon and soil health measurements
  - Dissolved Organic Carbon (DOC)
  - Microbial Biomass Carbon
  - Microbial Biomass Nitrogen
  - Soil nutrition analysis; soil pH, electrical conductivity, Colwell P, and Mehlich extraction of a range of soil nutrients including K, P, and S.
  - Soil Texture

- Pasture Production and nutrient composition analysis
  - Pasture growth
    - Summer and Autumn growth under irrigation - Main Trial Site and Small Plot Trial
    - Winter and Spring growth from winter rainfall – Producer Demonstration Sites
  - Plant nutritional values

- Livestock production
  - Yearling live weight gain over 80 - 120 days recorded monthly
  - Calculate operating costs to determine the live weight gain cost of production in $/kg live weight.

- Anti-methanogenic properties of pastures
  - Comparison of the anti-methanogenic properties of fodder grown under each fertiliser regime through in-vitro testing of methane production from pasture samples.

- Cost-benefit analysis
  - Analysis of fertiliser costs against productivity and emissions benefits

4.3.0 Material Required – Main Trial Site

Main trial site area fenced into the 6 main replicate paddocks with each replicate then divided again between December and May each year of the trial using either permanent or temporary fencing.

Fertiliser products applied as per protocol

- Machinery to implement project objectives
- Yearling calves for backgrounding
- Cattle yards and weighing equipment

4.3.1 Pre-Experimental Work

Fence trial site into 6 paddocks.

- Each of the 6 paddocks were divided again into two equal paddocks to allow two replicates of calves to improve statistical power of analysis
- Laneway system included in design to allow low stress movement during weighing

Soil Sampling

- 4 randomly placed quadrants of 25m x 25m were located within each of the 6 paddocks
- Each quadrant's location referenced to ensure all soil samples are taken from within the same quadrant

Pasture

- Pasture cages placed along W feed transects that represent the pasture in each of the cells for sampling during the trial period.
- Conduct a pasture survey by paddock and W transect including:
  - Pasture Species
  - % of each Species

Baseline sampling and ongoing testing to be conducted before 15 April of year 1 (the date for the first fertiliser application) as per below field sampling and testing methodology to generate base data.

4.3.2 Fertiliser Application Regime

Fertiliser application regimes are outlined in the following tables. The fertiliser regimes were determined by the initial soil testing results and adjusted for seasonal conditions and available water for irrigation. Applications were carried out in the same application windows each year.

Table 1. Indicative fertiliser costs and annual application rates for the main trial site

Fert regime	Fert Type	App Timing	$/ton	Kg/Ha	Ave $/Ha
Synthetic Fertiliser	Super (potash)	Autumn	$600 - $700	120	$78
	Urea/MoP	Spring	$800 - $1200	120	$120
	Urea	Summer	$800 - $1200	120	$120
				Total	$318.00
Biomineral Fertiliser	Biomineral cropping	Autumn	$1500 - $1950	80 – 120	$172.50
	Biomineral cropping	Spring	$1500 - $1950	80 – 120	$172.50
	Biomineral NS	Summer	$1950 - $2700	80 - 120	$232.50
				Total	$577.50

Table 2. Actual fertiliser cost for the project by year and trial site

	Year	2022	2023	2024	2025	
Trial	**Fertiliser Regime**	**Cost/Ha**	**Cost/Ha**	**Cost/Ha**	**Total Cost/Ha**	**Total Cost**
Main Trial Site	Biomineral	$493	$488	$469	$221	$1,671
	Synthetic	$242	$311	$226	$88	$867
Small Plot Trial	Biomineral	$622	$669	$885	$346	$2,522
	Synthetic	$265	$301	$231	$88	$885
Bridgetown PDS	Biomineral	$493	$251	$251		$995
	Synthetic	$216	$149	$143		$508
Benger PDS	Biomineral	$493	$251	$251		$995
	Synthetic	$216	$149	$143		$508
Witchcliffe PDS	Biomineral	$493	$251	$251		$995
	Synthetic	$216	$133	$143		$492

Table 3. Main Trial Site Actual Fertiliser Applications by rate, timing and cost

	Date	Biomineral / Synthetic plots	Fertiliser	Application rate		Cost $/ton delivered	Cost/Ha
Autumn 22	5-May-22	Biomineral	Biomineral plus microbes	125	kg/ha	$1,973	$247
	6-May-22	Synthetic	Super potash 5in1	120	kg/ha	$699	$84
Spring 22	6-Aug-22	Biomineral	Biomineral plus microbes	125	kg/ha	$1,973	$247
	18-Aug-22	Synthetic	Urea 68%/MoP 32%	120	kg/ha	$1,317	$158
Summer 23	4-Feb-23	Biomineral	Slow release N	120	kg/ha	$1,973	$237
	4-Feb-23	Synthetic	Urea	120	kg/ha	$1,317	$158
Autumn 23	20-May-23	Biomineral	Biomineral plus microbes	80	kg/ha	$1,570	$126

	20-May-23	Synthetic	Super potash 5in1	120	kg/ha	$699	$84
Spring 23	2-Sep-23	Biomineral	Biomineral plus microbes	80	kg/ha	$1,570	$126
	2-Sep-23	Synthetic	Urea	100	kg/ha	$695	$70
Summer 24	8-Feb-24	Biomineral	Slow release N	80	kg/ha	$2,717	$217
	8-Feb-24	Synthetic	Urea	100	kg/ha	$830	$83
Autumn 24	20-May-23	Biomineral	Biomineral plus microbes	80	kg/ha	$1,570	$126
	20-May-23	Synthetic	Super potash extra 3in1	120	kg/ha	$612	$73
Spring 24	2-Sep-23	Biomineral	Biomineral plus microbes	80	kg/ha	$1,570	$126
	2-Sep-23	Synthetic	Urea	100	kg/ha	$693	$69
Summer 25	4-Feb-23	Biomineral	Slow release N	80	kg/ha	$2,767	$221
	4-Feb-23	Synthetic	Urea	100	kg/ha	$882	$88
Total Cost		**Biomineral**					**$1,671**
		Synthetic					**$867**

Table 4. Main Trial Site Nutrient Application rates by individual application

	Date	Fertiliser	kg/Ha	N	P	K	S
Fertiliser nutrient units		Biomineral plus microbes(10-7-4.5)		10	7	4.5	4.6
		Biomineral plus microbes(10-6.7-4.4)		10	6.7	4.4	4.5
		Slow release N		37			15
		Super Potash Extra 3:1			6.5	12.4	7.6
		Super Potash 5:1			7	8.4	8.7
		Urea		46			
		Urea 68% / MoP 32%		31.28		16	

Biomineral Fertiliser applications	Apr-22	Biomineral plus microbes (10-7-4.5)	125	12.5	8.8	5.6	5.8
	Aug-22	Biomineral plus microbes (10-7-4.5)	125	12.5	8.8	5.6	5.8
	Feb-23	Slow release N	120	44.4			18.0
	May-23	Biomineral plus microbes (10-6.7-4.4)	80	8.0	5.4	3.5	3.6
	Sep-23	Biomineral plus microbes (10-6.7-4.4)	80	8.0	5.6	3.6	3.7
	Feb-24	Slow release N	80	29.6			12.0
	May-24	Biomineral plus microbes (10-6.7-4.4)	80	10.0	6.7	4.4	4.5
	Aug-24	Biomineral plus microbes (10-6.7-4.4)	80	10.0	6.7	4.4	4.5
	Feb-25	Slow release N	80	29.6			12.0
		Total		**164.6**	**41.9**	**27.2**	**69.8**
Synthetic Fertiliser applications	Apr-22	Super Potash 5:1	120	0.0	8.4	10.1	10.4
	Aug-22	Urea 68% / MoP 32%	120	37.5		19.2	
	Feb-23	Urea	120	55.2			
	May-23	Super Potash 5:1	120	0.0	8.4	10.1	10.4
	Sep-23	Urea	100	46.0			
	Feb-24	Urea	100	46.0			
	May-24	Super Potash 3:1 Extra	130	0.0	8.5	16.1	9.9
	Aug-24	Urea	100	46.0			
	Aug-24	Urea	100	46.0			
		Total		**276.7**	**25.3**	**55.5**	**30.8**

4.3.3 Cattle Production

- Up to 96 calves @ 230 - 280kg live weight range divided randomly into 2 equal mobs
- Each mob was then divided again into 2 equal mobs, grazed on the same fertiliser replicate which was divided into 2 paddocks to give two replicates of the live weight gain data.
- Trial entry between 15 December and 15 January each year
- Administer full veterinary protocols and settling period on hay for 5 days post weaning.
- Background for 80 - 120 days
    - Target daily weight gain of 0.3% of body weight
    - Total weight gain of 90 to 110kg live weight
    - Exit weight 340 - 390 kg live weight
- Cattle depart property between 1 April to 15 May each year as sale weight is achieved
- Cattle production to be monitored by measuring monthly live weight gain. This will allow productivity metrics such as Kg of beef produced per hectare to be calculated for each treatment.

4.3.4 Pasture Field Sampling

Pasture Sampling Plan

Sample on:

- Monthly during the cattle production trial depending on water availability and length of trial (3 - 5 x January to May)
- July, August and October during Winter and Spring with the timings between measuring growth adjusted depending on seasonal conditions, (longer times over winter and shorter periods in spring).

At the start of the trial period a 'W feed transect' was positioned within each of the 6 paddocks. The pasture cages were then placed randomly along the W feed transect and the pasture samples taken from within these W transects each time using a 1/4m quadrant. From within the pasture cages 6 samples were taken at each sample date. Each of the samples were weighed to measure production. The samples were then mixed and a sub sample of 0.5kg was sent for quality testing twice a year for the MTS and SPT trials and annually for the PDS's.

4.4 Soil Sampling Plan

4.4.0 Main Trial Site

- Initial Sampling: March 2022 prior to fertiliser application commencement
- Interim Sampling: March 2024 reduced scale of testing at the end of year 2 to give an indication of how results were progressing.
- Final Sampling: March 2025 or end of project and mirror initial sampling and testing regime.
- Soil samples were collected from within the four randomly placed quadrants of 25 × 25 m within each of the six paddocks. Within each quadrant, twenty soil samples of fixed volume at five depths (0 10, 10-20, 20-30 and 40-50cm) were taken.
- Each quadrant's location was marked to ensure the soil samples were taken from the same site each time
- Table 5 shows the soil samples that were taken from each quadrant, with the sampling regime completed for each replicate each sampling time.
- The soil sampling plan was conducted across each biomineral fertiliser replicate and each synthetic fertiliser replicate.

Table 5. Field sampling plan for the main trial site March 2025 (Replicated for synthetic treatment)

Main Trial Site (MTS) - Bridgetown								
Trial	Fertiliser	Replicate	Quadrant	Depth				
MTS	Biomineral	Rep 1	Quad 1	0 - 10cm	10 - 20cm	20 - 30cm	30 - 40cm	40 - 50cm
MTS	Biomineral	Rep 1	Quad 2	0 - 10cm	10 - 20cm	20 - 30cm	30 - 40cm	40 - 50cm
MTS	Biomineral	Rep 1	Quad 3	0 - 10cm	10 - 20cm	20 - 30cm	30 - 40cm	40 - 50cm
MTS	Biomineral	Rep 1	Quad 4	0 - 10cm	10 - 20cm	20 - 30cm	30 - 40cm	40 - 50cm

- Table 6 shows the soil quality parameters that were tested for across all the 5 trials/demonstrations. More details around each of the soil quality parameters are detailed in the results section.

Table 6. Soil quality parameters measured across the project

Year	Test
Mar-22	Soil synthetic carbon, organic carbon, total carbon and total N Basic soil analyses Mehlich all nutrients including trace elements Particle size analysis Soil health (soil microbial biomass)
Mar-24	Soil synthetic carbon, organic carbon, total carbon and total N Basic soil analyses Mehlich all nutrients including trace elements Particle size analysis Soil health (soil microbial biomass)
Mar-25	Soil synthetic carbon, organic carbon, total carbon and total N Basic soil analyses Mehlich all nutrients including trace elements Particle size analysis Soil health (soil microbial biomass)

4.4.1 Small Plot Trial

Within the small plot trial, the nutrient application rates of the biomineral fertiliser and the synthetic fertilisers were applied at equivalent rates. The objective of the small plot trial, by applying equivalent nutrient rates, is to assess the impact of the microbe blend applied to the bio mineral fertiliser and how it impacts soil C, soil micro-biology and pasture production. This trial within the whole the project allowed assessment of the impact of biology above the effect different nutrient application regimes have on production. It is acknowledged that the application of biomineral fertiliser at the unit rates equivalent to conventional fertiliser systems is cost prohibitive and contrary to the production systems biomineral fertilisers are aiming to generate, however this trial is of value in isolating the effect of biology away from nutrient application.

The small plot trial was carried out within the same paddock on which the main trial was being conducted. This removed the impact of different environmental conditions and property history. The small plot trial was 2 treatments, bio mineral and synthetic fertilisers with 3 replications, as per Figure 2.

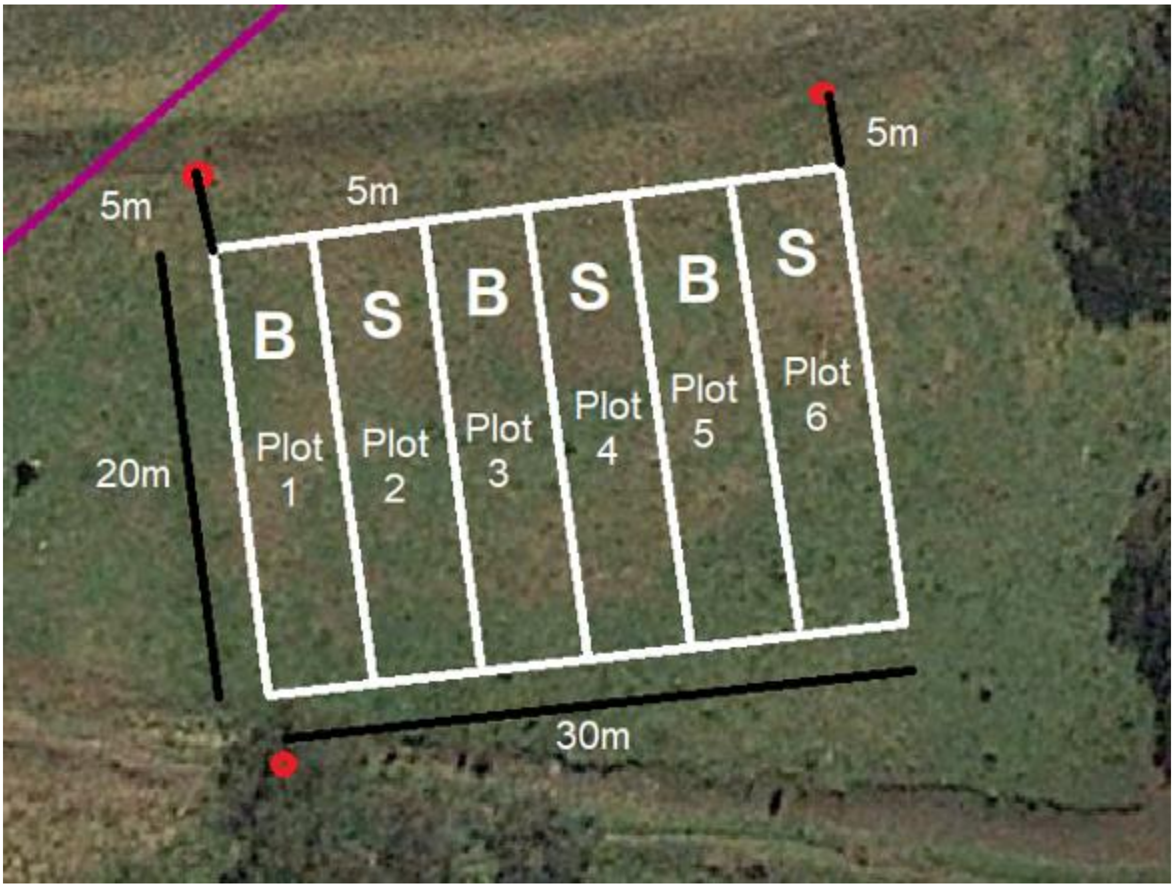


Figure 2. Small plot trial design (B = biomineral / S = Synthetic)

Nutrient applications were equal for nitrogen and phosphorus rates within the small plot trial, the two main nutrients in pasture production. Potassium and Sulphate could not be matched due to fertiliser types used across the trial. Actual application rates were determined from the results of the initial soil testing and adjusted in line with seasonal conditions.

Table 7. Small Plot Trial Site Fertiliser Applications Timing, Rates and Costs per ha

	Date	Biomineral / Synthetic plots	Fertiliser	Application rate		Cost $/ton delivered	Cost/Ha
Autumn 22	5-May-22	Biomineral	Biomineral plus microbes	125	kg/ha	$1,973	$247
	6-May-22	Synthetic	Super potash 5in1	125	kg/ha	$699	$84
	6-May-22	Synthetic	Urea	27	kg/ha	$1,230	$33
Spring 22	6-Aug-22	Biomineral	Slow release N	150	kg/ha	$2,505	$376
	18-Aug-22	Synthetic	Urea	120	kg/ha	$1,230	$148

Summer 23	4-Feb-23	Biomineral	Slow release N	150	kg/ha	$1,973	$296
	4-Feb-23	Synthetic	Urea	120	kg/ha	$1,317	$158
Autumn 23	20-May-23	Biomineral	Biomineral plus microbes	80	kg/ha	$1,570	$126
	20-May-23	Synthetic	Super potash 5in1	80	kg/ha	$699	$56
	20-May-23	Synthetic	Urea	17.5	kg/ha	$1,250	$22
Spring 23	2-Sep-23	Biomineral	Slow release N	125	kg/ha	$1,981	$248
	2-Sep-23	Synthetic	Urea	100	kg/ha	$655	$66
Summer 24	8-Feb-24	Biomineral	Slow release N	125	kg/ha	$2,717	$340
	8-Feb-24	Synthetic	Urea	100	kg/ha	$830	$83
Autumn 24	20-May-23	Biomineral	Biomineral plus microbes	80	kg/ha	$1,570	$126
	20-May-23	Synthetic	Super potash extra 3in1	83	kg/ha	$612	$51
	20-May-23	Synthetic	Urea	18	kg/ha	$830	$15
Spring 24	2-Sep-23	Biomineral	Slow release N	150	kg/ha	$2,796	$419
	2-Sep-23	Synthetic	Urea	120	kg/ha	$693	$83
Summer 25	4-Feb-23	Biomineral	Slow release N	125	kg/ha	$2,767	$346
	4-Feb-23	Synthetic	Urea	100	kg/ha	$882	$88
Total Cost		**Biomineral**					**$2,522**
		Synthetic					**$835**

Table 8. Small Plot Trial Nutrient Application Rates and Timing

	Date	Fertiliser	kg/Ha	N	P	K	S
Fertiliser nutrient units		Biomineral plus microbes (10-7-4.5)		10	7	4.5	4.6
		Biomineral plus microbes (10-6.7-4.4)		10	6.7	4.4	4.5
		Slow release N		37			15
		Super Potash Extra 3:1			6.5	12.4	7.6
		Super Potash 5:1			7	8.4	8.7
		Urea		46			
Biomineral Fertiliser applications	Apr-22	Biomineral plus microbes	125	12.5	8.8	5.6	5.8
	Aug-22	Slow release N	150	55.5			22.5
	Feb-23	Slow release N	150	55.5			22.5
	May-23	Biomineral plus microbes	80	8.0	5.4	3.5	3.6
	Sep-23	Slow release N	125	46.3			18.8
	Feb-24	Slow release N	125	46.3			18.8
	May-24	Biomineral plus microbes	80	10.0	6.7	4.4	4.5
	Aug-24	Slow release N	150	55.5			22.5
	Feb-25	Slow release N	125	46.3			18.8
		Total		**335.8**	**20.8**	**13.5**	**137.6**
Synthetic Fertiliser applications	Apr-22	Super Potash 5:1	125	0.0	8.8	10.5	10.9
		Urea	27	12.4			
	Aug-22	Urea	120	55.2			
	Feb-23	Urea	120	55.2			
	May-23	Super Potash 5:1	80	0.0	5.6	6.7	7.0
		Urea	17.5	8.1			
	Sep-23	Urea	100	46.0			
	Feb-24	Urea	100	46.0			
	May-23	Super Potash 3:1 Extra	83	0.0	5.2	9.9	6.1
		Urea	18	8.3			
	Aug-24	Urea	120	55.2			
	Feb-25	Urea	100	46.0			
		Total		**332.4**	**19.6**	**27.1**	**23.9**

4.4.1.1 Soil and Plant Testing Regime Small Plot Trial

Soil Testing regime for the small plot trial is detailed in Table 9. Soil samples were collected from within each of the 5m x 20m plots with samples taken randomly over the entire plot. Within each plot, twenty soil samples of fixed volume using a soil sampling tube of 4cm in diameter and 50cm deep were collected using random sampling from underneath the pasture stands of annual grasses, legumes and perennials. Samples were taken at 3 depths 0 - 10cm, 10 - 30cm and 30 - 50cm.

Table 9. Field sampling plan for the small plot trial March 2025

Small Plot Trial (SPT) - Bridgetown					
Trial	Fertiliser	Replicate	Depth		
SPT	Synthetic	Replicate 1	0 - 10cm	10 - 30cm	30 - 50cm
SPT	Bio mineral	Replicate 2	0 - 10cm	10 - 30cm	30 - 50cm
SPT	Synthetic	Replicate 3	0 - 10cm	10 - 30cm	30 - 50cm
SPT	Bio mineral	Replicate 4	0 - 10cm	10 - 30cm	30 - 50cm
SPT	Synthetic	Replicate 5	0 - 10cm	10 - 30cm	30 - 50cm
SPT	Bio mineral	Replicate 6	0 - 10cm	10 - 30cm	30 - 50cm

Plant testing in the SPT was conducted twice each season for both biomass and quality, through the following means.
Pasture growth

- 2 pasture cages per plot
- 12 cages in total for small plot trial

Plant nutritional values:

- 1 test per fertiliser regime per sampling time
- 2 testing times each year in line with main trial site times

4.4.2 Producer Demonstration Sites

The three producer demonstration sites were implemented to complement the research component of this project as a comprehensive adoption pathway. The producer demonstration sites involved 3 commercial demonstration sites as a vehicle to enable producers in the Southwest, South Coast and Great Southern regions to build knowledge, awareness and skills.

The three producer demonstration sites were located and carried out for three years in the below districts:

- Bridgetown Boyup Brook region – Great Southern
- Nannup, Scott River region – South Coast
- Harvey, Peel region – Southwest

Each site involved:

- 2 paddocks of similar soil type, side by side.
- 5 – 20 Ha in size
  - 1 treated with synthetic fertilisers
  - 1 treated with biomineral fertilisers
- Both were grazed over winter/spring with the cattle present on property under the standard grazing methods of the individual producers.
- Each PDS was designed to allow for replicated data, albeit with reduced sampling, and generate all the information being captured at the MTS including soil carbon, carbon budgeting, soil health, pasture production.

Soil Testing Regime:

For PDS 1, 2 and 3 soil samples were collected from within 3 randomly placed quadrants of 25m x 25m within each of the 2 paddocks. Within each quadrant, twenty soil samples of fixed volume using a soil corer of 4cm in diameter and 50cm deep were collected using random sampling within each quadrant from underneath the pasture stands of annual grasses, legumes and perennials. For PDS 1 soil samples were taken at 5 depths 0-10cm, 10-20cm, 20-30cm, 30-40cm and 40-50cm (Table 10). For PDS 2 and 3 soil samples were taken at 3 depths 0 10cm, 10 30cm and 30 50cm (Table 11).

Table 10. PDS1 Control Site Soil Testing Regime

Producer Demonstration Site - 1								
Trial	**Fertiliser**	**Replicate**	**Quadrant**			**Depth**		
PDS1	Synthetic	Paddock 1	Quad 1	0-10	10-20	20-30	30-40	40-50
PDS1	Synthetic	Paddock 1	Quad 2	0-10	10-20	20-30	30-40	40-50
PDS1	Synthetic	Paddock 1	Quad 3	0-10	10-20	20-30	30-40	40-50
PDS1	Bio mineral	Paddock 2	Quad 1	0-10	10-20	20-30	30-40	40-50
PDS1	Bio mineral	Paddock 2	Quad 2	0-10	10-20	20-30	30-40	40-50
PDS1	Bio mineral	Paddock 2	Quad 3	0-10	10-20	20-30	30-40	40-50

Table 11. PDS2 & PDS3 Soil Testing Regime

Producer Demonstration Site - 2 and 3						
Trial	**Fertiliser**	**Replicate**	**Quadrant**		**Depth**	
PDS2	Synthetic	Paddock 1	Quadrant 1	0 - 10cm	10 - 30cm	30 - 50cm
PDS2	Synthetic	Paddock 1	Quadrant 2	0 - 10cm	10 - 30cm	30 - 50cm
PDS2	Synthetic	Paddock 1	Quadrant 3	0 - 10cm	10 - 30cm	30 - 50cm
PDS2	Bio mineral	Paddock 2	Quadrant 1	0 - 10cm	10 - 30cm	30 - 50cm
PDS2	Bio mineral	Paddock 2	Quadrant 2	0 - 10cm	10 - 30cm	30 - 50cm
PDS2	Bio mineral	Paddock 2	Quadrant 3	0 - 10cm	10 - 30cm	30 - 50cm

PDS Site Plant Testing:

• Pasture growth:

- 3 pasture cages per treatment
- 6 cages in total per PDS site
- 2 samples measured per pasture cage each testing time
- Growth measured 3 – 4 times each winter/spring depending on seasonal production.

• Plant nutritional values

- 2 tests each site annually
- Pasture growth samples blended during the sampling and then 0.5 kg sent for testing

- Pasture anti-methanogenic properties through in-vitro testing of methane production
  - 2 tests each site annually
  - Pasture growth samples blended during the sampling and then 0.5 kg sent for testing

PDS Fertiliser Application Rates, Timings and Costs per hectare are outlined in the below tables:

Table 12. Producer Demonstration Sites Fertiliser Applications

	Trial	Date	Paddock	Fertiliser	Application rate kg/ha	Cost $/ton del	Cost/Ha
Autumn 22	PDS	5-May-22	Bio	Biomineral + microbes	125	$1,973	$247
	PDS	6-May-22	Syn	Super potash 5in1	120	$699	$84
Spring 22	PDS	6-Aug-22	Bio	Biomineral + microbes	125	$1,973	$247
	PDS	18-Aug-22	Syn	Urea 68%/MoP 32%	100	$1,317	$132
Autumn 23	PDS	20-May-23	Bio	Biomineral + microbes	80	$1,570	$126
	PDS	20-May-23	Syn	Super potash 5in1	120	$699	$84
Spring 23	PDS	2-Sep-23	Bio	Biomineral + microbes	80	$1,570	$126
	PDS	2-Sep-23	Syn	Urea	100	$655	$66
Autumn 24	PDS	20-May-23	Bio	Biomineral + microbes	80	$1,570	$126
	PDS	20-May-23	Syn	Super potash extra 3in1	120	$612	$73
Spring 24	PDS	2-Sep-23	Bio	Biomineral + microbes	80	$1,570	$126
	PDS	2-Sep-23	Syn	Urea	100	$693	$69
Total Cost	**PDS**		**Bio**				**$996**
	PDS		**Syn**				**$508**

Table 13. Nutrient Application for the Producer Demonstration Sites

	Date	Fertiliser	kg/Ha	N	P	K	S
Fertiliser nutrient units		Biomineral + microbes (10-7-4.5)		10	7	4.5	4.6
		Biomineral + microbes (10-6.7-4.4)		10	6.7	4.4	4.5
		Super Potash Extra 3:1			6.5	12.4	7.6
		Super Potash 5:1			7	8.4	8.7
		Urea		46			
		Urea 68%/MoP 32%		31.3		16	
Biomineral Fertiliser applications	May-22	Biomineral + microbes(10-7-4.5)	125	12.5	8.8	5.6	5.8
	Aug-22	Biomineral + microbes (10-7-4.5)	125	12.5	8.8	5.6	5.8
	May-23	Biomineral + microbes (10-6.7-4.4)	80	8.0	5.4	3.5	3.6
	Sep-23	Biomineral + microbes (10-6.7-4.4)	80	8.0	5.4	3.5	3.6
	May-24	Biomineral + microbes (10-6.7-4.4)	80	8.0	5.4	3.5	3.6
	Aug-24	Biomineral + microbes (10-6.7-4.4)	80	8.0	5.4	3.5	3.6
		Total		**57.0**	**38.9**	**25.3**	**25.9**
Synthetic Fertiliser applications	Apr-22	Super Potash 5:1	125	0.0	8.8	10.5	10.9
	Aug-22	Urea	100	46.0			
	May-23	Super Potash 5:1	120		8.4	10.1	10.4
	Sep-23	Urea	100	46.0			
	May-24	Super Potash Extra 3:1	120		7.8	14.9	9.1
	Aug-24	Urea	100	46.0			
		Total		**138.0**	**25.0**	**35.5**	**30.4**

4.4.3 Anti-Methanogenic Methodology

Grab samples of pasture were taken each February from 2023 to 2025, at the main trial site (MTS) and the Small Plot Trial (SPT), and in October 2023 and 2024 from the three producer demonstrations sites (PDS). The samples were taken to the University of Western Australia where they were frozen before freeze-drying and grinding to pass through a 1 mm sieve. Each sample was prepared in triplicate and tested in vitro in a batch rumen culture system using the methods of Durmic et al. (2010), where gas volume (mL/g dry matter (DM)) and concentrations of methane (percentage and mL/g of dry matter) were measured as indirect indicators of plant fermentability. Briefly, in the laboratory, the processed pasture samples were added to rumen inoculum taken from fistulated sheep, buffered with artificial saliva and incubated at 24oC in a closed fermentation system (test tube). After 24 h, accumulated fermentation gas was measured from the headspace using a pressure transducer and a subsample of the gas was taken and analysed by spectrophotometry for methane concentrations. A positive control of oaten chaff substrate and a negative control of no substrate were used as internal standards in the assay.

An advantage of using the closed batch culture system using a mixed rumen microbial community is that it is a rapid and relatively cost effect way to undertake an initial screening of many samples. A disadvantage is that in a closed system the end-products of the microbial fermentation accumulate, leading to an altered microbial community. Data generated from this assay are indicative only but are a useful starting point for more rigorous testing (Durmic et al., 2025).

For the MTS and the SPT, Genstat outputs were generated using analysis of variance where fertiliser treatment, Biomineral or Synthetic, was the factor and fermentability and methane were variates within each sampling date.

5. Results

5.1 Soil Testing Results

5.1.0 Soil Carbon and Nitrogen analysis

At the MTS and SPT baseline soil carbon and nitrogen in the top 10 cm were at the upper level of expectations for agricultural soils of Western Australia (Zhao et al. 2024).

For the analyses of the change in total soil carbon and nitrogen from 2022 to 2025 for the MTS at each of the five soil depths, there were no significant differences for Biomineral or Synthetic fertiliser treatments (Table 14 & 15). Soil nitrogen and carbon tended to increase at all depths over time and for both fertiliser treatments, but the changes were not significant. In 2022 most of the soil nitrogen (~87%) and carbon (~72%) was held in the top 0 to 10cm of soil and these percentages tended not change over time.

Table 14. The effect of a Biomineral or a Synthetic fertiliser on soil carbon change ($P<0.05$) from 2022 to 2025 from soil samples taken at five depths at the Main Trial Site

Fertiliser	Depth	Soil Carbon (%)				
	(cm)	2022	2025	Change	S.E.	F pr.
Biomineral	0-10	5.31	6.81	1.5	0.63	0.74
Synthetic		5.99	7.77	1.78	0.51	
Biomineral	10-20	1.79	1.87	0.08	0.08	0.35
Synthetic		2.31	2.22	-0.09	0.14	
Biomineral	20-30	0.87	0.84	-0.03	0.09	0.96
Synthetic		0.96	0.94	-0.02	0.18	
Biomineral	30-40	0.56	0.61	0.05	0.06	0.77
Synthetic		0.62	0.71	0.09	0.12	
Biomineral	40-50	0.44	0.48	0.04	0.06	0.84
Synthetic		0.53	0.58	0.05	0.02	

Table 15. The effect of a Biomineral or a Synthetic fertiliser on soil nitrogen change (P<0.05) from 2022 to 2025 from soil samples taken at five depths at the Main Trial Site

Fertiliser	Depth	Soil Nitrogen (%)				
	(cm)	2022	2025	Change	S.E.	F pr.
Biomineral	0-10	0.42	0.52	0.1	0.028	0.71
Synthetic		0.54	0.62	0.08	0.05	
Biomineral	10-20	0.11	0.12	0.01	0.006	0.22
Synthetic		0.15	0.15	0.002	0.006	
Biomineral	20-30	0.05	0.06	0.01	0.002	0.95
Synthetic		0.06	0.07	0.01	0.012	
Biomineral	30-40	0.03	0.04	0.01	0.005	0.62
Synthetic		0.04	0.06	0.02	0.007	
Biomineral	40-50	0.03	0.04	0.01	0.002	0.11
Synthetic		0.03	0.05	0.02	0.001	

For the analyses of the change in total soil carbon and nitrogen from 2022 to 2025 for the SPT at each of the three soil depths, there were no significant changes for Biomineral or Synthetic fertiliser treatments (Table 16 & 17).

Table 16. The effect of a Biomineral or a Synthetic fertiliser on total soil carbon change (P<0.05) from 2022 to 2025 from soil samples taken at three depths at the Small Plot Trial

	Depth	*Soil Carbon (%)*				
	(cm)	*2022*	*2025*	*Change*	*S.E.*	*F pr.*
Biomineral	0-10	7.01	7.57	0.56	0.91	0.87
Synthetic		6.39	6.7	0.31	1.18	
Biomineral	Oct-30	1.25	2.03	0.78	0.39	0.26
Synthetic		1.31	1.54	0.23	0.15	
Biomineral	30-50	0.77	0.75	-0.02	0.47	0.93
Synthetic		0.63	0.66	0.03	0.26	

Table 17. The effect of a Biomineral or a Synthetic fertiliser on total soil nitrogen change (P<0.05) from 2022 to 2025 from soil samples taken at three depths at the Small Plot Trial

	Depth	*Soil Nitrogen (%)*				
	(cm)	*2022*	*2025*	*Change*	*S.E.*	*F pr.*
Biomineral	0-10	0.56	0.61	0.05	0.07	0.95
Synthetic		0.52	0.56	0.04	0.08	
Biomineral	Oct-30	0.08	0.13	0.05	0.02	0.23
Synthetic		0.08	0.1	0.02	0.01	
Biomineral	30-50	0.04	0.05	0.01	0.02	0.77
Synthetic		0.04	0.05	0.01	0.01	

5.1.1 Soil Health Analysis

At the MTS and SPT baseline Microbial Biomass Carbon (MBC), Microbial Biomass Nitrogen (MBN) and Dissolved Organic Carbon (DOC) in the top 10 cm were indicative of healthy soil (Table 18, 19 & 20). All soil health indicators related to microbial activity in the top 10 cm remained at healthy levels throughout the experiment.

For the analyses of the change in MBC, MBC and DOC from 2022 to 2025 for the MTS at each of the three soil depths, there were no significant differences for Biomineral or Synthetic fertiliser treatments. The MBC tended to decrease from 2022 to 2025 at each of the three soil depths.

Table 18. The change in Microbial Biomass Carbon (MBC) (P<0.05) from either a Biomineral or an Synthetic fertiliser from 2022 to 2025 from soil samples taken at three depths at the Main Trial Site

Fertiliser	*Depth (cm)*	*Microbial Biomass Carbon (mg/Kg)*				
		2022	*2025*	*Change*	*S.E.*	*F pr.*
Biomineral	0-10	724	694	-30	42.9	0.15
Synthetic		854	617	-237	132.8	
Biomineral	Oct-20	167	107	-60	25	0.35
Synthetic		135	116	-19	46.6	
Biomineral	20-30	73	46	-27	22.4	0.59
Synthetic		68	56	-12	14.2	

Table 19. The change in Microbial Biomass Nitrogen (MBN) (P<0.05) from either a Biomineral or an Synthetic fertiliser from 2022 to 2025 from soil samples taken at three depths at the Main Trial Site

Fertiliser	*Depth (cm)*	*Microbial Biomass Nitrogen (mg/Kg)*				
		2022	*2025*	*Change*	*S.E.*	*F pr.*
Biomineral	0-10	48	53	5	3.3	0.23
Synthetic		50	49	-1	5.2	
Biomineral	10-20	12	7	-5	1.4	0.31
Synthetic		10	8	-2	3.5	
Biomineral	20-30	5	3	-2	1.5	0.54
Synthetic		5	4	-1	1.1	

Table 20. The change in Dissolved Organic Carbon (DOC) (P<0.05) from either a Biomineral or an Synthetic fertiliser from 2022 to 2025 from soil samples taken at three depths at the Main Trial Site

Fertiliser	*Depth (cm)*	*Dissolved Organic Carbon (mg/Kg)*				
		2022	*2025*	*Change*	*S.E.*	*F pr.*
Biomineral	0-10	70	77	7	9	0.52
Synthetic		86	90	4	9.8	

Biomineral	10-20	47	45	-2	4.5	0.35
Synthetic		54	41	-13	4.2	
Biomineral	20-30	33	43	10	5.4	1
Synthetic		36	30	-6	3.8	

At the SPT at soil depth of 0-10 cm, MBC and MBN increased for Biomineral but decreased for Synthetic (P<0.05) from 2022 to 2025 (Table 21, 22 & 23). At depth 30-50 cm, DOC increased for Synthetic but decreased for Biomineral (P<0.05). It is noted that quadrat measurements were not genuine replication and there were some significant soil health differences between treatment plots at the pre-trial stage in 2022.

Table 21. The effect of a Biomineral or a Synthetic fertiliser on change (P<0.05) in Microbial Biomass Carbon (MBC) from soil samples taken at three depths at the Small Plot Trial from 2022 to 2025

Fertiliser	*Depth*	*Microbial Biomass Carbon (mg/Kg)*				
	(cm)	*2022*	*2025*	*Change*	*S.E.*	*F pr.*
Biomineral	0-10	451	776	325	39	0.009
Synthetic		873	545	-292	130	
Biomineral	20-30	56	70	14	11	0.13
Synthetic		75	65	-10	6.2	
Biomineral	30-50	42	44	2	4.6	0.1
Synthetic		34	48	14	3.1	

Table 22. The effect of a Biomineral or a Synthetic fertiliser on change (P<0.05) in Microbial Biomass Nitrogen (MBN) from soil samples taken at three depths at the Small Plot Trial from 2022 to 2025

Fertiliser	*Depth*	*Microbial Biomass Nitrogen (mg/Kg)*				
	(cm)	*2022*	*2025*	*Change*	*S.E.*	*F pr.*
Biomineral	0-10	32	62	30	3.6	0.01
Synthetic		55	45	-10	8.7	
Biomineral	10-30	4	4	0	1	0.28
Synthetic		5	4	-1	0.6	
Biomineral	30-50	3	3	0	0.5	0.31
Synthetic		2	3	1	0.4	

Table 23. The effect of a Biomineral or a Synthetic fertiliser on change (P<0.05) in Dissolved Organic Carbon (DOC) from soil samples taken at three depths at the Small Plot Trial from 2022 to 2025

Fertiliser	*Depth*	*Dissolved Organic Carbon (mg/Kg)*				
	(cm)	*2022*	*2025*	*Change*	*S.E.*	*F pr.*
Biomineral	0-10	81	79	-2	6.4	0.18
Synthetic		67	67	0	3.4	

Biomineral	10-30	36	54	18	11	0.59
Synthetic		33	44	11	3.5	
Biomineral	30-50	47	37	-10	2.4	0.004
Synthetic		25	36	11	2.8	

5.1.2 Soil Chemistry Analysis

Soil chemistry interpretations were completed for both the MTS and the SPT. At the MTS, soil pH was adequate for pasture productivity throughout the trial. Soil pH measured in $CaCl_2$ ranged from 5.55 to 5.26 from surface to 50 cm depth in 2022 and tended to increase over time, although, the changes were not significant overall or between treatments. At the SPT, soil pH was adequate for pasture productivity throughout the trial and there were no significant changes over time or differences between treatment groups ($P<0.05$).

At the MTS and SPT, there were slight traces of salinity from surface to 50 cm depth when baseline measurements were taken in 2022 (DPIRD, 2025). There was no significant change in salinity from surface to 50 cm depth from 2022 to 2025 in either treatment.

In 2022, at the MTS and SPT, all the macro-and micro-nutrients were available in the surface soil and at lower depths except Al, Ca and Mg. (Z. Solaiman, personal communication, 2025). There was a small proportion of significant changes at both sites. At the MTS: S at 10 to 20 cm and 40 to 50 cm; Fe at 0 to 10 cm; and Mn at 10 to 20 cm and 20 to 30 cm.

5.2 Change in soil carbon and chemistry discussion

The project investigated the potential of a Biomineral fertiliser to microbially enhance the rhizosphere and increase the sequestration of soil carbon. A commercial fertiliser treatment (Synthetic) was included in the study as a reference point for the effect of standard practice fertiliser management on soil health and carbon sequestration. We observed the effects of the fertilisers on total soil nitrogen and carbon, microbial mass of carbon and nitrogen, dissolved organic carbon and soil macro and micro-nutrients. At the Main Trial Site, we found no treatment effect and so reject the hypotheses that the Biomineral treatment would improve soil health and the sequestration soil carbon.

However, at the Small Plot Trial, there were two significant findings that warrant discussion. First, microbial biomass carbon and nitrogen increased over time with the Biomineral treatment. The changes were found in the top ten cm of soil and suggest some efficacy of the Biomineral fertilisers for enhancing microbial activity in the rhizosphere and giving rise to the potential for the stimulation of enhanced nutrient cycling. Second, converse to expectations, dissolved organic carbon at 30-50cm increased over time in the Synthetic treatment. There remains a level of uncertainty around these observations that might have been alleviated with more sample replication within plots. The disparity between observations at the Main Trial Site and the Small Plot Trial places further uncertainty over any efficacy from the Biomineral treatment.

Overall, there was no evidence supporting our expectation that the Biomineral fertilisers would increase soil carbon and nitrogen accumulation lower into the soil profile through enhanced microbial activity. An important aim for the project was to observe the building of carbon lower in the soil profile though the extension of root systems and improved pasture resilience. Leaf and stem dry mass has a positive and linear relationship with root dry mass (Atwell et al., 1999). Surface water can be depleted by evaporation and extraction by roots and can leave deep soil layers with higher moisture levels. As root systems become more extensive, they have greater capacity for accessing soil moisture and nutrients, growing more above ground biomass and sequestering more carbon. The finding, that the Biomineral treatment did not increase carbon and nitrogen in the depleted lower soil depths, places further doubt on the Biomineral efficacy (Tables 14 – 17).

A potential limitation of the study was that significant accumulation of soil carbon and nitrogen is likely to be over a longer period than allowed for in this study. It has been documented that improving soil carbon and nitrogen by changing soil use and management practice is a slow process that can only be evaluated with long-term experiments of over twenty years (Körschens, 2006; Rasmussen et al., 1998). In a Swiss conventional farming system, over thirty-seven years, Maltas et al., (2018) observed that, with the addition or organic carbon to the soil, there was a gradual increase in soil organic carbon that eventually became significant. If we accept the importance of long-term studies, we should consider that there was also a tendency at the Main Trial site for the accumulation of total soil carbon and nitrogen throughout the soil profile in both treatment groups. It becomes apparent, the need to commit to long-term and rigorous field studies to fully understand soil management effects.

There were several influences that may have contributed to the lack of measured effect from the Biomineral fertiliser at the Main Trial Site. It is probable that the topsoil at the main trial site had reached a "steady state" of soil organic carbon prior to the commencement of the study and the potential to increase this pool was limited. According to Chan et al., (2011) improved soil nutrition and grazing of permanent pasture over a long-term leads to a steady state of soil organic carbon. Of particular relevance was the effect of a healthy surface soil on establishing productive perennial grasses prior to the experiment and the positive effect of the established pasture on soil carbon sequestration. The average stored carbon in the top 10 cm at the Main Trial Site was around 6.9%, which is higher than most agricultural soils in Western Australia (0.7 to 4.2%) (Zhao et al., 2024). Further analysis of the soil showed that pH, salinity and macro- and micronutrients at the Main Trial Site and Small Plot Trial were indicative of soils that were not limiting to optimum pasture performance. Salinity was classified as slight in 2022 and increased in both treatments from 2022 to 2025 but remained in the "slightly saline" category (DPIRD 2025). The increase was likely caused by dry summers in 2024 and 2025 where there was less flushing of salt through the soil profile. Irrigation water contained low levels of salt that likely accumulated in the soil profile.

There was a small proportion of significant differences in soil chemical components (5 out of 70 for the Main Trial Site and 2 out of 36 for the Small Plot Trial) but the differences were in line with false significance rates expected with a large number of statistical tests. Using $P<0.05$ as an expected error rate would imply false positive significance in 4 out of 70 tests for Main Trial Site and 2 out of 36 tests at the Small Plot trial. The conclusion was that a long history of good soil nutrition prior to the experiment provided for optimum pasture production and soil carbon sequestration in the top 10 cm of soil where changes due to treatments would have been difficult to quantify.

The pasture, which was described as perennial grasses (dominated by kikuyu) and legumes, had been maintained for at least forty years under irrigation. This is unusual for southwest Western Australia where annual grass and legume pastures are typically grown under dryland conditions. Perennial pastures are known to have a greater potential to sequester carbon than annual grass and legume pastures (Pauli et al., 2018). Of the perennial grasses, Kikuyu, a C4 subtropical pasture species grown in temperate regions, is known to have the highest potential to sequester carbon close to the surface and lower into the soil profile, due to its persistent and extensive root system

(Thomas et al., 2012; Sanderman et al., 2013). High levels of microbial biomass carbon in the surface soil at both sites was further evidence that soil health was already at optimum levels prior to the experiment. In work by Gogoi et al., (2010), a bio-fertiliser increased microbial biomass carbon from 47.3 mg/Kg of soil in the control to 136.2 mg/Kg, which was a 55% higher than the effect of a synthetic fertiliser. In the current experiment, microbial biomass carbon was higher than any of the Gogoi et al., (2010) values at pre-trial (range from 451 to 873 mg/Kg). The positive influence of a long-term, perennial kikuyu pasture on carbon sequestration and soil health was likely to have masked any treatment effect.

Low soil moisture and relatively high phosphorus levels might have influenced the flow of microbial biomass and the limited rate of carbon sequestration to depths below ten cm. Dissolved organic carbon did increase for both fertiliser regimes between 10 – 30cm in the small plot trial. Rainfall is known to be the limiting factor for microbial biomass in southern Australia (Soil Quality, 2025). As a result of the droughts experienced in 2022 and 2023, low availability of water for irrigation impacted negatively on pasture growth and in turn feed quality. The microbial biomass of carbon tended to decrease from 2022 to 2025 at each of the three soil depths and this is likely due to fluctuations in microbial activity in the low-moisture soils. Tshewang et al (2022) found that, in a glasshouse experiment, a microbial consortium inoculant in a low Phosphorus (3 mg/Kg) sandy soil, maintained at 70% moisture significantly improved the shoot and root biomass of perennial pasture grasses, relative to the unamended control, although soil carbon and soil health were not measured. In the current study, Phosphorus levels were higher, ranging from 37 to 40 mg/Kg in the top 10 cm and soil moisture would almost certainly have fallen below 70% during the dry summer months.

A key aspect of the study was the differences in nutrient composition between the two treatments. Specifically, the Biomineral treatment relied on improved soil health and carbon sequestration through enhanced microbial activity rather than the direct addition of nitrogen and potassium to the soil. At the Main Trail Site, the Synthetic fertilised soils received forty percent more nitrogen than the Biomineral soils over the three-year trial, due to differences in fertiliser compositions. Despite the imbalance of fertiliser nutrients there was no difference between treatments for the change in soil carbon, nitrogen, soil health and fertility. Further to this, the project found no significant difference in pasture production between the two treatments. This implies an efficiency from the Biomineral treatment of more dry matter production and sequestered carbon and nitrogen per unit of nitrogen input than the Synthetic treatment. Potentially, the efficiency was twofold. First, the slow-release of nitrogen from the Sulphur-coated fertiliser most likely resulted in less nitrogen leaching from the system than the plots fertilised with urea and second, the microbial activity in the inoculated Biomineral soil was proportionally, greater. These findings pose questions for potential environmental and economic benefits from the use of Biomineral fertilisers.

Microbial biomass is a measure of the carbon and nitrogen present in the living components of soil. Although microbial biomass accounts for only a small fraction of total soil carbon and nitrogen, it is essential for nutrient cycling and carbon flow. In a study by Zhao et al., (2024), the microbial biomass of carbon in garden beds with added compost was higher than in control plots, indicating a higher rate of soil microbial activity and a healthier soil. However, in the current study, no organic carbon added to the soil. Organic carbon in the form of manures would have increased the organic substrate source for the Biomineral microbes and increased soil microbial biomass and the pool of total soil carbon. However, adding this variable to the experimental design would have been counterproductive to the hypothesis being tested in this project, which was to assess the ability of two different fertiliser regimes to sequester carbon in the soil, not simply add it to the soil.

5.3 Adoption Outcomes

The project drew a large amount of interest from producers and the general industry with strong interest shown from growers in methods to reduce their carbon footprint and a keen interest in wanting to better understand their emissions profile. Across the group of producers surveyed a wide range of alternative fertilisers were already being trialled, including biomineral fertilisers. This project was able to deliver producers an independent analysis of the production outcomes of an alternative fertiliser away from the traditional synthetic fertilisers. The outcomes form this project do not recommend a practice change to biomineral fertilisers, instead project learnings have allowed people to better assess alternative and traditional fertiliser options and enact change appropriately.

68 core and observer producers completed the entry survey. The full data set from the entry survey are in appendix 16 with the summary of their production data below:

- **291,139 Total hectares managed.**
- **25,235 Total cattle managed.**
- **153,277 Total sheep managed.**

72 core and observer producers completed the exit survey. The full data set from the entry survey are in appendix 14 & 15 with the summary of their production data below:

- **178,706 Total hectares managed.**
- **30,426 Total cattle managed.**
- **148,244 Total sheep managed.**

5.3.0 70% of all core and observer producers increase their knowledge around biomineral fertilisers, soil carbon, strategies to increase it and carbon accounting by 60%.

Through the extension component of the project considerable work was conducted to increase producer knowledge. The results from the exit survey for the questions covering the change in knowledge are outlined below.

The survey assessed farmers' beliefs about the importance of achieving carbon neutrality with 41.67% believing it is extremely important to work towards carbon neutrality. The survey gauged interest in learning about soil carbon and its implications with 74.32% expressed a desire to learn more about soil carbon and carbon accounting. The survey explored respondents' understanding of soil carbon and its effects on farming, with 54.67% understanding they can actively improve soil carbon through farming techniques. The survey identified perceived productivity benefits of soil carbon with 86.49% believe soil carbon increases water holding capacity.

Results from the exit survey show 61 of 74 or 82.43% of the participants increased their knowledge rating between the start and the end of the project, well above the targeted 70%. However, the soil carbon knowledge rating from producers was at 5.62 at the start of the project increasing to 7.20 at the project completion resulting in an increase in producer knowledge of 28.1% well below to targeted 60%.

The project was unable to achieve both of the first extension objective, for 70% of participating producers knowledge in understanding of soil carbon, strategies to improve it and carbon accounting to increase by 60%.

Changes in Understanding of Soil Carbon
The survey measured changes in understanding of soil carbon before and after the project.

- Before the project, the average understanding was rated at 5.62 out of 10.
- After the project, the average understanding improved to 7.20 out of 10.

Attitudes Towards Carbon Neutrality
The entry survey assessed farmers' beliefs about the importance of achieving carbon neutrality.

- 36.76% believe it is extremely important to work towards carbon neutrality

The exit survey results for these questions were as follows:

- 41.67% believe it is extremely important to work towards carbon neutrality.
    - An increase of 13.35% across the duration of the project
- 25.00% think it is important but not realistic with current technology.
- 20.83% believe it is important only if production and profitability are maintained.
- 11.11% feel it is not up to individual farmers but rather a collective responsibility.

Interest in Soil Carbon Education
The entry survey gauged interest in learning about soil carbon and its implications.

- 58.82% expressed a desire to learn more about soil carbon and carbon accounting.

The exit survey gauged interest in learning about soil carbon and its implications.

- 74.32% expressed a desire to learn more about soil carbon and carbon accounting.
    - An increase of 15.50% across the duration of the project
- 10.81% are interested but lack the time to learn.
- 8.11% want to learn in alternative formats rather than traditional workshops.

Understanding of Soil Carbon Impact
The entry survey explored respondents' understanding of soil carbon and its effects on farming.

- 47.06% Yes, I know what they are and am actively improving soil carbon through farming techniques.
- 17.65% know about soil carbon but lack strategies to improve it.
- 23.53% are interested in learning more about soil organic carbon and organic matter levels.

The exit survey explored respondents' understanding of soil carbon and its effects on farming.

- 54.67% Yes, I know what they are and am actively improve soil carbon through farming techniques.
- 21.33% know about soil carbon but lack strategies to improve it.
- 13.33% are interested in learning more about soil organic carbon and organic matter levels.

Perceived Benefits of Soil Carbon
The entry survey identified perceived productivity benefits of soil carbon.

- 80.00% believe soil carbon increases water holding capacity.
- 92.31% also think it enhances nutrient cycling and cation exchange capacity.
- 20.00% feel it reduces parasite loads.

The exit survey identified perceived productivity benefits of soil carbon.

- 86.49% believe soil carbon increases water holding capacity.
- 93.24% also think it enhances nutrient cycling and cation exchange capacity.
- 47.30% feel it reduces parasite loads.

5.3.1 75% of livestock producers to consider the importance of implementing production systems changes to reduce operational greenhouse gas emissions within their operation.

The exit survey results covered the extension objective for producers considering a production system change. From the exit surveys 86.77% have demonstrated a willingness to change fertiliser practices and 64.29% are considering a change in fertiliser practices. The difference between a *willingness to change* and *considering a change* is in the likelihood of change. A producer who is willing to change will change when the right product is demonstrated while a producer who is considering change will take more time to change and potentially watch the new product for a period before changing. The average of these two results is 75.53%, demonstrating the project has achieved the second primary extension objective of over 75%.

There was a large increase in the number of producers surveyed who are considering a change to biomineral fertilisers despite the projects results. The driver for this is a large number of smaller producers with a desire to shift away from synthetic fertilisers, who were encouraged by the production results and where decisions are influenced more heavily by non-economic factors.

Consideration of Changes to Fertiliser Regime – entry survey

The survey explored specific changes respondents are considering for their fertiliser regime.

- 13.56% are considering switching to biomineral fertilisers.
- 33.90% are considering changing but have not decided on a specific type.
- 47.46% are not considering any changes.

Consideration of Changes to Fertiliser Regime – exit survey

The survey explored specific changes respondents are considering for their fertiliser regime.

- 22.86% are considering switching to biomineral fertilisers.
    - An increase of 9.30% across the duration of the project
- 34.29% are considering changing but have not decided on a specific type.
- 7.14% are considering changing that isn't a biomineral fertiliser
- 35.71% are not considering any changes.

Fertiliser Usage and Practices

The survey examined current fertiliser usage among respondents.

- 58.73% use synthetic fertilisers often, while 20.63% use them sometimes.
- 20.51% use biomineral fertilisers often, and 25.64% use them sometimes.
- 19.44% use organic fertilisers often, with 36.11% using them sometimes.

Willingness to Shift Fertiliser Practices

The survey assessed the likelihood of changing fertiliser practices.

- 29.41% are very likely to shift away from synthetic fertilisers.
- 41.18% are likely to make the change.
- 16.18% are possibly considering a shift.

Future Changes to Increase Soil Carbon

The entry survey results on intentions to increase soil carbon sequestration.

- 32.26% are considering changes to increase soil carbon.

- 41.94% are unsure about making changes.
- 25.81% are not considering any changes.

The exit survey investigated intentions to increase soil carbon sequestration.

- 43.06% are considering changes to increase soil carbon.
- 30.56% are unsure about making changes.
- 26.39% are not considering any changes.

5.3.2 75% of core producers (minimum 10) to have trialled or started the process to implement a new fertiliser regime.

There were 10 core producers involved in the project who assisted in structuring the best practice fertiliser regimes across the main trial site and the 3 Producer Demonstration Sites. Of the 10 core producers 7 have trialled the process of implementing a new fertiliser regime using biomineral fertilisers over selected areas of their property during the 3-year timeframe of the project.

The other 3 core producers have been closely following the results and would have implemented a new fertiliser regime had the results shown a positive benefit cost analysis, however due to the results they are continuing to monitor the outcome of future work around biomineral fertilisers and the impact of any potential requirements for producers to account for carbon emissions.

The core producers were actively engaged and willing to change their fertiliser practices had the results demonstrated an economic return equivalent to the synthetic fertilisers.

The project was unable to achieve the 3rd extension outcome of over 75% of the core producers trialling or to be in the process of implementing a new fertilise regime.

5.3.3 40% of observer producers (minimum 60) to have trialled or started the process to implement a new fertiliser regime.

There were 60 observer producers for the project again with the majority located across the South West of Western Australia and throughout the greater agricultural region of WA. From the exit survey results there is a strong willingness to move away from synthetic fertilisers with biomineral fertilisers being one of the key alternatives for the change.

- 37.93% of entry producers surveyed use biomineral/organic fertiliser often.
- 39.95% of exit producers use biomineral/organic fertiliser (proxy for implementing a new fertiliser regime). The project was unable to achieve the 4th extension outcome.

From the survey results the high portion of alternative fertilisers was not due to the outcomes of the project but demonstrates producers' willingness to use or try alternative types of fertiliser away from synthetic fertilisers despite the lack of proven outcomes.

While farm production levels were maintained during the process of changing from synthetic to biomineral fertilisers, the negative benefit cost analysis of the biomineral fertiliser regime compared to the synthetic regime has likely impacted the observer producer's willingness to consider a biomineral fertiliser regime. The interest from producers in exploring alternative fertilisers remains high, the majority are however choosing to observe the results for a further period before committing to a change.

From the project it is not expected or advised a practice change to biomineral fertilisers given project results. However, part of the project learnings has informed and allowed people to better assess alternative and traditional fertiliser options and then use this information to enact change appropriately.

Fertiliser Usage and Practices

The survey examined current fertiliser usage among respondents.

- 58.73% use synthetic fertilisers often, while 20.63% use them sometimes.
- 20.51% use biomineral fertilisers often, and 25.64% use them sometimes.
- 19.44% use organic fertilisers often, with 36.11% using them sometimes.

Willingness to Shift Fertiliser Practices

The survey assessed the likelihood of changing fertiliser practices.

- 35.85% are very likely to shift away from synthetic fertilisers.
- 28.30% are likely to make the change.
- 24.53% are possibly considering a shift.

Consideration of Changes to Fertiliser Regime

The survey explored specific changes respondents are considering for their fertiliser regime.

- 22.86% are considering switching to biomineral fertilisers.
- 34.29% are considering changing but have not decided on a specific type.
- 35.71% are not considering any changes.

5.3.4 Summary of all the adoption/extension work delivered

Over the 3 years the project ran a large component of the work involved adoption and extension. Given the results from the project a change in practice isn't expected or advised. However, the project outcomes and learnings have enabled people or producers to assess alternative and traditional fertiliser in more detail and enact change appropriately. Additionally, significant value has been realised in extending broader soil health principles and management practices, as well as understanding emissions accounting and reductions. Below is a summary of all the adoption/extension work delivered.

Field Days/workshops/Field walks delivered during the project:

12 field days/workshops/field walks were delivered during the project period. The days were held across a wide area from Albany to Benger to Toodyay and Scott River. A total of 405 participants attended the field days to give an average of nearly 34 per event.

A range of topics were covered across the 12 field days and workshops although all topics were relevant to subject of soil health, soil carbon, fertilisers and producers' journeys with alternative fertiliser uses and results. A summary of speaker topics covered at the days are listed below:

- Milyeanup Farm journey to Alternate Fertilisers and soil health
- Alternative fertilisers to Synthetics
- Improving Soil Health
- Soil Carbon Project – Biomineral vs Synthetic Fertilisers

- Humates and its effect on soil
- Managing low pasture growth in winter pasture
- Fertiliser strategies what/when/where/how
- Mineral balances and foliar recipes based around natural plant hormones like Gibberellic acid
- Nitrogen & essential trace minerals in the coldest time of year

The standout topics which really created interest from producers were around the alternative fertilisers and how they targeted to work with the plant's growth mechanisms like humates and gibberellic acid to encourage stronger and more active growth independent of simply providing synthetic nutrients to meet plant growth requirements. Additionally, there was always strong interest received across producers on topics covering soil carbon, carbon neutrality and strategies to reduce carbon emissions given how relevant and topical this issue is to many producers.

Table 24 summaries the number of producers, their hectares farmed along with the number of livestock of the attendees to a sample of the field days held over the life of the project. The satisfaction scores and value ratings demonstrate the success of the days held and the timeliness of the project in the current environment. The survey results also demonstrate the high intent to change and benefit of the field days and workshops to the high knowledge and skills acquisition increase.

Table 24. Attendee's satisfaction and knowledge changes summary from field days and workshops held over the life of the project

Year	Activity	Ha's	Cattle	Sheep	Producers	Advisors	Satisfaction score (out of 10)	Value rating (out of 10)	Intent to change %	Knowledge and skills acquisition increase %
2022	3x Field days, 1 workshop	8,200	5,266	15,265	24	14	9	8.5	23%	45%
2023	Observer Producers, Bridgetown Field Day	20,387		20,189	54		8.1	9		
2024	Toodyay, Bridgetown, Albany, Palgarup workshops				60		8.9			
	Total	28,587	5,266	35,454	138	14				
	Average	366.5	219	455			8.67	8.75	23%	45%

9 articles were published across the project as listed below:

- Article 1: Can biomineral fertilisers improve soil carbon sequestration
- Article 2: Who, where and how do I start implementing a new fertiliser regime
- Article 3: Fertiliser Impact on Soil Carbon Project - Results from Baseline Testing
- Article 4: How do I start implementing a new fertiliser regime
- Article 5: Soil constraints - management strategies when looking to sequester soil carbon
- Article 6: Impacting soil microbial activity and the potential long-term effect of Soil Carbon
- Article 7: Soil carbon cycling and the forms of stored soil carbon
- Article 8: The importance of pasture quality for grazing cattle and the impact GHG Emissions
- Article 9: Understand your soil's potential for sequestering carbon

Articles are available on t <link future food page>.

Electronic articles and E-news communications

Through the grower group Future Food Network a large number of Electronic articles and E-news communications were delivered through the various formats, reaching the high number of followers detailed below:

Electronic Direct Mail

- 944 recipients for each communication
- Over 50 E-news communications were sent during project period

Facebook/168 followers – **Instagram**/1022 followers - **LinkedIn**/617 followers

YouTube

- Youtube videos were released during the project with examples including:
  - Soil Carbon Project – Virtual Field Walk – Bridgetown
  - Soil Carbon Project Bridgetown Site Overview
  - Soil Carbon Project – Soil Sampling Strategy Video

5.4 Pasture Production

5.4.0 Main Trial Site Pasture Growth

The main trial site pasture production trial was carried out each summer and autumn during the project. The pasture growth was measured through the use of pasture cages 900mm x 900mm placed within each of the main trial site replicates with growth measurements recorded 3 times each season.

A summary of the main trial site pasture growth results is detailed below in table 24.

Table 26. Main trial site pasture growth for the 3 years of the project

Year	Treatment	Total (tons DM)	Start Date	Finish Date	Days	Daily growth (kg/day)
2023	Biomineral	13.80	17/1/23	22/4/23	95	145.3
2023	Synthetic	15.08	17/1/23	22/4/23	95	158.7
2024	Biomineral	7.93	30/12/23	29/3/24	90	88.2
2024	Synthetic	7.33	30/12/23	29/3/24	90	81.5

2025	Biomineral	8.88	30/12/24	29/3/25	89	99.8
2025	Synthetic	8.49	30/12/24	29/3/25	89	95.4
Average	Biomineral	10.21			91	111.07
Average	Synthetic	10.30			91	111.87

While the outright growth rate of the pasture is a function of irrigation water availability, the difference in growth rate between the two treatments is a result of the fertiliser applied. There was no significant difference between the two treatments. The synthetic fertiliser treatment had the highest daily growth rate in 2023 and the biomineral fertiliser treatment had the slightly higher growth rate in 2024 and 2025.

The very similar growth rates between the two treatments gives confidence in the production potential of the biomineral fertiliser compared to the synthetic fertiliser, in that pasture production will be maintained across the initial three years of the change in fertiliser strategy. This is notable in the context of relative nutrient rates applied between treatments, where 37 kg/ha/year more N was applied per ha to the synthetic treatments then the biomineral treatments (see table 4).

5.4.1 Main Trial Site Feed Quality

Feed quality measurements were recorded in the main trial site each summer at the same time the cattle production trial was being carried out. One of the hypotheses being tested was that the biomineral fertiliser would improve the nutrient density of the pasture as the project progressed which would be demonstrated in the feed quality.

The feed quality results from the synthetic fertiliser pasture samples were consistently higher throughout the trial, with both crude protein and metabolizable energy slightly higher than the samples from the biomineral plots, as seen in table 25 and 26.

There was no clear pattern from the feed quality tests results to quantify that by applying a biomineral fertiliser the nutrient density of the pasture will increase or improve. Table 27 shows the average of each of all the feed quality parameters tested and highlights the minor and variable differences between the different fertiliser types.

Only the Neutral Detergent Fibre results from the biomineral samples were consistently higher than the synthetic fertiliser samples.

Table 27. Feed quality results from 2023 samples for the main trial site

		MTS Biomineral Feb-23	MTS Synthetic Feb-23	MTS Biomineral Apr-23	MTS Synthetic Apr-23
Dry Matter	%	24.4	20.5	14.3	20.5
Moisture	%	75.6	79.5	85.7	79.5
Crude Protein	% of DM	12.1	14.2	10.6	11.9
Acid Detergent Fibre	% of DM	28.5	28.2	28.9	28.2
Neutral Detergent Fibre	% of DM	63.9	62.6	64.8	62.8
Digestibility (DMD)	% of DM	63.9	64.7	59.0	58.7
Digestibility (DOMD)	% of DM	61.0	61.7	56.8	56.5
Est. Metabolisable Energy	MJ/kg DM	9.4	9.5	8.5	8.5

Table 28. Feed quality results from 2024 and 2025 samples for the main trial site

		MTS Biomineral Feb-24	MTS Synthetic Feb-24	MTS Biomineral Mar-24	MTS Synthetic Mar-24	MTS Biomineral Feb-25	MTS Synthetic Feb-25
Dry Matter	%	25.7	23.1	20.5	20.3	22.8	25.5
Moisture	%	74.3	76.9	79.5	79.7	77.2	74.5
Crude Protein	% of DM	15.9	17.1	15.9	16.0	10.7	11.9
Acid Detergent Fibre	% of DM	29.8	27.6	27.3	27.0	28.2	28.2
Neutral Detergent Fibre	% of DM	63.2	60.3	62.2	61.8	64.3	63.7
Digestibility (DMD)	% of DM	62.9	64.9	66.7	66.8	65.3	66.5
Digestibility (DOMD)	% of DM	60.1	61.7	63.3	63.4	62.1	62.6
Est. Metabolisable Energy	MJ/kg DM	9.2	9.5	9.8	9.9	9.6	9.8

CP = Crude Protein - The amount of true protein and non-protein-nitrogen in a feed and ultimately provides the building blocks of the body, the amino acids. CP is calculated as Nitrogen content x 6.25.

ADF = Acid Detergent Fibre - The residue that remains after extraction of plant material with an acid detergent solution. ADF gives an indication of the fibre material that may be indigestible to ruminants.

NDF = Neutral Detergent Fibre - The residue remaining after extraction of plant material with a neutral detergent solution - mainly cell wall material that provides “rumen-fill” when forage/roughage is eaten.

DDM = Digestible Dry Matter - The difference between the DM consumed and the DM excreted in the faeces, expressed as a percentage of the DM consumed. DDM is estimated using a laboratory procedure calibrated against DDM values for feedstuffs measured in feeding trials with live animals, usually sheep.

ME = Metabolisable Energy - The energy in the feed available to the animal to maintain body activity, growth & lactation. ME is calculated from DDM and is expressed as Mega Joules (MJ) per kg DM.

Table 29. Average feed quality results for the main trial site across the project

		MTS Biomineral Average	MTS Synthetic Average
Dry Matter	%	21.5	22.0
Moisture	%	78.5	78.0
Crude Protein	% of dry matter	13.0	14.2
Acid Detergent Fibre	% of dry matter	28.5	27.9
Neutral Detergent Fibre	% of dry matter	63.7	62.2
Digestibility (DMD)	% of dry matter	63.6	64.3
Digestibility (DOMD)	% of dry matter	60.7	61.2
Est. Metabolisable Energy	MJ/kg DM	9.3	9.4

5.4.2 Small Plot Trial Pasture Production

The small plot trial pasture production was measured in line with the main trial site. The small plot trial aim was to measure the pasture growth and quality while the nutrients were applied at the same levels, differing from all the other trials where the fertilisers were applied at best practice rates.

Growth measurements were recorded 3 times each summer as the pasture was grown under surface irrigation. The total pasture production as dry matter is recorded for each fertiliser in the table below (table 28) for each year. The biomineral treatment produced on average the highest pasture production at 11.18 tons DM/year compared to 11.04 tons DM/year for the Synthetic treatments or a 1.26% uplift in production.

The synthetic fertiliser application rates were reduced to match the biomineral application rates, to ensure the key elements, nitrogen and phosphorus, were applied at equivalent rates. As with the main trial site, the results were similar between treatments, in that there is no loss in production by switching from synthetic fertiliser to biomineral fertiliser. Importantly, these results do not indicate the biological inoculant associated with biomineral fertilisers generate plant growth beyond that of equal application of key nutrients via synthetic fertiliser.

Table 30. Small plot trial annual pasture production and daily growth rates across the 3 years of the project

Year	Treatment	Total (tons DM/Ha)	Start Date	Finish Date	Days	Daily growth (kg/Ha/day)
2023	Biomineral	16.73	17/1/23	22/4/23	95	176.1
2023	Synthetic	17.29	17/1/23	22/4/23	95	182.0
2024	Biomineral	7.93	30/12/23	29/3/24	90	88.2
2024	Synthetic	7.33	30/12/23	29/3/24	90	81.5
2025	Biomineral	8.88	30/12/24	29/3/25	89	99.8
2025	Synthetic	8.49	30/12/24	29/3/25	89	95.4
Average	Biomineral	11.18			91	121.35
Average	Synthetic	11.04			91	119.62

5.4.3 Small Plot Trial Feed Quality

Pasture samples were tested for feed quality from each plot at the first cutting time and then either second or third cutting time for the small plot trail. The results of the average across each fertiliser treatment for each sampling time are outlined in table 31.

Crude protein results across the synthetic treatments were above the average for the biomineral treatment at all sampling points except for one, averaging 1.24% higher protein. The same results were seen in metabolisable energy although the difference between the treatments was smaller at 0.16 MJ/kg DM higher. The NDF and ADF in the biomineral treatment were on average higher than the synthetic plots.

Table 31. Feed quality results from 2023 for the small plot trial

		SPT Biomineral Feb-23	SPT Synthetic Feb-23	SPT Biomineral Apr-23	SPT Synthetic Apr-23
Dry Matter	%	24.1	23.5	21.0	21.5
Moisture	%	75.9	76.5	79.0	78.5
Crude Protein	% of DM	14.9	16.9	11.8	13.0
Acid Detergent Fibre	% of DM	28.8	27.7	28.8	27.6
Neutral Detergent Fibre	% of DM	63.4	61.2	63.1	61.7
Digestibility (DMD)	% of DM	63.6	64.4	57.3	59.2

Digestibility (DOMD)	% of DM	60.7	61.4	55.4	57.0
Est. Metabolisable Energy	MJ/kg DM	9.3	9.4	8.2	8.6

Table 32. Feed quality results from 2024 and 2025 for the small plot trial

		SPT Biomineral Feb-24	SPT Synthetic Feb-24	SPT Biomineral Mar-24	SPT Synthetic Mar-24	SPT Biomineral Feb-25	SPT Synthetic Feb-25
Dry Matter	%	23.3	25.2	19.3	19.3	26.3	22.9
Moisture	%	76.7	74.8	80.7	80.7	73.7	77.1
Crude Protein	% of DM	13.9	12.8	15.1	16.5	11.6	14.3
Acid Detergent Fibre	% of DM	28.6	29.4	27.9	27.3	28.1	28.0
Neutral Detergent Fibre	% of DM	61.3	63.8	61.4	60.8	65.6	61.2
Digestibility (DMD)	% of DM	64.8	63.6	66.6	67.9	65.5	66.5
Digestibility (DOMD)	% of DM	61.7	60.7	63.2	64.3	62.4	63.1
Est. Metabolisable Energy	MJ/kg DM	9.5	9.3	9.8	10.1	9.7	9.8

Table 33. Average feed quality results for the small plot trial across the 3-year project

		SPT Biomineral Average	SPT Synthetic Average
Dry Matter	%	22.8	22.5
Moisture	%	77.2	77.5
Crude Protein	% of dry matter	13.5	14.7
Acid Detergent Fibre	% of dry matter	28.4	28.0
Neutral Detergent Fibre	% of dry matter	63.0	61.7
Digestibility (DMD)	% of dry matter	63.6	64.3
Digestibility (DOMD)	% of dry matter	60.7	61.3
Est. Metabolisable Energy	MJ/kg DM	9.3	9.4

It was expected that if a difference was to be seen between the fertiliser treatments, then it would occur in the final year of the trial once the impact of the biomineral fertiliser had time to influence the soil function and health which could then impact plant growth and feed quality. From the results seen in table 12 the pasture quality improvement didn’t occur as expected across the life of the project.

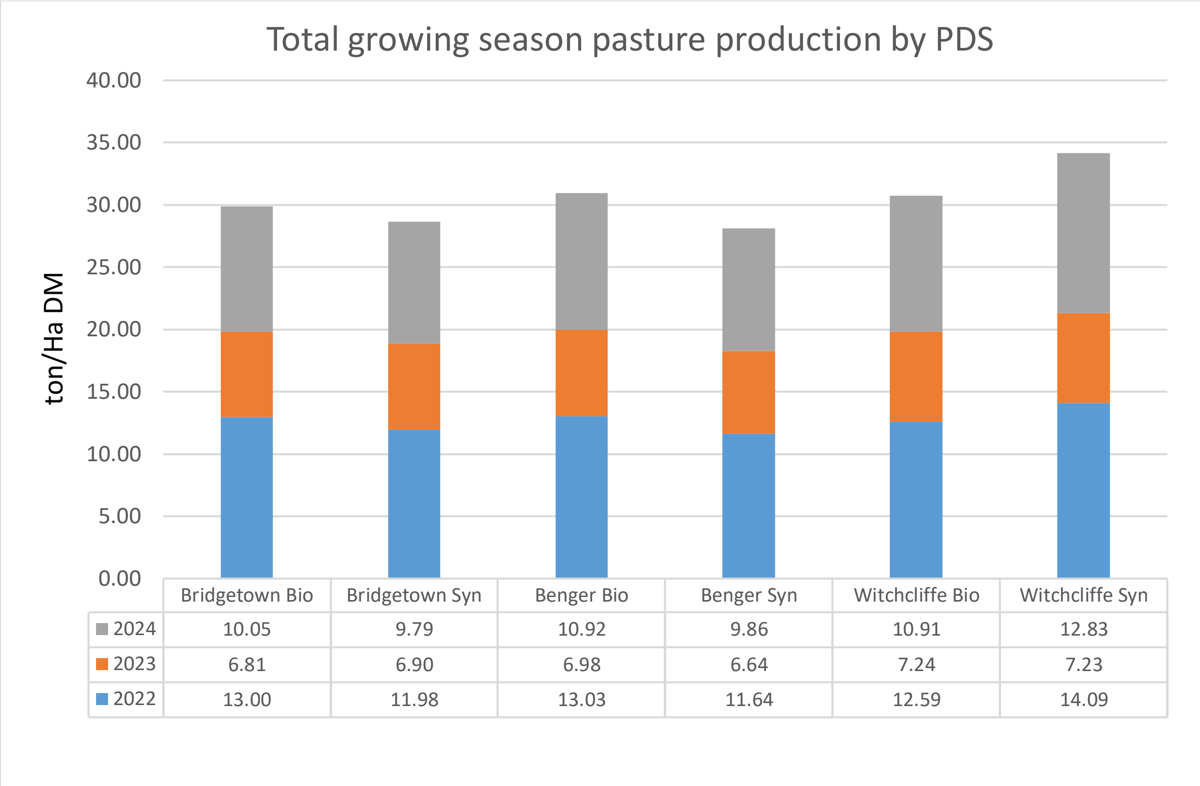
5.4.4 3 x PDS Site Pasture Growth

Pasture production was measured across the three demonstration sites for the entire growing season using pasture cages for the three years of the project. The measuring period ran from late May/early June, or the break of the season through to beginning of October, depending on when the season finished. Rainfall patterns in the last 2 years of the project saw very little rainfall be received in Spring resulting in minimal pasture growth being measured into the Spring months.

Pasture production measurements were recorded 3 times each season and the results for each recording are detailed in Figure 3. Across the 3 producer demonstration site the biomineral fertiliser treatments produced higher pasture production at Bridgetown and Benger and the synthetic treatment recorded the higher pasture production at Witchcliffe.

Across the three PDS site the biomineral treated plots recorded marginally higher pasture production at 10.17 ton/DM/season compared to the synthetic plots at 10.11 ton/DM/season. The pasture production recorded across the three producer demonstration sites answers the hypothesis that no loss in pasture production is expected when changing from a synthetic fertiliser to a biomineral fertiliser.

Figure 3. Cumulative and annual growing season pasture production for each PDS by fertiliser type



5.4.4.1 Bridgetown PDS

The pasture production results for the producer demonstration site at Bridgetown are outlined in table 32. The impacts of the seasonal conditions can be clearly seen in the total pasture produced in each calendar year. 2023 was an exceptionally dry year with very minimal rainfall recorded after the middle of August. The rainfall received at the Bridgetown property from 2020 to 2024 is shown in Figure 4. The rainfall received in the year prior to the start of the project was exceptionally high with the rainfall received in 2023 only half of 2021.

Table 34. Bridgetown PDS annual pasture production and daily growth rates across the 3 years of the project

Year	Treatment	Total (tons DM/ha)	Start Date	Finish Date	Days	Daily growth (kg/ha/day)
2022	Biomineral	13.00	6/5/22	28/10/22	175	74.3
2022	Synthetic	11.98	6/5/22	28/10/22	175	68.5
2023	Biomineral	6.81	28/5/23	21/10/23	146	46.6
2023	Synthetic	6.90	28/5/23	21/10/23	146	47.3
2024	Biomineral	10.05	12/6/24	19/10/24	129	77.9
2024	Synthetic	9.79	12/6/24	19/10/24	129	75.9

Average	Biomineral	9.95	150	66.28
Average	Synthetic	9.56	150	63.87

At the Bridgetown PDS the biomineral treatment recorded higher pasture production in 2022 and 2024 than the synthetic treatment and was marginally lower in 2023 than the synthetic treatment. Across the 3 years of the project the biomineral treatment produced slightly higher pasture production 9.95 tons of DM/season compared to the synthetic plots at 9.56 tons DM/season.

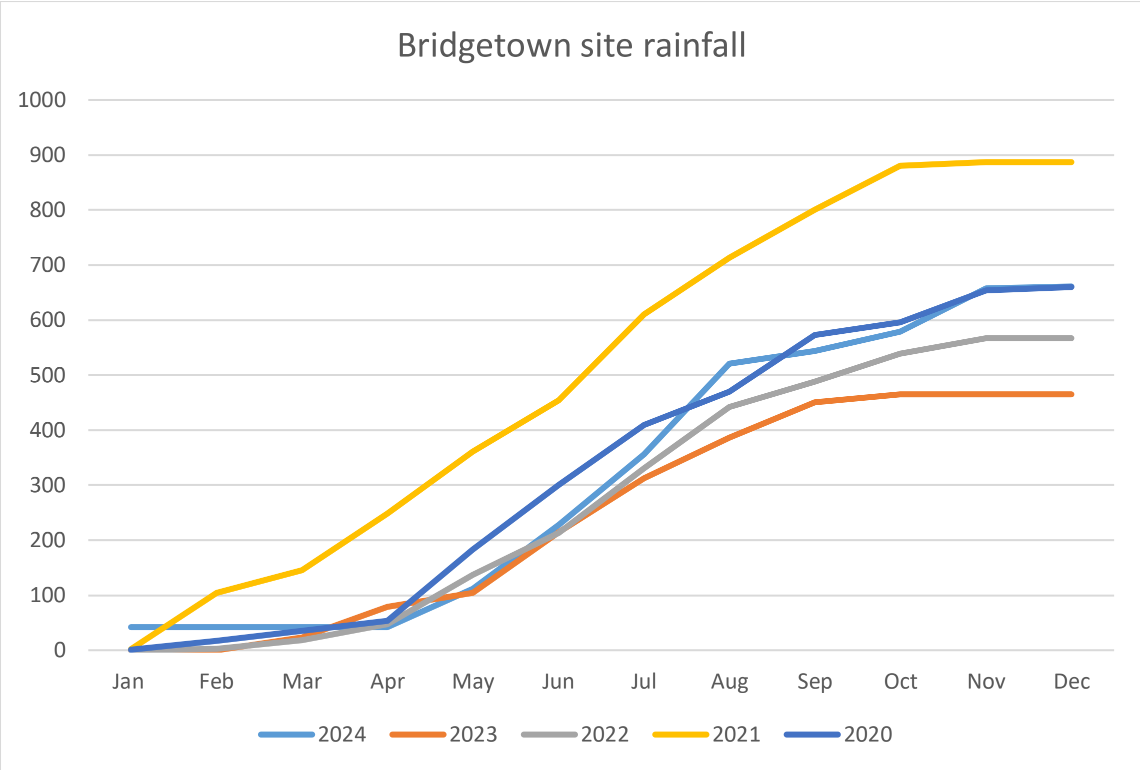


Figure 4. Main Trial Site annual rainfall 2020 to 2024

5.4.4.2 Benger PDS

The pasture production results for the producer demonstration site at the Benger PDS are outlined in table 33. The cattle grazing across the paddock at the Benger PDS dislodged the pasture cages at the start of the second season which is the reason behind the start date of 4th of August in 2023.

The biomineral fertiliser treatments recorded higher pasture production for all three seasons at the Benger PDS. The biomineral pasture treatment produced 9.91% more pasture on average across the three years compared to the synthetic pasture treatment. The largest daily growth rate was seen in the final year at 8.4 kg/day indicating the biological function of the biomineral fertiliser may have been starting to have an effect.

Table 35.Benger annual pasture production and daily growth rates across the 3 years of the project

Year	Treatment	Total (tons DM)	Start Date	Finish Date	Days	Daily growth (kg/ha/day)
2022	Biomineral	13.03	6/5/22	29/10/22	176	74.0
2022	Synthetic	11.64	6/5/22	29/10/22	176	66.1
2023	Biomineral	6.98	4/8/23	26/10/23	83	84.1
2023	Synthetic	6.64	4/8/23	26/10/23	83	80.0
2024	Biomineral	10.92	13/6/24	18/10/24	127	86.0
2024	Synthetic	9.86	13/6/24	18/10/24	127	77.6
Average	Biomineral	10.31			129	81.37
Average	Synthetic	9.38			129	74.59

5.4.4.3 Witchcliffe PDS

The pasture production results for the producer demonstration site at Witchcliffe are outlined in table 34. The Witchcliffe site is located on the South West coast of Western Australia and receives the highest rainfall of the three PDS sites as well as the coolest temperatures. As expected the Witchcliffe site recorded the highest annual pasture production of the three sites.

At the Witchcliffe PDS the synthetic fertiliser treatment produced more pasture in 2022 and 2024 than the biomineral fertiliser treatment, with the treatments equal in 2023. On average across the three seasons of the project the synthetic fertiliser treatment produced 1.13 ton DM/ha per year more pasture than the biomineral fertiliser or 7.93 kg DM/ha of pasture per day.

Table 36. Benger annual pasture production and daily growth rates across the 3 years of the project

Year	Treatment	Total (tons/Ha DM)	Start Date	Finish Date	Days	Daily growth (kg/ha/day)
2022	Biomineral	12.59	5/6/22	19/11/22	167	75.4
2022	Synthetic	14.09	5/6/22	19/11/22	167	84.4
2023	Biomineral	7.24	1/6/23	20/10/23	141	51.3
2023	Synthetic	7.23	1/6/23	20/10/23	141	51.3
2024	Biomineral	10.91	12/6/24	19/10/24	129	84.6
2024	Synthetic	12.83	12/6/24	19/10/24	129	99.5
Average	Biomineral	10.25			146	70.44
Average	Synthetic	11.38			146	78.37

5.4.5 PDS1 Feed Quality

5.4.5.1 PDS1 Feed Quality – Bridgetown

Feed quality for the Bridgetown PDS are outlined below in tables 35 and 36. Pasture feed quality was recorded from the first cut each year to determine the influence of the different fertiliser treatments on the feed quality.

At the Bridgetown site the Biomineral fertiliser treatment recorded higher Crude Protein and Metabolisable Energy for two out of three years than the synthetic treatment. The difference was the highest in the final year of the project with the protein being 3.1% higher and the M/E 2.6 MJ/kg.

Additionally, the Digestibility, ADF and NDF in the pasture all saw improvement on the biomineral treated paddock compared to the synthetic paddock across the three years of the demonstration site.

Table 37. Feed quality results from each sample point for the main trial site across the life of the project

		PDS1 Biomineral Jul-22	PDS1 Synthetic Jul-22	PDS1 Biomineral Aug-23	PDS1 Synthetic Aug-23	PDS1 Biomineral Jul-24	PDS1 Synthetic Jul-24
Dry Matter	%	10.6	11.3	14.6	16.5	8.2	17.7
Moisture	%	89.4	88.7	85.4	83.5	91.8	82.3
Crude Protein	% of dry matter	22.3	21.3	17.5	20.3	22.6	19.5
Acid Detergent Fibre	% of dry matter	21.2	18.0	29.6	28.5	24.4	25.9
Neutral Detergent Fibre	% of dry matter	37.5	34.3	50.2	51.4	38.1	47.9
Digestibility (DMD)	% of dry matter	77.7	80.0	62.4	56.0	68.6	53.7
Digestibility (DOMD)	% of dry matter			59.7	54.2	65.0	52.3
Est. Metabolisable Energy	MJ/kg DM	11.7	12.1	9.1	8.0	10.2	7.6

Table 38. average feed quality results for PDS 1 across the 3 year project

		PDS1 Biomineral Average	PDS1 Synthetic Average
Dry Matter	%	11.1	15.2
Moisture	%	88.9	84.8
Crude Protein	% of dry matter	20.8	20.4
Acid Detergent Fibre	% of dry matter	25.1	24.1
Neutral Detergent Fibre	% of dry matter	41.9	44.5
Digestibility (DMD)	% of dry matter	69.6	63.2
Digestibility (DOMD)	% of dry matter	62.4	53.3
Est. Metabolisable Energy	MJ/kg DM	10.3	9.2

5.4.5.2 PDS2 Feed Quality – Benger

Feed quality for the Benger PDS are outlined below in tables 37 and 38. Pasture feed quality was recorded from the first cut each year to determine the influence of the different fertiliser treatments on the feed quality.

At the Benger site the crude protein in the pasture cuts was higher across the biomineral treatments in the first two seasons compared to the synthetic treatment but then reversed in the final year. M/E was very similar between both treatments across the three years. The Synthetic treatments recorded higher NDF in the final two seasons otherwise there was no clear benefit in feed quality from either of the fertiliser types.

The results from this PDS add support to the hypothesis that there is no reduction in production by switching from a synthetic fertiliser to a biomineral fertiliser.

Table 39. Feed quality results from each sample point for the main trial site across the life of the project

		PDS2 Biomineral Jul-22	PDS2 Synthetic Jul-22	PDS2 Biomineral Aug-23	PDS2 Synthetic Aug-23	PDS2 Biomineral Jul-24	PDS2 Synthetic Jul-24
Dry Matter	%	14.5	15.0	13.6	16.8	11.3	10.2
Moisture	%	85.5	85.0	86.4	83.2	88.7	89.8
Crude Protein	% of dry matter	19.7	18.5	19.3	17.6	21.5	23.0
Acid Detergent Fibre	% of dry matter	20.9	21.1	26.0	28.1	25.5	25.1
Neutral Detergent Fibre	% of dry matter	37.9	37.9	44.2	49.9	42.2	43.7
Digestibility (DMD)	% of dry matter	76.3	77.1	67.4	66.5	66.1	70.0
Digestibility (DOMD)	% of dry matter			63.9	63.1	62.8	66.1
Est. Metabolisable Energy	MJ/kg DM	11.5	11.6	10.0	9.8	9.8	10.4

Table 40. average feed quality results for PDS 2 across the 3 year project

		PDS2 Biomineral Average	PDS2 Synthetic Average
Dry Matter	%	13.1	14.0
Moisture	%	86.9	86.0
Crude Protein	% of dry matter	20.2	19.7
Acid Detergent Fibre	% of dry matter	24.1	24.8
Neutral Detergent Fibre	% of dry matter	41.4	43.8
Digestibility (DMD)	% of dry matter	69.9	71.2
Digestibility (DOMD)	% of dry matter	63.4	64.6
Est. Metabolisable Energy	MJ/kg DM	10.4	10.6

5.4.5.3 PDS3 Feed Quality – Witchcliffe

Feed quality for the Witchcliffe PDS are outlined below in tables 39 and 40. Pasture feed quality was recorded from the first cut each year to determine the influence of the different fertiliser treatments on the feed quality.

The feed quality change over time seen in the below chart is very similar to the pattern recorded at the Bridgetown site. The crude protein and metabolizable energy both improved in the biomineral treatments compared to the synthetic treatments from year one to year three. By the final year the crude protein in the biomineral plot was 5.8% higher than the synthetic plot and the M/E was 1.9 MJ/kg DM higher. Digestibility also recorded the same pattern and by year three was 11.1% higher in the biomineral treated paddock.

The results from the Witchcliffe PDS adds support that the biomineral fertiliser improves pasture quality.

Table 41. Feed quality results from each sample point for the main trial site across the life of the project

		PDS3 Biomineral Jul-22	PDS3 Synthetic Jul-22	PDS3 Biomineral Aug-23	PDS3 Synthetic Aug-23	PDS3 Biomineral Jul-24	PDS3 Synthetic Jul-24
Dry Matter	%	11.4	10.2	11.2	16.0	10.7	14.7
Moisture	%	88.6	89.8	88.8	84.0	89.3	85.3
Crude Protein	% of dry matter	21.1	22.3	19.8	16.8	22.8	17.0
Acid Detergent Fibre	% of dry matter	21.1	21.8	26.3	28.0	21.7	37.8
Neutral Detergent Fibre	% of dry matter	37.5	37.4	50.0	55.4	42.4	62.0
Digestibility (DMD)	% of dry matter	74.6	75.4	62.3	57.5	65.0	53.9
Digestibility (DOMD)	% of dry matter			59.6	55.5	61.9	52.5
Est. Metabolisable Energy	MJ/kg DM	11.2	11.4	9.1	8.3	9.6	7.7

Table 42. average feed quality results for PDS 3 across the 3 year project

		PDS3 Biomineral Average	PDS3 Synthetic Average
Dry Matter	%	11.1	13.6
Moisture	%	88.9	86.4
Crude Protein	% of dry matter	21.2	18.7
Acid Detergent Fibre	% of dry matter	23.0	29.2
Neutral Detergent Fibre	% of dry matter	43.3	51.6
Digestibility (DMD)	% of dry matter	67.3	62.3
Digestibility (DOMD)	% of dry matter	60.8	54.0
Est. Metabolisable Energy	MJ/kg DM	10.0	9.1

5.5 Cattle Production

5.5.0 Cattle Production Trial

The cattle production trial data was from 78 days in 2023, 82 days in 2024 and 81 days in 2025, starting in late December and finishing by the end of March. The drought conditions experienced through 2023 and 2024 resulted in reduced water availability despite the considerable monies spent on water infrastructure throughout the project to increase the available water. All calves were either sold through the traditional auction system or kept on property for breeding purposes.

Picture 1: cattle grazing in replicate 3 of the main trial site.

Table 43. Cattle production trial statistical output (DPIRD WA, Applied Statistician)

Growth g/day			
Group	2023 7/1-26/3 (78 days)	2024 29/12-20/3 (82 days)	2025 30/12-21/3 (81 days)
a. Statistical analysis on group basis			
Bio 2023 even (kg/hd)	371.8	382.6	579.2
Bio 2023 odd (kg/hd)	432.3	422.0	617.3
	402.1	402.3	598.3
Syn 2023 even (kg/hd)	380.9	379.1	640.9
Syn 2023 odd (kg/hd)	342.6	409.3	633.2
	361.8	394.2	637.1
p-value (T-test)	0.377	0.775	0.184
b. Statistical analysis on animal basis			
Biomineral (kg/hd)	402.7	402.7	598.3
Synthetic (kg/hd)	361.3	394.5	637.1
LSD	55.3	59.1	58.8
p-value (ANOVA)	0.141	0.783	0.193

Table 41 is a summary of the statistical analyses of the cattle production data on both a group basis (groups of about 24 animals) and on an individual animal basis. The group basis analysis is considered to be more correct, however it is a weaker statistical test. The individual animal test could be over stating the significance, however as there was no significant differences in cattle production between the type of fertiliser in either of the statistical analysis methods, the analysis methodology is inconsequential. Appendix 1 is the Genstat output for the statistical analyses on an individual animal basis, which against demonstrates there was no significant difference in cattle production from different fertiliser types.

Daily weight gain is one of the key drivers for the benefit cost analysis of any cattle operation growing out calves and the data generated form the trial has been utilised in the benefit cost analysis of the project in section 4.5. The average daily weight gains for each fertiliser treatment across the three seasons of the project are below:

Biomineral Fertiliser– 467.5 g/day

Synthetic Fertiliser - 464.3 g/day

One of the aims of the project was to assess the ability of the biomineral fertiliser, to increase soil carbon sequestration, while at least maintaining productivity and profitability. One of the measures of productivity was cattle production. The results clearly demonstrate the biomineral fertiliser's ability to maintain productivity.

Part of the second pathway biomineral fertilisers were to reduce carbon emissions was by increasing nutrient density of pastures and subsequently increasing weight gain efficiency of livestock. The results demonstrate biomineral fertilisers within the first three years of their use, do not increase nutrient density and the subsequent weight gain efficiency.

5.5.1 Anti-Methanogenic/In Vitro testing results

5.5.1.1 Anti-Methanogenic Background

An overall aim of this project was to explore the potential of a biomineral fertiliser to improve soil health and subsequently the quality of the pastures produced. The specific aim for the in vitro part of the project was to demonstrate the methane potential of the pastures as influenced by the Biomineral and Synthetic fertilisers. If the Biomineral fertilised pastures produced pasture with higher digestibility (lower fibre) than the Synthetic fertilised pastures it was likely that methane formation would be proportionately lower.

5.5.1.2 Anti-Methanogenic Findings

Main Trial Site

For the MTS, there were no significant differences in fermentability or methane formation between treatments in any year (Table 42). The fermentability correlated strongly with pasture digestibility, which was also found to be similar between treatments and within seasons. As a result of the droughts experienced in 2022 and 2023 available water for irrigation impacted negatively on pasture growth and in turn feed quality over the three-year period of the experiment. The pasture, although lower in quality than anticipated, was of consistent quality and subsequently fermentability was similar each year. However, no statistical comparison between years was made for fermentability or methane formation due to potential variability in laboratory conditions, particularly rumen inoculum.

The fermentability of the MTS pasture tended to be lower in February than the October, spring pastures at the PDS. No statistical analysis was made between the different sites. This is indicative of more mature, lower digestible summer pasture compared to highly digestible, lush spring pasture.

Table 44. The effect of pasture grown at the Main Trial Site under a Biomineral or Synthetic fertiliser regimen on fermentability and methane formation in a batch culture system. ns = not significant (P<0.05)

Pasture sampling date	Fertiliser treatment	Fermentability (gas ml/g DM)	F pr. (P<0.05)	Methane (%)	F pr. (P<0.05)
February 2023	Biomineral	305	ns	4.1	ns
	Synthetic	309		4.3	
February 2024	Biomineral	300	ns	5.4	ns
	Synthetic	305		4.6	
February 2025	Biomineral	305	ns	7.8	ns
	Synthetic	307		7.8	

Smal Plot Trial

For the SPT, there were no significant differences in fermentability or methane formation between treatments in 2023 (Table 43). Methane formation appeared to be higher along with gas production in 2025 than the two previous years and similar between treatments. This indicates a seasonal effect on fermentation characteristics rather than a treatment effect.

Table 45. The effect of pasture grown at the Small Plot trial under a Biomineral or Synthetic fertiliser regimen on fermentability and methane formation in a batch culture system. ns = not significant (P<0.05), nt= No statistical test

Pasture sampling date	Fertiliser treatment	Fermentability (gas ml/g DM)	Methane (%)	F pr. (P<0.05)
February 2023	Biomineral	311	4.5	ns
	Synthetic	310	4.5	
February 2024	Biomineral	304	4.2	nt
	Synthetic	305	4.5	
February 2025	Biomineral	316	8.0	nt
	Synthetic	312	8.9	

Producer Demonstration Sites

The fermentability of pasture samples tended to be higher from the PDS (spring samples) than the MTS and the SPT (summer samples). The differences can be explained by the effect of season on feed quality.

There were several differences between treatments for fermentability and methane formation at the PDS (Table 44). At the Benger site in 2023, pasture from the Biomineral treatment was 5.4% more fermentable and produced about half the concentration of methane. In 2024, at the Witchcliffe site, the Synthetic treatment tended to be less fermentable but also produced a lower concentration of methane, while at Bridgetown this effect was observed from the Biomineral treatment. These anomalies are most likely due to variation in pasture species between plots. The nature of mixed-sward pastures is variety in annual and perennial grasses and legume species. Each species fluctuates in nutritional value throughout the season which may mask a treatment effect. Greater replication and mixing of samples might have homogenised the laboratory samples.

Table 46. The effect of pasture grown at the Producer Demonstration Sites under a Biomineral or Synthetic fertiliser regimen on fermentability and methane formation in a batch culture system

Site	Fertiliser treatment	Pasture sampling date	Fermentability (gas ml/g DM)	Methane (%)
Bridgetown	Biomineral		339	9.1
	Synthetic		339	8.5
Benger	Biomineral		358	4.3
	Synthetic	October 2023	339	8.5
Witchcliffe	Biomineral		334	8.3
	Synthetic		335	6.3
Bridgetown	Biomineral		346	3.7
	Synthetic		356	9.0
Benger	Biomineral	October 2024	344	6.2
	Synthetic		332	6.8
Witchcliffe	Biomineral		348	9.7
	Synthetic		325	4.3

Overall, the fermentability of pastures tended to be higher during October than in February. This was a seasonal effect of Spring pasture in a vegetative phase when fibre (NDF) levels were typically lower than later in the season. During the late Spring and Summer period pasture tends to be in a reproductive or senescing phase and Fibre levels increase. The high R2 value (Figure 5) demonstrated a strong inverse relationship between NDF levels of the pasture samples and the accumulation of microbial fermentation gas in the headspace in vitro. As NDF levels increased, fermentation gas decreased, which is typically due to a slower degradation of plant fibre. Unexpectedly, the high NDF values were not associated with increased methane formation. In a ruminant animal, high plant NDF levels typically slow the fermentation process and the associated breakdown of fibre by cellulolytic microbes leads to increased methane formation. A ruminant animal can be regarded as an "open fermentation system" because feed and water enter the system and microbial end-products are flushed through and do not accumulate. It is difficult to replicate an open fermentation system in the laboratory, but it is likely that the nature of the closed system that was used, masked any nutritional effect on methane formation.

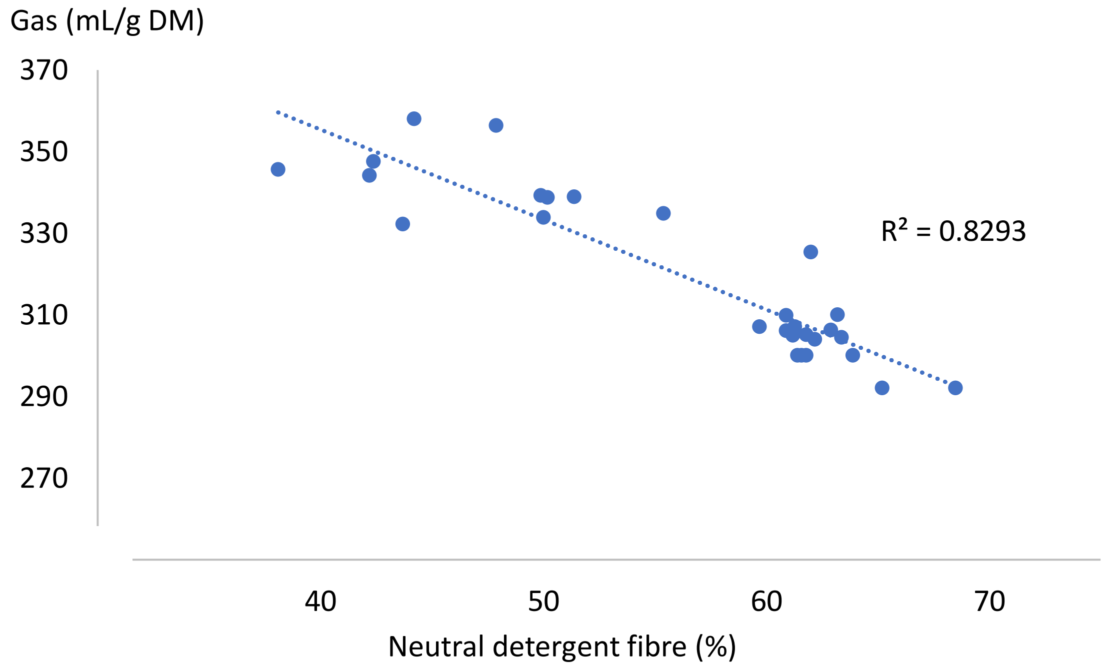


Figure 5. The strong inverse relationship between Pasture Neutral Detergent Fibre and gas accumulation (as a proxy for fermentability) in a 24 h incubated batch culture system

A more sophisticated in vitro system such as the Rumen Simulation technique (RUSITEC) may have been more suitable for this work because it is a continuous "open fermentation". It was not possible to use the RUSITEC for the current work because of other limitations, including high labour and financial cost (Durmic et al., 2025). The batch culture system that was used would have been effective at detecting bioactive compounds that inhibit methanogenesis (Durmic et al., 2010) rather than nutritional influences. If future work on Biomineral fertilisers produces a treatment effect on pasture composition, it may be useful to examine the effect on methane formation using methodology such as a RUSITEC.

5.6 Benefit Cost Analysis

5.6.0 Fertiliser Application Summary by trial

The cost of the fertiliser applications by year by trial are detailed below in table 45. Fertiliser prices were very high in 2022 and some of 2023 and then started to drop in price across 2024 and 2025. The fertiliser applications by trial are covered in more detail in the next 3 sections.

High rates of the biomineral fertiliser used across all the biomineral plots in the project for the first season in an attempt to increase the spread density of the microbes contained in the fertiliser coating to speed up the soil microbial activity buildup with the aim of seeing results in the trial period of 3 years.

The first year's higher rates have inflated the costs of the biomineral plots. As can be seen in the fertiliser costs table the cost of using biomineral fertilisers is above the cost of synthetic fertilisers.

It is proposed that as the microbiological activity increases over time in the soil as a result of the change in fertiliser then the biomineral fertiliser rates can drop further to potentially come in line with synthetic fertilisers by price, however this was outside of the scope of the project.

Secondly it is worth noting that the pasture production and feed quality levels were similar between the two fertiliser types at the best practice rates applied across the trial period. Future work should include testing the fertiliser application rate response of biomineral fertilisers to examine at what rates production drops and or increases.

5.6.0.1 Main Trial Site

Table 4 in the methods section details the fertilisers applied, the rates, timing and costs per ha for all the fertilisers applied across the main trial site across the project. The total cost of the biomineral fertiliser for the 3 years of the project was $1671/ha compared to $867/ha for the synthetic fertiliser plots, or $558/ha per year for the biomineral fertiliser and $289/ha per year for the synthetic fertiliser.

The main trial site was on a paddock that was surface irrigated from January through to April each year, plus the winter rainfall growing season. The higher application rates and therefore the increased costs per ha reflect the higher production potential that comes from an irrigated site.

5.6.0.2 Small Plot Trial

Table 7 in the methods section details the fertilisers applied, the rates, timing and costs per ha for all the fertilisers applied across the small plot trial across the project. The total cost of the biomineral fertiliser for the 3 years of the project was $2522/ha compared to $835/ha for the synthetic fertiliser plots, or $841/ha per year for the biomineral fertiliser and $278/ha per year for the synthetic fertiliser.

While the cost of the biomineral fertiliser appears high the aim of the small plot trial was to apply both synthetic and biomineral fertilisers at the equivalent nutrient rates across the trial period to act as a proxy control in fertiliser trial methodology for the entire project as the remaining four trials all had the fertilisers applied at best practice rates.

Fertiliser trial methodology traditionally compares different fertiliser at equivalent nutrient application rates. The small plot trial also examines if there is a benefit in production by increasing the application rates of biomineral fertilisers.

5.6.0.3 Producer Demonstration Sites

Table 12 in the methods section details the fertilisers applied, the rates, timing and costs per ha for all the fertilisers applied across the producer demonstration sites across the project. The total cost of the biomineral fertiliser for the 3 years of the project was $996/ha compared to $508/ha for the synthetic fertiliser plots, or $332/ha per year for the biomineral fertiliser and $169/ha per year for the synthetic fertiliser.

Similarly to the other trials the cost of biomineral fertiliser was considerably higher than applying best practice synthetic fertiliser. It is worth noting that the rates for the final two years of the project of the biomineral fertiliser were reduced from 125 kg/ha down to 80 kg/ha to reduce costs and be in line with best practice. The higher rate was use in year 1 in an attempt to promote early microbiological activity for the trial period through the application of the microbe coating.

The cost of the biomineral fertiliser reduced to $252/ha compared to $146/ha for the synthetic fertiliser. Synthetic fertiliser cost fell in the final 2 years of the trial due to the purchase cost of fertilisers declining.

5.6.1 Main Trial Site Benefit Cost Analysis Commercial Operating Drivers

The benefit cost analysis drivers were recorded each year of the project for each fertiliser system and the comparison completed each year. The drivers and the impact of each driver are detailed below:

The BCA drivers will impact the benefit cost analysis in the below ways:

- Cost of Fertiliser – straight to the costs line.
- Winter pasture production – increase or decrease in carrying capacity of cows during winter and in turn calf production. Synthetic winter baseline equates to 180 PTIC cows.
- Summer pasture production – Both fertiliser treatments allowed all produced calves to be carried through the summer on the irrigation although for a reduced period of time for year 2.
- Calf Growth rate – impacts final sale weight and post weaning weight.
- Starting calf weight – is the average of the calves starting weight for each fertiliser group for each year and then averaged across all the calves used in the project.
- Calves available for sale – total calves bred less the heifers kept for breeding and deaths. The numbers mirror the commercial operations of the farming operation.
- Cows available for sale – Is the cow number required to be sold to maintain the herd size allowing for the introduction of heifers. Cows are sold at an equal weight for both fertiliser types.

Table 47. The benefit cost analysis commercial production drivers for the main trial site 2022 to 2024

Benefit Cost Analysis Drivers	Biomineral	Synthetic	Unit
Cost of Fertiliser (dryland 170 Ha)			
2022	$494	$216	$/ha
2023	$252	$150	$/ha
2024	$252	$142	$/ha
Average	$333	$169	$/ha
PDS1 pasture production			
2022	74.3	68.5	kg/day DM
2023	46.6	47.3	kg/day DM
2024	77.9	75.9	kg/day DM

PDS pasture production	66.28	63.87	kg/day DM
Cow Breeding unit carrying capacity	187	180	
Calves produced	187	180	head
less - keeper heifers	20	20	head
less - deaths	3	3	head
Sale calves	164	157	head
Sale cows	18	18	head
Starting calf weight (average)			
2022	296.85	297.91	kg/head
2023	308.55	319.42	kg/head
2024	353.25	355.38	kg/head
Combined Ave starting weight	321.89		kg/head
Daily growth rates			
2023	0.31	0.38	kg/head/day
2024	0.41	0.40	kg/head/day
2025	0.60	0.64	kg/head/day
Average daily growth rates	0.44	0.47	kg/head/day
Days grazing irrigated pasture	90	90	days
Calf finish (sale) weight	361.52	364.28	kg/head
Cost of Fertiliser (irrigated 24Ha)			
2022	$731	$400	$/ha
2023	$469	$237	$/ha
2024	$473	$230	$/ha
Average	$558	$289	$/ha
Livestock sale values	Biomineral	Synthetic	
Calves	$3.10	$3.10	$/kg live weight
Cows	$2.20	$2.20	$/kg live weight

5.6.2 Main Trial Site or Whole of Farm BCA

The benefit cost analysis has been determined through the MLA's cost of production calculator. Figure 9 shows the cost of production under synthetic treatments for producing beef across the whole farm at the Bridgetown site in the final year of the project. The cost of production in terms of $/kg lwt reduced considerably in year 3 from the previous two years (year 1 - $2.83 $/kg lwt year 2 - $2.69 $/kg lwt) as the calves weighed considerably more than in previous years with 2025 sale weights averaging 404 kg lwt compared to 2024 weights which only averaged 353 kg lwt. Cattle prices also improved across 2024 and into 2025

The cost of production under synthetic fertiliser was $1.99/kg lwt with a positive margin of $0.79 $/kg lwt sold.

Figure 10 shows the cost of production under biomineral treatments for producing beef. The cost of production was higher at $2.25 $/kg lwt primarily driven by the higher cost of fertiliser resulting in a lower positive margin of $0.53 $/kg lwt sold.

Figure 9. MLA Cost of Production Calculator for the Synthetic Fertiliser treatment.

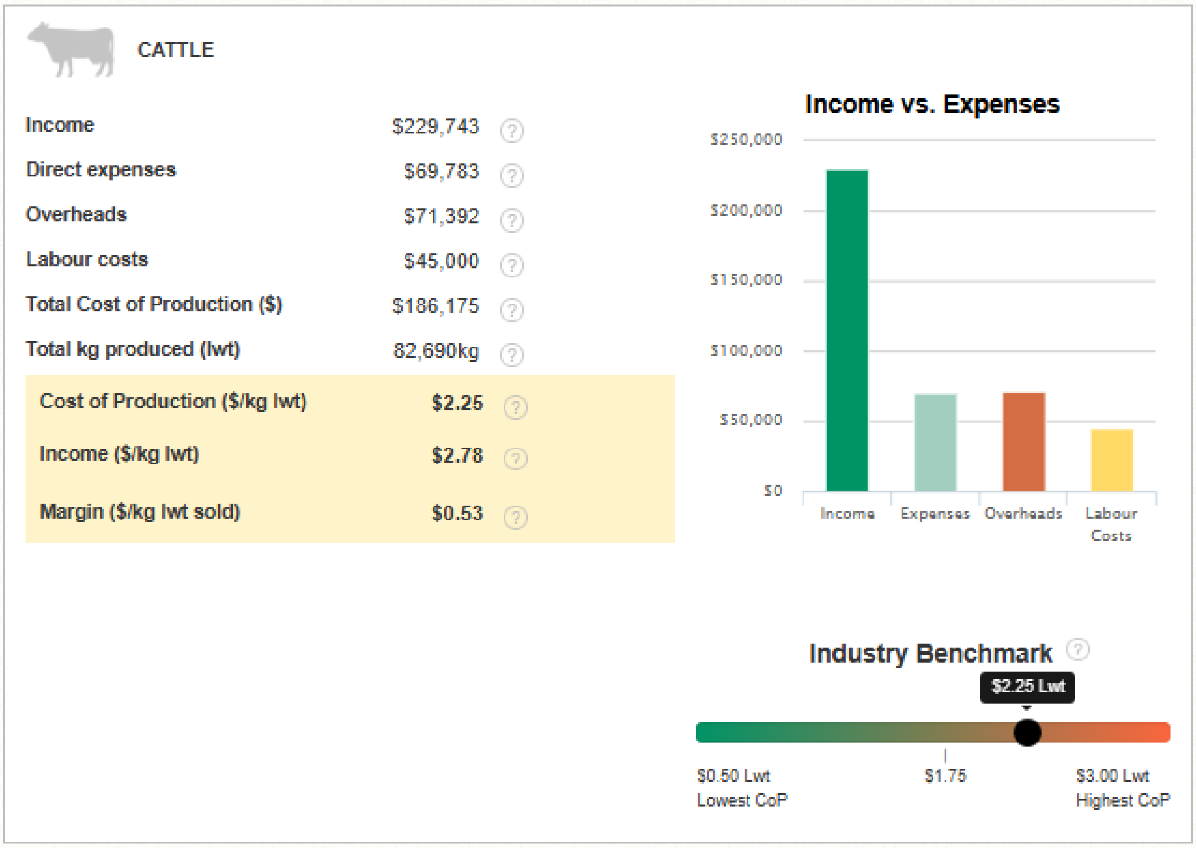


Figure 10. MLA Cost of Production Calculator for the Biomineral Fertiliser treatment.

5.6.3 Main Trial Site Benefit Cost Analysis Carbon Drivers

The Main trial site benefit cost analysis including carbon drivers covers the main trial site of the project. In terms of production for the commercial operation the cows are grazed across the pasture on the farm which is representative of the PDS's production/change in carbon rates. The calves are then weaned in late December and then put onto the irrigated pasture which is representative of the main trial site.

The change in soil carbon (%) can be used in a benefit cost analysis as change in carbon %'s can be directly calculated as a change in Australian Carbon Credit Unit's (ACCU) which can be valued as a change in value in terms of $/ha using the current market price for an ACCU.

Tables 46 and 47 below outline the change in soil carbon at the main trial site and PDS1 between the two sample points in time.

At the main trial site the weighted average change in soil carbon from 2022 to 2025 was:

- Biomineral: 0.33% increase in soil carbon
- Synthetic: 0.36% increase in soil carbon

At Producer Demonstration Site 1 the weighted average change is soil carbon from 2022 to 2025 was:

- Biomineral: -0.03% reduction in soil carbon
- Synthetic: -0.13% reduction in soil carbon

Table 48. Main trial site change in soil carbon (%) at each depth from 2022 - 2025

Main Trial Site - change in soil carbon % from 2022 - 2025						
		Change	Change	Change	Change	Change
Rep	Fertilizer	0-10	10-20	20-30	30-40	40-50
1	Biomineral	1.31	0.22	0.08	0.15	0.14
4	Biomineral	2.67	-0.06	-0.22	-0.05	-0.06
5	Biomineral	0.51	0.09	0.04	0.04	0.05
	Average	1.50	0.08	-0.03	0.05	0.04
6	Synthetic	2.58	-0.29	-0.28	-0.02	0.08
2	Synthetic	1.92	0.18	0.32	0.32	0.07
3	Synthetic	0.85	-0.17	-0.10	-0.03	0.02
	Average	1.78	-0.09	-0.02	0.09	0.05

Table 49. PDS 1 change in soil carbon (%) at each depth from 2022 - 2025

PDS1 - change in soil carbon % from 2022 - 2025						
		Change	Change	Change	Change	Change
Quadrant	Fertilizer	0-10	10-20	20-30	30-40	40-50
1	Biomineral	-0.33	0.12	-0.09	-0.04	0.10
2	Biomineral	-0.33	-0.07	0.02	-0.02	0.12
3	Biomineral	-0.34	0.30	0.06	-0.13	0.20
	Average	-0.33	0.12	0.00	-0.06	0.14
1	Synthetic	0.12	-0.24	-0.07	-0.08	0.18
2	Synthetic	-0.37	-0.95	-0.33	-0.07	0.05

3	Synthetic	-0.39	0.04	-0.08	0.02	0.15
	Average	-0.21	-0.38	-0.16	-0.04	0.13

5.6.4 Carbon Emissions Accounting

5.6.4.1 Carbon Emissions between Synthetic and Biomineral fertiliser operations

Carbon budgeting or Green House Gas emissions were modelled for the final year of the project to determine the impact of the different types of fertilisers on the carbon emissions on the overall farming operations.

This calculator chosen for determining the baseline GHG emissions was developed by the University of Melbourne and revised by Integrity Ag & Environment Pty Ltd and is intended for use in grazing beef cattle and sheep enterprises. It is referred to as:

A Greenhouse Accounting Framework for Beef and Sheep properties based on the Australian National Greenhouse Gas Inventory methodology Dunn J, et al (2020).

The drivers for the change in net green house gas emissions for the project are changes in:

1) Carrying or breeder capacity
2) Calf growth rates
3) Fertiliser use

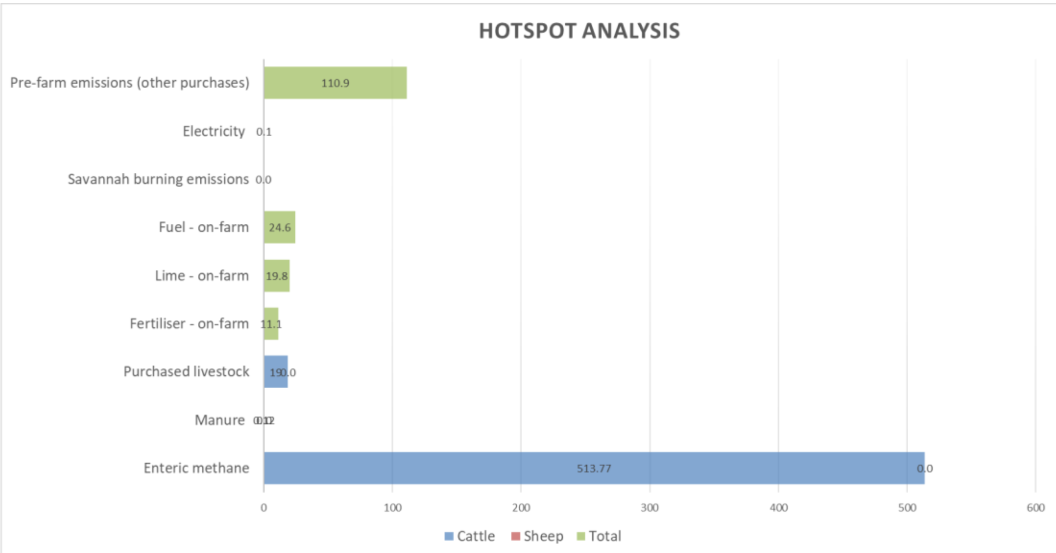


Figure 6. 2024 GHG emissions hotspot analysis for the Bridgetown operation using synthetic fertilisers (net farm emissions 790 t CO2e/farm).

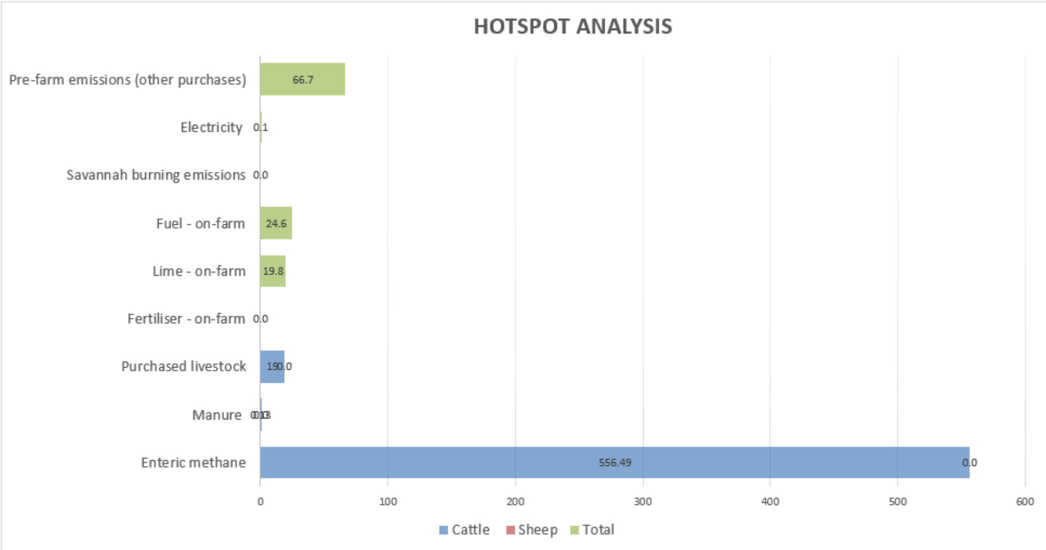


Figure 7. 2024 GHG emissions hotspot analysis for the Bridgetown operation using biomineral fertilisers. (net farm emissions 752 t CO2e/farm)

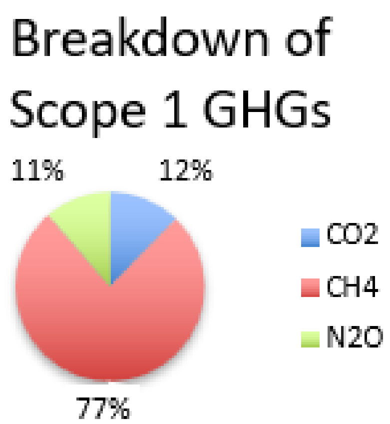


Figure 8. Breakdown of Scope 1 GHG's for 2024 hotspot analysis for the Bridgetown operation using biomineral fertilisers

Figure 6 and figure 7 detail the green house gas emissions from the farming operation the main trial site and PDS1 are held on. Figure 6 details the results in 2024 from the beef and sheep greenhouse accounting tool. It shows a net farm emissions of 790 tons of CO2 equivalent per annum when using synthetic fertilisers.

Figure 7 details the results in 2024 from the beef and sheep greenhouse accounting tool. It shows a net farm emissions of 752 tons of CO2 equivalent per annum when using biomineral fertilisers, a fall of 38 tons of CO2 equivalent per annum. The reduction in emissions is a result of the lower emissions attributed to purchased fertiliser, largely due to the reduced application if nitrogen. The reduction more than offsets the increase in emission due to the higher number of cows/breeders as a result of the increase in pasture production.

To calculate an operations net emissions the impact of the change in soil carbon needs to be overlayed onto the production emissions.

5.6.4.2 Carbon sequestration required to be carbon neutral for biomineral and synthetic fertiliser operations

The Main Trial Site results include the small plot trial and the Bridgetown PDS. The main trial site is located on a 194 hectare property and operates a 180 cow beef breeder cattle herd.

The results from the beef and sheep greenhouse accounting tool show an output of:

Synthetic fertiliser emissions:

- 790 tons of CO2 equivalent per annum
- 4.34 tons of CO2 equivalent per breeding cow
- 4.07 tons of CO2 equivalent per Ha

Biomineral fertiliser emissions:

- 752 tons of CO2 equivalent per annum
- 4.02 tons of CO2 equivalent per breeding cow
- 3.87 tons of CO2 equivalent per Ha

What is required to offset the GHG emissions from the Bridgetown property in terms of increasing soil organic carbon for each fertiliser system? Every one ton of soil organic carbon sequestered is equivalent to 3.67 ton of carbon dioxide equivalents. Soil bulk density is assumed at 1.3 t/m3 and the calculation accounts for the change in carbon within the top 50cm of soil. 1% soil organic carbon is equal to 65 tons of carbon/ha.

Synthetic fertiliser

4.07 ton of CO2e/ha emissions = 1.11 ton of soil organic carbon

Therefore 1.11 tons of soil organic carbon is required to be sequestered to offset the 4.07 ton of CO2e/ha emissions:

or

0.017% soil carbon sequestration is required in year one for carbon neutrality using synthetic fertiliser. (Edward T, 2021)

Biomineral fertiliser

3.87 ton of CO2e/ha emissions = 1.05 ton of soil organic carbon

Therefore 1.05 tons of soil organic carbon is required to tbe sequestered to offset the 3.87 ton of CO2e/ha emissions:

or

0.016% soil carbon sequestration is required in year one for carbon neutrality using synthetic fertiliser. (Edward T, 2021)

5.6.4.3 Carbon Emissions accounting between Synthetic and Biomineral fertiliser operations including change in soil carbon

The drivers to calculate the total CO2e emissions for each fertiliser regime including both the commercial production operations and the change in soil carbon levels to 50cm.

At the main trial site the weighted average change in soil carbon from 2022 to 2025 to 50cm was:

- Biomineral:
  1. 0.33% increase in soil carbon
  2. 21.45 ton carbon/ha
  3. 78.72 ton CO2e/ha
- Synthetic:
  1. 0.36% increase in soil carbon
  2. 23.4 ton carbon/ha
  3. 85.87 ton CO2e/ha

At Producer Demonstration Site 1 the weighted average change in soil carbon from 2022 to 2025 to 50cm was:

- Biomineral:
  1. (0.03)% reduction in soil carbon
  2. (1.95) ton carbon/ha
  3. (7.16) ton CO2e/ha

- Synthetic:
  1. (0.13)% reduction in soil carbon
  2. (7.45) ton carbon/ha
  3. (27.34) ton CO2e/ha

Commercial cattle production operation CO2e emission:

- Biomineral: 3.87 tons of CO2 equivalent per Ha
- Synthetic: 4.07 tons of CO2 equivalent per Ha

The combined carbon emissions calculation for the commercial operation is detailed below

Table 50. Annual Carbon Emissions accounting between Synthetic and Biomineral fertiliser operations including change in soil carbon for the Bridgetown commercial operation

	Biomineral	Synthetic
MTS		
Area ha	24	24
change in C02e/ha	78.72	85.87
total change (3 years)	1889.28	2060.88
Annual change	629.76	686.96
Dryland production area	170	170
change in C02e/ha	-7.16	-27.34

total change	-1217.2	-4647.8
Annual change	-405.7	-1549.3
Cattle production emissions area	194	194
change in C02e/ha	-3.87	-4.07
total change	-750.78	-789.58
Combined emissions tons CO2e	**-526.8**	**-1651.9**
Emissions tons CO2e/ha	**-2.71**	**-8.51**

The annual carbon emissions between 2022 and 2025 under each fertiliser regime are detailed in table 48. The production system using biomineral fertiliser emits a net 526.8 tons of CO2e per year across the 194 ha property or 2.71 tons of CO2e/ha compared to the production system using synthetic fertiliser emitting a net 1651.9 tons of CO2e or 8.51 ton CO2e/ha.

The primary drivers for the reduced emissions under the biomineral fertiliser system are the much smaller decline in soil carbon across the dryland area of the farm compared to the synthetic fertiliser and the reduced emissions in the cattle production system as a result of reduced nitrogen fertiliser application.

5.6.5 Main Trial Site or Whole of Farm BCA including Carbon Emissions and Change in Soil Carbon

The benefit cost analysis showed a difference in margin between the two systems in the final year of the project at $0.26 ($/kg lwt sold) (table 49). The cost of production under the synthetic fertiliser is $1.99 ($/kg lwt) compared to the biomineral fertiliser cost of production which is $2.25 ($/kg lwt).

The impact of the change in soil carbon on the two fertiliser regimes on the BCA can be calculated utilising the change in ACCU (CO2 equivalent) at the spot price. The change in total income is:

Table 49. The calculation for the benefit cost analysis of the two fertiliser regimes adjusted for the change in soil carbon

	Biomineral	Synthetic
Cattle sales income:	$229,743	$226,263
Carbon emissions as ACCU's	-3.87	-4.07
Change in Soil Carbon/ha as ACCU's	1.16	-4.44
ACCU value ($ at 13/8/25)	$35.90	$35.90
Change in Soil Carbon ($/ha)	-$97.29	-$305.51
Total ha	194	194
Change in income due to soil carbon	-$18,874.26	-$59.268.94
Total income	$210,868.74	$166,994.06

Total kg produced (lwt)	82,690	81,610
Cost of Production ($/kg lwt)	**$2.25**	**$1.99**
Income ($/kg lwt)	**$2.55**	**$2.05**
Margin ($/kg lwt)	**$0.30**	**$0.06**

By overlaying the annual carbon sequestration and emissions over the different fertiliser regimes on the benefit cost analysis the outcome is changed significantly. The biomineral fertiliser regime generates a profit of $0.30/kg lwt while the synthetic fertiliser regime returns a smaller profit of $0.06/kg lwt.

It is important to note that the above calculations are hypothetical for the purpose of the project in an effort to put a dollar value on emissions and the change in soil carbon between the different fertiliser treatments. The changes in soil carbon are not statistically significantly and so must be considered in this context .

It is also worth considering that if the project outcomes were to be realised inside a soil carbon project, there are discounts against ACCU generation that are incurred in ERF projects which reduce the income, plus considerable costs which are incurred when running a carbon project. The reduced income and expenses have not been accounted for in the analysis of the results.

6. Conclusion

This project provide an in-depth comparison of biomineral fertilisers against conventional synthetic fertilisers in terms of productivity, soil health, carbon outcomes, and profitability. The findings are mixed, but they provide valuable insights for both producers and the wider red meat industry.

Soil Carbon and Emissions
Across all sites and trials, there was no significant difference in soil carbon sequestration between biomineral and synthetic fertilisers during the three-year project period. Both systems recorded small changes in soil carbon, with outcomes largely influenced by seasonal rainfall variability and unusually high baseline carbon levels at the project's commencement. While the hypothesis that biominerals would increase sequestration above synthetic fertilisers was not supported, whole-farm greenhouse gas modelling indicated that the biomineral system delivered a modest reduction in net emissions compared with synthetics. This was due to lower fertiliser-related emissions rather than enhanced sequestration.

Pasture Production
Pasture growth across the main trial site, small plot trial, and producer demonstration sites showed that biomineral fertilisers can maintain production levels equivalent to synthetic fertilisers. Production levels were maintained under the biomineral fertiliser regime despite the reduction in nutrient application rates. Differences between treatments were minor and inconsistent across years and locations. For producers, this result is important; switching to biomineral fertilisers does not come at a cost to overall pasture productivity.

Feed Quality
Feed quality results were more variable. Synthetic fertilisers generally produced higher crude protein and metabolisable energy values across the main trial site and small plot trial. However, at some producer demonstration sites, particularly Bridgetown and Witchcliffe, the biomineral treatments recorded improvements in crude protein, digestibility, and metabolisable energy in later

years, suggesting potential longer-term soil biological benefits may not have been fully expressed within the three-year timeframe.

Cattle Production
Livestock growth rates were consistent across fertiliser treatments. Average daily liveweight gains were statistically equivalent, demonstrating that biomineral fertilisers can sustain cattle production at levels comparable to synthetics. This is a key result, as it shows that productivity can be maintained under a biomineral system without compromising animal performance.

Economic Outcomes
The greatest limitation identified in the results is cost. Biomineral fertilisers were consistently more expensive than synthetic fertilisers across all sites. It is worth noting the costs associated with the small plot trial should not be analysed in a commercial manner as the trail was designed to match the nutrient inputs levels and not to apply the fertilisers at best practice or at commercially optimal rates. Future work should include testing the fertiliser application rate response of biomineral fertilisers to examine at what rates production drops and or increases.

The high costs associated with the biomineral fertilisers eroded profitability, even though productivity was maintained. While there may be potential for application rates to decline over time as soil biological activity improves, this was not examined or demonstrated within the project period.

Adoption Insights
The project was unsuccessful in achieving the targeted value proposition objectives of increasing soil carbon by 1.4% in 3 years in the SW Western Australia >600mm rainfall. There were however several positive adoption insights, listed below, that were drawn from the project. There is strong interest from producers to understand the net carbon position of their operation and strategies that can be implemented to reduce the net position including changing fertiliser practices.

i. 81.4% of all core and observer producers increased their knowledge around biomineral fertilisers, soil carbon, strategies to increase it and carbon accounting by an average of 28.1%.
ii. 75.53% of livestock producers are considering the importance of implementing production system changes to reduce operational greenhouse gas emissions within their business.
iii. 70% of the core producers have trialled or have started the process to implement a new fertiliser regime.
iv. The results from the survey highlighted that a high number of smaller land holding producers already do or are in the process of implementing an alternative fertiliser regime away from synthetic fertilisers as they are not driven by economics and are largely undeterred by the finding of this project.

Overall Conclusion
The results demonstrate that biomineral fertilisers are a technically viable alternative to synthetic fertilisers for pasture-based livestock systems. They maintained productivity and supported equivalent animal performance, while offering modest greenhouse gas reductions. However, they did not deliver superior soil carbon sequestration within the project timeframe, and their higher cost limited profitability relative to conventional systems.

For the red meat industry, these findings suggest that biomineral fertilisers could form part of a sustainable production strategy, particularly if cost barriers are reduced and if longer-term benefits to soil health and feed quality are confirmed. Adoption will depend on demonstrating durable carbon outcomes and achieving cost competitiveness with synthetic fertilisers.

6.1 Key findings

- **Pasture Production** – Biomineral fertilisers maintained comparable yields to synthetic fertilisers, with no productivity penalty observed across sites, despite significantly less nitrogen being applied.

- **Feed Quality** – Mixed results were recorded, with synthetic fertilisers generally producing higher crude protein and metabolisable energy, though some sites showed improvement under biomineral treatments over time.

- **Cattle Production** – Growth rates were statistically equivalent between fertiliser types, confirming that biomineral fertilisers can sustain livestock productivity.

- **Soil Carbon** – The use of a biomineral fertiliser did not increase soil carbon sequestration above that of an synthetic fertiliser within the first three years of changing from an synthetic fertiliser to a biomineral fertiliser system.

- **Green House Gas Emissions** – Whole-farm greenhouse gas modelling suggested a slight reduction in net emissions under the biomineral system.

- **Economic Performance** – Biomineral fertilisers were consistently more costly than synthetics, reducing short-term profitability despite maintaining productivity.

6.2 Benefits to industry

1. **Maintained Productivity with Reduced Emissions Risk**
    - Results confirm that biomineral fertilisers can maintain pasture and livestock productivity at levels comparable to synthetic fertilisers.
    - Whole-farm greenhouse gas modelling showed modest reductions in emissions, providing producers with a potential pathway to demonstrate improved sustainability credentials.
    - Increasing demand from consumers and supply chains for low-emission, environmentally responsible production systems means biomineral fertilisers may offer a reputational advantage.

2. **Soil Health and System Resilience**
    - Biomineral fertilisers were linked to improved pasture quality at some sites, and non-significant evidence suggests potential long-term soil biological benefits.
    - Such benefits could build greater resilience against variable rainfall and soil degradation pressures, important for industry sustainability and productivity under changing climatic conditions.

3. **Producer upskilling**
    - Producers were upskilled in there knowledge and ability to quantify the feedbase productivity differences, or lack of, between alternative fertilisers and synthetic fertilisers. Additionally, the project upskilled producers in the method of generating a benefit cost analysis model should they implement an alternative fertiliser regime.
    - Producers were also upskilled in a method to generate there own farm operation carbon emissions output and the different key inputs that impacted this output.

7. Future research and recommendations

1. Long-Term Carbon Monitoring

- Extend trials beyond three years to capture potential soil carbon responses to biomineral fertiliser use in the long term, particularly under variable soil and seasonal conditions.

2. Optimising Fertiliser Application Rates

- Conduct biomineral application rates trials to determine the optimal application rates, based on both production and cost.
- Evaluate whether higher initial application rates of biomineral fertilisers are necessary to achieve purported outcomes.

3. Broader Regional Testing

- Dependent on future work being completed around optimising application rates and cost alignment, then the further research would involve:
  - Expand testing across multiple agricultural zones and soil types to confirm consistency of results and identify where biominerals perform best.
  - Include both high-rainfall and low-rainfall environments to capture the role of climate variability in outcomes.

4. Target soil with lower baseline soil carbon level

- Complete the experiment again but target a soil with lower baseline soil carbon levels which should give an increased opportunity for the soil to sequester carbon.

5. Integration with Alternative Practices

- Study synergistic effects of biominerals combined with organic amendments (e.g., compost, manure, biochar) and optimum grazing practices.
- Determine whether such integration influences soil carbon sequestration and pasture nutrient density.

8. References

Black, J.L.; Davison, T.M.; Box, I. Methane Emissions from Ruminants in Australia: Mitigation Potential and Applicability of Mitigation Strategies. Animals 2021, 11, 951. https://doi.org/10.3390/ani11040951.

Durmic, Z., Duin, E.C., Bannink, A., Belanche, A., Carbone, V., Carro, M.D., Crüsemann, M., Fievez, V., Garcia, F., Hristov, A. and Joch, M., 2025. Feed additives for methane mitigation: Recommendations for identification and selection of bioactive compounds to develop antimethanogenic feed additives. Journal of dairy science, 108(1), pp.302-321.

Durmic, Z., Hutton, P., Revell, D.K., Emms, J., Hughes, S. and Vercoe, P.E., 2010. In vitro fermentative traits of Australian woody perennial plant species that may be considered as potential sources of feed for grazing ruminants. Animal Feed Science and Technology, 160(3-4), pp.98-109.

Janssen, P. H. 2010. Influence of hydrogen on rumen methane formation and fermentation balances through microbial growth kinetics and fermentation thermodynamics. Anim. Feed Sci. Technol. 160:1–22.

Moate, P.J.; Williams, S.R.O.; Deighton, M.H.; Wales, W.J.; Jacobs, J.L. Supplementary feeding of wheat to cows fed harvested pasture increases milk production and reduces methane yield. In Proceedings of the 5th Australasian Dairy Science Symposium, Hamilton, New Zealand, 19–21 November 2014; pp. 176–178.

Sun, X., Cheng, L., Jonker, A., Munidasa, S. and Pacheco, D., 2022. A review: Plant carbohydrate types—The potential impact on ruminant methane emissions. Frontiers in Veterinary Science, 9, p.880115.

9. Appendix

9.1 Soil Testing Results

9.1.0 2022 data

Appendix 1 – 2022 – Soil EC (Salinity) and pH

Appendix 2 – 2022 – Soil Texture

Appendix 3 – 2022 – Carbon and Nitrogen

Appendix 4 – 2022 – Mehlich Data

Appendix 5 – 2022 – Soil health data

9.1.1 2024 data

Appendix 6 – 2024 – C _N data

Appendix 7 – 2024 – Soil health data

9.1.2 2025 data

Appendix 8 – 2025 – Carbon and Nitrogen

Appendix 9 – 2025 – Soil nutrients data

Appendix 10 – 2025 – Soil Health

Appendix 11 - 2025 – Gravel, pH and EC

9.2 Fertiliser Applications

Appendix 12 – Fertiliser application summary

9.3 Cattle Production Data

Appendix 13 – MLA cattle prod trial all data

9.4 Cattle Production Data

Appendix 14 – Exit survey response answer summaries pt 1

Appendix 15 – Exit survey response answer summaries pt 2

Appendix 16 - Exit survey response answer summary