Final report

Improving profit from pasture through increased feed efficiency

Project code:P.PSH.1000

Prepared by:
E. Charmley, C. McSweeney, F. Alvarenga, P. Greenwood, S. Denman, G. Bishop-Hurley

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Meat & Livestock Australia Limited
PO Box 1961
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Abstract

Feed efficiency underpins the profitability of beef enterprises. Efficient conversion of nutrients into beef influences growth and reproductive performance. For pasture-based beef enterprises the drivers that influence efficiency are poorly understood. Through an integrative approach including grazing behaviour and efficiency, feedbase evaluation and digestive performance in the rumen this project aimed to identify key factors that showed demonstrative improvements in efficiency in both temperate and tropical conditions. These drivers were examined through series of co-ordinated studies. Key nutrient deficiencies were identified, and tactical supplementation devised. Measurement is impossible without knowing feed intake. This knowledge gap of measuring efficiency on pasture was addressed with development of new understanding of grazing behaviour and pasture intake using on-animal sensors. The interplay between the diet, grazing behaviour and rumen fermentative efficiency was revealed through integrated pasture-pen feeding experiments that quantified the relative importance of genotype, animal behaviour and digestive efficiency. The project has produced novel supplementation strategies, novel pasture intake methods and new insights into efficiency on pasture. These outputs will require ongoing development and adoption with commercial and industry partners.

Executive summary

Background

Production efficiency is a key focus for industry transformation as it provides the most cost-effective approach to increase production and profitability whilst achieving reduced GHG emissions intensity. This multi-component, interdisciplinary project aims to produce more efficient grazing cattle through understanding the rumen digestive/microbiome complex, grazing behaviour and pasture intake.

With a focus on Horizon 3 research (new knowledge), the project develops new and innovative outcomes for uptake by commercial entities driving innovation in the industry (Horizon 2 – extends existing knowledge). At the same time, key, readily adoptable outcomes are generated throughout the project that have ready application with producers.

The results will increase understanding of grazing efficiency, develop methods to measure efficiency and develop potential novel supplementation strategies. Commercialisation of the outcomes and integration with the feeding standards project P.PSH.0998, will provide the industry with a suite of new tools to allow pasture-based systems of red meat production to remain competitive into the future.

Objectives

This project studied ruminant efficiency, acknowledging the interplay between characteristics of the pasture sward, animal behaviour and the resulting digestive efficiency in the animal across the grazing life of an individual within a herd. This proposal delivers outcomes under a series of integrated experiments in five key areas:

- next generation supplementation for optimum ruminant function,
- survey of breeder properties to determine nutrient deficiencies,
- refining a pasture intake measurement tool based on grazing behaviour,
- identifying superior efficiency rumen phenotypes, and
- Identifying traits for superior grazing efficiency.

Methodology

An integrated approach was used that included:

- Herd surveys to identify key nutrient deficiencies and structured feeding trials to address these deficiencies
- Development of grazing behaviour algorithms using on animal sensors to measure intake in temperate and tropical pastures
- Integrated grazing studies to understand the relative importance of the phenotype, the diet and the animal behaviour in determining feed efficiency on pasture.

Results/key findings

The research demonstrates positive benefits for industry that have significant impact when implemented in a co-ordinated, additive fashion. These include,

- the provision of methyl donors to nutritionally stressed breeders can influence calf performance in the short and potentially long term
- an algorithm that can predict pasture intake from a combination of grazing behaviours including time spent grazing, ruminating and bite rate
- identification of key pasture/animal factors that contribute to performance on pasture with the objective of using key indicators to predict future performance.

Benefits to industry

The adage "you can't manage what you can't measure" is particularly relevant for the grazing industry. This research demonstrates that previously unmeasurable components of the pasture/animal interface influencing performance and efficiency can now be measured. The path to adoption for these developments will involve intermediary development with the private agri-sector, research and development corporations (RDCs), state departments and the entrepreneurial spirit of early adopters in the industry. Outputs of this project will help the industry adopt an integrative management model that embraces new technology and understanding. This will lead to improved pasture management and profitability of grazing beef enterprises.

Future research and recommendations

The outcomes of this project were expected to be further developed through a continuation of the Livestock Productivity Partnership. It is strongly recommended that targeted support will be required to ensure adoption. A mixed model that includes researchers, RDCs, agri-tech companies, feed manufacturers, extension and consultancy agents and producers in a co-operative development and extension model is envisaged. A successful MDC model could be a suitable vehicle to allow this to happen.

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1 Background

At the time of project development we envisaged an integrated R, D and A network to accelerate production efficiency gains and concomitant environmental benefits in the ruminant industries to meet the goals outlined in the Meat Industry Strategic Plan (MISP 2020). It blends near-market, medium-term and long-term R&D into a framework of continuity for an outcome driven research agenda. It will identify gaps in understanding and link nutrition to the genetic potential and ensure integration of Horizon 3 research in the rumen.

Production efficiency is a key focus for industry transformation as it provides the most cost-effective approach to grow production and profitability whilst achieving reduced GHG emissions intensity. For instance, a 1 kg change in carcass weight of beef is valued at $100 m to the industry; an increase in market specification and compliance is valued at $51 m pa and an increase of 1% in weaning rate of cattle is valued at $50 m pa. The sheep industry strategic plan projects an increase in industry value on-farm of $100 m by 2020 through implementing improvements in efficiency that reduce cost of production through increased weaning percentage, achieving realised genetic gain and increased live weight gain due to improved nutrition. Such changes would reduce intensity of GHG emissions by at least 2.5%. If change in production efficiency is to occur, coordinated investment across a spectrum of research initiatives is now required. Much of the near market investment through industry levy is focussed on short and medium-term operational research. But to achieve the gains required in production efficiency to make a major impact on farm incomes, a blend of operational and strategic-basic research is required.

Agricultural policy is currently driven by the acknowledgement that the sector needs to increase farm production and profitability concurrent with reducing its resource requirements. This is partly driven by the consumer and partly by the industry itself focussing on policies that increase the sectors' financial returns. Effective and detailed consultation on the development of a research agenda focussed on production efficiency was undertaken in 2016 by CSIRO, UWA and, NSW DPI. This project, together with the LPP project P.PSH.0998 "Revise Australian feeding standards to better achieve product specifications and improve ruminant efficiency" emanated from that groundwork.

If change in production efficiency is to occur, coordinated investment across a spectrum of research initiatives is now required. This project studied ruminant efficiency, acknowledging it is an interplay between the characteristics of the pasture sward, the behaviour of the animal and the resulting digestive efficiency in the animal across the grazing life of an individual within a herd. The program encompasses in depth, discovery science linked to broader field-scale production studies. The Design Led Thinking approach was considered and modified to ensure long term producer profitability, sustainability, and global competitiveness for the sector. As a problem-solving methodology it was well-suited at the outset for investigating ill-defined problems that is human-centred, possibility-focused, and hypothesis-driven.

This multi-component, interdisciplinary project is leading to more efficient grazing cattle through understanding the rumen digestive/microbiome complex, grazing behaviour and pasture intake, and by applying this knowledge to practical feeding and management programs. The team collaborated with commercial cattle enterprises and genomic resource projects to develop a range of discovery and application studies that allow exploitation of the microbiome/animal-pasture interface to increase feed conversion efficiency and utilisation of pasture by grazing cattle.

The project has engaged with agri-tech providers (CeresTag) feed companies (DSM, Ridley) and pastoralists (AACo, NAPCo) to evaluate new products and grazing techniques that require the integrated rumen-animal-pasture interactions to understand mechanisms behind increased productivity. Throughout the project we:

1) used Design Led Thinking methodology with producers and stakeholders

2) sought alignment of study sites to cover geographic and climatic variability

3) included program wide coordination of engagement events

4) coordinated adoption/extension activities with other LPP projects.

2 Objectives

This project studies ruminant efficiency, as interplay between the characteristics of the pasture sward, the behaviour of the animal and the resulting digestive efficiency in the animal across the grazing life of an individual within a herd. This proposal delivers outcomes under a series of integrated experiments in five key areas:

- next generation supplementation for optimum ruminant function,
- survey of breeder properties to determine nutrient deficiencies,
- refining a pasture intake measurement tool based on grazing behaviour,
- identifying superior efficiency rumen phenotypes, and
- Identifying traits for superior grazing efficiency.

The program encompasses discovery science to generate new knowledge linked to field-scale production studies. The detailed discoveries were tested and applied in production-scale grazing trials. Likewise detailed grazing behaviour studies informed rumen studies regarding the nature and patterns of feed entering the rumen on a time scale from hours to seasons. Under extensive grazing conditions the animal is free to express a range of grazing behaviours depending on the area of the paddock, the heterogeneity of the sward and the amount and quality of feed on offer. At this macro-level we explored the influence of genotype, grazing behaviour, and management to study seasonal response in grazing efficiency, pasture intake, rumen digestion and performance. This information provided broad direction for the discovery science that in turn informed modified field studies with practical applications. Knowledge and tools from rumen and grazing studies informed and designed the measurements and observations used in the field scale studies. Variability in grazing efficiency and growth efficiency was characterised within and between genotypes.

The Design Led Thinking (DLT) approach was one of several attempts to quantify adoption, ensuring long term producer profitability, sustainability and global competitiveness for the sector. It is a problem-solving methodology especially well-suited for investigating ill-defined problems that is human-centred, possibility-focused, and hypothesis-driven. As the project developed DLT was adapted to meet the specific requirements of Horizon 2 and 3 research which covers much of the science in this project. To assist DLT an industry and scientific oversight committee was considered.

However, the overhead in terms of time and cost was considered too much and a more informal canvassing of key producers and advisors was used as a less cumbersome and more agile method for ground-truthing the research agenda. A meeting was held with the MLA adoption team on 29th May 2018 in Armidale where it as agreed to work in synergy with the MLA to ensure effective communication of the research project with potential end-users of the technologies developed.

Animal Ethics approval was sought through the relevant committees for the various experiments throughout the project. Projects, committee and approval numbers are listed below:

1. Next generation Supplements (CSIRO):

- 2018-35 (CSIRO QUEENSLAND ANIMAL ETHICS COMMITTEE)

2. Nutrient deficiency survey (CSIRO):

- CSIRO Wildlife and Large Animal AEC).
- Small-scale experiments (CSIRO/NSW DPI) CSIRO Wildlife and Large Animal AEC).
- ARA 18/20 Increasing Profit from Pasture through Increased Feed Efficiency: Livestock Productivity Partnership project Year 1
- ARA 19/18 Increasing Profit from Pasture through Increased Feed Efficiency: Livestock Productivity Partnership project YEAR 2
- ARA 20/19 Increasing Profit from Pasture through Increased Feed Efficiency: Livestock Productivity Partnership project YEAR 3
- ARA 21/20 Increasing Profit from Pasture through Increased Feed Efficiency: Livestock Productivity Partnership project YEAR 4
- ARA 22/10 Increasing Profit from Pasture through Increased Feed Efficiency: Livestock Productivity Partnership project YEAR 5

Field-scale measurements (Townsville; CSIRO) CSIRO Wildlife and Large Animal AEC).

- ARA 2019-33 Superior phenotypes based on Rumen Function and Grazing Efficiency.

2.1 Next generation supplements

Typically, commercial supplements that are used in northern Australian beef enterprises contain macro-nutrients (crude protein, sulphur, and phosphorus) to correct deficiencies in these nutrients from the forage. However, other nutrients are also important as the source of labile methyl groups (e.g., methionine, choline and methionine co-factors) which are essential for animal tissue metabolism, foetal development and immune function by altering DNA synthesis and gene expression. Poor nutrition in the late dry season and increased nutrient requirements during the onset of lactation in northern production systems likely leads to a shortfall in methionine, choline or cobalt/Vit B12 co-factors. Our hypothesis is that supplementation of undernourished pregnant cattle with methyl-donor compounds that were protected from rumen metabolism (RP) and co-factors will improve rumen efficiency and the metabolic and immune status of the cow resulting in an increase of productivity gains of offspring later in life.

While the rumen microbiota has a specific requirement for these nutrients it is well established that organic forms of nitrogen (e.g., peptides and amino acids) and sulphur (e.g., S containing amino acids such as methionine) are used more efficiently for growth and function of the rumen than the inorganic nutrients. Apart from the benefits of these organic nutrients to rumen efficiency, some (e.g., methionine) are also important as the source of labile methyl groups which are essential for animal tissue metabolism. Methylation of DNA is a critical epigenetic modification influencing metabolism, immune function, and overall health of animals. Dietary deprivation of one or more methyl-group containing nutrients can alter tissue metabolism, fetal development and immune function at least in part by altering DNA synthesis and gene expression. Therefore, the major methyl donors in the diet (methionine, choline, folate) and the associated co-factor (Vitamin B12) help maintain the pool of methyl groups for the animal tissue through the synthesis of homocysteine. The supply of vitamin B12 which is synthesised by the rumen bacteria is also dependent upon adequate nutrition to the rumen especially cobalt availability. However, the net absorption of these compounds is often inadequate to meet requirements for methyl donor compounds needed by the animal. So, in summary deficiencies of one or more methyl donors (methionine, choline/betaine and folate) or the co-factor Vit B12 can alter DNA synthesis and methylation.

The transition from pregnancy to lactation represents a stage where the demand for methyl groups is markedly increased. Poor nutrition in the late dry season and increased nutrient requirements during the onset of lactation in northern production systems likely leads to a shortfall in methionine and choline and thus a deficiency in methyl groups for tissue metabolism and perhaps a deficiency in cobalt/Vit B12 which is an essential co-factor required for the formation of methionine. Positive effects of supplementing rumen-protected methionine (RPM) have been observed in terms of increased milk production, feed intake, and milk fat yield as well as a better immune-metabolic status in dairy cattle. Data revealed that RPM supplementation up-regulates DNA methyl transferases and other metabolic genes in the 1-carbon metabolism pathway during the peri-parturient period. Clearly, methyl donor supplementation to the pregnant heifer/cow in the late dry season could have implications at the molecular level not only in the mother but also the developing fetus and calf, for it has been reported that maternal diet during pregnancy induces DNA methylation changes in fetal tissues in ruminants.

Deficiency in supply of labile methyl groups to the animal tissue can be diagnosed as both high plasma homocysteine and methylmalonic acid levels but measurements have not been recorded from cattle in northern Australia.

This project identified the key nutrients/co-factors that need to be fed to the rumen when supply of compounds such as methyl groups to the tissues is limiting productivity in breeder cow operations. The hypothesis is that supplementation of undernourished pregnant cattle with methyl-donor compounds and co-factors will improve rumen efficiency and the metabolic and immune status of the cow resulting in an increase in re-conception, and productivity gains of offspring later in life. We tested elements of this hypothesis using a typical group of pregnant heifers in a pen feeding study at Lansdown Research Station where animals were provided poor quality roughage hay.

The treatments with methyl donor compounds were provided at different stages of pregnancy and impacts on cow and calf performance monitored. Detailed measurements of rumen function and blood metabolites were conducted to elucidate the mechanisms involved and their relationship to animal efficiency. An optimized supplement cocktail was developed for inclusion into lick-block formulations. This study linked with related work being conducted in LPP by Prof Hegarty in western Queensland (J12691 - Optimizing nutritional supplement use in Australia’s northern beef industry)

2.2 Nutrient deficiency field survey

In conjunction with the next generation supplementation trial, a survey of commercial cattle operations in eastern Australia identified regions where deficiencies in methyl donors and co-factors exist that may be responsive to the supplementation strategies identified from the pen feeding studies. Covid 19 restrictions curtailed travel. Therefore, legacy samples collected from sites across Queensland were used. These were augmented with samples from cattle being sampled for rumen, tissue, and faecal material through linkage to related projects in LPP. By the end of this project locations were identified that could form the basis of demonstration sites for the new technology under industry conditions. The outputs from the pen feeding trial (rumen and tissue markers for methyl donor deficiency in pregnant cows) could be used to guide the sampling regime for a future survey trial.

2.3 Intake measurement

Feed efficiency cannot be determined on pasture without a knowledge of both the output (e.g., kg gain) and the input (e.g., DM intake). Identifying the superior phenotype under grazing requires the development of a reliable method of determining intake on pasture. Analysis of the GPS data from collars was used to develop an algorithm attuned to both southern and northern grazing conditions. The collar components are shown in Figure 1.

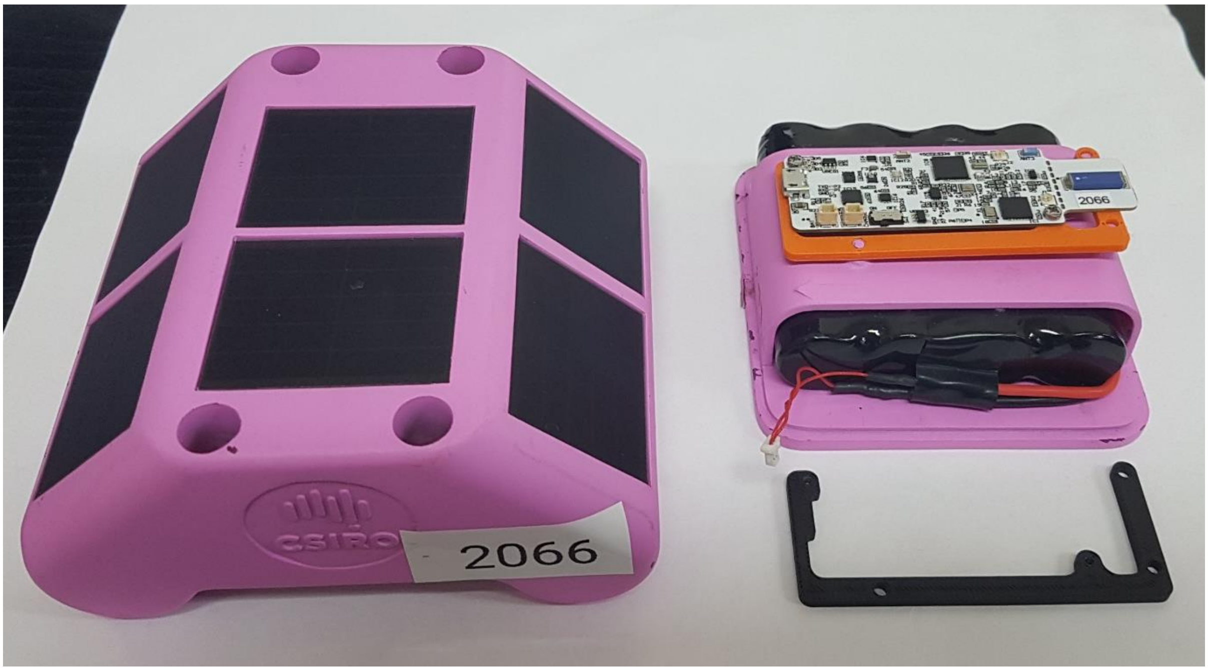


Figure 1*. Image showing Loci2 printed circuit board attached using orange adaptor bracket to existing enclosure. A black version of the bracket is also shown bottom right of image*.

The objective of this activity was to validate and refine systems to quantify the feed intake of grazing cattle using digitally equipped sensor devices linked to a wireless sensor network. Data on GPS position, direction and speed of movement, position and movement of the head (up versus down, side to side), bite rate can be recorded in real time to characterise grazing behaviour and from this, feed intake. Behaviour-based algorithms have been developed to infer feed intake from grazing behaviour under temperate and tropical conditions. The intake algorithm that was developed for temperate grazing systems by CSIRO and NSW DPI (International Patent Application No. PCT/AU/050569 “System for Monitoring Pasture Intake” (CSIRO and NSW DPI)) was refined and improved with the addition of new data and variables and tested from small scale to commercial scale environments. Concurrent developments included the adoption of machine learning to expedite algorithm development and on-device data processing to reduce the size of data to be transmitted via telemetry. This work is ongoing and will be completed and reported in the final report in January 2023.

The interactions between grazing behaviour and sward characteristics were studied in relation to pasture intake. Detailed information has been collected on the sward using remote sensing that integrates data from multispectral and radar images. Together with ground-based validation using sward measurements and NIR analysis of faeces and herbage, a complete picture is built of the sward characteristics which, when linked to animal behaviour over time, elucidates environmental factors influencing intake. Meanwhile these characteristics of behaviour and intake will influence ruminal digestion which will be studied in the grazing animal to quantify the impact of animal behaviour on rumen function and efficiency.

2.4 Superior rumen phenotyping

In this component of the project learnings from the next generation supplement trial and the survey assisted in planning measurements of the rumen and grazing behaviour. Research was conducted under controlled (pens) and semi-controlled (replicated paddocks) conditions in divergent groups of cattle selected as high and low productivity phenotypes from commercial grazing operations in both southern and northern Australia. Previous studies have demonstrated the complex interactions between the sward, grazing behaviour, rumen fermentation and microbiology and animal performance, consequently the rumen and grazing components of the work were super-imposed on a common grazing research platform.

2.4.1 Rumen Function

Central to grazing efficiency is the functioning of the rumen. Therefore, rumen samples were routinely collected on grazing and pen studies in Townsville. Studies were conducted at Lansdown Research Station, using animals selected under commercial industry conditions as either high or low efficiency phenotypes. The study identified the underlying physiological/adaptive traits in the rumen which determine productivity under non-limited (wet season) and limited (dry season) nutrient conditions. The animals were fed both high- and low-quality forage diets in pens and paddocks to reflect seasonal nutritional conditions. Feed intake was measured (predicted in paddocks) and analyses were performed for rumen physiological parameters that characterise efficiency of fermentation in combination with biochemical markers of feed N conversion efficiency. Rumen samples were collected for rumen microbial ecology analysis, fermentation profiles and metabolomics analysis. By identifying the underlying physiological/adaptive traits in the rumen which determine productivity under non-limited (wet season) and limited (dry season) nutrient conditions we can determine if these traits can be applied to genetic selection for digestive efficiency. This discovery information will also be used to inform potential supplementation strategies with macro- and micro-nutrients to modify and /or address deficiencies in the metabolic pathways within the microbiome. The understanding of the interactions and influences of the host-microbe partnership in rumen digestion will inform when, if and how it is possible to exert changes on the rumen.

2.4.2 Efficiency on pasture

The objective of this activity, which was conducted concurrently with the rumen studies above, was to gain a better understanding of the drivers of grazing efficiency of cattle and to validate and refine systems to quantify the feed efficiency of grazing cattle. Using digitally equipped sensor devices including collars linked to a wireless sensor network, data on GPS position, direction and speed of movement, position, and movement of the head (up versus down, side to side), bite rate and bite size can be recorded in real time. This data will be used to construct intake and behavioural algorithms using machine learning to understand grazing behaviour in detail. This work is ongoing and will be included in the final report in January 2023.

2.4.3 Pasture analysis

Detailed information was collected on the sward using remote sensing and ground-based surveys that integrates data from multispectral and radar images. Together with ground-based validation using sward measurements and NIR analysis of faeces and herbage, a complete picture has been developed of the sward characteristics which, when linked to animal performance and behaviour over time, elucidates environmental factors influencing productivity. The interactions between grazing behaviour and sward characteristics were studied in relation to pasture intake. Meanwhile these characteristics of behaviour and intake influences ruminal digestion which was recorded in the grazing animal to quantify the impact of animal behaviour on rumen function. This work is ongoing and will be included in the final report in January 2023.

2.4.4 Initiation of large-scale deployments in QLD and NSW (July to December 2022).

2.4.4.1 Queensland

A grazing property in central Queensland has been selected (Cungelella Station, Springsure) This property is part of an unrelated project funded under the Managing Emissions from Ruminant Livestock (MERiL) program and provides an excellent platform for testing collar performance. Four hundred tropical composite steers are being evaluated in four 300 ha paddocks. Over a ten-month period, selected individuals will be monitored for grazing behaviour and intake using GPS collars. The functionality of these collars under larger scale deployments will provide valuable information in the transfer of behavioural technology across scale and ultimately onto small ear tag sized monitoring devices.

2.4.4.2 New South Wales

Next generation CSIRO-NSWDPI eGrazor collars will be deployed at Glen Innes on 100 weaner heifers from the Southern MultiBreed (SMB) project co-funded by NSW DPI, UNE, Meat & Livestock Australia (MLA) and the Commonwealth Government through the MLA Donor Company (MDC). The SMB project provides a unique opportunity to evaluate the eGrazor collars and its ability to identify more efficient animals based on their behaviour. It is an opportunity to deploy and assess the collars for a longer period (up to 4-month) in a larger number of heifers (up to 100). This enables grazing efficiency traits to be assessed based on animal behaviour within and across breeds (Angus, Hereford, and Wagyu) by examining such traits in individuals from different breeds but with a similar “life experience”. Methods will be similar to those outlined above for Queensland.

3 Methodology and Results

3.1 Research overview

The research program included a series of co-ordinated field trials conducted in Armidale and Townsville led by principal investigators in Armidale, Townsville, and Brisbane (Table 1).

Table 1. Overview of research trials

Section	Description	Investigators	Date
3.2	Next generation supplements	McSweeney, Martinez-Fernandez, Denman	2018 - 2019
3.3	Nutrient deficiency field survey	McSweeney, Martinez-Fernandez, Denman	2019 - 2020
3.4	Development of intake algorithm	Greenwood, Bishop-Hurley, Alvarenga	2018 - 2021
3.5	Grazing efficiency studies in temperate conditions	Greenwood, Bishop-Hurley, Alvarenga	2019 - 2022
3.6	Grazing efficiency studies in tropical conditions	Charmley, Bishop-Hurley, McSweeney, Denman, Martinez-Fernandez	2019-2022
3.7	Large scale experiments		
	Armidale	Alvarenga, Bishop-Hurley	2022
	Lansdown	Charmley, Bishop-Hurley	2022

3.2 Next generation supplements

3.2.1 Methods

Eighty pregnant Brahman-cross first-calf heifers were purchased, calved at Lansdown from November 2019, were rebred and 45 in calf once bred cows were selected for the trial from the original 80. These pregnant cows (late-gestation), fed a poor-quality hay, were randomly allocated to 3 groups: Control (125 g /head/day baseline supplement: 30% urea); Choline: (125 g/head/day baseline supplement + 17.5 g/head/day RP-choline + 1 g cobalt + 2 g B12 co-factors); and Methionine: (125 g/head/day baseline supplement + 21 g/head/day RP-methionine). Supplementation started 3 months before calving and continued for 2 months of lactation. Animal body weight, rumen and blood samples were collected during late pregnancy and lactation to study the treatments effect on rumen fermentation and microbial profile and animal methyl donor levels and epigenetic changes. Calf weight and blood samples are also being collected to study the effect on the offspring.

- Rumen samples: Rumen fermentation profile (NH_3, VFAs) and microbial profiling. Monitoring of metabolites linked with degradation of supplements in the rumen were also be analysed.
- Blood samples: Urea plasma, methyl donor levels, epigenetic changes, vitamin levels, reactive oxygen species.

3.2.2 Next generation supplements results

A significant ADWG was observed for pregnant cows supplemented with Methionine ($P<0.001$) with significant increases in blood methionine and homocysteine which are important intermediates in the 'one carbon' metabolic cycle involved in methylation reactions in the body. Metabolic intermediates associated with methionine metabolism were analysed to determine the downstream effects of methionine supplementation on synthesis of other amino acids of nutritional and health importance (Table 2). Interestingly, significant higher total VFAs concentration and a shift to propionic acid production was observed ($P<0.05$) in the Choline group (Table 2). Illumina Miseq sequencing of rumen microbial community structure showed increases of fibrolytic microbial populations (*Fibrobacteraceae* and *Ruminococcaceae* families) in animals supplemented with Methionine and Choline (Figure 2). The effects on the rumen were unexpected as the nutrients in the methyl donor supplements were rumen protected which suggest that a proportion of the compounds was used by rumen microorganisms or nutrients were recycled to the rumen.

Table 2. Supplement effects on body weight, blood urea nitrogen and rumen fermentation parameters in pregnant cows supplemented for 14 weeks.

	Treatments				
	Control	Methionine	Choline	SEM	*P-value*
Body weight (kg)	469	488	460	6.85	0.265
ADWG (kg)[1]	0.199^{b}	0.327^{a}	0.085^{c}	0.02	0.001
Blood urea nitrogen mg/100 mL	15.6	12.8	15.3	0.60	0.121
$\delta\ ^{15}$Nplasma protein	9.70	9.46	9.61	0.04	0.093
Ammonia-N mg/100dL	5.11	4.21	5.47	0.32	0.274
Total VFA mM	48.9^{b}	53.0^{ab}	60.6^{a}	1.54	0.012
Acetate %	76.0	75.6	75.7	0.12	0.281
Propionate %	14.8^{b}	15.2^{ab}	15.4^{a}	0.09	0.034
iso-Butyrate %	0.33	0.29	0.30	0.03	0.804
n-Butyrate %	7.74	7.92	7.53	0.08	0.158
iso-Valerate %	0.42	0.49	0.44	0.02	0.299
n-Valerate %	0.42	0.41	0.42	0.01	0.996
n-Caproate %	0.23	0.17	0.15	0.02	0.220
ratio A:P	5.13^{a}	4.99^{ab}	4.92^{b}	0.03	0.043
Serum metabolites (µmol/L)					
Methionine	17.1^{b}	279.9^{a}	13.4^{b}	16.40	0.001
Total homocysteine	6.59^{b}	25.86^{a}	5.04^{b}	1.41	0.001
Methylmalonic acid (MMA)	1.09	0.71	0.82	0.11	0.361
2-methylcitric acid 2 (2-MCA 2)	0.0043	0.0047	0.0044	0.00	0.948

[1] Average daily weight gain calculated from day 0 (non-supplemented) to week 14 on supplementation.

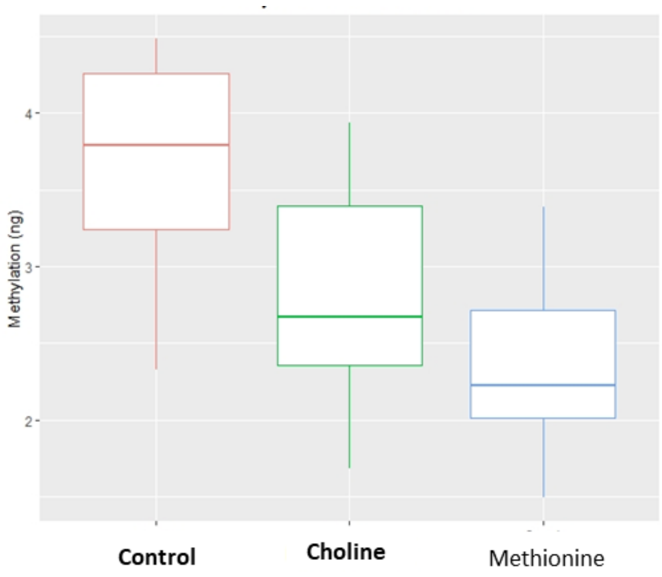


Figure 2. Methylation status of DNA in female calves.

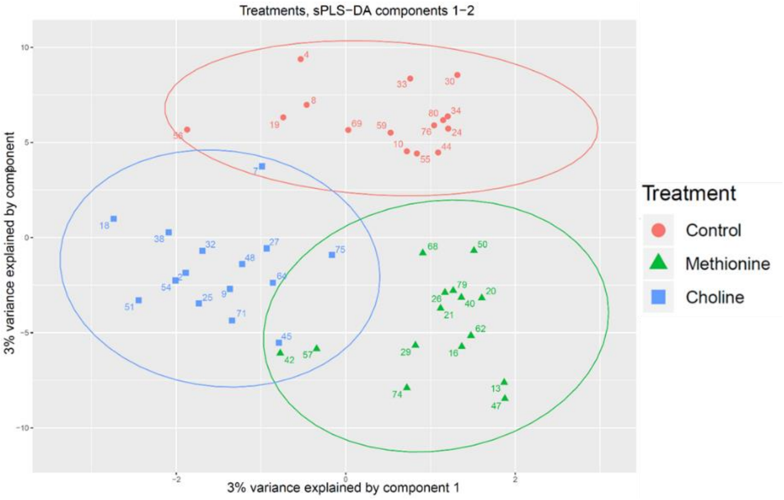


Figure 3. Sparse partial least squares discriminate analysis of rumen microbiome in treated cows

Female calf birth weights were not significantly different between treatments while growth of the calves from Methionine supplemented cows was greater even 4-5 months after the supplements had been withdrawn and the animals weaned (Table 3). However, the male calves did not show a response to the supplements. Unexpectedly the degree of DNA methylation was significantly lower in the female offspring of the Methionine supplemented cows (Figure 3). Sites of methylation of the genomes of the calves is being analysed to determine whether methionine supplementation had an influence on the pattern of DNA methylation in the developing foetus. Offspring will continue to be monitored to determine any epigenetic changes due to supplementation of the dam and their effects on performance and feed efficiency later in life. The trial findings should generate new supplement formulations containing micro-nutrients essential for optimum tissue metabolism in pregnant and lactating beef cows.

Table 3. Cow supplement effects on female calf performance

	Cow treatment				
	Control	Methionine	Choline	SEM	P-value
Females	5	9	6		
Birth liveweight (kg)	31.2	29.5	30.8	0.86	0.67
ADWG (kg) birth to end of cow supplementation (age 5-7 weeks)	0.621^b	0.809^a	0.660^b	0.03	0.01
Liveweight at weaning (age 5-6.5 months)	177.4^b	201.0^a	179.0^b	4.0	0.03
BUN (mg/dL) at weaning	23.0^a	19.1^b	19.7^b	0.57	0.03
Liveweight (kg) 3 weeks post weaning	177.7^b	206.1^a	182.7^b	3.93	0.01

3.2.3 Collaborations and future research

Preliminary discussions have occurred with Ridley AgriProducts who have expressed an interest in this project and the supplements being evaluated for pregnant and lactating beef cattle under northern Australian pastoral systems. They have supplied all the supplements for the trial. A financial commitment to ongoing work and formal participation as an LPP member will be dependent upon the outcomes of the current trial. This collaboration provides the opportunity to extend the supplementation work to field trails under commercial conditions in the latter stages of the LPP five-year program. In addition, CSIRO has been in discussion with the Chinese Academy of Agricultural Sciences regarding technology to develop rumen-protected amino acid which might be manufactured at a cost suitable for lick-block supplementation in extensive grazing systems.

3.3 Nutrient deficiency field survey

3.3.1 methods

The field survey was performed using recently collected and legacy rumen, faecal and blood samples from cattle grazing naturalised grass pastures from properties (Figure 4) in the Northern Territory, north-west Queensland, Lansdown Research Station, property at Ayr, Belmont Research Station and Brian Pastures Research Station. Budgetary limitations and travel restrictions due to the COVID-19 pandemic precluded a broader survey of properties. The samples collected were analysed for macro (Na, K, P, Ca, Mg, Fe, Cu, Zn) and micro (Mo, Se, Co, Ni, T) minerals by ICP-MS facility at CSIRO, St Lucia, QLD. Rumen fluids, blood sera, and faecal samples were processed as follows. In all cases, exact weights, volumes and dilution factors were recorded for later back-calculation of weight per volume concentrations for each trace element. Any water used in dilution steps was appropriately deionised. For blood samples, 1-2 mL of serum collected from each animal was transferred to 10 mL polypropylene tubes. Similarly, 2-3 mL of rumen fluid from each animal was first clarified by centrifugation, and then transferred to 10 mL tubes. Faecal samples were first lyophilized before 100 mg of each sample was weighed into separate microcentrifuge tubes. Two millilitres of acidified deionized water (1:100 HNO_3) was added, allowed to soak, and mixed using a bead-beater. Subsequently, solids were separated via centrifugation and 1.5 millilitres of clarified supernatant was transferred to fresh 10 mL polypropylene tubes. For all rumen fluid, blood or faecal samples, acid hydrolysis reactions were set-up as follows: equivolume of Suprapur 65% v/v Nitric Acid was added to processed samples, and sealed tubes were heated for 4 h at 70 °C. Once cool, samples were first diluted to 10 mL total volume in 0.65% HNO_3 acidified deionized water, and then serially diluted as appropriate in the same diluent.

An Elan DRCII Inductively Coupled Plasma Mass Spectrometer (PerkinElmer Inc., USA) was used to measure the concentration of bulk and trace metals using standard protocols. For quantification, a secondary set of mixed element standards was sourced (High Purity Standards, USA), separate to the calibration standards (Perkin Elmer, USA), and diluted to multiple concentrations as appropriate before analysis. Finally, relevant weighed amounts, volumes and dilution factors of standards and samples were used to calculate PPM concentrations of macro-elements Na, Mg, P, and K, and PPB concentrations of micro-elements Ca, Mn, Fe, Co, Ni, Cu, Zn, Se, Mo, and W.

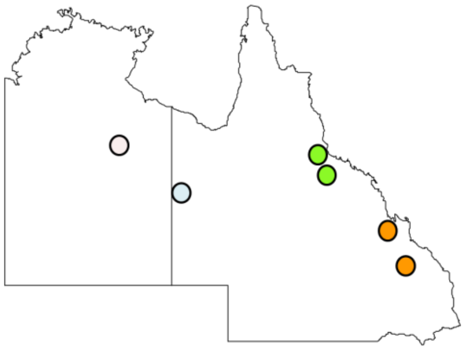


Figure 4. Location of properties surveyed for mineral deficiencies

3.3.2 Nutrient deficiency survey results

Potential mineral deficiencies for cobalt, copper and zinc are presented from a property on the Barkley Tableland during the mid-dry season, late-dry season and early-wet season respectively (Figure 5). The supplemented group were receiving a commercial inorganic mineral supplement. The results show that the concentration of these minerals is influenced by season with levels tending to be low in the wet season. However, there was no apparent increase in sample concentration in response to the mineral supplement suggesting that low-cost inorganic forms of these mineral may be inefficiently absorbed. These same minerals (Zn, Cu and Co) were also low in animals from some of the other properties sample.

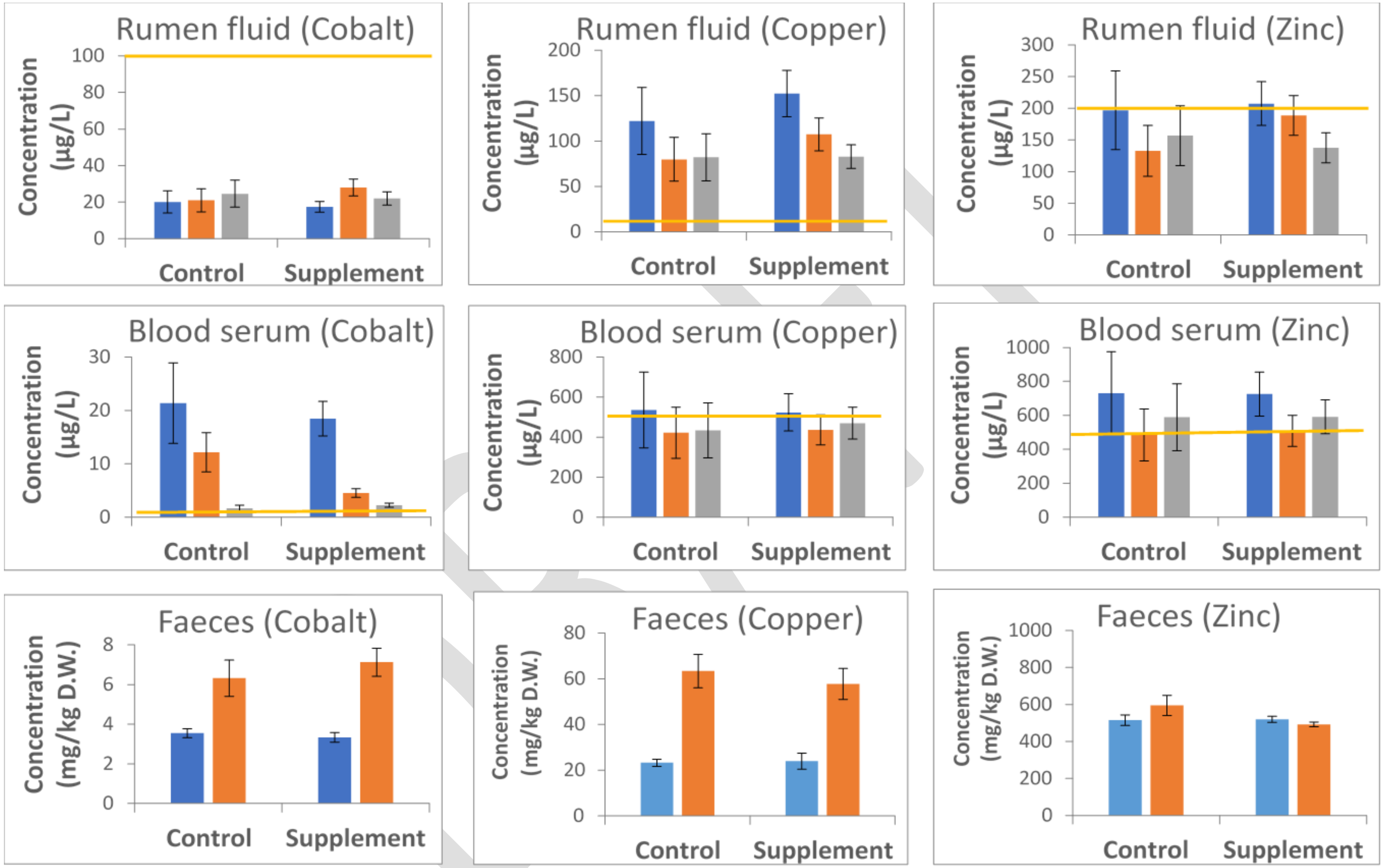


Figure 5. Mineral levels in rumen fluid, blood serum and faeces of pregnant and lactating cows. Blue (Mid-dry Season), Orange (Early-wet season), Grey (Mid-wet season). Yellow lines indicate deficiency levels.

Northern Territory Property: An un-supplemented group of pregnant and lactating cows, and a supplemented group receiving a commercial inorganic mineral supplement were tested. The results showed that the concentration of these minerals was predominantly influenced by season (Table 4). Potential mineral deficiencies for Ca, Mn, and Cu were observed from the property on the Barkley Tableland progressively through the wet season. Similarly, Co and Mo were borderline deficient in the mid-wet and early-wet season respectively. Interestingly this trend was reversed with Mo in the mid-wet, where animals showed marginally high levels (when coupled with copper deficiency). Mo pasture levels are lowest in dry season, rising throughout the wet season. Higher than normal molybdenum (and sulphur from soluble protein) can induce copper deficiency, so this increase in the mid-wet supports the copper serum findings. When mineral supplementation was compared, there was no apparent increase in sample concentration suggesting that low-cost inorganic forms of these mineral may be inefficiently absorbed.

Table 4. Mean serum (± s.e.) levels of all Barkley Tableland NT cows

Mineral	Season		
	Mid-dry	Early-wet	Mid-wet
Ca (mean ppm)	77 ± 24	51 ± 15*	38± 11*
Mn (mean ppb)	31 ± 10	18 ± 5	3 ± 1*
Cu (mean ppb)	526 ± 167	434 ± 129*	461 ± 137*
Mo (mean ppb)	19 ± 6	11 ± 3	98 ± 30
Co (mean ppb)	19 ± 6	6 ± 2	2 ± 1†

* potential deficiency

North-west Queensland property: Pregnant and lactating cows were sampled from a property in north-west Queensland on the border between Queensland and the Northern Territory during the late-wet season and mid-dry season consecutively (Table 5). These cows had marginally low blood serum levels for Cu and potential low-level Zn deficiency, and Ni deficiency during the dry season sampling. Serum Ca was low during the dry season.

Table 5. Mean serum (± s.e.) levels of all NW QLD cows

Mineral	Season	
	Late-wet	Mid-dry
Cu (mean ppb)	841 ± 14	596 ± 12
Zn (mean ppb)	853 ± 14	586 ± 17*
Ni (mean ppb)	2402 ± 52	945 ± 24*
Ca (mean ppm)	82 ± 1	55 ± 1

* potential deficiency

Lansdown Research: Growing weaners were sampled for blood serum, faeces and rumen fluid at Lansdown Research Station over the course of a year on four occasions (late-dry, mid-wet, early-dry and mid-dry seasons) (Table 6). The animals appeared deficient for blood serum in Ni during the mid-wet and early-dry season, while Ni was marginally low also in the mid and late and dry seasons. Cu, Zn and Ca were also lower during mid-wet and early-dry seasons. This trend of low levels of serum minerals during the wet season tended to be correlated with high levels in rumen fluid and faeces which may indicate low bioavailability during the wet season.

Table 6. Mean serum (± s.e.) levels of all Lansdown QLD cows

	Season			
Mineral	Late-dry	Mid-wet	Early-dry	Mid-dry
Ni (mean ppb)	2006 ± 92	1431 ± 48*	963 ± 21*	1927 ± 19
Cu (mean ppb)	854 ± 23	667 ± 9	639 ± 9	817 ± 11
Zn (mean ppb)	936 ± 25	741 ± 9	802 ± 10	926 ± 9
Ca (mean ppm)	83 ± 2	61 ± 1*	66 ± 1	73 ± 1

* potential deficiency

Ayr Property: Pregnant and lactating cows were also sampled from a property near Ayr, Queensland prior to the wet season in two consecutive years (Table 7). These cows had marginally low blood serum levels for Cu during both years and Mo during the second year, while serum Ca appeared deficient during the second year. In general, micronutrient and trace mineral serum levels decreased in the second year when pasture supply was good.

Table 7. Mean serum (± s.e.) levels of all Ayr QLD cows

	Year	
Mineral	2017	2018
Cu (mean ppb)	575 ± 11	526 ± 2
Mo (mean ppb)	32 ± 3	9 ± 2
Ca (mean ppm)	85 ± 4	25 ± 1*

* potential deficiency

Belmont and Brian Pastures Research Stations: Growing steers grazing a Rhodes grass pasture were sampled during the early-dry season (Table 8). The observations on these properties were limited to rumen fluid samples which were interpreted in relation to data collected from the other properties where rumen samples could be correlated with blood serum samples. On that basis steers at Belmont and Brian Pastures Research Stations appeared to have marginally low levels of Co, Zn and Mn.

Table 8. Mean serum (± s.e.) levels of all Belmont and Brian Pastures Station QLD cows

	Research Station	
Mineral	Belmont	Brian Pastures
Co (mean ppb)	27 ± 6	54 ± 3
Zn (mean ppb)	142 ± 34	190 ± 44
Mn (mean ppb)	244 ± 57	219 ± 50

Conclusions Macro mineral deficiencies were not detected on any property which probably reflected the fact that P supplementation was standard practise in regions where P was low and met the requirements of the animal. The micro elements Zn and Cu appeared either low or deficient on several of the properties tested. Cobalt was low on three of the properties. Even though some of the properties were supplementing with micro-minerals, low levels of some elements still occurred in animals which indicates that inexpensive forms of inorganic minerals that are widely used by industry are poorly absorbed and ineffective in some cases. Deficiencies predicted from this study should be verified by abattoir liver analysis of reproducing animals from different regions and correlated with blood serum levels which appeared to be the next best predictors of deficiency.

3.4 Development of the intake algorithm

3.4.1 Methods

General methodologies for developing and refining behaviour-based algorithms, estimation of intake, and determination of cattle location and distances travelled are included in Greenwood et al. (2014, 2016, 2017), Smith et al. (2016) and McGavin et al. (2018). These include cattle selection and training, pasture intake plots and their management, pasture biomass measurements, benchmark pasture intake data using pasture biomass disappearance and marker methods, sensor devices, behavioural annotation and classification using sensor devices, and use of GPS.

3.4.1.1 Animals and training for pasture intake experiments

Cattle for pasture intake experiments used to develop and refine sensor algorithms were selected based on temperament and suitability for specific experimental needs, were extensively handled, and accustomed to halters and restraint whilst feeding from troughs and buckets in yards. They were trained to graze within larger (up to 0.5 ha) and smaller (4 x 4 m) plots divided by electric fencing. They were also trained to enter and be restrained within 3 × 3 m pens for dosing, sampling, feeding of supplement and/or deployment of sensors.

3.4.1.2 Pasture intake plots and management

Grazing plots at the CSIRO FD McMaster Laboratory Chiswick comprise ten rectangular plots each of 0.5 ha (25 m × 200 m) that can be sub-divided to experimental specifications using electric fencing (Figure 6). The upper 0.25 ha of each plot comprises permanent mixed grass pasture (predominantly perennial ryegrass and prairie grass). The lower 0.25 ha was sown annually with a high-performance Italian ryegrass. Grazing plots were managed to provide pasture on offer to experimental specifications. Watering points within the grazing plots allow pasture intake experiments to be conducted on up to 30 cattle each within an individual grazing plot.

Figure 6. Arial photographic images of pasture intake plots used to assess pasture biomass measurement devices and estimate individual animal intake of Italian ryegrass (Lolium multiflorum cv. Surge) pasture. Each plot has a holding pen and crush for deployment of sensing devices, dosing with chemical markers, and sample collection (Greenwood et al., 2014)

3.4.1.3 Pasture measurements

Pasture biomass on offer within grazing plots prior to and during experiments was determined using one or more repeatedly calibrated pasture measurement devices or methods: C-Dax pasture height meter, Farmtracker rising plate meter, Greenseeker NDVI, Grassmaster capacitance meter, ruler height, visual biomass score and/or botanal, depending on the needs of the specific experiment. Measurements were made to maximise coverage within plots. On each calibration day, quadrats (50 × 50 cm) representative of the range of pasture availability within and between each grazing plot were measured using the pasture measurement methods, then the pasture cut, bagged, weighed, dried (minimum of 48 hours at 65 °C) and re-weighed to determine pasture DM/ha for each quadrat. Pasture calibration equations were generated for each device on each calibration day. Pasture exclusion cages were also deployed to estimate regrowth or senescence of pasture, and levels of faecal contamination during experiments were estimated.

3.4.1.4 Pasture intake estimates using biomass disappearance

For longer-term grazing studies, daily pasture dry matter intake (DMI) by each steer was estimated from pasture measurement device estimates of DM/ha for each plot on each day measured, as the slope of the regression of pasture DM/ha on day across the entire pasture intake period multiplied by plot size. For short-term, fine scale grazing studies pasture DMI by each steer was estimated from pasture measurement device estimates of DM/ha for each grazing plot multiplied by plot size prior to and after the grazing bout.

3.4.1.5 Pasture intake estimates using chemical markers

We have also established methods for chemical marker estimation of pasture intake during longer-term studies. When allocated to individual plots one week prior to the experimental pasture intake period, cattle were dosed once with chromic oxide using a controlled release devise (manufactured at CSIRO FD McMaster Laboratory, Chiswick, Armidale) with a release rate of 1.7 g/d Cr_2O_3. In addition, the animals were dosed twice a day with n-alkanes in gelatine capsules at the rate of 320 mg/day of both C_{32} and C_{36} divided equally between the two daily doses. Animals were dosed with n-alkanes at 0900 h and 1500 h daily for a seven-day adaptation period to allow the marker to reach equilibrium and during the pasture intake measurement period.

During the intake period, fresh faecal samples were collected twice daily in the morning and the afternoon from faecal matter on the pasture and, if necessary, from rectal samples at the times of dosing with alkanes. The fresh faecal matter on pasture was scooped into collection bags while taking care to avoid contamination with soil and vegetative matter. The samples from each collection period were thoroughly mixed and a sub-sample taken and dried in an oven at 60 ºC, then ground to pass through a 1 mm screen. Representative pasture samples from each plot and composite samples of green stem, green leaf and dead pasture material were taken at the start, during and/or end of the intake period and were dried and ground to pass through a 1 mm screen and analysed for n-alkanes content. The n-alkanes were extracted and analysed using gas chromatography (GC), and chromic oxide digested then analysed by atomic absorption spectroscopy (AAS), following methods established by CSIRO.

3.4.1.6 Pasture morphological and nutritional characteristics

Pooled, dried pasture samples were made from quadrat calibration cuts from each plot just before, during and/or at the end of the pasture intake period. The proportion of green leaf (leaf blade) and green stem and dead material were determined by sorting and weighing these components in 30 g representative sub-samples, and ratios of green leaf to stem and green to dead calculated. The nutritional content of the pastures at the beginning, during and/or and at the end of the pasture intake period was also determined in representative sub-samples from composite samples of the calibration cuts in each plot. These nutritional content analyses were undertaken at the NSW Department of Primary Industries Feed Quality Service, Wagga Wagga Agricultural Institute.

3.4.1.7 Sensor deployments, behaviour classification and algorithm development

CSIRO electronic cattle monitoring collars and/or other devices were deployed on cattle during pasture intake experimental periods. Cattle behaviour annotation methods and a cattle behaviour model (Smith et al. 2016) has been used to continuously classify the behaviour of each animal across consecutive, non-overlapping time intervals spanning the duration of the pasture intake period. The model used observations from the accelerometer within the collars to discriminate between five different cattle behaviours based on their respective motion patterns and head orientation. The five behaviours classified were Grazing, Ruminating, Resting, Walking and an aggregated class of all 'Other' less frequent behaviours (drinking, sexual behaviour, grooming).

Additional behaviour classification of specific pasture intake events (bites) was undertaken using a new CSIRO sensor device (Loci2). These data will allow relationships between pasture DMI and sensor derived behaviour classifications to be determined using this device, including relationships with time spent grazing, ruminating and resting, grazing intensity (bites/unit time) and bite size.

Details specific to the development of a new Loci2 (LoRa based low power embedded) device with multiple sensors to be used within this project are described in Section 4 below (from Milestone 2).

Using a range of methodologies, and methods available with collaborators, pasture intake algorithms established using the Loci2 device will be refined to enable their use in varying grazing environments including tropical pastures, and for temperate and tropically adapted cattle (Figures 7 and 9). Combined with Loci2 GPS and energy harvesting and storage capacity, they will also enable behaviour and intake to be determined across location within grazing paddocks over extended time-periods.

Figure 7. CSIRO behaviour monitoring collars deployed on 30 Angus steers grazing in perennial and annual pasture plots at CSIRO FD McMaster Laboratory Chiswick, Armidale.

3.4.2 Results - Intake algorithm development

Perennial pasture grazing plots at CSIRO FD McMaster Laboratory were used following irrigation due to dry conditions to generate benchmark pasture intake data from biomass disappearance for algorithm development using cattle wearing sensor devices. This ensured adequate pasture on offer for field testing of sensor devices on cattle, which was undertaken using 10 steers and for behavioural annotation data collection for refinement of sensor algorithms to classify behaviours. Group grazing in a pasture paddock was also undertaken as part of this senor deployment.

The behaviour classification algorithm produces 5 behaviour classifications: grazing, ruminating, walking, resting and other. A significant relationship between time spent grazing and DMI as a percentage of LW was evident. Relationships between pasture DMI and time spent ruminating, walking or in other behaviours were not evident, nor were there significant relationships with starting or final pasture DM per ha and LW when analysed by regression. Multiple regression analyses did not identify any algorithms within which pasture DMI was significantly associated with multiple behaviours. On high digestibility annual ryegrass pasture, which assume pasture dry matter disappearance estimates pasture intake, resulted in the following relationships:

1. Pasture intake (kg DM/head/d) = –6.46 + 2.61 x grazing (hours), $r^2 = 0.59$, RSD = 1.66 kg DM, $P = 0.006$ (Greenwood *et al*. 2017)

The eGrazor sensor collar was deployed in March 2020 to assess behaviours of 8 cattle and associations with pasture availability and rate of pasture intake (disappearance) for 6-hour periods on 8 separate days, grazing one plot per day (see Table 9). This data will enable more detailed assessments of behaviours including bite characteristics and their associations with pasture availability and intake. Data on the range of pasture availability and species composition within grazing plots was also obtained.

Table 9. Pasture dry matter on offer (kg/ha), hourly pasture intake (kg DM/head) and total intake (kg DM/head) during 6-hour grazing periods on 8 separate days for 8 heifers wearing eGrazor sensor collars grazing one plot per day.

Time (min)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Mean ± SD
	A. Pasture on offer (kg DM/ha)								
0	2482	2802	2639	2321	2512	2288	2621	2461	2516 ± 170
60	2177	2535	2369	2143	2317	2112	2390	2254	2287 ± 143
120	1924	2299	2136	1981	2136	1951	2191	2072	2086 ± 129
180	1724	2095	1940	1833	1969	1806	2024	1916	1913 ± 121
240	1576	1923	1781	1700	1817	1676	1890	1785	1768 ± 114
300	1481	1781	1658	1582	1680	1561	1788	1679	1651 ± 106
360	1438	1671	1573	1479	1557	1462	1720	1598	1562 ± 100
Difference 0-360	1044	1130	1066	842	955	825	902	863	953 ± 115
	B. Pasture intake (kg DM/head/hour)								
0-60	2.386	2.085	2.109	1.387	1.528	1.374	1.810	1.615	1.787 ± 0.374
60-120	1.975	1.840	1.820	1.271	1.414	1.254	1.556	1.419	1.569 ± 0.277
120-180	1.564	1.594	1.532	1.154	1.301	1.135	1.301	1.222	1.350 ± 0.187
180-240	1.154	1.349	1.244	1.038	1.187	1.015	1.047	1.025	1.132 ± 0.122
240-300	0.743	1.104	0.955	0.922	1.073	0.895	0.793	0.828	0.914 ± 0.128
300-360	0.332	0.858	0.667	0.805	0.959	0.775	0.538	0.631	0.696 ± 0.199
	C. Total DM intake over 6 hours (kg/head)								
0-360	8.15	8.831	8.327	6.578	7.463	6.449	7.045	6.740	7.448 ± 0.895

Results are fitted values from quadratic regression equations for each day. Pasture on offer was determined hourly using calibrated rising plate meter pasture height measurements. On each measurement occasion, approximately 225 pasture measurements were made in total along 15 pre-determined transects within a 25 m x 25 m grazing plot. Pasture was a mix of temperate grass species, with Prairie grass the dominant species.

3.4.2.1 Further development of eGrazor platform

In preparation for the upcoming final deployments in this project in late 2022, CSIRO has designed and is in the process of manufacturing a new version of the eGrazor collar based on their Loci4 PCBA. The existing platform, having seen 5 years of use, could not be re-manufactured since many components had become obsolete and there were not enough devices for the upcoming work. The opportunity was taken to update the design of the case to overcome some usability issues and include narrowband internet of things (NBIoT; low-power wide-area network (LPWAN) radio technology standard developed by 3GPP for cellular devices and services) as a communications option on the PCBA. The main features of the new PCBA include:

- GNSS
- 3-axis accelerometer
- 9-axis accelerometer
- Improved processor for ML
- SD card for storing raw data
- BLE communications for short range communications
- Long range wide area network (LoRAWAN) communications

The case and collar (Figure 8) have been designed by an industrial engineer and they are being manufactured by injection moulding in July-August 2022. Improvements have been made in the usability of the collar including fitting to the animal, sealing against moisture and reduced complexity to deploy and post-deployment. In addition to the redesigned case and PCBA, the software has also been updated and improvements made to the onboard algorithms. The software has been updated to allow algorithms to be added or modified. A description of the new behaviour algorithms can be found in Arablouei et al. (2022).

Figure 8. Angus cow fitted with new eGrazor collar – June 2022.

3.4.3 Algorithm development for tropical conditions

Following on from the successful development of sensor collars by CSIRO Agriculture & Food and Data 61 staff in Brisbane and their testing and evaluation by NSW DPI and Agriculture & Food staff at Chiswick, testing was initiated at the tropical site on Lansdown Research Station, south of Townsville.

Twenty Brangus cattle of mixed sex weighing between 300 and 400 kg were selected for a 6-week study and randomly allocated to one of four 15 ha paddocks (Figure 9). Each weaner was fitted with the sensor collar, that in addition to the Chiswick collars was equipped with bite rate monitoring capability. The purpose of the study is to correlate visual observations of behaviours with activity patterns from the collars derived from animal movement. The objective will be to determine if algorithms developed under southern grazing conditions are applicable to northern pastures which have a different structure. This work is ongoing and will be included in the final report in January 2023.

A B

*Figure 9. Examples of extreme grazing behaviour under northern pasture conditions (A) browsing seca stylo (*Stylosanthes scabra*) (B) selecting green material from bare ground.*

Subsequently, three collar deployments were conducted throughout 2020 and 2021. In 2020, Covid restrictions resulted in the postponement of the main feed efficiency study to 2021 (as approved by MLA). However, 16 GPS collars were deployed to cattle in a smaller grazing trial studying animal performance on grass – leucaena pastures. Animal behavioural data, that included browsing, a feature unique to northern grazing systems in woodland grazing environments. Collars were deployed from 5th August to 3rd September 2020.

In 2021, GPS collars were again deployed to cattle grazing grass – leucaena pastures. Twenty-four collars were deployed to four groups of six steers from May 13th to July 14th 2021.

The main collar deployment was conducted in association with the feed efficiency grazing trial with 56 Brahman heifers. Collars were deployed to all animals from 9th February to 19th May and again from 28th September to 17th November 2021, corresponding to wet and dry season grazing conditions.

3.5 Grazing Efficiency studies in temperate conditions

3.5.1 Methods

3.5.1.1 Animals and training for pasture intake experiments

Angus heifer weaners (*n* = 40) were sourced from NSW DPI Elizabeth Macarthur Agricultural Institute and relocated to the CSIRO Chiswick Pasture Intake and Efficiency Facility. The heifers were selected based on their EBVs (Estimated Breeding Values) determined from their genomic EBVs and their mid parent EBVs for RFI in BREEDPLAN (ABRI 2017), which are determined from feedlot data. Heifers were selected for the study based on their RFI-f-EBVs to create Low-RFI-f EBV (high feedlot efficiency) and High-RFI-f EBV (low feedlot efficiency) groups (*n* = 20/group) that differed significantly in RFI-f EBV and RFI-post-weaning (RFI-p) EBV, while being as balanced as possible and not differing in 600-day-weight EBV and then mature-cow-weight EBV (Table 10). The heifers underwent intensive handling and training and were adapted to experimental conditions prior to commencing studies on grazing efficiency that include sensor behaviour and intake algorithm deployments.

Table 10. Estimated breeding values (EBV) for 600-day weight, mature cow weight and residual feed intake-feedlot (RFI-f) and RFI-post-weaning (RFI-p) of the 40 heifers selected for study.

Values are mean ± SD, and values in parentheses are the range. SEM: Standard error of the mean.

	RFI-f EBV group			
Trait	High	Low	SEM	*P*-value
Number of heifers	20	20		
600-day weight EBV	98.5 ± 10.6	99.2 ± 12.4	1.87	0.806
	(83 - 125)	(81 - 124)		
Mature cow weight EBV	75.2 ± 16.6	80.2 ± 15.4	2.59	0.168
	(50 - 101)	(56 - 109)		
RFI-f EBV	0.49 ± 0.22	-0.33 ± 0.13	0.029	<0.001
	(0.14 - 0.98)	(-0.68 - -0.16)		
RFI-p EBV	0.33 ± 0.16	-0.19 ± 0.12	0.023	<0.001
	(0.07 - 0.67)	(-0.47 - -0.03)		

The selected Angus heifers underwent several grazing efficiency experiments (Table 11) during their lifecycle, from 6-month to 42-month-old and the data generated will be analysed within and across experiments. Heifers were randomly allocated into two replicates, each with same number of Low-RFI-f EBV and High-RFI-f EBV animals. Replicates were as balanced as possible for RFI-f, RFI-p, 600-day-weight, and mature-cow-weight EBVs and for LW. Each replicate grazed one of eight paddocks comprising mixed perennial temperate grasses at 7-day intervals during repeated 28-day cycles, Phase 1 and 2. Animals were weighed weekly with electronic scales (Tru-Test MP600 weigh bars, DataMars, Mineral Wells, Texas, USA) in a cattle crush within the yard and race system (yard weighed) on nine occasions during the 8-week study. The animals were also weighed on every occasion they consumed water during the study by an in-field walk-over-weigh system that automatically drafted them back into their replicates.

The phenotyping facility structure includes a walk through crush with weighing platform (sitting at ground level so that it doesn't impede animal gait), 2 x spear gates to control the flow of cattle, a yard system, adjoining paddocks to allow animals to enter from the paddocks, automatic data recording which will enable downloads from sensor devices, an exit from the weigh facility without human intervention (Stress-Free Voluntary Weighing), and automated drafting gates that allow for individual animals to be diverted back into experimental groups.

All studies include behaviour measurements and intake algorithm estimates at pasture, combined with pasture biomass and disappearance measurements and frequent in-field (walk-over-weigh) liveweight measurement, plus pasture biomass mapping and species prevalence and disappearance. Except for the NFE testing that was undertaken on feedlot and obtained intake and efficiency phenotypes to compare with their behaviour and performance at pasture and their NFI-f EBVs. The Animals divergent in RFI-f-EBVs are being used to compare behaviour, rumen, intake and efficiency phenotypes at pasture and in feedlot and with their NFI-f-EBVs. Behaviour is being measured at pasture and in feedlot using the CSIRO-NSW DPI eGrazor collars. This study is also assessing body composition and conformation and rumen characteristics.

Table 11. Summary of experiments undertaken at CSIRO-Chiswick Pasture Intake and Efficiency facility using the Angus heifer sourced from NSW DPI Elizabeth Macarthur Agricultural Institute selected based on their EBVs for RFI

Trial	Period	Animal age	n	Paddock size (ha)
Performance and animal behaviour of Angus weaner heifers grazing severely drought-affected pasture	July-August 2019	6-month-old	40	1.25
Performance and animal behaviour of Angus heifers grazing mixed perennial temperate grasses	April-June 2020	15-month-old	32	0.62
NFE testing and animal behaviour assessment of Angus heifers on feedlot	August-October 2020	22-month-old	38	NA
Performance and animal behaviour of Angus heifers in late pregnancy	May-June 2021	31-month-old	36	1.25
Performance and animal behaviour of Angus cows in the first trimester of lactation	February 2022	42-month-old cow 5-month-old calf	10 – Cow 10 - Calf	1.25

3.5.1.2 Pasture intake estimates using biomass disappearance and mapping

For longer-term grazing studies, group estimates of pasture intake determined using biomass disappearance were performed at a frequency (e.g., weekly pre- and post-grazing) appropriate for the experimental design (e.g., replicate groups within multiple grazing paddocks) and duration (e.g., 2 months). Biomass availability pre- and post-grazing and pasture disappearance were determined using C-Dax pasture height meter, Farmtracker rising plate meter, Crop Circle NDVI with GPS to enable mapping of pasture availability and disappearance within grazing paddocks. Pasture exclusion cages were also deployed to estimate regrowth or senescence of pasture during experiment.

Figure 10. Aerial image of grazing paddock arrangement used for CSIRO behaviour and intake monitoring collar deployment at CSIRO FD McMaster Laboratory Chiswick, Armidale. The experimental site is arranged in 2 rows each of 4 grazing paddocks each of 1.25 ha. The cattle are automatically weighed and drafted into 2 replicates using a Remote Livestock Management System. Cattle grazed each paddock for one week across 2 grazing cycles (High then Low pasture availability) each of 4 weeks.

Figure 11. CSIRO behaviour monitoring collars deployed on 40 Angus heifers divergent in net feed intake estimated breeding values grazing drought affected pastures at CSIRO FD McMaster Laboratory Chiswick, Armidale.

3.5.1.3 Hardware and algorithm development, machine learning and communication

CSIRO has recently developed and manufactured a new LoRa based low-power embedded device (Loci2) with multiple sensors (Radios [LoRa, BLE], GPS, IMU [accelerometer, magnetometer and gyroscope], temperature, pressure and humidity) – see Figure 1. This device has been chosen as the platform for the CSIRO monitoring collars over the next 2-3 years. The Ichanaea platform, previously used in the CSIRO monitoring collars, had become obsolete due to the age of the design and components used and lack of support.

Advantages of the new platform over the previous one includes:

- Better radios (range and power usage)
- Lower power sensors (particularly GPS)
- More powerful MCU (microcontroller)
- Increased non-volatile memory (ROM) for code and data
- Components readily available to manufacture boards.

The software stack was rewritten from scratch specifically for this project. Leveraging previous knowledge and experience within CSIRO meant this was achieved relatively quickly. The decision to proceed as above was taken to ensure that the platform has the capacity and capability to implement the classification algorithms on the device.

Although the Loci2 printed circuit board (PCB) is a different size and shape to the Ichnaea, the existing collar case and method of attachment to the cattle has been retained (Figure 1). An adaptor bracket has been designed and 3D printed to allow the Loci2 to be secured in place of the Ichnaea inside the case. Reusing the case and collar, which has been deployed successfully over the last 18 months, saved time.

Since the behaviour monitoring system has been modified significantly, it will be thoroughly tested in the lab and field prior to deployment on animals. However, static tests do not always highlight all the issues that can arise when devices are deployed on animals.

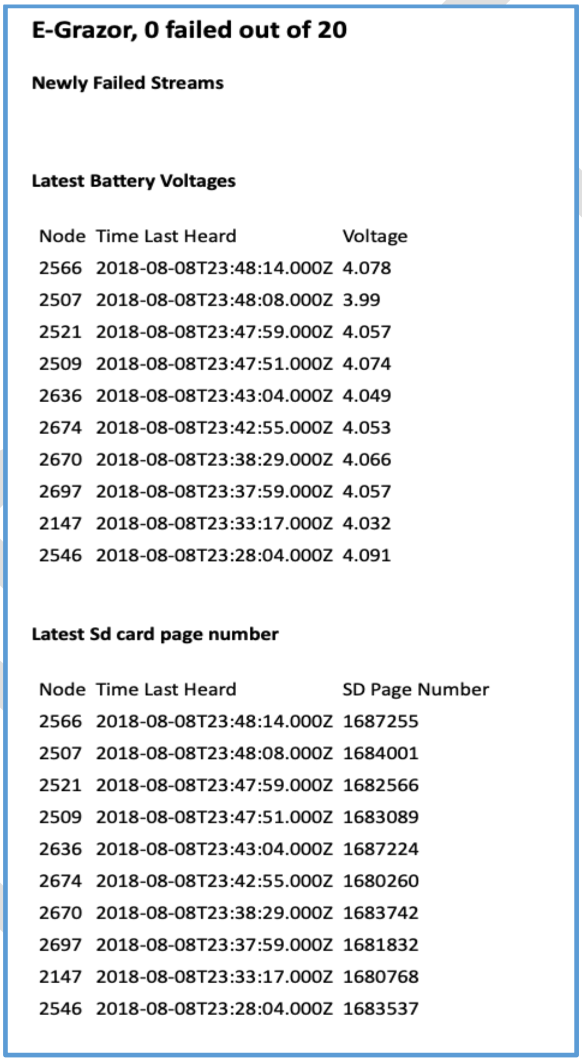
3.5.1.4 Bench testing

Five devices were tested for 7 days on the bench using just a battery for power and GPS repeater to provide a GPS signal. Each was monitored for continuous operation in real time and following the end of deployment from archived data stored on the on-board microSD card. A communications data backhaul system consisting of an off the shelf conduit (relay data to the cloud – LoRaWAN based communications) and proprietary relays (transfer data from collar node to conduit – LoRa based communications) have been assembled to provide real-time monitoring of the devices during deployments. Basic engineering and location information is sent every minute to allow the functionality of the devices to be determined during a deployment. This ensures that any problems are identified early and speeds up the testing process.

During the bench testing phase, the platform performed well although the battery on one device failed after 3 days. At the end of the deployment the data from the microSD cards was downloaded and inspected. Four nodes operated continuously for the length of the deployment.

Eight devices were assembled and placed outside and four were in an open area and four in a shaded area. As before in the bench testing deployment, the devices were sending data in real time to the cloud for monitoring purposes. At the end of the 3-week deployment on-board data was assessed for completeness. The trial was successful and the Loci2 board, housing and collar were considered suitable for deployment on cattle.

Historically, the CSIRO monitoring collars have been operated in an archival mode. Collars are prepared and deployed on animals. Raw data is stored on the devices and some engineering data are relayed through a LoRa base station to the cloud. This data allows the operation of the devices to be monitored to ensure that they are working correctly. A daily email is generated as a quick way to identify any problems (Figure 12). This allows the team to assess the devices and replace any that are not working correctly. This is important to ensure that we get paired sensor data and ground-truth data from each animal in the experiment. At the end of the experiment, the collars are removed, the data downloaded from the micro-SD cards, parsed and securely stored. This process results in large amounts of data and requires the use of a HPC system to model and/or generate daily behaviours for the cattle.



E-Grazor, 0 failed out of 20

Newly Failed Streams

Latest Battery Voltages

```
Node  Time Last Heard             Voltage
2566  2018-08-08T23:48:14.000Z  4.078
2507  2018-08-08T23:48:08.000Z  3.99
2521  2018-08-08T23:47:59.000Z  4.057
2509  2018-08-08T23:47:51.000Z  4.074
2636  2018-08-08T23:43:04.000Z  4.049
2674  2018-08-08T23:42:55.000Z  4.053
2670  2018-08-08T23:38:29.000Z  4.066
2697  2018-08-08T23:37:59.000Z  4.057
2147  2018-08-08T23:33:17.000Z  4.032
2546  2018-08-08T23:28:04.000Z  4.091
```

Latest Sd card page number

```
Node  Time Last Heard             SD Page Number
2566  2018-08-08T23:48:14.000Z  1687255
2507  2018-08-08T23:48:08.000Z  1684001
2521  2018-08-08T23:47:59.000Z  1682566
2509  2018-08-08T23:47:51.000Z  1683089
2636  2018-08-08T23:43:04.000Z  1687224
2674  2018-08-08T23:42:55.000Z  1680260
2670  2018-08-08T23:38:29.000Z  1683742
2697  2018-08-08T23:37:59.000Z  1681832
2147  2018-08-08T23:33:17.000Z  1680768
2546  2018-08-08T23:28:04.000Z  1683537
```

Figure 12. *Example of daily email for monitoring collar functionality*

Annotation data is collected by either videoing the cattle for later annotation of annotating the cattle activity by an observing directly in the field. CSIRO have developed an Android application to allow annotation data to be captured electronically in the field or later from video recordings (Figure 13). The app provides a convenient method of synchronising the sensor data with observation data by using GPS time on both. Video recording some cattle activity provide a valuable resource for later review and training.

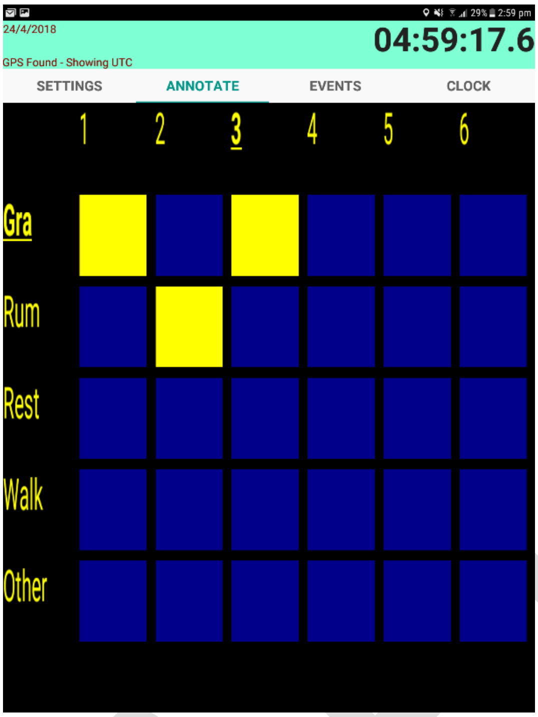


Figure 13. *Screen capture of application to capture annotation data*

During 2019, the software on the collars was upgraded. The process followed when the collars software is modified includes planning and implementing the changes, bench testing the new software followed by field testing the software. Field testing involves preparing the collars as if they were to be deployed on cattle but leaving them sitting on a table for fence outside for several weeks and reviewing the data. The changes that have been made to the functionality of the collars includes developing machine learning (ML) algorithms that are able to be run on the devices themselves. Based on previous data collected using the collars algorithms suitable for operation on embedded devices (cattle monitoring collars) have been developed and implemented. To be implemented on the collars the algorithms need to be computationally simple and use minimal clock cycles. Table 12 shows the precision and recall statistics for a model used on the collars. These models compute and send cattle behaviours to the cloud every five minutes. In addition, a ML algorithm has been added to the collar to count the number of bites of the animal. This is also currently reported at 5-minute intervals.

Table 12. *Precision and recall statistics for behaviour classification algorithm used on collars*

	Precision (%)	Recall (%)
Grazing	95.96	98.97
Ruminating	84.00	86.28
Resting	86.34	85.82
Other	57.12	19.21

The gateways at both trial sites have been updated with more up to date hardware (Figure 14).

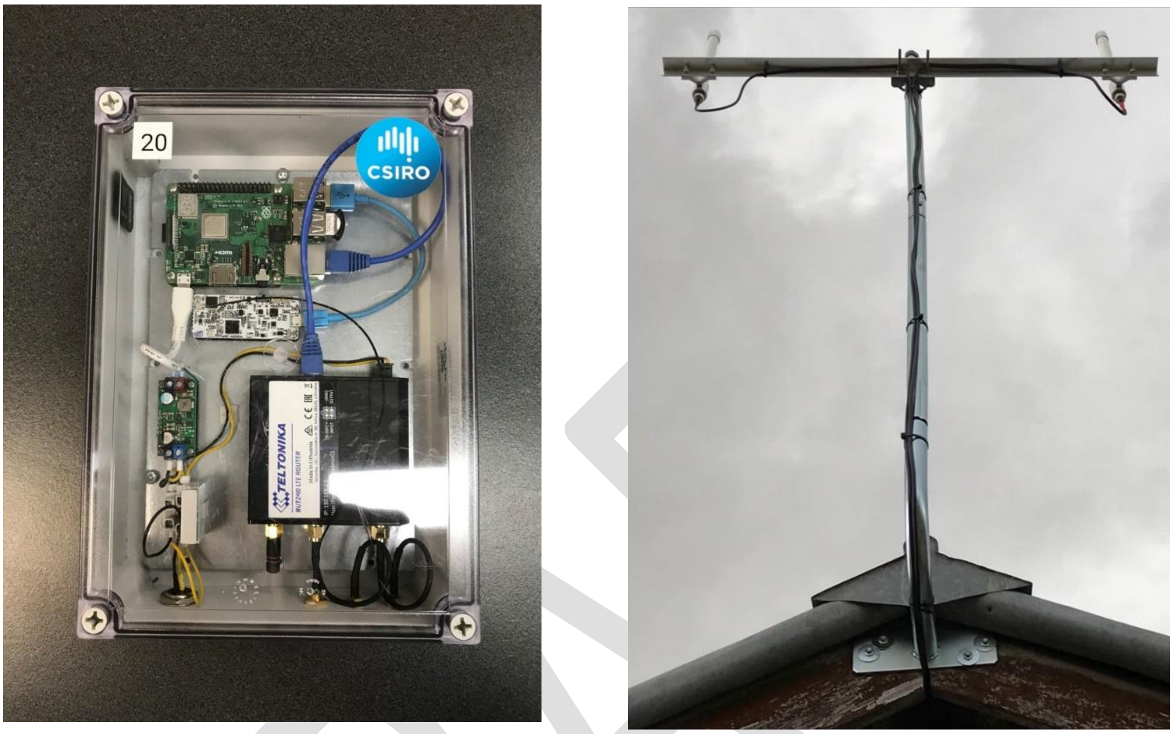


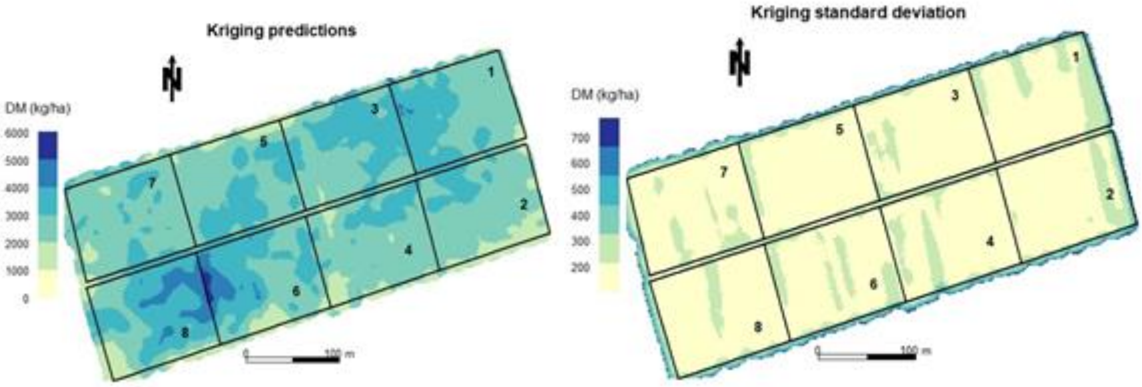
Figure 14. *Pictures of the gateway and LoRa antenna installed at the trial sites*

3.5.2 Results - Grazing Efficiency studies in temperate conditions

Cattle growth and pasture data analyses and mapping are completed for the grazing trial in Armidale with 40 Angus heifers, selected based on their RFI-f EBVs, which ran from July to August 2019 during drought. The results are included in Alvarenga et al., 2021 and Dobos et al., 2021. Briefly, Alvarenga et al. (2021) suggested that Low-RFI-f EBV weaner heifers maintain LW better than their High-RFI-f EBV counterparts when nutrition from pasture becomes limiting. They suggest that heifers selected based on their RFI-f EBVs (feedlot-efficiency EBVs) may rank similarly in efficiency as in feedlot, although pasture-intake data for the Low- and High-RFI-f EBV heifers are required to confirm this.

Dobos et al. (2021) tested the performance of a rapid pasture meter to measure SH in severely drought-affected, heterogeneous pastures grazed by beef heifers. Calibration equations were found to be linear because there was limited pasture growth during the study period. Geostatistical methods were employed to investigate the spatial variability in SH, DMY, change in SH and DM disappearance pre- and post-grazing. Surface maps of spatial variability identified areas of grazing intensity and could be used for determining efficiency of pasture utilisation (Figures 15 and 16). Addition of animal location data within the paddock to calculate residence times would improve understanding of the factors influencing grazing efficiency. Incorporation of this methodology into rapid, non-destructive pasture data collection devices would assist producers and their advisers in improving grazing management decisions. Analyses of data for cattle grazing mixed perennial temperate grasses are underway and will be delivered in the final report.

(a)



(b)

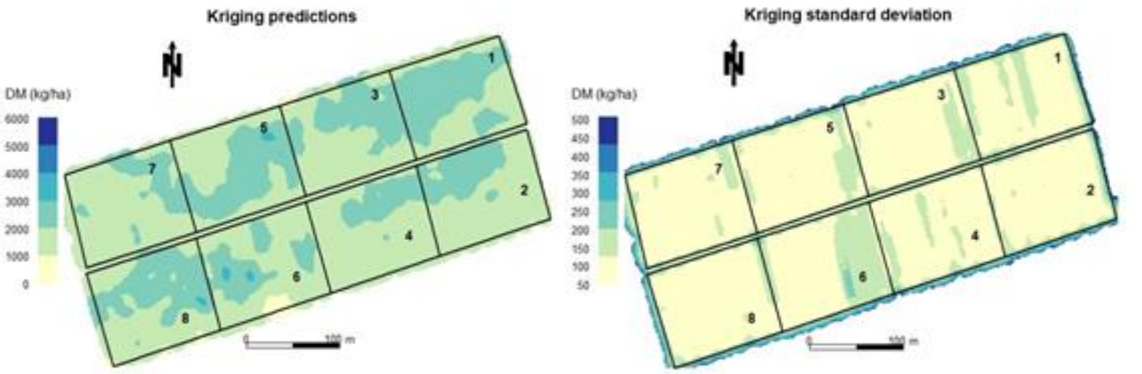
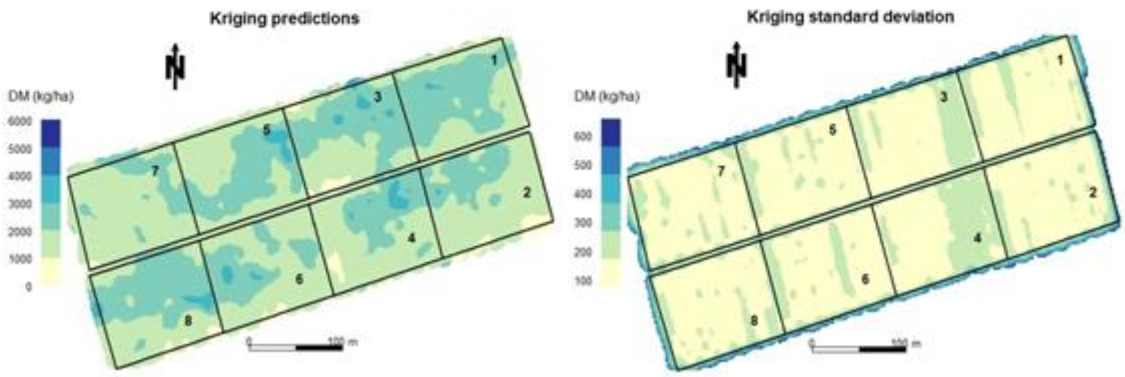


Figure 15. Example of interpolated kriging predictions and standard deviations of pasture DM yield across the eight grazing paddocks (a) pre-grazing and (b) post-grazing during phase 1. (Dobos et al., 2021)

(a)



(b)

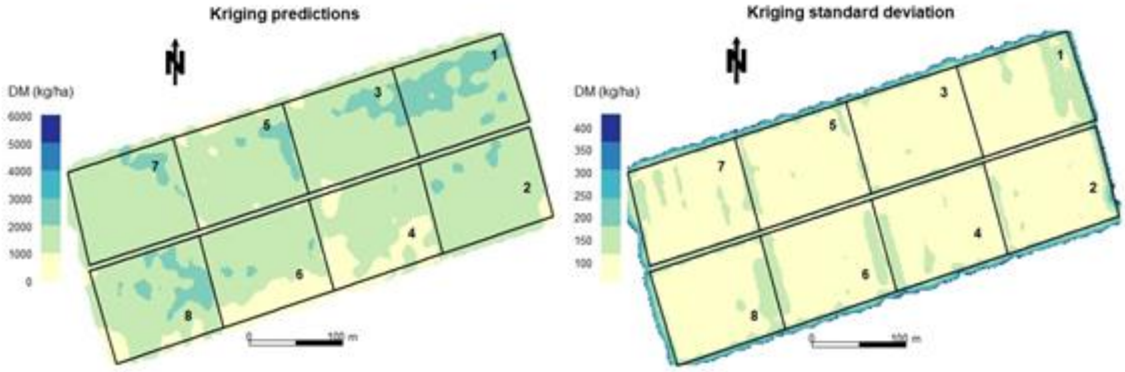


Figure 16. Example of interpolated kriging predictions and standard deviations of pasture DM yield across the eight grazing paddocks (a) pre-grazing and (b) post-grazing during phase 2. (Dobos et al., 2021)

Despite the drought, there was relatively abundant pasture dry matter on offer at the start of the 2019 study (2.8 t DM/ha) and during Phase 1 due to the grazing paddocks being locked up for 12 months to enable this research to occur. Pasture availability continued to decline due to grazing coupled with no measurable re-growth during trial. This resulted in 1.5 t DM/ha on offer at conclusion of the study (Table 13).

Table 13. Mean pasture on offer and pasture disappearance during the two 4-week grazing phases (Phase) during drought (Alvarenga et al. 2020a)

Results are for 8 grazing paddocks of 1.25 ha, each grazed for one-week by one of 2 replicates of 20 heifers during two 4-week grazing phases (total number of pasture measurements = 32).

	Phase			
Variable	1	2	*P*-value	SEM
Number of grazing plots	8	8		
Dry matter on offer pre-graze (kg/ha)	2834	1890	<0.001	106.1
Dry matter on offer post-graze (kg/ha)	1850	1494	0.001	88.0
Dry matter disappearance				
kg/ha	984	396	<0.001	6.2
kg/head/day	8.84	3.55	<0.001	0.134

Pasture mapping revealed the distribution of pasture availability and disappearance (Figure 17) for each of the 8 grazing paddocks of 1.25 ha, which differed between paddocks and grazing Phases. This data will allow for comparison with heat maps of the location of grazing and other cattle behaviours from the collar sensor data. They will also allow for comparison, calibration and/or validation of Sentinel and other satellite image data.

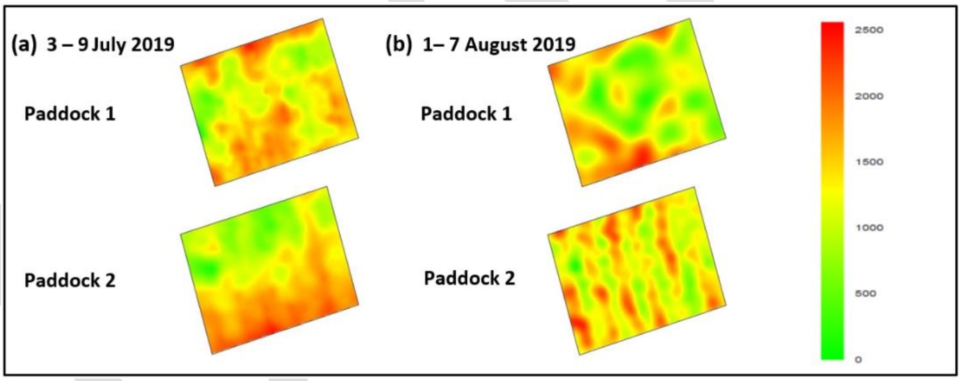


Figure 17. Example maps of dry matter disappearance (kg/ha) for two 1.23 ha paddocks during (a) Phase 1 and (b) Phase 2 using data from a Pasture Meter XC-1 (Dobos et al. 2020)

The on-going walk-over-weighing and yard weighing data will enable further validation and modelling of the duration of liveweight measurements from walk-over-weighing needed to obtain reliable estimates of growth rate or rate of liveweight loss to calculate residual (net) feed intake at pasture. We found highly correlated liveweights using our walk-over-weigh and yard systems (Figure 18), but poorer correlations with average daily gain or average daily loss when pasture is highly limiting to cattle growth performance although the correlation improved as the measurement period increased (Alvarenga et al. 2020b).

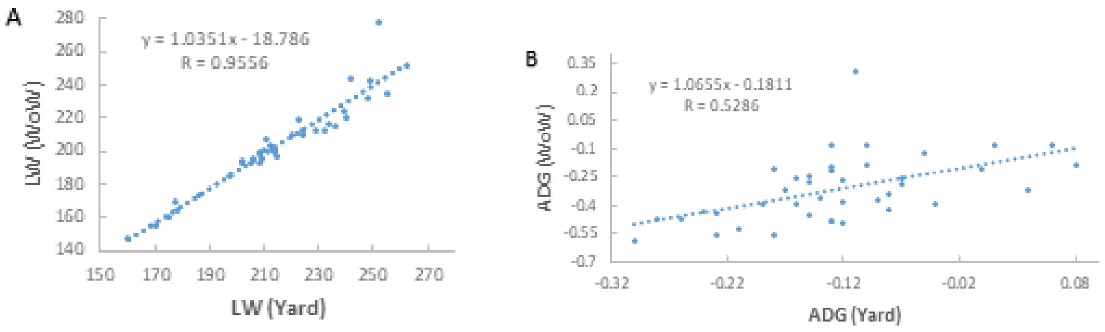


Figure 18. Correlation between Walk-over-Weighing (WoW) and Yard weighing (Yard) for (A) Liveweight (LW) on the end of Phase 2 and (B) Average Daily Gain (ADG) calculated as slope of weekly LWs on day over 56 days for Angus heifers grazing drought affected pasture.

Preliminary data on behaviours using the latest behaviour classification algorithm has been generated (Table 14). This algorithm produces 6 behaviour classifications: grazing, ruminating, walking, resting, drinking and other. The data are for 30 heifers that have complete data sets for the 8 weeks grazing drought affected pasture. The behaviour classifications will be compared with behaviour classifications from an earlier algorithm that produces 5 behaviour classifications: grazing, ruminating, walking, resting and other. The behaviour classification algorithm for drinking performed poorly in the most recent study and substantially overestimated time spent drinking. This was most likely due to the limited amount of behaviour annotation data available to develop the algorithm. Results for time spent grazing and pasture intake estimates derived from the sensor devices for the July-August 2019 trial appear consistent with greater pasture DM availability during Phase 1 (weeks 1 to 4) than Phase 2 (weeks 5 to 8) and very low pasture digestibility and crude protein and energy concentrations (Alvarenga et al., 2021). The results for rumination and increasing rumination relative to grazing time may also relate to the very low pasture digestibility and declining pasture availability across the study. The results for time spent walking relate well to distance of the paddocks from the watering point (which is within the walk-over-weigh and auto-drafting facility), and declining pasture availability between Phases 1 and 2. These results (Table 15) were reflected in the heifer liveweights and LW changes during each Phase: in Phase 1 heifers gained weight, but during Phase 2 they lost weight (Alvarenga et al., 2021).

Table 14. Least squares means for behaviours and dry matter intake algorithm (from Greenwood et al. 2017) estimates as determined using CSIRO behaviour monitoring collars and affected by week and phase of study and RFI-f-EBV group

Mean values are for 30 Angus heifers within 2 replicate groups grazing each of 8 paddocks of 1.25 ha for one-week periods during two 4-week grazing Phases.

Variable	n	Graze (hours/d)	Dry matter intake estimate (kg/d)	Ruminate (hours/d)	Ruminate to Graze ratio	Rest (hours/d)	Walk (hours/d)
Week							
1	30	6.96	11.7	9.68	1.43	2.09	2.62
2	30	7.34	12.7	9.23	1.29	2.14	2.71
3	30	7.48	13.1	8.99	1.23	2.14	2.81
4	30	6.72	11.1	8.88	1.39	2.05	3.53
5	30	6.24	9.8	9.12	1.53	2.24	3.52
6	30	6.05	9.3	9.30	1.59	2.34	3.38
7	30	5.26	7.3	9.49	1.93	2.04	3.83
8	30	3.88	3.7	10.26	2.85	1.70	4.28
SED		0.280	1.44	0.329	0.131	0.239	0.239
P-value		<0.001	<0.001	<0.01	<0.001	0.26	<0.001
Phase							
1	30	7.14	12.2	9.26	1.343	2.08	2.89
2	30	5.39	7.6	9.47	1.949	2.10	3.76
SED		0.238	0.62	0.289	0.107	0.226	0.220
P-value		<0.001	<0.001	0.45	<0.001	0.96	<0.001
RFI-F-EBV							
High	13	6.16	9.6	9.51	1.70	1.97	3.31
Low	17	6.31	10.0	9.24	1.62	2.20	3.15
SED		0.238	0.62	0.289	0.107	0.226	0.220
P-value		0.54	0.54	0.35	0.44	0.45	0.44

Average pasture dry matter disappearance (kg DM/head/d) and time spent grazing (hours/head/d) provide estimates of pasture intake in addition to algorithm estimates of intake from sensor behaviour data. Correlations for these measurements and the other behaviours were determined for each replicate group for each weekly grazing period (n = 16 behaviour measurements and intake estimates).

Correlation of pasture intake estimates (generated from average time spent grazing) with pasture disappearance was 0.74 ($P < 0.001$), suggesting the current pasture intake algorithm accounted for 55% of variation in pasture intake within this experiment. This finding is consistent with our earlier research on individual cattle in which time spent grazing accounted for up to 60% of variation in pasture intake (Greenwood *et al*. 2017). The rank correlation between average pasture dry matter disappearance and pasture intake estimated from sensor behaviour (time spent grazing) was higher at 0.84 ($P < 0.001$).

The preliminary analyses of this study and our previous research on high digestibility annual ryegrass (Greenwood *et al*. 2017), which assume pasture dry matter disappearance estimates pasture intake, resulted in the following relationships:

1. Pasture intake (kg DM/head/d) = –6.93 + 2.09 x grazing (hours), $r^2 = 0.55$, RSD = 2.30 kg DM, $P = 0.001$ (July-August 2019 LPP study)

2. Pasture intake (kg DM/head/d) = –6.46 + 2.61 x grazing (hours), $r^2 = 0.59$, RSD = 1.66 kg DM, *P* = 0.006 (Greenwood *et al*. 2017)

These algorithms result in the same rankings of the heifers for pasture intake, but the algorithm of Greenwood *et al*. (2017) for intake of high digestibility pasture overestimated intake of the drought affected pasture in the preliminary analyses of the July-August 2019 study (Table 13). Further analyses of the sensor data will enable a more reliable assessment of the scale of any differences between pasture intake predictions.

Correlations between pasture dry matter disappearance and time spent in other behaviours were ruminating -0.35 (*P* = 0.18), ratio of ruminating to grazing ratio -0.65 (*P* = 0.007), resting 0.10 (*P* = 0.70), walking -0.69 (*P* = 0.003). Rank correlations between pasture dry matter disappearance and other behaviours were -0.36 for ruminating (*P* = 0.17), -0.74 for ruminating to grazing ratio (*P* = 0.001), 0.14 for resting (*P* = 0.61) and -0.67 for walking (*P* = 0.004).

These preliminary analyses will be repeated when the data set is complete and will include behaviours and pasture intake estimates from current and earlier behaviour classification algorithms, and improved behaviour classification algorithms as they become available. We will assess relationships between behaviours, other animal and pasture factors, and estimates of pasture intake from this and earlier studies on individuals and groups of cattle.

In 2020, 32 from the 40 Angus heifers selected based on their RFI-f-EBVs (Low-RFI-f-EBV and High-RFI-f-EBV) were used in a study to evaluate their performance when grazing mixed perennial temperate grasses. The Fifteen-month-old heifers grazed within two replicates of 16, each with 8 Low-RFI-f-EBV (High feedlot efficiency) and 8 High-RFI-f-EBV (Low feedlot efficiency) heifers. Each replicate group grazed one of eight 0.61 ha paddocks mixed perennial temperate grasses at 7-day intervals during repeated 28-day cycles: Phase 1, 4,298 kg DM/ha on offer; Phase 2, 2,961 kg DM/ha on offer. Liveweight and ADG were analysed by linear regression with RFI-f-EBV group (Low or High) and Phase (1 or 2) and their interaction as fixed effects. Initial and final LW did not differ between High- and Low-RFI-f-EBV heifers or between Phase 1 and 2 (Table 13). Liveweight change (LWc) and ADG did not differ between Low-RFI-f-EBV and High-RFI-f-EBV. However, ADG and LWc differed between Phases 1 and 2 (mean 250 vs -120g, *P=0.002* and 7 vs -3kg, *P=0.002*; respectively).

Table 15. Mean liveweight, liveweight change and average daily gain of heifers divergent in residual feed intake estimated breeding values (RFI-f-EBV) for two 4-week grazing phases (Phase)

Variable	RFI-f-EBV group					P-values		
	Phase 1		Phase 2					
	High	Low	High	Low	SEM	RFI-f-EBV	Phase	RFI-f-EBV x Phase
Number of heifers	16	16	16	16				
Initial liveweight (kg)	359.4	351.3	367.1	362.8	4.46	0.493	0.291	0.833
Final liveweight (kg)	363.4	361.3	362.7	360.5	4.12	0.799	0.927	0.997
Liveweight change (kg)[1]	4	10	-4.44	-2.31	1.77	0.226	0.002	0.562
Average daily gain (g/d)[1]	143	357	-158	-82	63.21	0.226	0.002	0.563

[1] Calculated from difference between initial LW and final LW; standard error of the mean (SEM).

This study demonstrated that there was a significant difference due to Phase. Heifers gained 7.0 kg LW in Phase 1 while in Phase 2 heifers lost -3.4 kg (*P=0.002)*. The LW loss coincided with pasture on offer, DM, dry matter digestibility, metabolisable energy (4298 vs 2961 kg/ha, *P<0.001*; 44.9 vs 53.6%, *P=0.001*; 45.2 vs 42.4%, *P=0.024*; 6.16 vs 5.69 MJ/kg DM, *P=0.027*; for Phase 1 and 2, respectively). This resulted in a higher pasture disappearance, expressed as % of LW/head/day in Phase 1 than in Phase 2 (2.07% vs 1.71%, SEM 0.09, *P=0.042*). The decline in pasture availability and nutritional quality as grazing progressed was also found in the 2019 study where heifers were grazing drought affected pasture (Alvarenga et al., 2021). There was no evidence that the variation on RFI-feedlot EBVs from Angus heifers affected their performance when grazing mixed perennial temperate grasses. However, pasture availability and quality significantly influenced LWC and ADG. These results are being assessed in conjunction with in-field walk-over-weighing, CSIRO-NSWDPI eGrazor sensor collars, and pasture mapping to develop methods for more comprehensive assessment of grazing efficiency.

Data from all post-weaning phases of growth have been collated and analysis are in progress to compare performance and rankings across the different phases and with the NFI-F-EBVs of the heifers. The phases that have been studied and will be incorporated into these analyses are:

- Early-post-weaning at pasture
    - Higher pasture availability
    - Lower pasture availability
- Pre-feedlot at pasture
    - Higher pasture availability
    - Lower pasture availability
- Feedlot

Analyses of data across these phases of growth will be delivered in the final report.

3.6 Grazing Efficiency studies in tropical conditions

3.6.1 Methods

3.6.1.1 Paddock studies

Evaluations of cattle on pasture extended from December 14th 2020 to November 10th 2021, approximately 11 months covering the transitions from dry to wet and wet to dry conditions. Stocking rate was reduced on March 10th when three heifers from each paddock were removed for Net feed efficiency measurements.

Detailed measurements of pasture biomass, botanical and chemical composition were taken at two-monthly intervals using a modified Botanal techniques (Tothill JC, Hargreaves JNG, Jones RM, McDonald CK (1992) 'BOTANAL – a comprehensive sampling and computing procedure for estimating pasture yield and composition 1. Field sampling.' (CSIRO: Brisbane)) and faecal sampling for NIR analysis. Measurements taken were:

- Pasture production, grass, legume, weed, ground cover
- Pasture samples for near infra-red spectrometry (NIRS): CP, digestibility, delta carbon (% non-grass)
- Faecal samples for NIRS: diet CP, faecal CP, digestibility, ash, energy, delta carbon.

GPS collars were deployed to 10 cattle per paddock for two periods of roughly 3-month duration (February to May and September to November). The following measurements were taken:

- Location for patch selectivity
- Grazing time x location for patch grazing
- Ruminating time to generate pasture quality index (ruminating/grazing)
- distance travelled or maximum speed as an index of temperament
- Bite rate for intake algorithm
- First field test of intake algorithm under northern conditions

At the beginning of the trial and every eight weeks, animals are transferred to yards for weight, faecal, blood and rumen sampling. Samples were taken for the following measurements:

- Weight for correlation with WOW data
- Faeces for faecal NIR, dietary N, faecal N, OM digestibility.
- Rumen for volatile fatty acids, ammonia
- Blood for N^{15}, ammonia

CiboLabs (cibolabs.com.au) provided satellite imagery for the paddocks throughout this period. Imagery has been correlated with on the ground measurements using Botanal techniques. These include:

- Three-band pseudo-colour Sentinel images
- Normalised difference vegetation index (NDVI)
- Fractional cover (bare ground) photosynthetically and non-photosynthetically active vegetation).

3.6.1.2 Pen studies

On two occasions, in March and July 2021, twelve cattle were removed from the pasture and housed in individual pens and fed chopped hay. Different cattle were used in each of the two pen studies. Cattle were adapted to hay feeding for 2 weeks then fed *ad libitum* for 12 weeks. Cattle were weighed at two-weekly intervals and sampled for blood, faeces and rumen fluid on one occasion at the mid-point of the trial. Voluntary feed intake with 10% refusals was determined by the difference between feed offered and refused every two or three days for determination of residual feed intake (RFI). Cattle were sampled for rumen contents and faeces at the mid-point of each pen trial. Faeces were analysed for diet nutritive value using faecal near infra-red reflectance spectroscopy (F. NIR). Rumen contents were analysed for pH, rumen ammonia and volatile fatty acids. In the first pen study the crude protein content of hay was 13%, while in the second study it was 11%.

3.6.2 Results

Results are presented below for the grazing efficiency trial that began in December 2020 and concluded in November 2021.

Pasture yield at the start of the trial averaged just over 2 t/ha and was similar across all four paddocks (Table 16). Due to a good wet season with a total of 753 mm rainfall (Figure 19), pasture growth was very strong with yield increasing to over 8 t/ha in April. All paddocks were dominated by tropical grasses throughout the season representing between 60 and 70 % of dry matter. Legumes, predominantly *Stylosanthes* and *Desmanthus* account for 10 to 15% of DM with the balance comprising weed species (Figures 20, 21, 22). The planned stocking rate of 2.3 ha/AE was based on previous stocking rates for these paddocks. However due to the exceptional season, the data shows that pasture biomass at the end of the study was higher than at the beginning. This implies that pasture intake would not have been influenced by availability, although poor performance at the end of the study indicated that pasture was limiting energy and protein intake to sustain only maintenance levels of performance. Paddocks 3 and 4 consistently yielded less biomass throughout the year than paddocks 1 and 2. However there were no differences in LW gain between heifers in the four paddocks, averaging 0.46, 0.46, 0.41 and 0.39 kg/d for paddocks 1 to 4, respectively.

Table 16. Pasture biomass, composition, bare ground and dead matter over the grazing season

	Paddock	Biomass (t/ha)	Grass (%)	Legume (%)	Weeds (%)	Bare ground (%)	Dead (%)
Dec 14	1	2.49	79	12	9	18	85
	2	2.14	83	8	8	14	79
	3	1.82	81	10	9	22	90
	4	1.77	84	9	7	23	93
	Mean	2.06	81.86	9.91	8.23	19.02	86.78
	s.e.	0.193	1.326	1.021	0.553	2.339	3.695
Feb 4	1	4.66	70	15	15	20	0.2
	2	3.51	60	20	17	15	0.5
	3	3.19	67	12	21	16	0.1
	4	3.11	70	9	21	14	0.2
	Mean	3.62	66.67	13.94	18.54	16.41	0.26
	s.e.	0.414	2.808	2.664	1.720	1.483	0.095
April 14	1	9.46	60	18	22	1	7
	2	9.2	64	15	21	4	10
	3	7.28	68	15	17	6	6
	4	7.03	74	8	18	4	9
	Mean	8.20	66.48	13.92	19.60	3.76	8.08
	s.e.	0.706	3.376	2.440	1.384	1.071	0.969
June 1	1	7.58	65	8	27	5	33
	2	7.98	66	12	22	8	37
	3	6.15	66	15	18	7	50
	4	6.66	72	8	25	7	50
	Mean	7.09	67.49	10.69	23.19	6.99	42.70
	s.e.	0.482	1.721	1.958	2.191	0.596	5.063
August 3	1	8.08	86	4	10	17	92
	2	7.96	86	1	13	8	89
	3	6.74	92	1	8	20	96
	4	6.91	90	4	7	18	96
	Mean	7.42	88.22	2.32	9.46	16.05	93.30
	s.e.	0.402	1.603	0.924	1.516	3.077	2.003
Nov 3	1	6.35	89	2	9	10	91
	2	5.45	77	6	17	21	96
	3	4.09	92	2	7	21	93
	4	4.05	94	3	3	15	95
	Mean	4.98	88.09	3.00	8.91	16.91	93.51
	s.e.	0.647	4.373	1.110	3.429	2.973	1.426

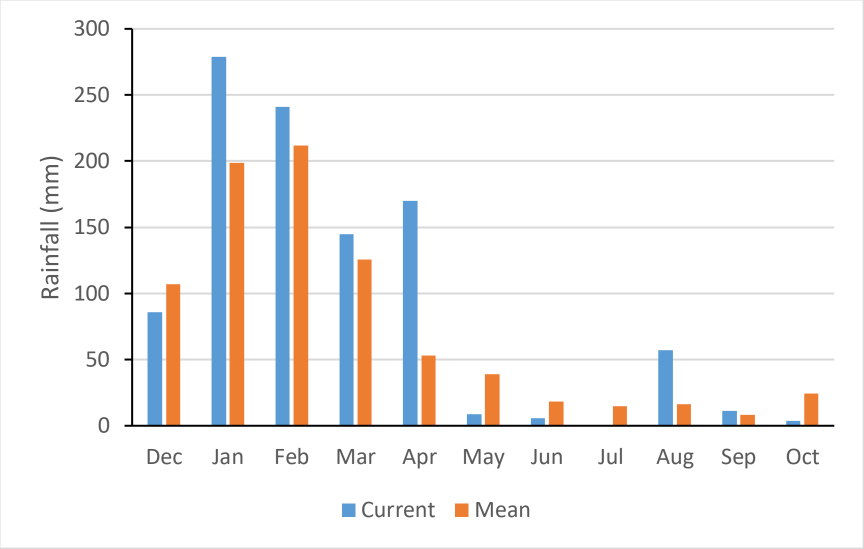


Figure 19. Monthly rainfall throughout the grazing trial to date compared to median rainfall for this site.

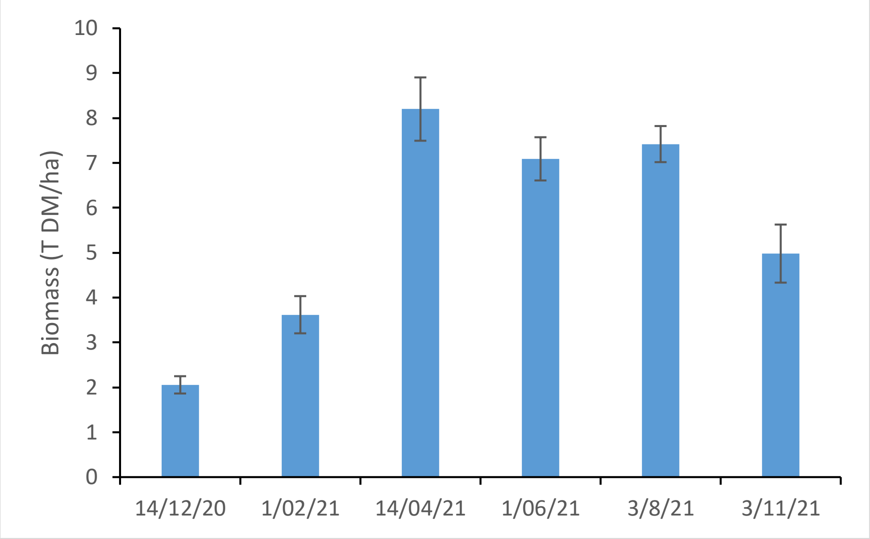


Figure 20. Change in pasture biomass over the grazing season.

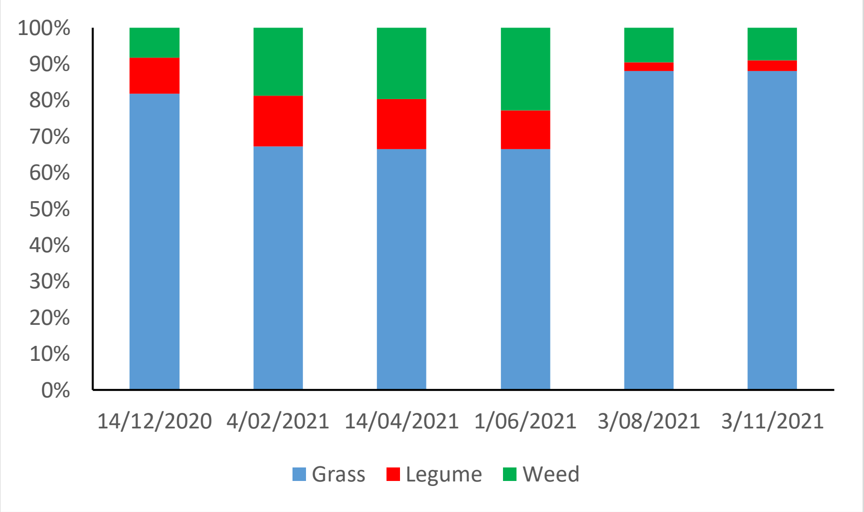


Figure 21. Pasture composition over the grazing season (% total).

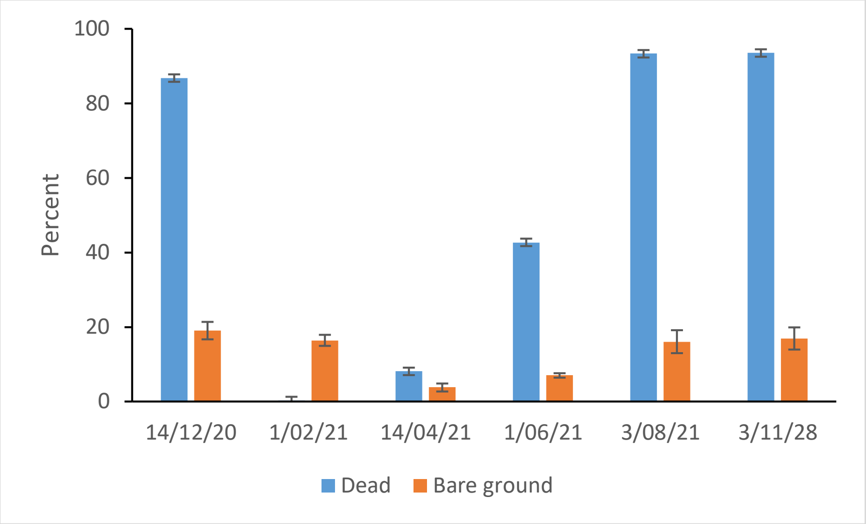


Figure 22. Dead pasture and bare ground over the grazing season (%)

3.6.2.1 *Nutritive value of pasture and diet*

Spatial distribution of biomass and components.

The spatial distribution of grass, legume and weed biomass was non-uniform across all paddocks at any point in time. (Figure 23).The distribution of biomass across time also changed sugesting that spatial grazing pressure and selection changed depending upon the season. Alternatively, growth rates of the various categories was non unifrom.

At the initiation of the trial, there was no evidence of green biomass. However this increased rapidly after the onset of rain with in excess of 90% of the grazing horizon being green in April. Thereafter, senescence set in and there was a gradual loss of green material in the grazing horizon. The yield of CP and ME is a function of diet quality and biomass. The CP yield was higher in Mango than Windmill paddocks in February, April and June corresponding with the higher legume in these paddocks. A similar, although less pronounced observation was made for ME.

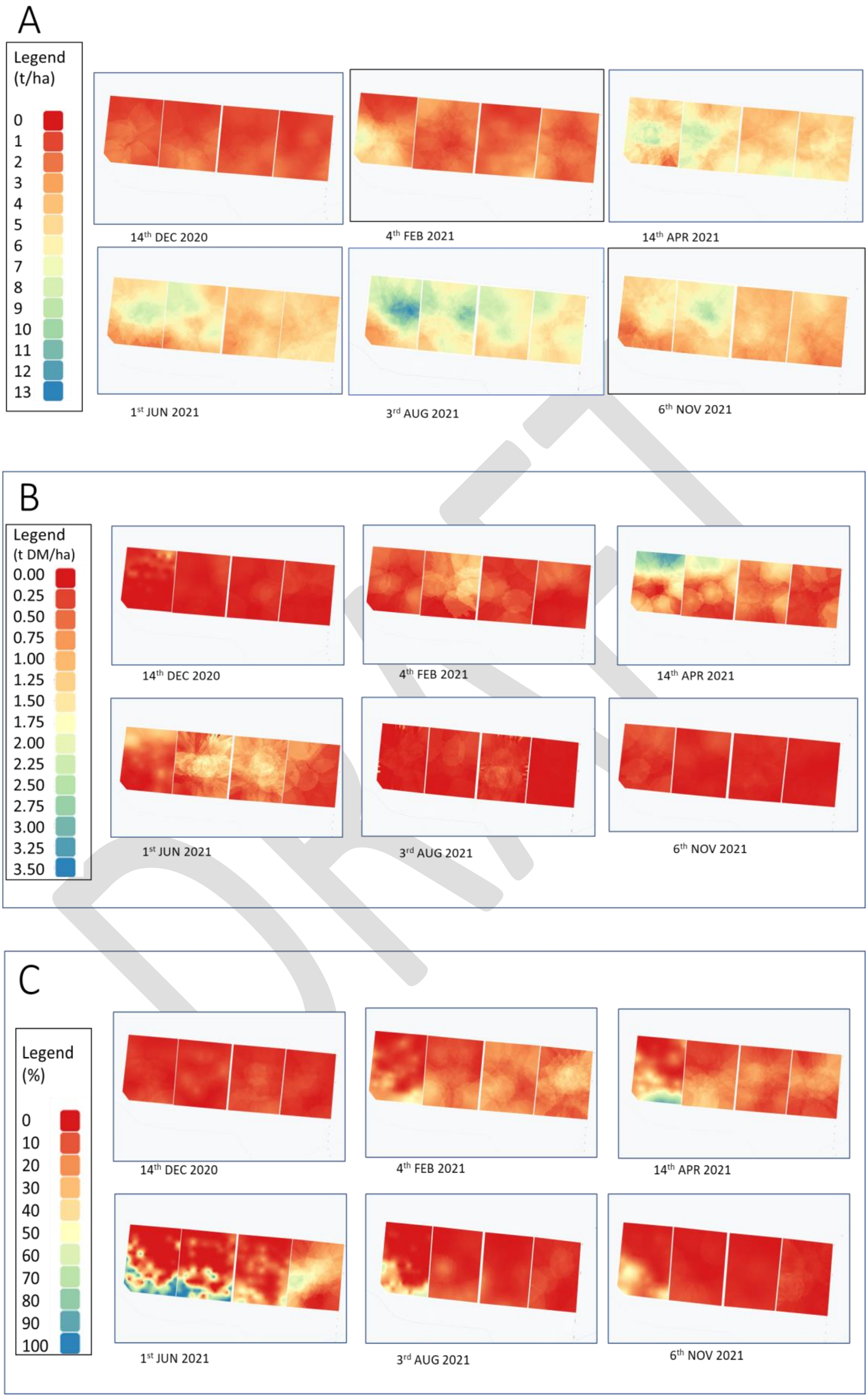


Figure 23. Spatial distribution of grass (A), legumes (B) and weeds (C) measured on 6 occasions throughout the trial.

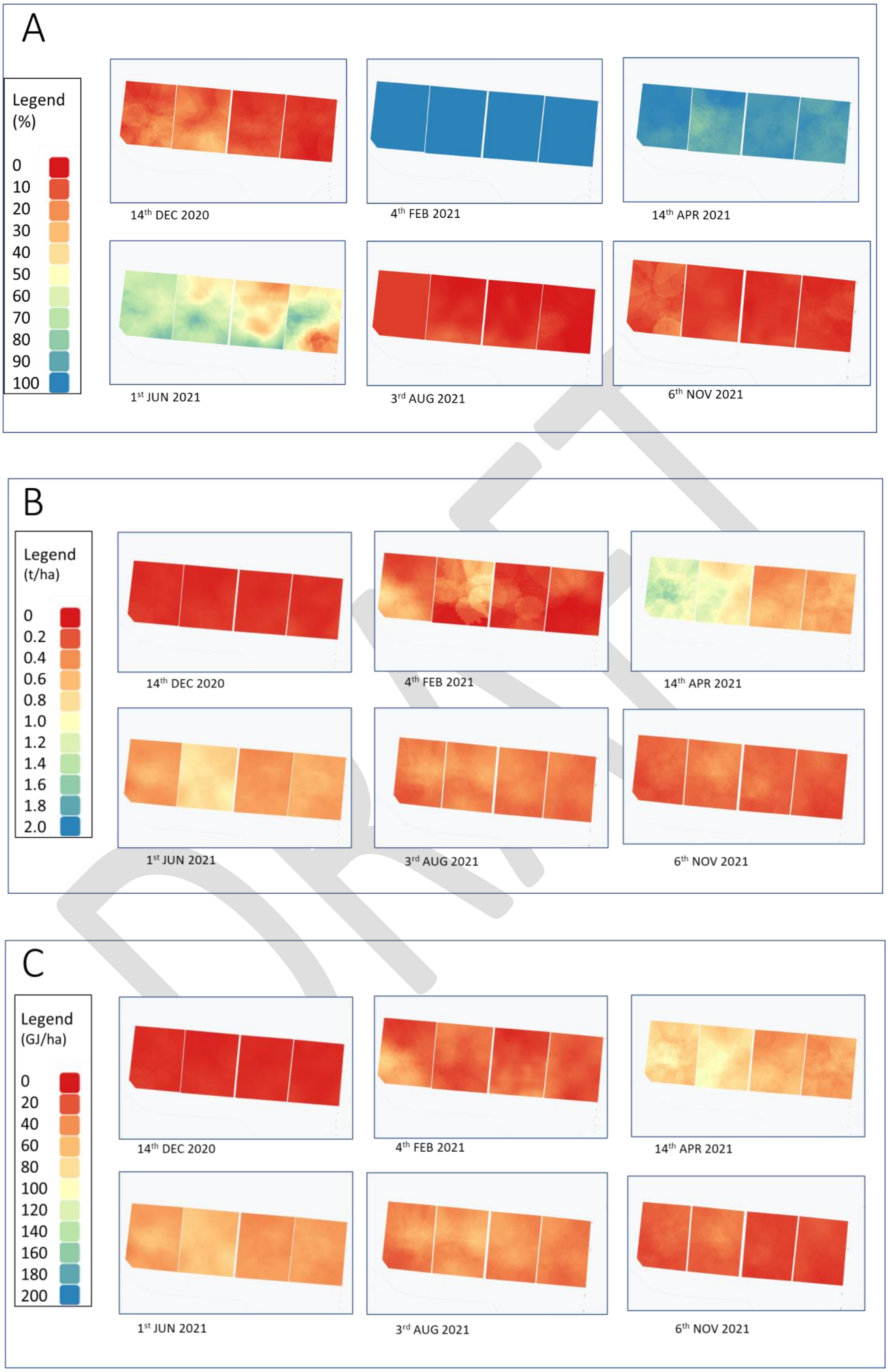


Figure 24. Spatial distribution of green (A; %), crude protein biomass (B, T DM/Ha) and metabolizable energy (C, GJ/ha) measured on 6 occasions throughout the trial.

Remote sensing

Figures 23, 24 and 25 show images from satellite portrayed in three ways to represent biomass, greenenss and ground cover. Reconciling the visual images with the corresponding ground-truthed data proved to be unsatisfactory with satellite imagery not corresponding with bilmass measuremetns made using the Botanal technique.

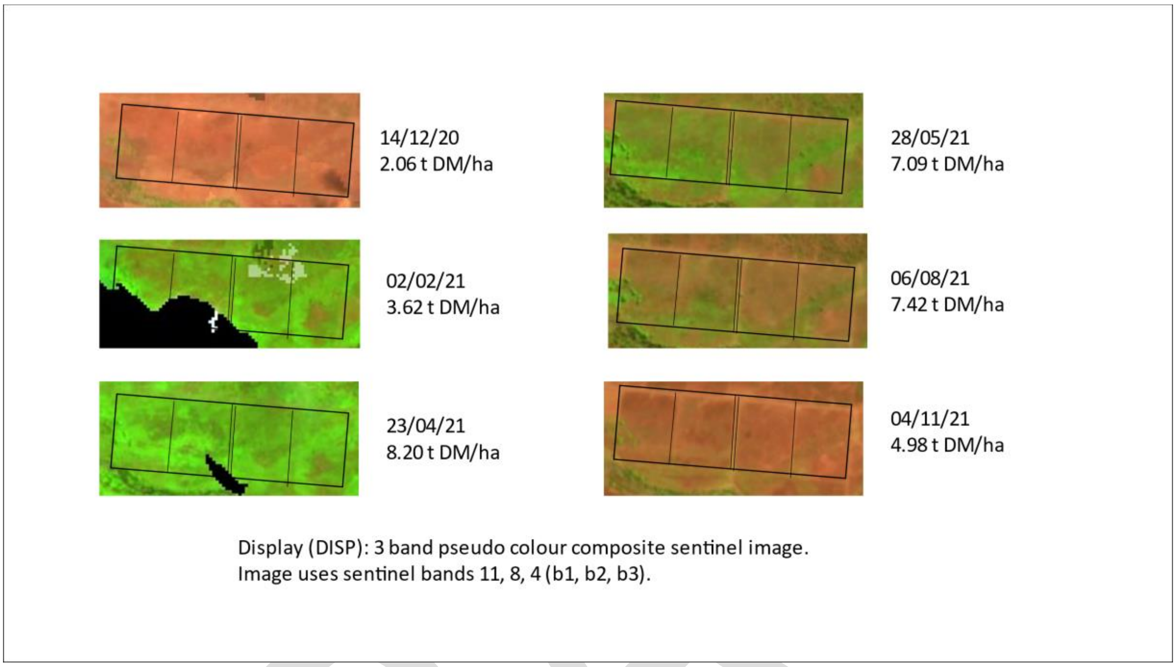


Figure 25. Pseudo-colour composite image representing biomass, taken on 6 occasions throughout the trial. Biomass data refers to estimates using ground based Botanal techniques. Black lines represent the paddock boundaries. Biomass data from Botanal measurements included for reference.

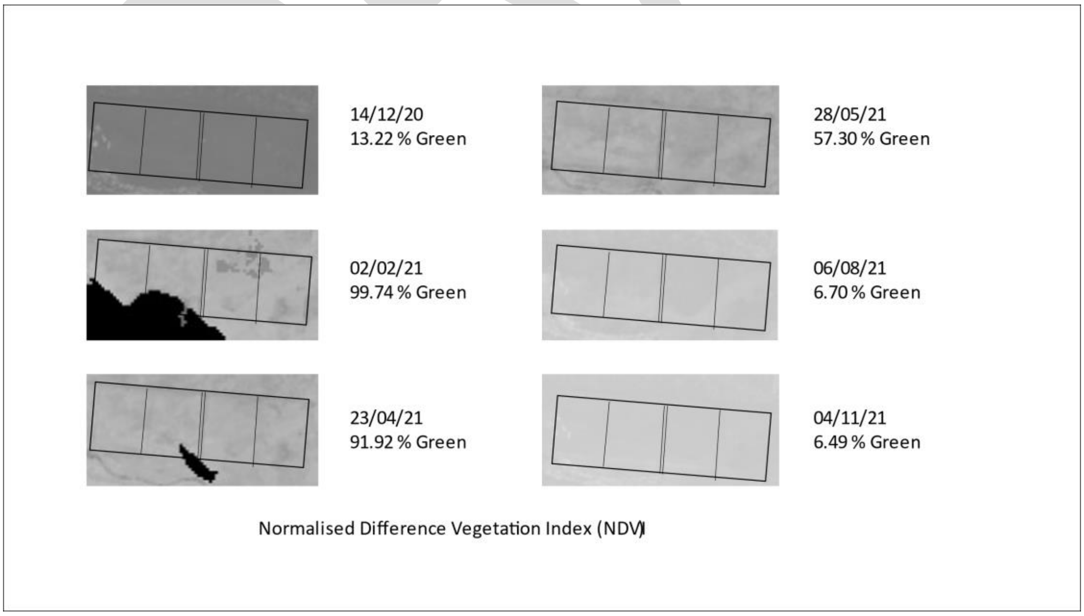
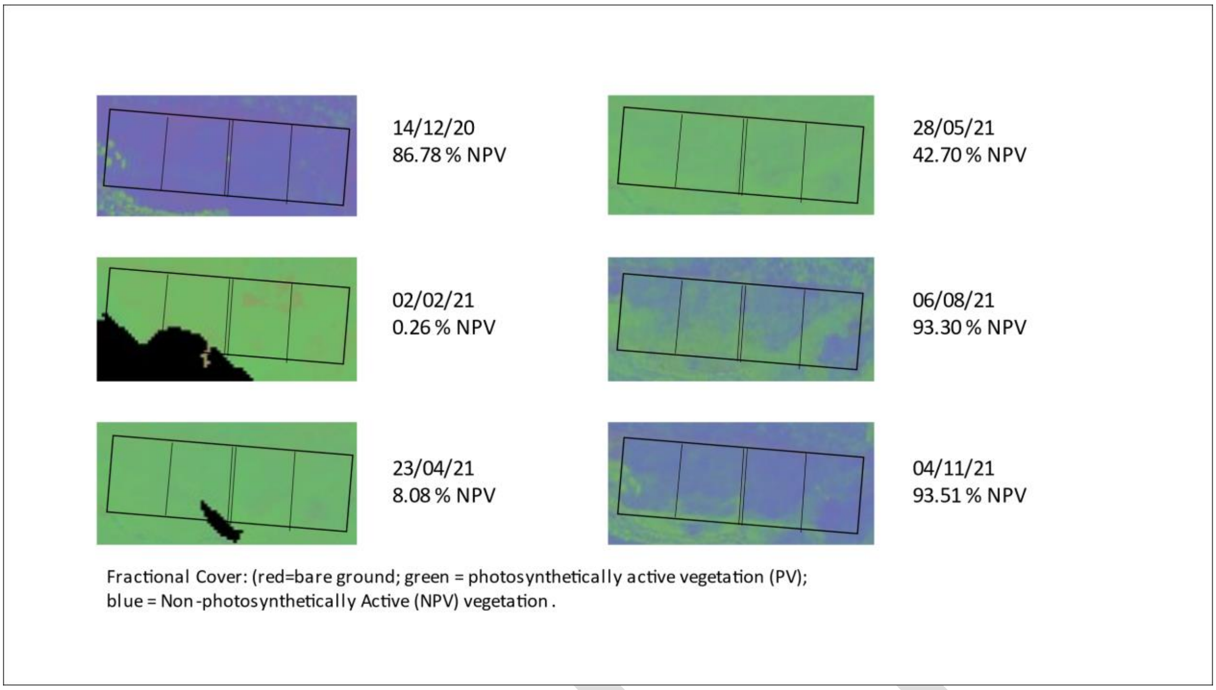


Figure 26. Normalised difference vegetation index (NDVI) representing active green biomass, taken on 6 occasions throughout the trial. Green data refers to percentage active ground cover using ground based Botanal techniques. Black lines represent the paddock boundaries.



Fractional Cover: (red=bare ground; green = photosynthetically active vegetation (PV); blue = Non-photosynthetically Active (NPV) vegetation.

Figure 27. Differentiation between bare ground (red), photosynthetically active vegetation (green) and non-photosynthetically active vegetation (blue) taken on 6 occasions throughout the trial. NPV data refers to estimates of dead matter using ground based Botanal techniques. Black lines represent the paddock boundaries.

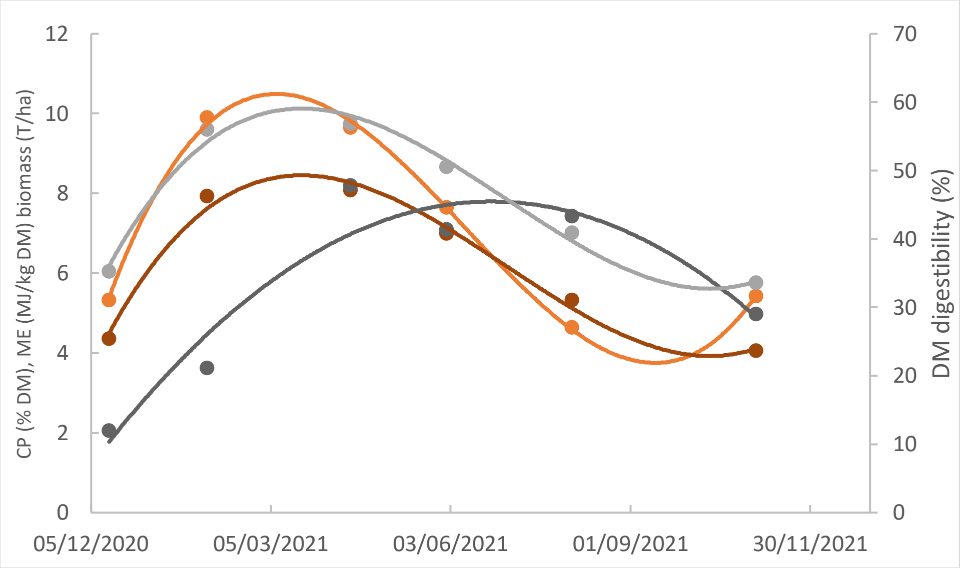


Figure 28. Polynomial relationships for DM digestibility (grey), crude protein (orange), metabolizable energy (brown) and Biomass (black) of pasture over the duration of the trial

Biomass and quality indices of biomass followed the expected trajectory over time. With break of season in January, there was a rapid increase in both biomass and quality (CP, DMD, ME). By March quality had begin to decline as the pasture matured but biomass continued to increase until August. At the end of the grazing trial CP had dropped to 5.3%, DMD to 34% and ME to 4.0 MJ/kg DM, all indicative of poor nutritive value, which would not support positive rates of gain.

Table 17. Pasture crude protein, DM and OM digestibility, Neutral and acid detergent fibre and metabolizable energy *over the grazing season.*

	Paddock	CP (% DM)	DMD (%)	OMD (%)	NDF (% DM)	ADF (% DM)	ME (MJ/kg DM)
Dec 14	Mango West	4.82	37.3	48.4	74.8	53.7	4.70
	Mango East	4.95	34.4	46.8	75.4	54.9	4.21
	Windmill West	5.82	36.7	45.7	73.5	53.7	4.60
	Windmill East	5.68	32.8	43.6	74.9	55.6	3.93
	Mean	5.32	35.3	46.1	74.7	54.5	4.36
Feb 4	Mango West	8.72	55.1	56.2	62.6	37.9	7.77
	Mango East	10.67	55.8	57.9	64.5	38.4	7.89
	Windmill West	9.97	57.9	59.0	63.0	36.6	8.24
	Windmill East	10.28	55.3	58.1	63.0	35.4	7.81
	Mean	9.90	56.0	57.8	63.3	37.1	7.93
Apr 14	Mango West	13.57	59.6	51.5	61.6	35.7	8.54
	Mango East	10.49	63.2	53.0	61.9	38.6	9.16
	Windmill West	7.15	54.0	49.6	65.3	42.7	7.58
	Windmill East	7.58	51.2	48.7	67.0	44.6	7.10
	Mean	9.66	56.9	50.7	64.0	40.5	8.08
June 1	Mango West	6.09	47.9	44.3	69.9	51.6	6.53
	Mango East	9.97	55.6	49.0	62.2	41.3	7.85
	Windmill West	6.88	49.4	43.9	66.6	46.4	6.79
	Windmill East	7.62	49.4	47.9	67.4	45.6	6.78
	Mean	7.64	50.6	46.3	66.6	46.2	6.99
Aug 3	Mango West	4.27	36.2	39.0	74.5	55.0	4.53
	Mango East	4.90	43.6	43.3	73.9	52.3	5.80
	Windmill West	4.82	43.6	44.5	72.4	51.6	5.79
	Windmill East	4.58	40.2	42.3	73.5	52.3	5.20
	Mean	4.64	40.9	42.3	73.6	52.8	5.33
Nov 3	Mango West	4.53	34.9	39.1	74.6	56.2	4.29
	Mango East	5.19	36.0	39.2	75.5	56.7	4.48
	Windmill West	6.43	30.5	37.8	76.8	56.0	3.54
	Windmill East	5.54	32.9	37.8	77.2	56.8	3.95
	Mean	5.43	33.6	38.5	76.0	56.4	4.06
	s.e.						

3.6.3 Animal performance on pasture

The sequential removal of heifers for the evaluation of net feed efficiency resulted in different groups of heifers being on pasture for different lengths of time. Table 18 shows the mean, minimum and maximum rates of gain for each of these groups up until the time they were removed from pasture. Those removed for the pen trial later in the grazing study had the lowest rates of gain because growth performance declined later in the grazing season (Figure 28). This was attributed in part to a decline in biomass as shown by the correlation between animal LW gain at the end of the trial and biomass (Figure 29). However, biomass was still above 4 t DM/ha, suggesting the main reason for poor animal performance was attributed to low nutritive value of the pasture (Figure 28).

Table 18. Performace of heifers on grass until removed for pen trials or at completion of trial.

		LW gain (kg/d)		
	n	Mean ± s.e.	Minimum	Maximum
On grass to 1st pen trial	56	0.67 ± 0.04	0.42	0.93
On grass to 2nd pen trial	44	0.70 ± 0.12	0.62	0.86
On grass throughout	32	0.45 ± 0.08	0.34	0.57

Hereafter, animal data refers only to those 32 heifers that remained on pasture throughout the entire trial. Heifers were divided into four efficiency groups according to their overall rates of gain throughout the trial. Faecal, blood, and rumen fermentation parameters were taken on four occasions throughout the trial, and at the end of the trial p8 backfat, condition score and hip height were recorded (Table 19). There was a strong time of year effect on all parameters measured, with parameters changing in response to changes in diet quality. Generally, the sampling periods in January and March were associated with typical responses to higher nutritive value; higher N in the diet and faeces, higher rumen ammonia and lower rumen pH. In contrast to time of year, efficiency group had no effect on any of the parameters measured. The only exception to this was a trend ($P<0.01$) towards the least efficient animals having lower total VFA concentration in rumen fluid. There were no significant interactions between time and efficiency group. The highest LWG heifers (most efficient) were significantly taller by 2 cm at the hip ($P=0.02$) compared to the lowest LWG group, but there were no differences in P8 backfat or body condition score ($P > 0.05$).

Table 19. Influence of time of year and efficiency group on animal performance, rumen fermentation and dietary characteristics of 32 Brahman heifers over an 11-month grazing period.

	Time of year					Probability (p =)		
	1/2/21	12/4/21	17/5/21	30/8/21	s.e.	Time	Efficiency	T x E
Plasma Nδ15	9.03	6.16	6.60	7.33	0.119	<0.001	0.985	0.991
Dietary N (% DM)	2.48	2.28	1.22	1.82	0.036	<0.001	0.200	0.876
Faecal N (% DM)	2.06	1.95	1.12	1.50	0.081	<0.001	0.566	0.842
DM digestibility (%)	65.1	58.3	52.9	57.1	0.55	<0.001		
Dietary non-grass (%)	-0.45	28.4	16.8	32.0	2.04	<0.001		
Rumen ammonia N	8.92	8.91	4.60	5.43	0.493	<0.001	0.285	0.811
Rumen pH	7.10	6.86	7.42	7.25	0.361	<0.001	0.491	0.737
Total volatile fatty acids (VFA; mg/dL)	65.4	65.0	51.8	47.2	3.07	<0.001	0.092	0.709
Efficiency group 1 (low)	54.2	55.8	51.3	45.6				
Efficiency group 2	70.9	66.5	49.8	49.5				
Efficiency group 3	62.4	67.6	54.4	45.8				
Efficiency group 4 (high)	74.2	70.0	52.0	48.1				
VFA (molar %)								
Acetate	72.2	71.0	75.6	73.3	0.348	<0.001	0.920	0.695
Propionate	13.0	13.0	14.1	13.5	0.163	<0.001	0.875	0.782
Iso-butyrate	1.10	1.49	0.531	0.935	0.060	<0.001	0.601	0.899
Butyrate	11.0	11.7	8.19	10.2	0.379	<0.001	0.896	0.908
Iso-valerate	1.10	1.44	0.630	1.25	0.053	<0.001	0.104	0.869
Valerate	1.28	0.818	0.648	0.631	0.092	<0.001	0.986	1.000
Caproate	0.311	0.464	0.212	0.217	0.028	<0.001	0.875	0.646
Acetate:propionate ratio	5.57	5.49	5.36	5.46	0.074	<0.001	0.941	0.594

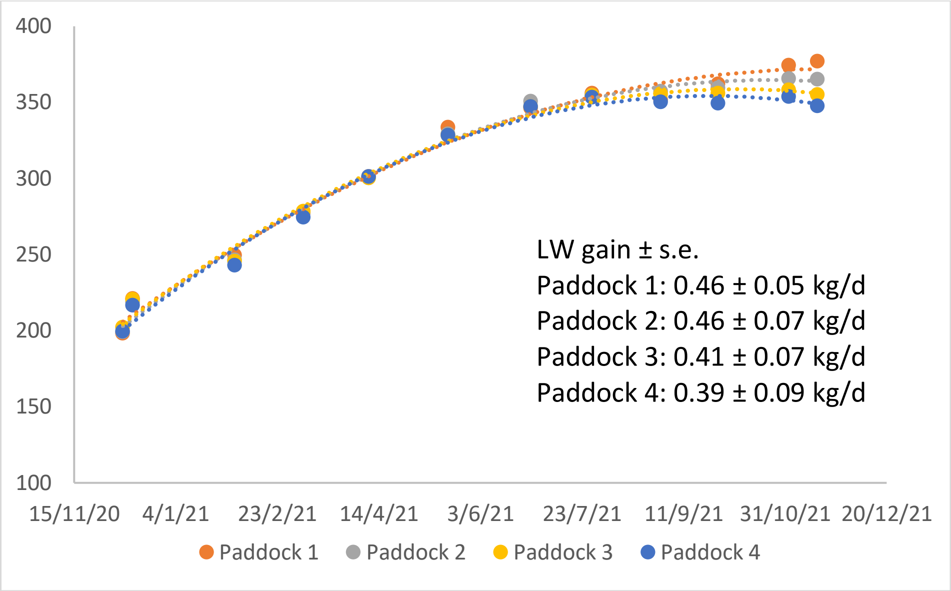


Figure 29. Effect of paddock on overall liveweight change of cattle throughout the trial.

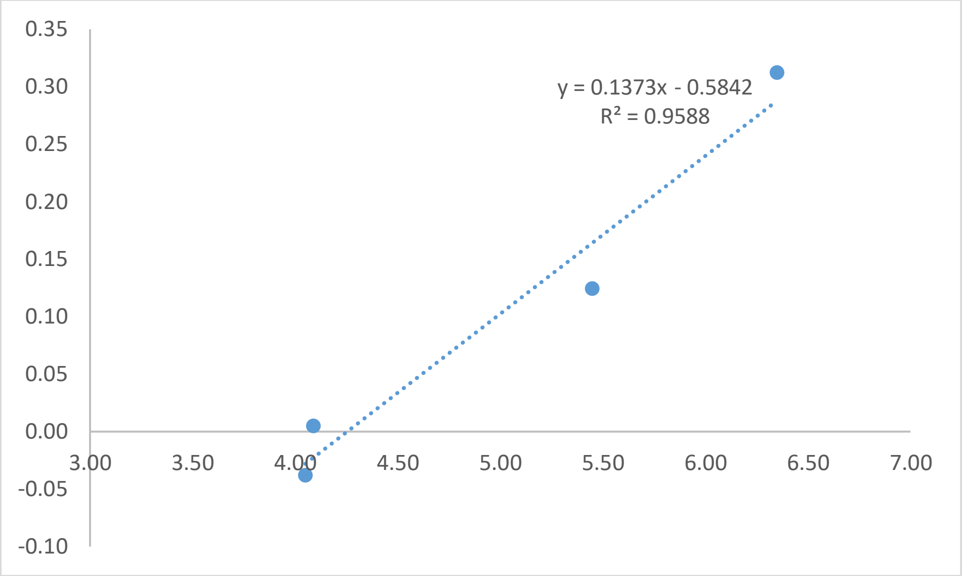


Figure 30. Correlation between biomass in the four paddocks at the end of the trial and LW change over the final 49 d.

Figure 31 shows the change in LW of cattle for the top and bottom performing animals in each paddock. In Mango West, there was little difference in performance, while in other paddocks there was a clear differentiation in performance, possibly due to higher yield of legume in this paddock as shown in Figure 29 B, particularly in April.

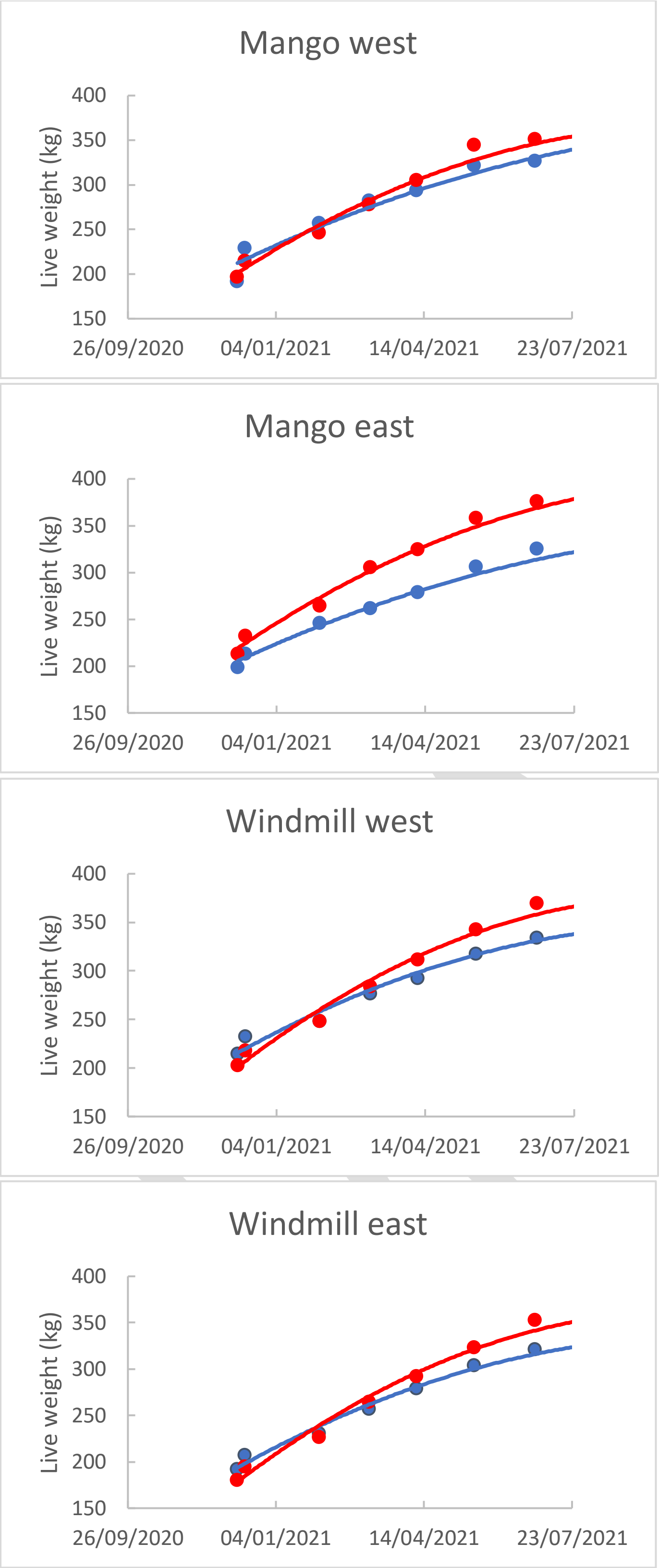


Figure 31. Live weight change of the top and bottom-performing cattle in each of the four paddocks.

3.6.4 Pasture quality and nutritional value of diet

Figure 32 shows the change in digestibility, CP and ME as measured from faecal NIR analysis of consumed feed. The pattern followed the characteristic increase in quality parameters in the wet season with a gradual decline as the pasture matured and senesced. Crude protein exhibited the greatest change over time, suggestive of the increased contribution from legumes to the diet in the early dry season.

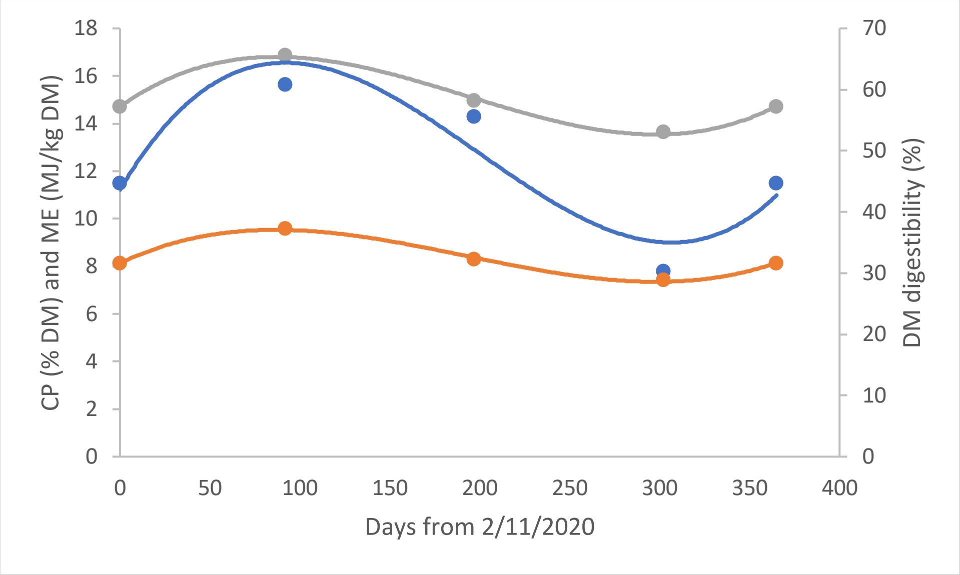


Figure 32. *Polynomial relationships for DM digestibility (grey), crude protein (blue) and metabolizable energy (red) of the diet over the duration of the trial*

There was a marked discrepancy between the nutritive value of the diet compared to the pasture (Figure 33). Diet CP was consistently six percentage units higher than the pasture regardless of the CP value of the pasture. For ME and DM digestibility the discrepancy was greater at lower values than higher values. This indicted that cattle were preferentially selecting leaf over stem resulting in higher pasture digestibility (Chagon and Stobbs, 1976). In contrast, the CP content of the diet was a consistant six percentage units higher than the pasture. This is indicative of a bais to wards intake of legume over grass throughout the grazing period (Coates 1996).

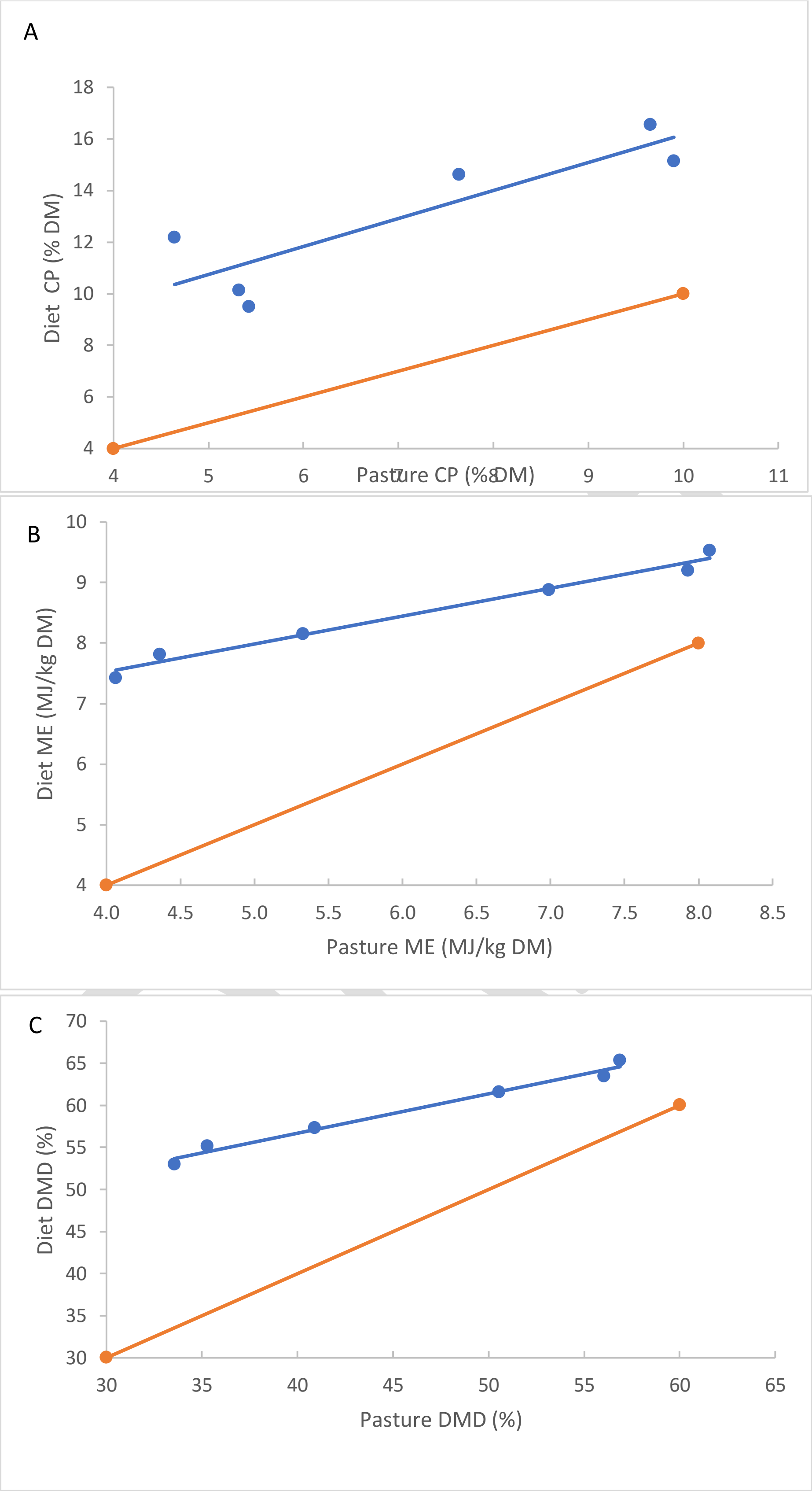


Figure 33. *Relationships between crude protein (A), metabolizable energy (B) and digestibility (C) in the diet and pasture. The red line represents unity*

The nutritive value of the diet was markedly higher than the pasture as shown for CP, ME and DMD in Figure 33. For DMD and ME, this discrepancy was greatest at lower DMD and ME values than at higher values, indicating heifers were more selective when digestibility (and hence ME) was lower. However for CP, the preference for higher CP dietary components was insensitive to CP content of the pasture.

3.6.4.1 *Tackling the issue of knowing intake on pasture*

Feed efficiency cannot be determined on pasture without a knowledge of both the output (e.g., kg gain) and the input (e.g., DM intake). Identifying the superior phenotype under grazing requires the development of a reliable method of determining intake on pasture. Analysis of the GPS data from collars will provide an algorithm attuned to northern grazing conditions in the final report. However, we are also evaluating other approaches one of which is the Minson and McDonald equation. The results summarised in Figure 33 show the correlation between measured intake of animals in the two pen trials and predicted intake using LW and LWG of cattle during these trials according to the equation:

$$\text{DM intake} = (1.185 + 0.00454LW - 0.0000026LW^2 + 0.315LWG)^2$$

The results demonstrate that the equation is representative of pen-based data and this method was used to evaluate the GPS derived intake algorithm based on grazing and ruminating time. This study was the first to evaluate the Armidale derived intake equation under tropical conditions.

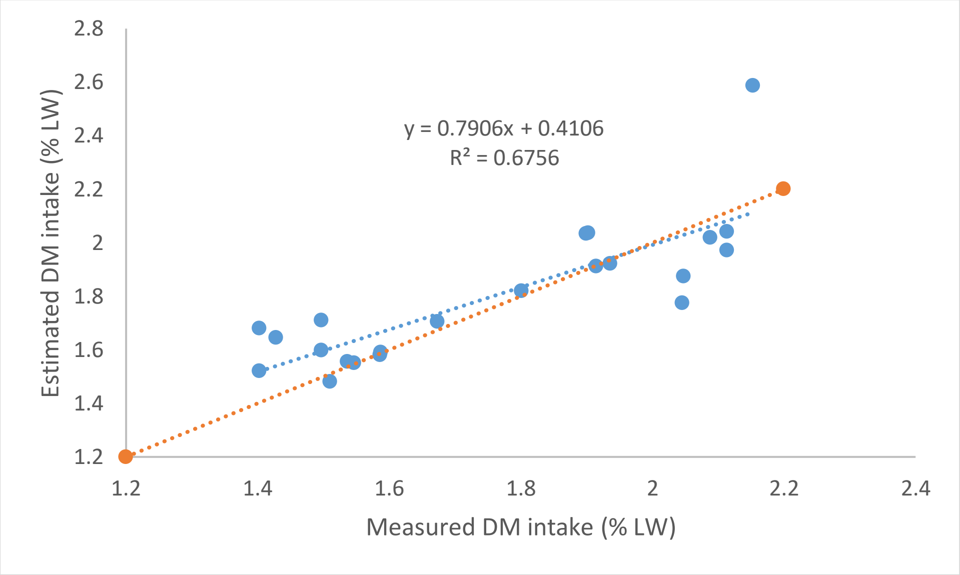


Figure 34. The relationship between estimated and measured DM intake in pen fed cattle.

The above equation was then used to estimate intake on pasture using the mean LW and LW gain between each crush weighing session. The mean intakes for all cattle during the ten periods and overall are shown in Figure 36. Mean dry matter intake across periods varied between 1.7 and 2.3% BW according to differences in LW gain throughout the trial. These data provide the framework for evaluation of other methods and developing a predictive tool to estimate DM intake based on animal and sward characteristics. These data are also critical to the objectives of the companion project P.PSH.0998 “revise Australian feeding standards to better achieve product specifications and improve ruminant efficiency”.

Figure 35. Heifers on net feed efficiency trial at Lansdown, September 2021.

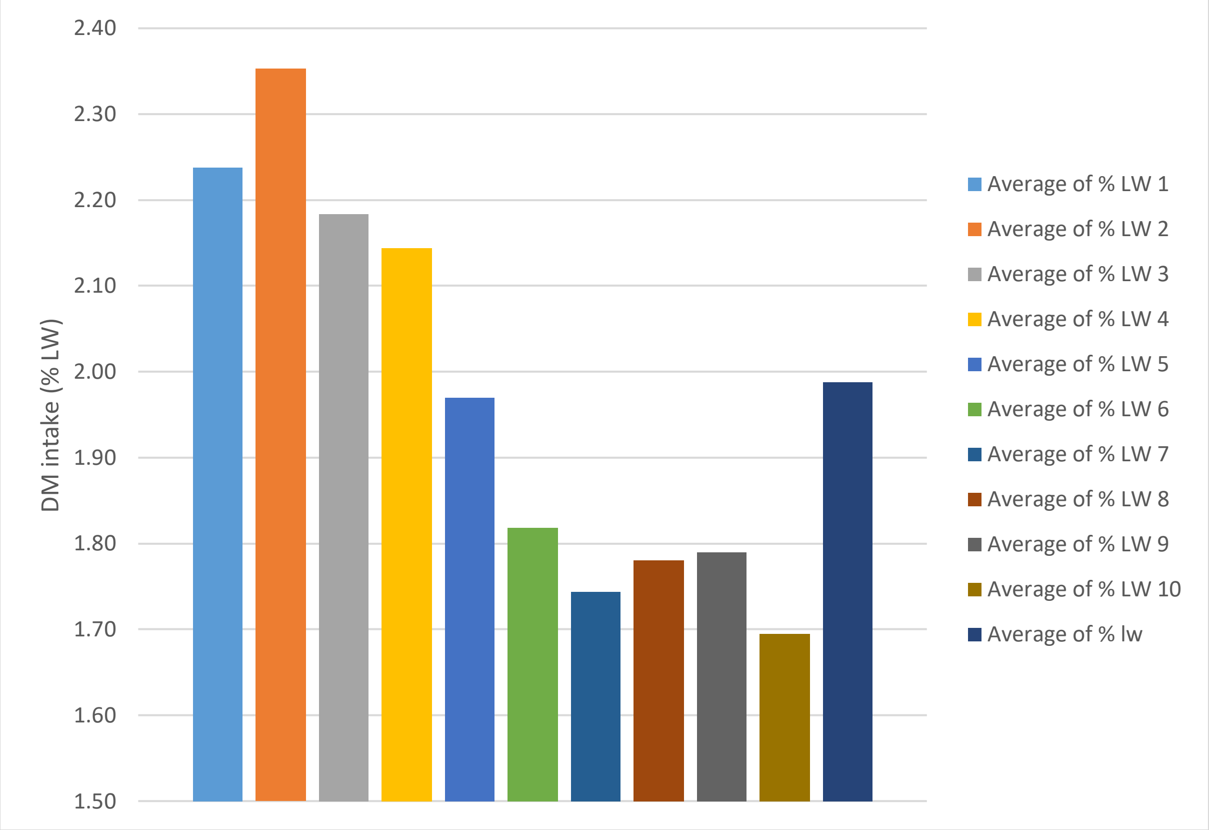


Figure 36. Estimated of DM intake (% LW) throughout the grazing study using the equation of Minson and McDonald (1987).

3.6.4.2 Validation of walk over weigh (WoW) method.

Due to technical difficulties WoW units were only functional from 2/2/21 to 28/6/21, during which time weight data measured in the crush and paddock (WoW) were used to derive LW gain using the regression of weight against time. Individual animal data for crush and WoW LW gain were compared using linear regression analysis. Successful LW gain data were obtained from 53 of the 56 head on trial. Figure 36 shows the close correlation between the two methods with the relationship approaching unity and an intercept close to zero. However, the R^2 was only 0.66 demonstrating that for the individual animal the WoW method may underestimate or over-estimate individual animal weights by up to 33%.

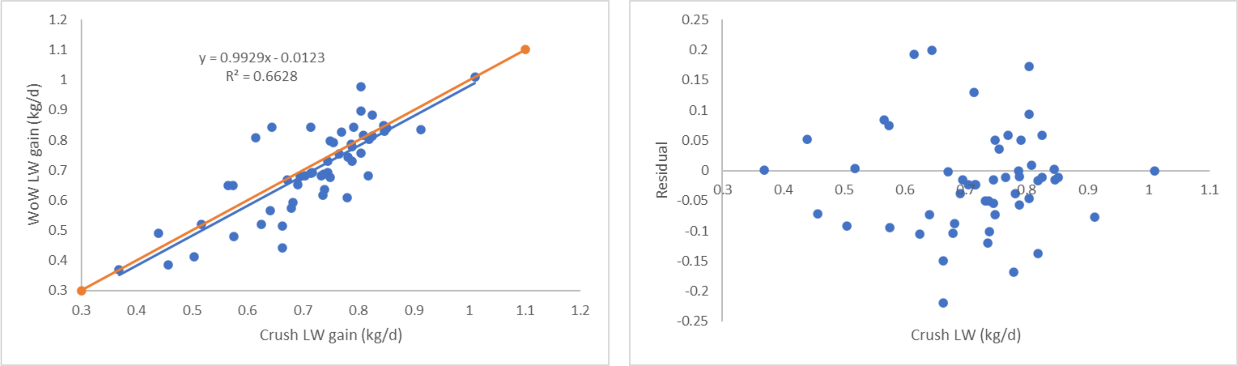


Figure 37. Relationship between LW gain estimated by regression of LW against time either by periodic measurement of LW in a crush versus continuous access to an in-paddock scale.

Figure 38. Heifers using the walk over weigh unit in February 2021.

Feed efficiency in pens

The hays used in the two pen trial was designed to differ in quality, broadly reflective of the expected diet quality of pasture at the time of pen feeding Table 17shows that this objective was achieved

Table 20. Nutritive value of hays fed in the two pen studies with corresponding data for diets of grazing cattle over the same time period.

	Pen trials		Corresponding diet on pasture	
	8/3/21 to 14/6/21	5/7/21 to 4/10/21	17/5/21	30/8/21
Crude protein (% DM)	13.4 ± 0.324	10.9 ± 0.456	14.9 ± 0.743	8.70 ± 0.803
DM digestibility (%)	60.8 ± 3.18	53.2 ± 5.21	58.9 ± 0.880	53.9 ± 0.876
NDF (% DM)	69.5 + 0.282	71.8 ± 0..432		
ADF (% DM)	41.0 ± 0.383	46.1 ± 0.654		

Rumen fermentation parameters were taken during the mid-point of each pen trial (Table 21). Dietary N was similar in both trials, but faecal N excretion was higher (P < 0.032) in trial 2. Total VFA was lower (P < 0.021) and acetate/propionate higher (< 0.003) in Pen Trial 2 compared to Pen Trial 1. Variation between trials in VFA ratios was generally small, although some differences were significant (P <0.05).

Table 21. Rumen fermentation and dietary characteristics of Brahman heifers during the pen trials 1 and 2.

Sample date	Pen trial 1 (8/3/21 to 14/6/21) 17/5/21	Pen trial 2 (5/7/21 to 4/10/21) 30.8/21	P =
Dietary N (% DM)	2.03 ± 0.076	2.20 ± 0.074	0.117
Faecal N (% DM)	1.65 ± 0.064	1.84 ± 0.062	0.032
DM digestibility (%)	58.8 ± 0.699	59.9 ± 0.683	0.278
Dietary non-grass (%)	11.3 ± 2.65	18.8 ± 2.59	0.046
pH	7.04 ± 0.060	6.97 ± 0.060	0.407
Total VFA (mg/dL)	57.5 ± 2.71	66.5 ± 2.67	0.021
VFA (molar %)			
Acetate	73.5 ± 0.294	73.2 ± 0.291	0.548
Propionate	14.0 ± 0.155	13.3 ± 0.154	0.004
Iso-butyrate	0.96 ± 0.051	1.04 ± 0.151	0.013
Butyrate	9.34 ± 0.335	9.87 ± 0.332	0.264
Iso-valerate	1.10 ± 0.045	1.21 ± 0.045	0.089
Valerate	0.83 ± 0.047	0.86 ± 0.047	0.674
Caproate	0.32 ± 0.016	0.36 ± 0.016	0.060
Acetate/propionate	5.28 ± 0.059	5.53 ± 0.058	0.003
Ammonia N (mg/dL))	7.70 ± 0.476	7.28 ± 0.476	0.532

Data for the first 84-day pen feeding trial with hay are shown in Table 20. Heifers on test ranged in initial LW between 233 and 332 kg and gained between 0.54 and 0.79 kg/d (Table 17). The DM intake averaged 1.98% LW, varying between 1.78 and 2.15 % LW. Feed to gain ratio averaged 9.2. Figures 28 and 29 show the variation in DMI relative to either LW gain or metabolic LW. Points above the line represent animals having poor efficiency as greater feed intake is required per unit of gain or metabolic weight. Points below the line represent more efficient animals. Full net feed efficiency calculations are yet to be completed. Table 18 and Figures 30 and 31 represent the same data for the second pen feeding trial. The quality of hay in Trial 2 was less than in Trial 1 (awaiting final results) which resulted in lower intake, gains and feed efficiency.

Table 22. Performance of heifers on hay (Pen trial 1).

	Mean (± s.e.)	Minimum	Maximum
Initial live weight (kg)	280 ± 8.56	233	332
Average live weight (kg)	301 ± 11.7	248	367
Metabolic LW (kg$^{0.73}$)	64 ± 1.8	56	74
Dry matter intake (kg/d)	5.93 ± 0.151	5.25	6.77
Dry matter intake (% LW)	1.98 ± 0.038	1.78	2.15
LW gain by difference (kg/d)	0.65 ± 0.022	0.54	0.79
LW gain by regression	0.65 ± 0.024	0.51	0.79
Feed:Gain	9.2 ± 0.25	7.9	10.7

Table 23. Performance of heifers on hay (Pen trial 2).

	Mean (± s.e.)	Minimum	Maximum
Initial live weight (kg)	356 ± 6.12	328	397
Average live weight (kg)	369 ± 6.40	338	410
Metabolic LW ($kg^{0.73}$)	75 ± 0.09	70	81
Dry matter intake (kg/d)	5.51 ± 0.125	4.98	6.12
Dry matter intake (% LW)	1.50 ± 0.038	1.28	1.67
LW gain by difference (kg/d)	0.28 ± 0.024	0.12	0.40
LW gain by regression	0.27 ± 0.023	0.11	0.36
Feed:Gain	21.2 ± 2.32	13.5	42.0

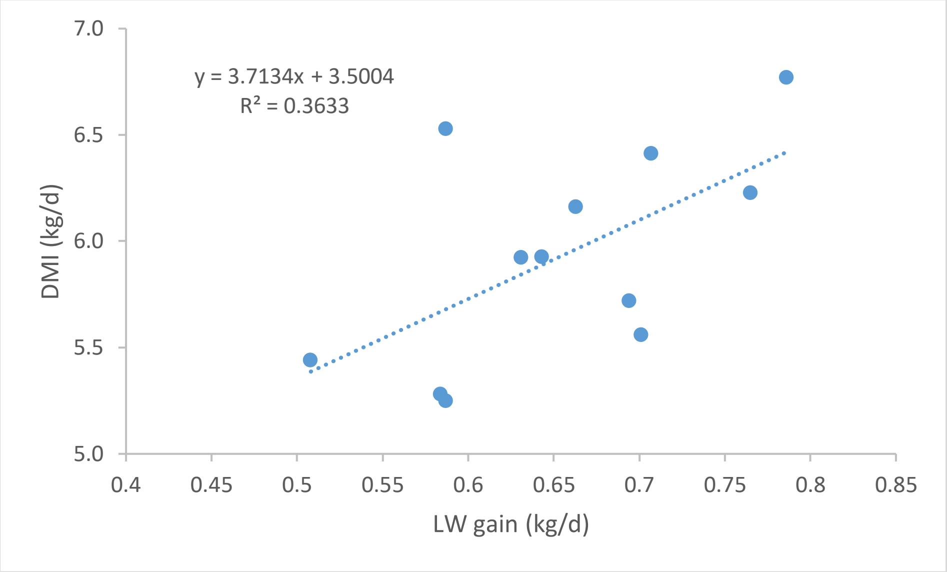


Figure 39. Relationship between dry matter intake and LW gain (Pen trial 1)

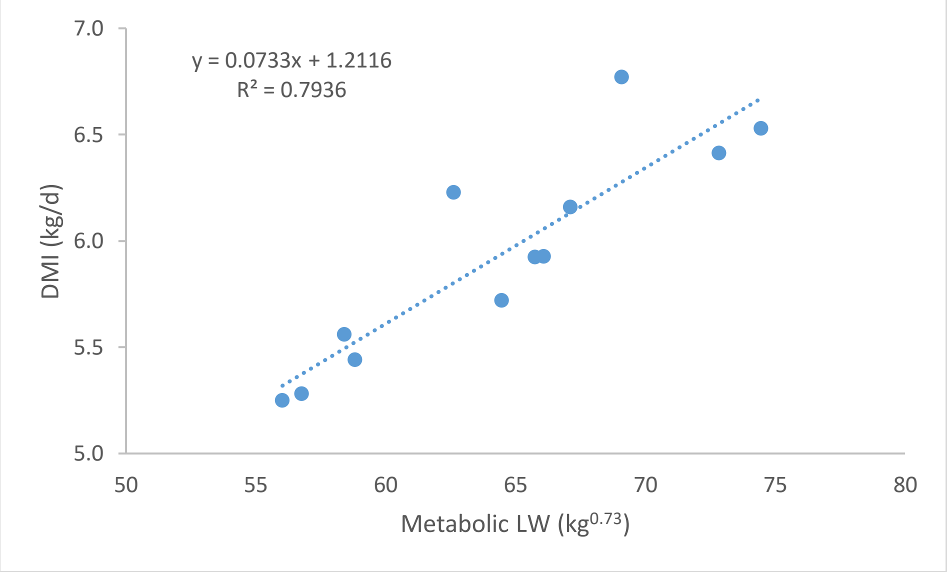


Figure 40. Relationship between dry matter intake and metabolic live weight (Pen trial 1)

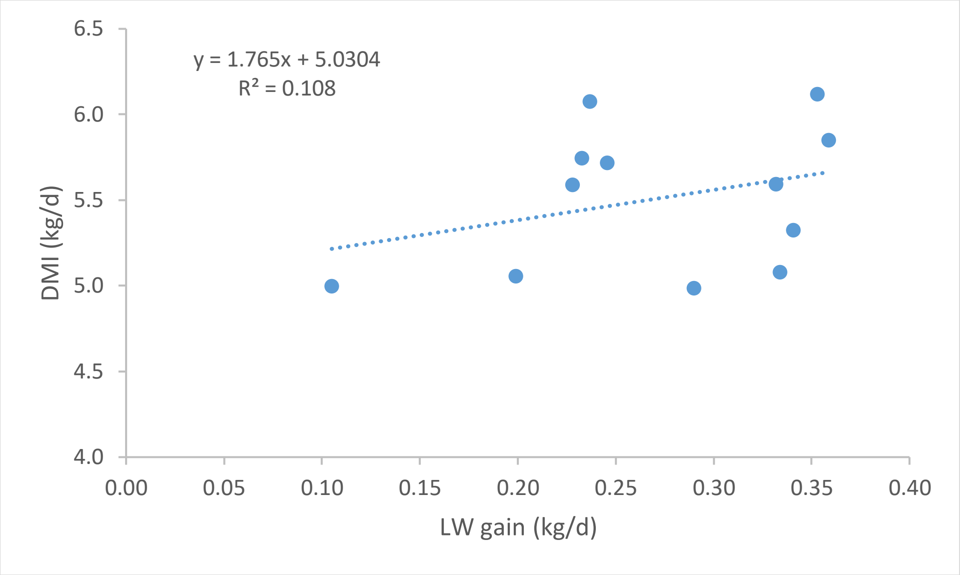


Figure 41. Relationship between dry matter intake and LW gain (Pen trial 2)

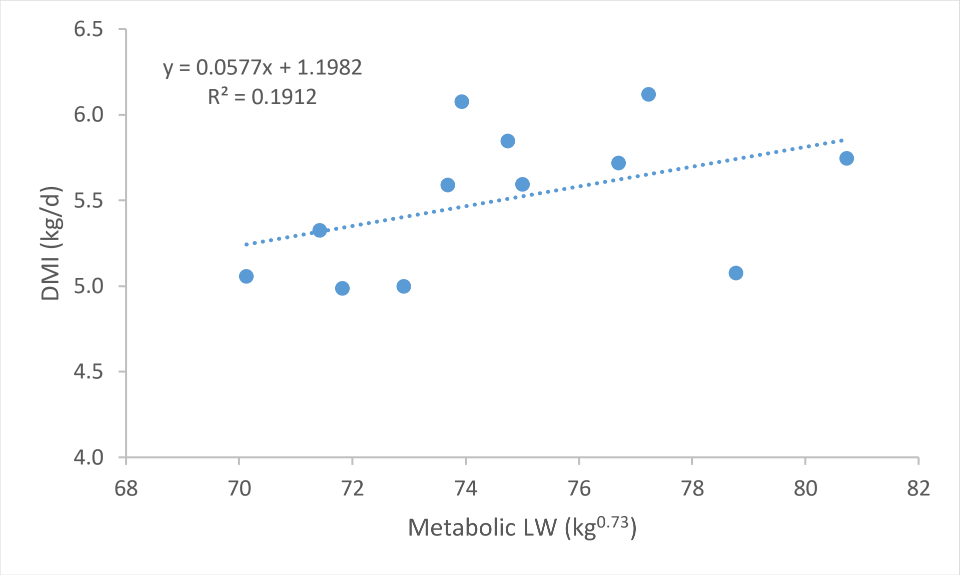


Figure 42. Relationship between dry matter intake and metabolic live weight (Pen trial 2)

The relationship between performance on pasture and performance in pens was explored to determine if improved intake and efficiency in pens was related to performance on grass (Figure 32). Clearly this is critical because a strong relationship would indicate that performance on pasture is influenced by the same factors as for animals under controlled feeding in pens. There were weak relationships between LW gain on pasture (the only measure of efficiency on pasture at this stage of analysis) and LW gain in pens ($R^2 = 0.25$), DM intake in pens ($R^2 = 0.19$) and Feed:Gain ratio ($R^2 = 0.18$). These results imply that other factors were influencing performance on pasture. Clearly pasture availability may influence intake in the late dry season and hence performance as shown in Figure 26. The eGrazor intake algorithm will be used to estimate DM intake from grazing and ruminating time and compared with estimates using the Minson and McDonald equation (1987).

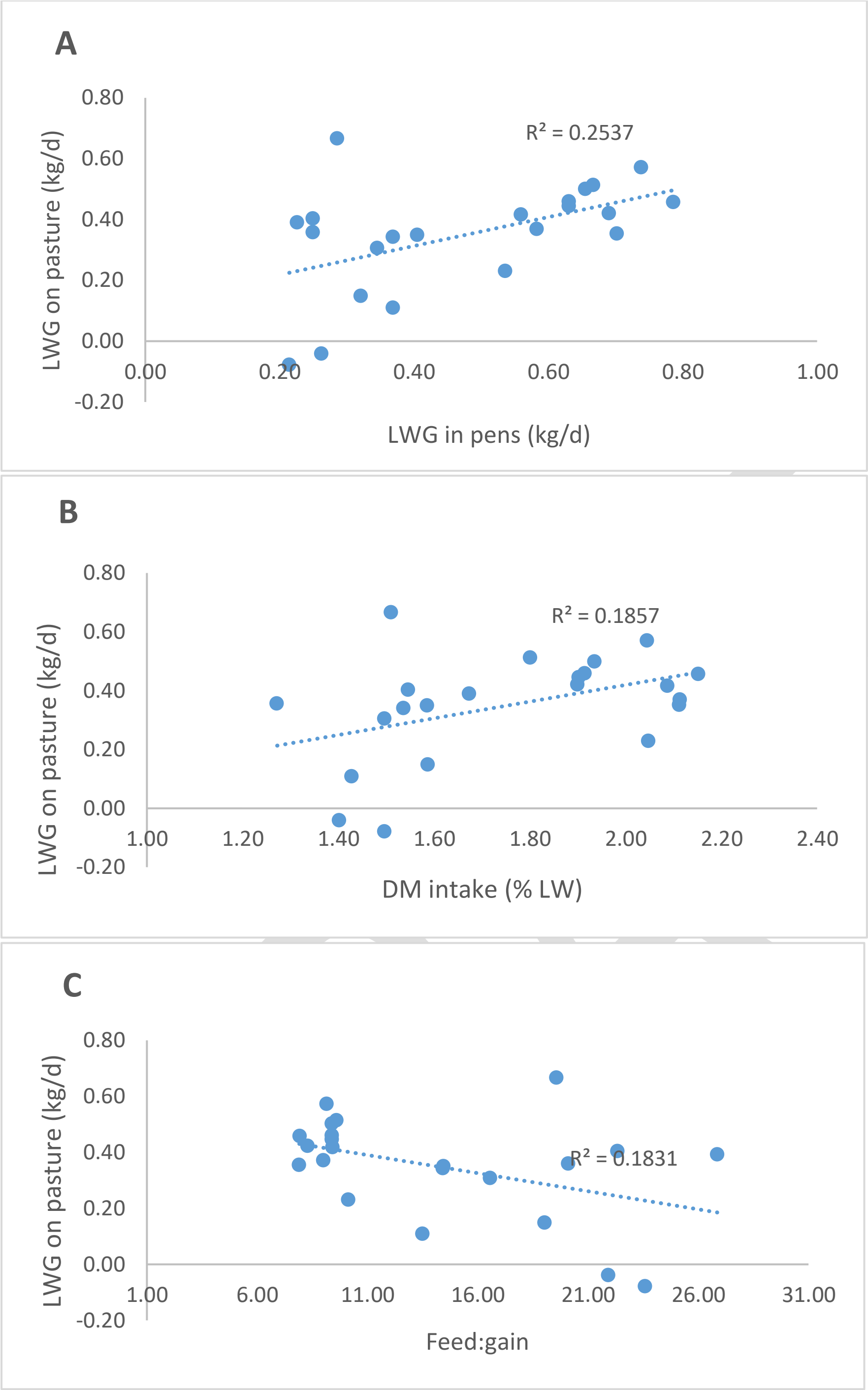


Figure 43. Relationships between LW gain on pasture and performance in pens - A, LW gain in pens, B, DM intake in pens and C, Feed to gain ratio in pens.

Tackling the issue of knowing intake on pasture

Feed efficiency cannot be determined on pasture without a knowledge of both the output (e.g., kg gain) and the input (e.g., DM intake). Identifying the superior phenotype under grazing requires the development of a reliable method of determining intake on pasture. Analysis of the GPS data from collars will provide an algorithm attuned to northern grazing conditions in the final report. However, we are also evaluating other approaches one of which is the Minson and McDonald equation. The results summarised in Figure 33 show the correlation between measured intake of animals in the two pen trials and predicted intake using LW and LWG of cattle during these trials according to the equation:

$$\text{DM intake} = (1.185 + 0.00454LW - 0.0000026LW^2 + 0.315LWG)^2$$

The results demonstrate that the equation is representative of pen-based data and this method will be one of several used to evaluate the GPS derived intake algorithm based on grazing and ruminating time.

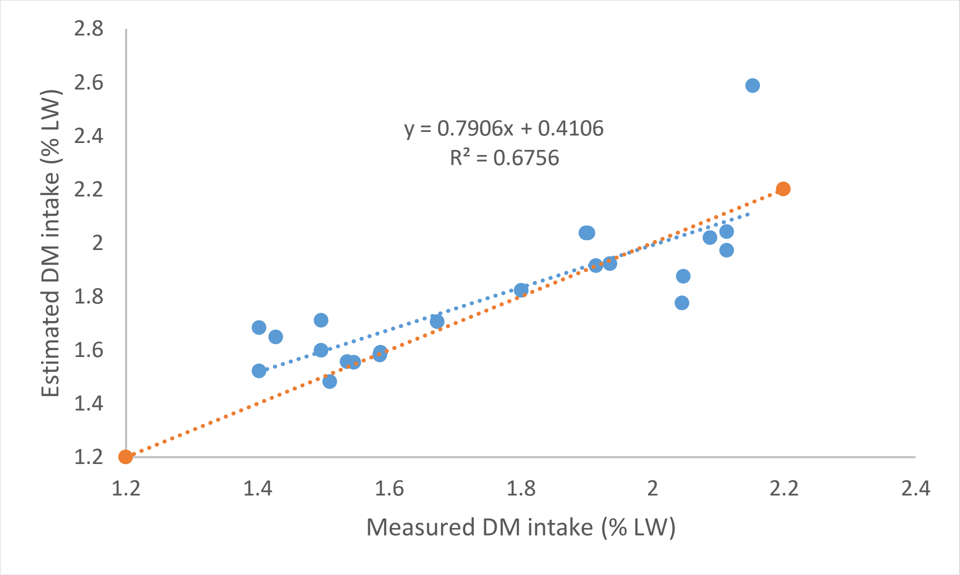


Figure 44. The relationship between estimated and measured DM intake in pen fed cattle.

The above equation was then used to estimate intake on pasture using the mean LW and LW gain between each crush weighing session. The mean intakes for all cattle during the ten periods and overall are shown in Figures 34 and 35. Mean dry matter intake across periods varied between 1.7 and 2.3% BW according to differences in LW gain throughout the trial. These data provide the framework for evaluation of other methods and developing a predictive tool to estimate DM intake based on animal and sward characteristics. These data are also critical to the objectives of the companion project P.PSH.0998 “revise Australian feeding standards to better achieve product specifications and improve ruminant efficiency”.

3.7 Large scale experiments - testing intake algorithm (July 2022)

The Glen Innes trial will begin in August 2022 and will evaluate the most recent version of the CSIRO-NSWDPI eGrazor collar. The Cungelella trial was scheduled between August and December 2022. However a severe outbreak of Buffel dieback occurred in the latter half of 2022 that resulted in the postponement of the trial until April 2023 at the earliest. Pastures were burned in December 2022. If pastures do not recover th trial will have to be further postponed or relocated to an alternate site. In lieu of data form larger paddocks data from four 16 ha paddocks at Lansdown will be presented.

3.7.1 Armidale and Glen Innes

Next generation CSIRO-NSWDPI eGrazor collars will be deployed at Glen Innes Research and Advisory Station in 100 weaner heifers from SMB project. The SMB project provides a unique opportunity to evaluate the eGrazor collars and its ability to identify more efficient animals based on their behaviour. It is an opportunity to deploy and assess the collars for a longer period (up to 6-month) in a larger number of heifers (up to 100). This enables grazing efficiency traits to be assessed based on animal behaviour within and across breeds (Angus, Hereford, and Wagyu) by examining such traits in individuals from different breeds but with a similar "life experience".

Heifers will be weighed weekly with electronic scales (Tru-Test MP600 weigh bars, DataMars, Mineral Wells, Texas, USA) in a cattle crush within the yard and race system (yard weighed). Also, the heifers will be weighed on every occasion they consumed water during the study, by using an in-field walk-over-weigh system (DataMars).

Estimates of pasture intake determined using biomass disappearance will be performed weekly. Biomass availability pre- and post-grazing and pasture disappearance will be determined using C-Dax pasture height meter, Farmtracker rising plate meter, Crop Circle NDVI with GPS to enable mapping of pasture availability and disappearance within grazing paddocks. Also, species prevalence and disappearance will be evaluated.

3.7.2 Townsville deployment

Up to 50 CSIRO-developed GPS collars were used for the study and deployed on two occasions from the 8/2/21 to 17/5/21 and from 27/9/21 to 1/11/21. Detailed analyses of data were taken on five occasions to correspond with pasture and rumen sampling protocols: 9th to 15th February, 12th to 18th April, 10th to 16th May, 28th September to 4th October and 25th to 31st October. Due to unforeseen data problems that are currently under investigation, only selected data are shown for demonstrative purposes.

Note: as this work was funded by both P.PSH.998 and P.PSH,1000 the complete data analysis is given in both reports for clarity and completeness.

3.7.2.1 Estimating distance travelled.

McGavin et al (2108) demonstrated the relationship between the fix rate (interval between successive GPS fix points) and distance travelled. As every point is associated with a positional error, this error increases as fix rate increases. However, distance travelled is calculated by summing the linear interpolation between positions (Rowliffe et al. 2012). Thus, as the fix rate decreases, apparent distance travelled also decreases as cattle do not walk in a straight line between GPS fixes but tend to meander. This tortuosity can vary depending on what the animal is doing. For example, it is greater when the animal is grazing compared to when it is walking to a waterpoint. McGavin et al. (2018) concluded that a fix interval of 5 to 10 seconds minimised both sources of error. In the current study a fix interval of 10 seconds was chosen. Figure 39 shows the apparent distance travelled for fix intervals from 1 to 600 sec in the current study. The data were fitted to a model;

$$\text{Distance travelled (km/d)} = 63.158 \times \text{fix interval (sec)}^{-0.441}.$$

Distance travelled was substantially larger than expected based on the data of McGavin et al. (2018). It was concluded that GPS error was larger in the current trial compared to previous studies included in the McGavin et al (2018) paper. Fortuitously, that paper include data collected in an earlier study conducted in the same paddocks used in this study. Using their relationship;

Distance travelled (km/d) = 13.23 x fix interval (sec)$^{-0.221}$

It was possible to estimate the increase in error between the two studies. As error is associated with every fix, the greater the number of fixes, the greater the cumulative error. However, our analysis indicated that error per fix decreased with fix interval. We estimated that the GPS positional error had increased 3-fold from 0.9 to 2.7 m at a fix interval of 10 seconds. Distance travelled (at GPS fix interval of 10 seconds) for unadjusted, adjusted by subtracting 1. 8 m from each GPS position and estimated using the equation for the same paddock data included in McGavin et al (2018) are shown in Table 19.

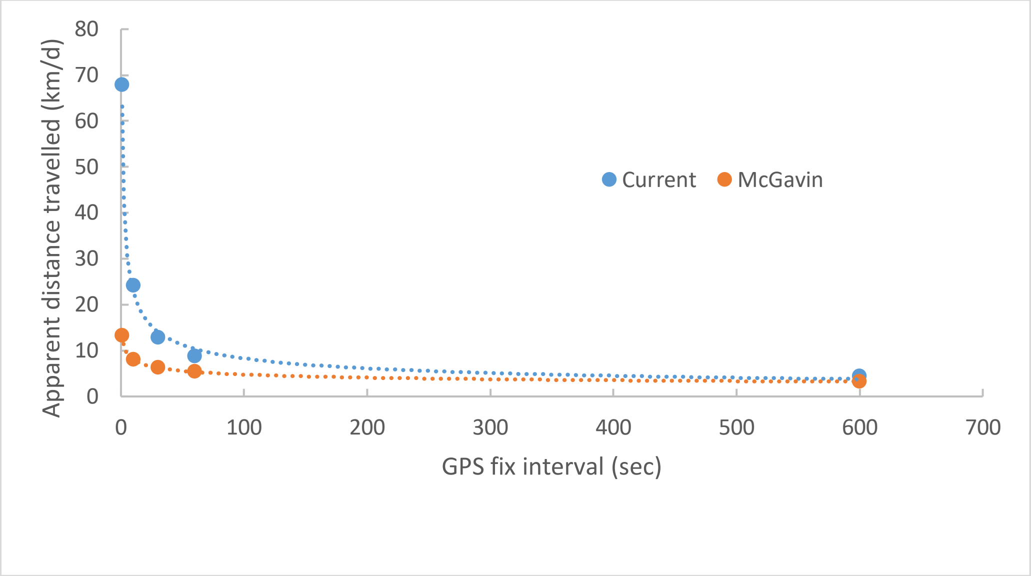


Figure 45. Relationship between fix interval and apparent distance travelled in current study (blue) and the study by McGavin et al (2018; red).

Table 24. Apparent distance travelled according to three methods based on GPS position

	Apparent distance travelled (km/d)		
	Current data (unadjusted)	Current data adjusted for increased error	Data using McGavin et al equation
GPS fix interval (s)			
1	67.86	-87.7	13.23
10	24.14	8.59	7.96
30	12.84	7.65	6.24
60	8.76	6.16	5.35
600	4.34	3.22	3.22

The chosen method of estimating distance travelled, albeit arbitrary, was compared with LW gain. The dates period chosen were close to the end of the study over 6 days at the end of September. Distance travelled was compared with LW gain measured either over the month beginning September 28th or over the entire trial. Data from 29 animals was successfully included in the relationship that showed a weak correlation between LW gain and distance travelled over six days at the end of September. (Figure 40). Ongoing analysis of the complete dataset will confirm if this relationship is simply casual or that performance is related to distance travelled.

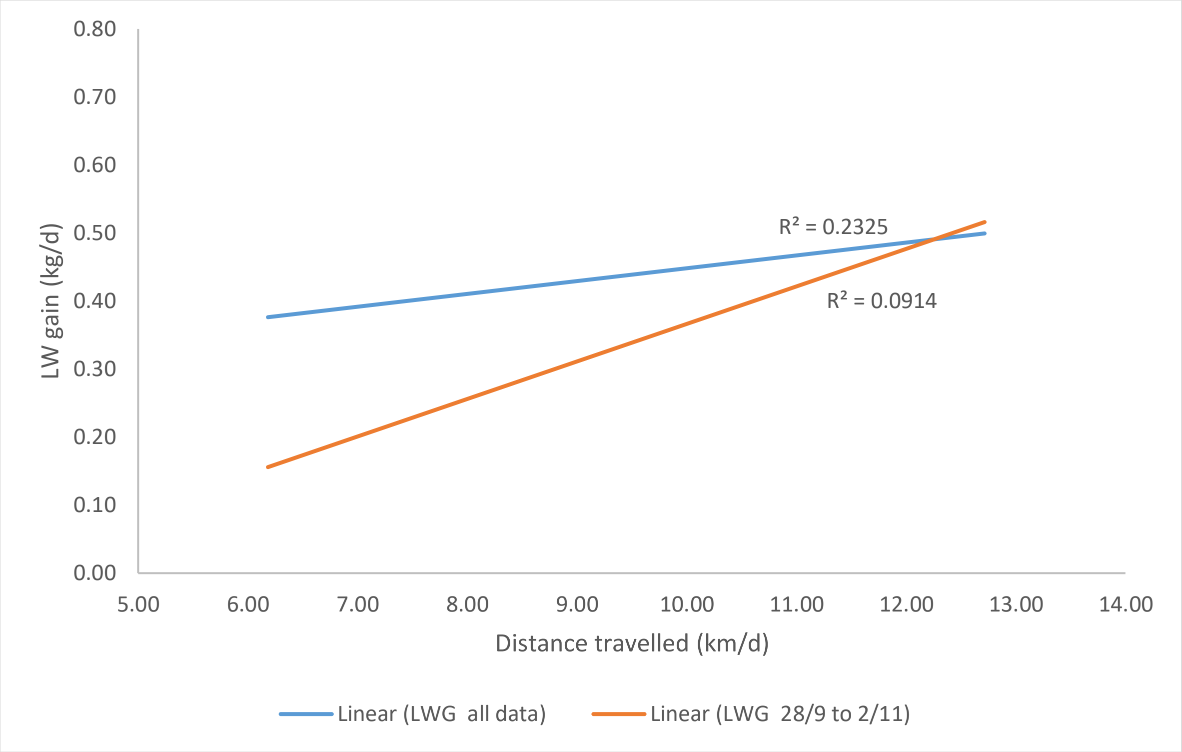


Figure 46. Relationship between distance travelled and LW gain over either the entire trial or between 28/9/21 and 2/11/21.

Grazing activity

Algorithms developed for behaviour classification under temperate conditions failed to differentiate behaviours under tropical conditions This result was unexpected and remains unresolved. Table 20 summarizes the data for the first measurement period, 9/2/21 to 15/2/21. The hours apparently spent in undefined or resting activities were overestimated, while grazing walking and ruminating activities were underestimated when compared with equivalent data collected under temperate conditions. In addition the standard errors were extremely high, suggesting a lack of uniform bias. In the Armidale study grazing and ruminating times were approximately 6 and 10 h/d, respectively.

Table 25. Behavioural classicisation for the first measurement period (9th – 15th February 2021) at Lansdown (tropical) based on algorithms developed at Chiswick (temperate).

	Hours/day				
Paddock	Walking	Grazing	Ruminating	Resting	Other
1	1.80 ± 0.40	1.22 ± 0.51	2.05 ± 0.44	8.93 ± 0.81	9.94 ± 0.82
2	0.90 ± 0.26	3.17 ± 0.83	2.35 ± 0.63	8.61 ± 1.04	8.97 ± 1.09
3	1.35 ± 0.23	3.45 ± 0.90	4.30 ± 0.96	7.39 ± 1.04	7.50 ± 0.92
4	1.64 ± 0.27	1.81 ± 0.39	2.23 ± 0.40	8.59 ± 0.59	9.72 ± 0.64

3.7.2.2 Estimating pasture intake

Examination of the data revealed that some behaviour classifications measured in September-October 2021 appeared to be reasonable. Figure 41 shows the spatial arrangement of activities for one animal (#20147) over 4 days beginning September 29th 2021. Current estimates of voluntary intake are derived from algorithms relating intake to grazing time (Greenwood et al. 2017):

$$\text{DM I (kg/d)} = -6.46 + 2.61 \times \text{Grazing hours}, r^2 = 0.59, \text{RSD} = 1.66 \text{ kg DM}.$$

The Greenwood et al. (2017) equation estimated DM intake to be 6.2 kg/d based on a grazing time of 4.85 h/d. This method is compared with an alternative model based on the energy requirements of activity, maintenance, and gain. From a knowledge of the distance travelled (km/d) and grazing and ruminating time (h/d) energy expenditure can be calculated. As the energetic requirements of these various behaviours are known the energy requirement of activity can be calculated. Daily recording of LW using walk over weigh technology allows for estimation of energy requirements for maintenance and growth.

$$\text{MEI} = \text{ME}_{\text{main}} + \text{ME}_{\text{gain}} + (\text{ME}_{\text{(walk)}} \times (\text{walk} + \text{graz km}) + \text{ME}_{\text{(graz)}} \times \text{graz hr} + \text{ME}_{\text{rum x}} \text{ rum hr}$$

From faecal sampling for NIR analysis the ME concentration of the diet is also known. Integrating these data allow for an estimate on intake based on detailed characterization of the energetics of the animal coupled with the energy content of the diet.

$$\text{DMI} = \text{MEI} / \text{ME}_{\text{diet}}$$

Data for heifer 20147 collected in late September - early October 2021 is used to demonstrate the approach. Heifer 20147 weighed 319 kg, was gaining at 0.0 kg/d and was consuming a diet with a DMD of 56%, equivalent to 7.9 MJ/kg DM. Using PISC (2007) the combined energetic expenditure for activity, maintenance and gain can be calculated (47.23 MJ/d). From the faecal NIR estimate of ME (7.9 MJ/d) the predicted DM I was 6.0 kg/d, close to that estimated from grazing time (Greenwood et al. 2017). Estimated intake using the equation of Minson and McDonald (1997) which relies solely on LW and LW change was 5.8 kg/d. This example shows the theory of the approach, but also demonstrates the proportional importance of energy requirements for activity in cattle grazing tropical pastures. In this example activity accounted for 31% of total energy requirement. As activity varies with paddock size, and pasture characteristics, the ability to measure activity should improve our understanding of pasture intake in extensive grazing conditions. While these preliminary observations are encouraging, further analysis is required to confirm the validity of the approach.

3.7.2.3 Linking behaviour to sward characteristics

The dataset from heifer 20147 that provided what we believe to be accurate behavioural data was mapped with corresponding Botanal-based Kriging prediction maps of various pasture characteristics. Figure 41 shows the spatial characteristics of grazing behaviours from the GPS collar and Figure 42 shows the smoothed response surface for pasture biomass While visualization is useful, examining the data behind the response surfaces allows for determination of metrics that can be used to augment intake prediction.

For example, biomass DM data were categorized in 1 t/ha assemblages. Preference indices were developed for the frequency rates with which cattle visited each biomass assemblage. As biomass increased, preference declined, suggesting that cattle avoided areas of high biomass, in favour of areas with lower biomass (Table 21). A preference index above 1 indicates preference, below 1 indicates avoidance. The standardised index shows that the heifer spent 33% of her time in areas with the biomass between 2 and 2.99 t/ha but only 17% of time in areas with biomass over 4 t/ha.

Table 26. Grazing preference of #20147 in relation to pasture biomass.

Biomass assemblage (t/ha)	Preference index	Standardised index
2 – 2.99	1.31	0.33
3 – 3.99	1.12	0.28
4 – 4.99	0.88	0.22
5 – 5.99	0.69	0.17

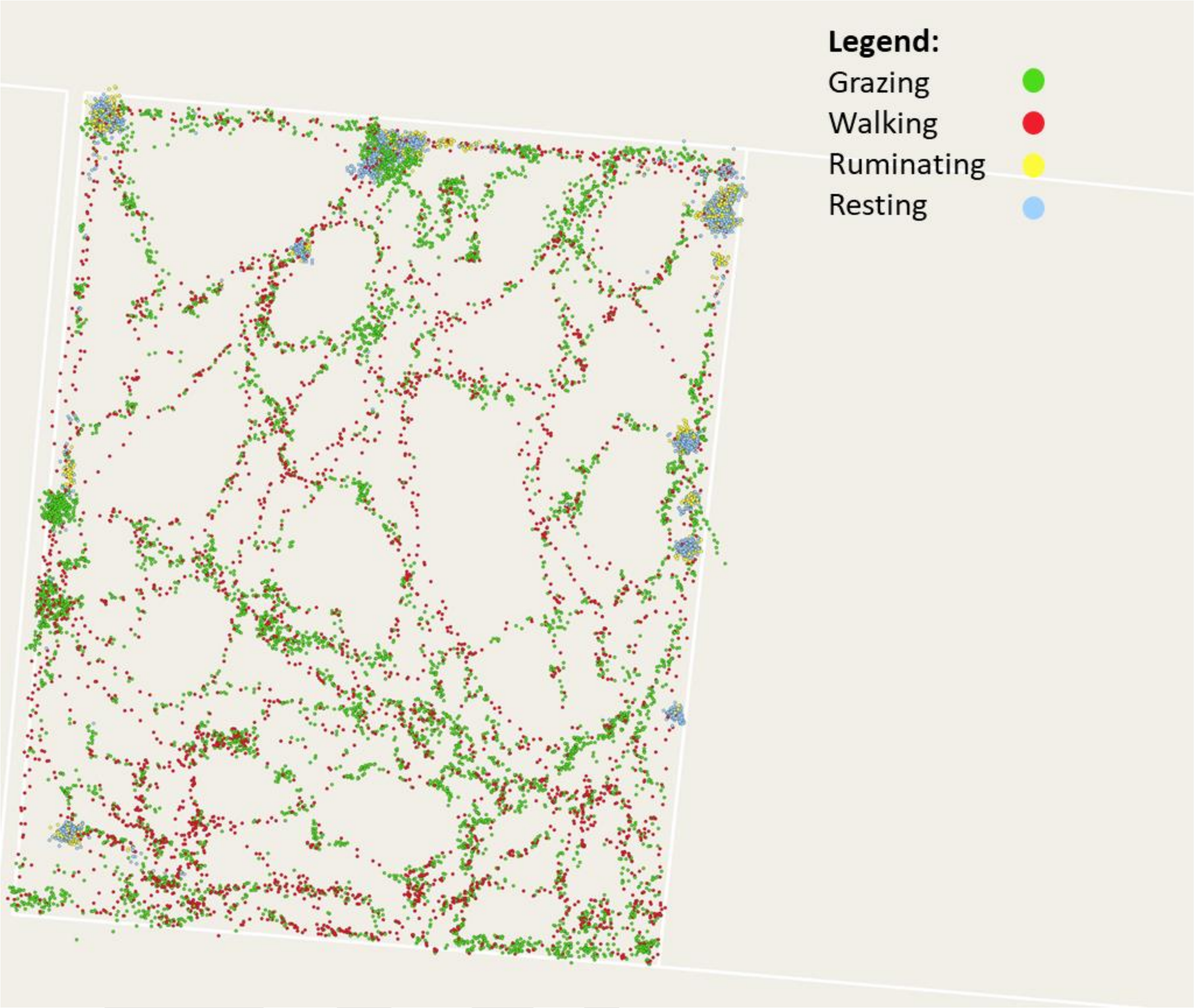


Figure 47 Activity map for heifer 20147 from 29 Sept to 1st Oct, 2021

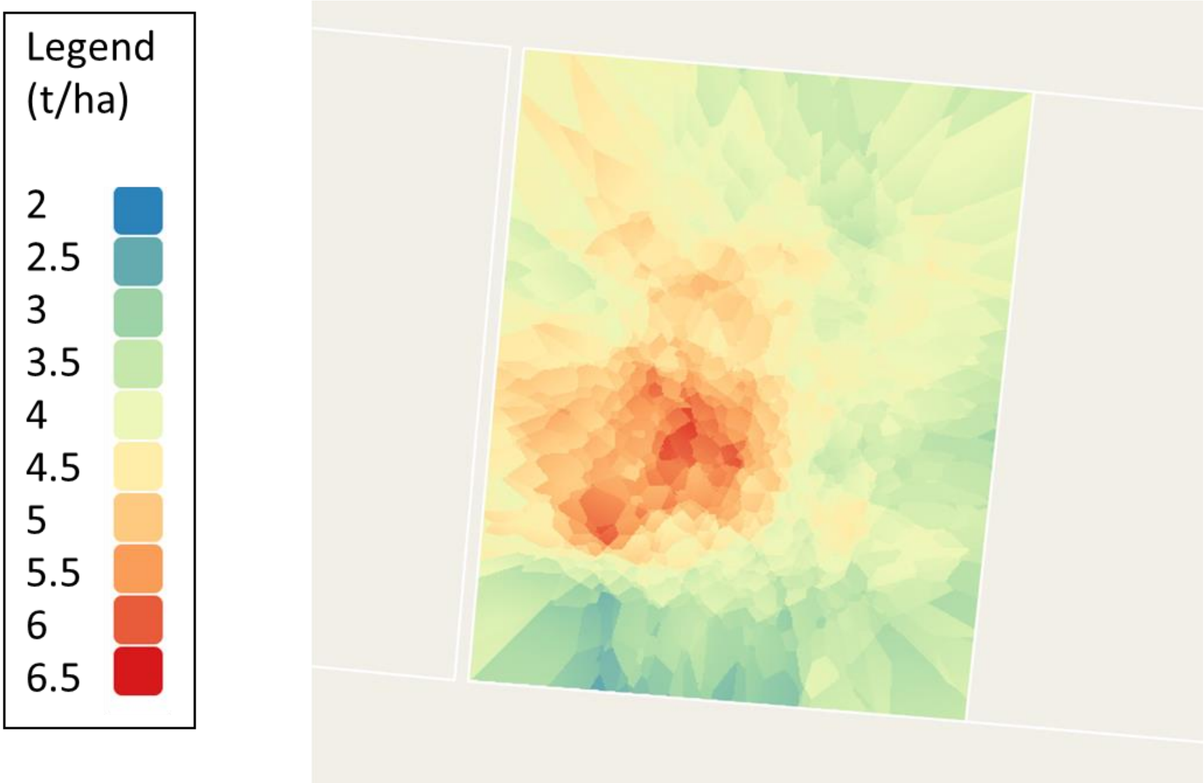


Fig. 6. Spatial distribution of biomass measured on Nov 6th, 2021.

4 Impact and adoption

The adoption model recommended for LPP (Figure 39) was better suited to Horizon 1 research and development, as seen in the forages program. While components of it were incorporated into the project, such as field days and invites to BeefUp forums the main impact of the research will require an intermediary step to move research findings to a commercialization end point. Watson et al. (2022) reviewed adoption strategies and why they appear to have failed the northern beef industry. They concluded that:

> adoption is a dynamic process that unfolds over time rather than a binary, momentary choice. It identified that there are a diverse range of dynamic pathways for agricultural practices and that these are multi-dimensional, multi-level and contain multi-actor processes, all influencing adoption. It highlighted that the diffusion of innovations through an industry is the net result of individual adoption journeys converging into common pathways.

Further they noted:

> a lack of engagement between producers and researchers; producers having a valid and valuable role in helping to ground truth the research and ensuring it has practical application; and the need for more opportunities for producers and researchers to collaborate and co-innovate.

We believe this project incorporated many of the features highlighted in this review, but the journey is incomplete. At the conclusion of this project, we will have established several technologies developed in close collaboration with producers and industry. To bring these to market and adoption, however, still requires ongoing investment and support that is not integral to this project. To ensure success, bridging support would help carry these nascent ideas to fruition and impact for the industry.

The LPP program review (MLA final report L.LPP.0001) acknowledged that a clear adoption pathway was not included in the initial program development of LPP and the subsequent introduction of design led thinking was too late to influence already approved projects, including P.PSH.1000. Consequently, without a clear path to impact and without specific funding to maximise adoption, this report strongly recommends that further support beyond the life of LPP will be required to maximise the impact of the technologies developed in this project.

The relevant section of the report “Product draft Impact assessments” As included in the LPP Program review final report (L.LPP.0001) is given in Appendix 11.2. While we agree with the assessment it should be pointed out that such an assessment was only possible for one scenario around adoption of the methyl donor supplement.

4.1 Key technologies developed within the project

4.1.1 Intake algorithm

The development of an intake algorithm for grazing cattle was a cornerstone of the project. Developments in this project rely on considerable investment in the physical design of an on-animal sensor and the informatics to run the algorithms (eGrazor) by CSIRO and NSW DPI and covered by background IP. The current project has allowed for significant improvement in the algorithm through extensive testing in tropical and temperate conditions. There are two key outcomes of this work

- a pasture intake tool for feedbase budgeting and grazing management
- a feed efficiency phenotype for inclusion into appropriate breeding programs.

The benefits of these outcomes for the industry are important particularly when incorporated into a broader suite of sensor-base management tools on the farm. Optimising pasture utilization to reduce overgrazing has both environmental and production benefits including reduced soil run-off, faster pasture regrowth, increased animal growth rates and improved reproductive efficiency. The fundamental importance of feed intake means that the technology has industry wide application. In recognition of this level of impact, Ceres Tag an agritech company, has taken up the rights to this technology and will shortly be selling the algorithm on a smart ear tag.

The ultimate goal of a pasture efficiency phenotype would allow for selection of superior genetics under the conditions where the genetics will be tested; across Australian grazing environments. Currently breed programs rely upon estimation of net feed efficiency under controlled feeding conditions on concentrate-based diets. While it is unclear if ranking of individuals differs under intensive and grazing conditions, the field trial conducted as part of this project will answer this question.

4.1.2 Novel supplements

Methyl groups are of singular importance in gene regulation that affects all aspects of an animal's physiology. It has been known that in high producing dairy cows a shortage of methyl donors can have negative impacts on performance and immune response. This trial was among the first to demonstrate a similar issue in pregnant beef cattle on very poor-quality diets. The nutrient survey conducted as part of this project, identified that such deficiencies were likely in parts of northern Australia. The use of several methyl donors or their precursors clearly demonstrated a production response in calves following short term supplementation to the pregnant dam. Particularly important in the extensive grazing environment was the observation that the production response in the calf lasted well beyond the immediate post-partum period and was still evident post weaning. This has clear implications for a northern supplementation strategy and the scientists continue to have discussion with commercial partners both in Australia and overseas.

4.1.3 Linkage to LPP project P.PSH.0998 (Revise Australian Feeding Standards)

The above project is intimately linked to P.PSH.1000 (current project). A revision to the basis of energy utilization in ruminants affects our understanding of the biology of feed efficiency, the control of feed intake and directly influences our ability to predict animal performance from dietary inputs. The work in the current project, not only builds on the outputs of P.PSH.0998 but also feeds back into the development of revised intake predictions. Combined, these two projects will allow for a significant revision of Australian feeding standards.

4.1.4 Feed efficiency on pasture

Section 3.7.2 was a large integrated trial, designed to identify key components of animal physiology and behaviour that influence efficiency of grazing cattle under extensive tropical and sub-tropical conditions. The inability to measure intake on pasture was a major limitation of any measurement of efficiency that implies a level of output (e.g. LW gain) relative to input (e.g. DM intake). The companion LPP project, P.PSH.998 focussed on developing an appropriate method for predicting intake from known variables related to the animal and the pasture. The project recommended that the Minson and McDonald (1987) equation and an equation based on the ME requirements of the animal and the ME content of the diet from faecal NIR (McLennan et al 2020) were the most appropriate methods for estimating intake. In this study the ME method showed promise but rigorous testing was limited due to problems with GPS-derived activity data.

Variation in LW gain among the cohort of heifers was small. Additionally, there were few significant differences in diet and rumen fermentation characteristics between animals when ranked and grouped according to LW gain. In the absence of marked differences in diet quality it was hoped that variation in grazing behaviour may have been related to variation in performance. While there was limited data to support this supposition, the failure of GPS collars to identify grazing activities limited our ability to link performance to grazing behaviour. Nevertheless, if data issues from GPS-enabled devices can be resolved through site-specific ground truthing this method should have greater utility in future.

The pen trials were designed to take cattle from pasture and measure intake and performance from a standard hay diet without the confounding potential effect of grazing variability. Although the sample size was small, differences in efficiency were seen which showed some correlation with performance on pasture.

Notwithstanding the problems associated with measurement of grazing behaviour we believe that differences among individuals in performance on pasture is probably related to pasture intake as no other differences were observed in diet digestibility, N partitioning or rumen fermentation characteristics.

In contrast to the lack of an animal effect on performance, the pasture effect was highly significant. Variation in diet quality over time and among paddocks always elicited highly significant effects on indices of digestion and animal performance. The sensitivity of performance to pasture quality is of critical importance in estimating intake and feed efficiency. Therefore, the refinement of the faecal NIR method to accurately estimate intake from pastures and forages of differing quality should be a priority for future work.

4.1.5 Design led thinking and other adoption models

Results are indicating that the methods and approaches taken in the planning phase of this project were appropriate. As noted earlier, adoption was not integrated into the project model. However, through LPP workshops and meetings, consultation with producers and extension personnel the design of individual projects was refined through a process of continuous engagement and feedback, which is actually the crux of design led thinking. In contrast to Program 1 (Feedbase) this program was not about farm-gate adoption, but about modernising the science that underpins red meat efficiency in Australia. Over the last 20 to 30 years, improved technologies, improved models and a more highly evolved genotype mean that a fundamental re-evaluation of ruminant nutrition was warranted. Collectively, the projects in the Livestock program have partially delivered on this critical need. As noted in the LPP review, further extension and adoption will be required before primary producers reap the full benefits of this program. Nevertheless, there are still important messages around pasture management, grazing technologies and supplemental feeding that can have direct benefit and these represent the “low hanging fruit” that can be delivered via Beefup forums and the usual MLA adoption strategies.

Figure 42 shows an example of an adoption template proposed by MLA in one iteration of how best to manage the adoption issue. While it demonstrates a useful tool for recording activities, it was not particularly useful for this project. In the feedbase program where there was a strong emphasis on producer engagement it would have had greater utility.

The strength of the animal program was the close interrelationship among projects as shown graphically in Figure 43. The weakness of the animal program is that further work is required to build on the strong foundation of the fundamentals for a revised model for predicting performance from feed or pasture intake and the influence of diet (specifically ingested ME and CP) quality on those predictions.

Year	**Expected Research outputs (confident for commerical application) -** including explanation	**Adoption activties built into current plan** (including which groups you are currently working with)	**Potential adoption activties which could be suitable for broader adoption -** If PDS, when is this suitable? e.g. one/two years following the research output?	**Regional Application (which will be replicated on a geographic map)**
2019	*e.g. Legume species suited for XYZ production system which provides increased production vs existing species*	*e.g. Field Day, Prodcuer Workshop, development of tech note*		*e.g. Qld, Northen NSW excluding Tablelands*
2020			*e.g. Set up well designed PDS Sites in regional location of X,Y,Z one year following the research output - suitable prodcuer groups or facilitators may be X?*	
2021				
2022				
2023				
2024				
2025				
2026				
2027				
2028				
2029	*e.g. Pasture persistance of new variety confirmed*		*e.g. Update NSW DPI and other industry programs and materials to reflect new findings* *Set up PDS in region X, Y and Z*	
2030				

Figure 48.Example of MLA adoption template that was considered unsatisfactory for the research in this project

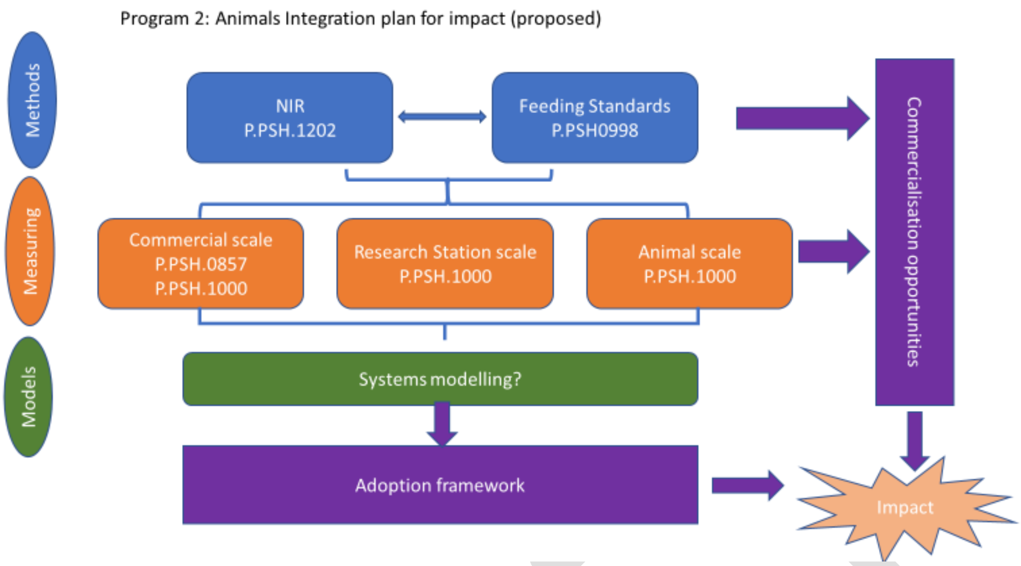


Figure 49. Conceptual framework

4.2 Linkage to other projects in LPP

The integrated nature of this project with the other three projects in the animal program remains a strength of the program. A conceptual framework of how the projects link across scale and research horizon is shown in Figure 38. The development of new methods in feed evaluation (P.PSH.1202) and nutrient requirements (P.PSH.998) directly support the measurement of animal response under grazing conditions (P.PSH.0857, P.PSH.1000) leading to the development of new technologies. Opportunity for commercial engagement is apparent both in the methods and measuring scale of endeavour. However, lacking in the program was the integration, testing and evaluating under semi-commercial and commercial conditions that allows for development of models and decision support tools (Apps) for direct use by industry. To maximise impact of this project (and others in the livestock program) the confluence of commercialisation opportunities within an adoption framework is required.

4.3 Research papers published under this project

Alvarenga FAP, Bansi H, Dobos RC, Austin KL, Donaldson AJ, Woodgate RT, Greenwood PL (2022) Performance of heifers divergent in RFI-feedlot EBVs grazing mixed perennial temperate grasses. *Proceedings of Australian Association of Animal Sciences Biennial Conference (abstract).*

Alvarenga FAP, Austin KL, Donaldson AJ, Woodgate RT, Greenwood PL, Dobos RC (2022) Predicting biomass of heterogeneous pastures using a handheld NDVI sensor. *Proceedings of Australian Association of Animal Sciences Biennial Conference (abstract).*

Alvarenga FAP, Bansi H, Dobos RC, Austin KL, Donaldson AJ, Woodgate RT, Greenwood PL (2021a) Performance of Angus weaner heifers varying in RFI-feedlot EBVs grazing severely drought affected pasture. Animal Production Science 61: 337-343

Alvarenga FAP, Bansi H, Austin KL, Woodgate RT, Greenwood PL (2021b) Comparison of walk-over-weigh and yard weighing of Angus weaner heifers grazing drought affected pasture**.** *Animal Production in Australia 33: vii*. (Proceedings of the 33rd Biennial Conference of the Australian Association of Animal Sciences).

Arablouei R, Wang L, Currie L, Yates J, Alvarenga FAP, Bishop-Hurley GJ (2022) Animal behavior classification via deep learning on embedded systems. *Computers and Electronics in Agriculture (in press)*

Arablouei R, Currie L, Kusy B, Ingham A, Greenwood PL, Bishop-Hurley GJ (2021) In-situ classification of cattle behaviour using accelerometry data. *Computers and Electronics in Agriculture* 183: 106045. https://doi.org/10.1016/j.compag.2021.106045

Arthur PF, Herd RM, Donoghue KA, Greenwood PL, Bird-Gardiner T (2019) Genetic improvement of pasture intake and efficiency in beef cattle: Are we there yet? Proceedings of the Association for the Advancement of Animal Breeding and Genetics 23:428-431.

Bansi H, Cowley FC, Hegarty RS, Alvarenga FAP, Greenwood PL (2021) *In vitro* gas production from rumen fluid of Angus weaner heifers varying in RFI-feedlot EBVs grazing drought affected pasture. *Animal Production in Australia 33: vii*. *(*Proceedings of the 33rd Biennial Conference of the Australian Association of Animal Sciences*)*

Bishop-Hurley GJ, Alvarenga FAP, Valencia P, Little B, Dobos RC, Ingham AB, Greenwood PL (2020) Sensor-Determined Behaviours and Pasture Intake Estimation in Extensive Grazing Systems. *American Society of Animal Science Production, Management and Environment Symposium*, ASAS-CSAS-WSASAS Annual Meetings, July 19-23, 2020. Abstract 346. [Invited Presentation by PL Greenwood]

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4.4 Post graduate training

Two post-graduates were trained through this project. NSW DPI hired Flavio Pereira Alvarenga to work on developing the intake algorithm and studying feed efficiency under temperate conditions. CSIRO hired Gonzalo Martinez Fernandez who studied the rumen function in supplementation and feed efficiency trials.

4.5 Field days

4.5.1 Field day at Lansdown on 7th September 2021

Approximately 100 visitors attended the one-day event and saw practical demonstrations of research on feed efficiency, agri-tech and methane mitigation. Presentations were a mix of demonstrations, trade displays, and posters. Scheduled talks by researchers including; Stu Denman, Greg Bishop-Hurley, Felista Mwangi, Ed Charmley, Mel Matthews, Rob Kinley and Gonzalo Martinez-Fernandez were given on specific research outcomes. Covid-19 restrictions prevented visitors from interstate and the majority of the audience were from the local area. Funding from MLA, Agrimix Pastures and Ceres is gratefully acknowledged.

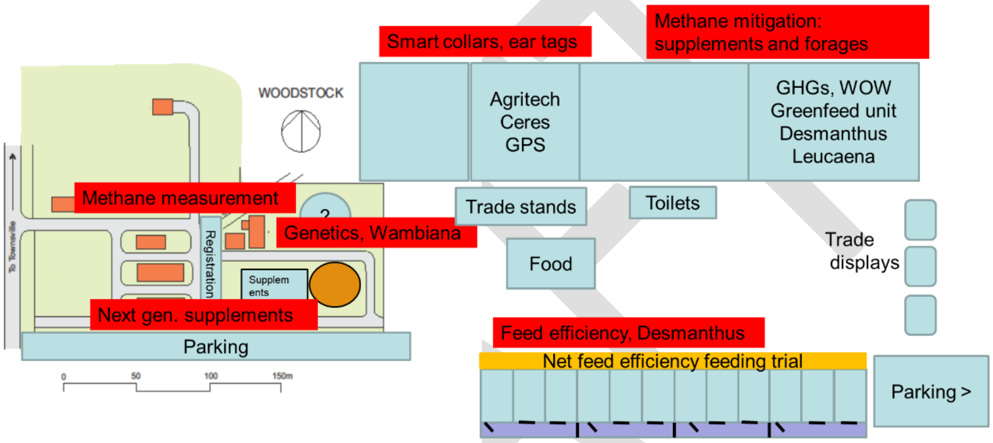

Figure 50. Site plan for field day

Figure 51. Producer talks on various LPP research.

Figure 52. WIN News interviewing local grazier, Michael Lyons who provide cattle for the Feed efficiency trial.

Figure 53. CSIRO technician explains an app to local graziers

4.5.2 Field day at Chiswick on 16th March 2022.

The ”***Livestock grazing efficiency – Research and Technical updates***” field day held at CSIRO Chiswick in Armidale on 16th March 2022 provided the latest in livestock grazing efficiency. The field day covered current research in grazing efficiency (Paul Greewood and Flavio Alvarenga – NSW-DPI); legume persistence (Carol Harris – NSW-DPI), current feeding standards? (Holland Dougherty - UNE, Hutton Oddy - NSW-DPI), dual purpose crops (Peter Hunt – CSIRO), Walk-over-Weighing system (Gregg Blatchly – Datamars); cattle eartag (Lewis Frost – Cerestag) and eGrazor collar (Greg Bishop-Hurley – CSIRO) technology.

The field day was well received. Approximately 50 visitors were in attendance with the following feedback received:

- 86% of survey respondents rated the field day as either excellent or good;
- 80% of survey respondents got the information that they were after;
- 91% of survey respondents said that they would use eGrazor collars in their commercial operation.

Figure 54. Paul Greenwood (NSW-DPI) summarizing the outcomes from the LPP grazing efficiency project.

Figure 55. Robin Dobos (NSW-DPI) showing to producers technologies to map variability of pasture sward height, availability and disappearance during grazing.

Figure 56. Demonstration cattle wearing the CSIRO-NSWDPI eGrazor sensor.

Figure 57. Morning tea break during the field day at Big Ridge demonstration site at CSIRO Chiswick near Armidale.

5 Conclusion

5.1 Covid impacts

In 2020 Covid restrictions at the workplace had a major effect on research progress. Through consultation with MLA it was agreed that while there was no requirement to introduce a contract variation or change milestones, the timing of certain components of the project would be influenced. The feed efficiency at Lansdown trial was delayed from 2020 to 2021. Additionally, the field survey had to be refocussed around an extensive extant sample repository from across Queensland and the Northern Territory. In New South Wales, the drought in 2020/21 also influenced research activity with pivoting towards more confinement feeding than was originally intended. As a result of these impacts on research activity it was agreed that active research would continue until the end of 2022. At the time of preparing the draft final report the following experimental work is still ongoing;

- Some sample analysis for the feed efficiency trial at Lansdown
- Pasture GIS and animal behaviour analysis of the feed efficiency trial at Lansdown
- All data analysis for the feed efficiency trial at Lansdown
- Completion of intake algorithm development
- Conduct of large-scale deployment of GPS collars in NSW and Queensland
- Data analysis of intake algorithm.

All these components will be completed by the end of 2022 and will be included in the final report.

5.2 Key insights and implications of the project.

Significant investment in the science of nutrition in cattle and sheep has been lacking over the last 20 to 30 years. For example, current feeding standards were mostly developed in the 80s and 90s and were based on research with animals of vastly different genetics to the animals in production today. The advent of genomics has had much less influence on animal nutrition, compared to animal breeding. The development of IT solutions are relatively new to the grazing industry and have not been widely used in research. Characterisation of feed quality and intake has not kept up with the increasing nutritional demands of superior genetics. In consequence of these deficiencies, the industry has been poorly served and rate of change in feed efficiency has slowed.

A step-change in efficiency in the beef sector was required. While one project cannot address all these deficiencies, by combining a suite of projects all focussed on a single initiative in the LPP has gone some way to bringing ruminant nutrition into the 21st century. The ability to measure previously unmeasurable traits such as pasture intake, biomass and quality will yield increased precision in grazing management. When combined with novel technologies such as smart ear tags that monitor grazing behaviour and remote weighing, benefits begin to multiply.

From a research perspective, new technologies and techniques allow research to be conducted on animals in their production environment. This represents a major step forward. Research results are immediately applicable to the commercial property and very importantly, producers become actively involved and engaged in the research outcomes, thus accelerating adoption.

As noted previously, adoption of the potential impacts of this project are at risk of not reaching the producer due to lack of an ongoing extension and adoption program. While the project has good industry contacts to commercialise aspects of the research, as scientists the project team lack the time, funding and skills to ensure widespread adoption. This challenge is further exacerbated by the need for ongoing research in certain areas. The ongoing R, D and A framework is not there to ensure a return on the initial investment in this project. We strongly urge MLA to consider solutions to this problem. The current emphasis on matched funding via the MLA Donor Company is one option but some research agencies cannot participate and private companies can be wary of IP restrictions and the 50/50 co-investment model. At the final LPP meeting a series of key elements were highlighted that were essential for full adoption of the livestock program. These should form the basis of an inclusive discussion about how to plan and fund the steps necessary to achieve impact (see Appendix 11.1).

6 Key findings

- Specific nutrient deficiencies exist across the northern beef industry
- Alleviation of deficiencies can improve productivity and efficiency
- Feed efficiency on pasture is a complex interplay between the animal and the pasture and required an integrated research effort to understand
- Key factors influencing efficiency are related to grazing behaviour which are mediated through modified rumen function
- Pasture intake can be estimated from grazing behaviour using on animal sensors
- Increased performance on pasture is partially due to increased feed intake and not improved efficiency.

7 Benefits to industry

The principal outcomes of this research are up-stream to the farm gate and provide new insights into how the industry can improve feed efficiency in grazing systems. However, there are practical applications in the near term provided these are adopted by appropriate intermediaries, such as Agri-Tech providers or feed companies

- pasture intake algorithm and app integrated into a smart ear tag (CeresTag)
- methyl donor supplement for pre-calving feeding of breeders in extreme pasture conditions
- pasture management handbook.

The wider impacts of this project, although some years into the future and dependent on ongoing investment are exciting. This is especially true if the aligned outcomes of all the animal projects in LPP are considered together. With the right support a future can be envisaged where the grazing industry will operate with a level of precision seen in more intensive sectors, such as feedlot or dairy. Such a scenario is detailed below.

Evaluation and prediction of pasture quality and availability is automated based on NIR, faecal NIR, satellite imagery and weather augmented modelling. A revolutionised feeding standards will accurately predict the expected intake and nutrient requirements of individual animals within the *herd. On-animal and in-paddock sensors will measure and monitor pasture and animal performance in real time. Linked management applications will allow for timely interventions such as adjusting stocking rates or tactical supplementation to ensure individuals meet future specifications for markets. The results of such a future approach would be*

- *the end of overgrazing and pasture degradation,*
- *Feed quality and intake controlled to meet requirements along the growth curve,*
- *breeder condition exacted to requirements to wean a calf every year,*
- *uniform mobs of cattle presented for sale or transfer within the enterprise that meet buyer or receiver expectations every time,*
- *slaughter cattle hit the highest price on the grid with regularity.*

While such a scenario seems fanciful, it is the stretch goal for an industry looking to move beyond the status quo. These scenarios are commonplace in the intensive industries and better understanding of the animal/pasture interface plus digital solutions could make this a reality in the grazing sector.

8 Future research and recommendations

Much of this has been covered in Section 6. In this section we address the specific instructions. The failure of LPP2 to be supported is a challenge, however the following specific research project ideas are listed

- Further research into the long-term effects of methyl donors on productivity. Alternative funding options are currently being explored
- Evaluation of the intake algorithm under different grazing environments, with relevance to northern Australia
- Detailed studies on the effect of passage rate on feed intake in cattle grazing swards of differing physical and chemical characteristics and the influence on the rumen microbiome

8.1 Practical application of the project insights

Australia is one of the few developed countries with a beef industry based predominantly on grazing. The industry therefore, relies on the ongoing input of Australian research and development to ensure continuous improvement in productivity and sustainability. A large, coordinated program of research as undertaken in this project can provide the scope and scale of new knowledge to achieve real change. The understanding of the importance of measuring efficiency in the paddock will eventually usher in a new era of precision livestock management on pasture around the individual animal and the specific grazing conditions. It has been acknowledged that the science conducted in this project will need ongoing development and extension to reach its full potential.

The ultimate ability of the producer to monitor in the paddock, weight change and feed intake on a continuous basis will allow for ongoing optimisation of the animal/pasture interface. Precision management over time and around the individual animal could ensure that every animal met the right specifications for whatever market they are destined for. The predictive capability, based on past performance of both the animal and the pasture would allow for management interventions to hit specifications at exactly the right time. While this might sound fanciful today and this project will not answer all challenges around such a scenario, it is a major initial step.

Genetic selection in the beef sector is challenging compared other sectors. Breeding objectives can be obscure and there are unintended consequences of selecting around single traits. In the case of feed efficiency on pasture the goal is especially difficult as we cannot measure feed intake and therefore cannot select for feed efficiency. The alternative is to select for efficiency under controlled feeding conditions. In the absence of a direct method, selection for increased growth rate inadvertently results in higher mature weights and, presumably, higher intakes, not more efficient converters of feed to gain. The idea of selecting for pasture based efficiency in genetic improvement programs would have a long term immeasurable benefit to the industry.

8.2 Development and adoption activities

- Coordinated communication plan to increase awareness of factors affecting efficiency and productivity on pastures.
- Linked to a communication plan, a development and adoption plan that includes on-farm demonstration sites (PDS) on using on-animal and in-paddock sensors to optimise pasture availability and quality with animal production.

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10 Appendix

10.1 LPP Workshop Notes – Animal Theme – 31 May 2022

Ed Charmley and Lindsey Perry facilitating

LPP Achievements (whole group discussion)

1. Lansdown and Chiswick Field Days
    - Good to have outreach and updates on the pipeline of work coming through the system. Field Day useful for CSIRO and DPI
    - Connections and field site collaboration (CSIRO field site/ DPI connections)
    - Positive feedback
    - On farm site, good. Liked practical tools demo
    - Weakness – no take home messages
    - Solid background work ready for management change – e.g., Spring to Autumn lambing

2. All solid science and knowledge incorporated into tools –Horizon 2 research and needs further development before extending to industry
3. Integrated multifaceted solutions.
4. NIR a good example of research that will have impact
5. Future impact through integrating learnings from all projects
6. Australian advantage thought leader -what we are doing here is ahead of where the rest of the World is (example, the Feeding standards work)
7. If, could, when, need to describe impact and work back – the so what question.
8. Specific incremental benefits along the way as well as the big benefit at the end
9. Positive long-term approach – allowing science to happen on areas not of direct benefit – hard to do in small three-year projects
10. Improvement of tools -> industry benefit (e.g. SCA, measuring new phenotypes)
11. Adoption – identify typology of producers seeing value in the tools
12. How to incentivise people to use feed testing at scale to justify the research investment. Need clear benefit message
13. Need to develop prediction tools. Growth trajectory to hit market specs at specific time
14. Will offering more tools solve the problem?
15. Drought Feed Calc – Fantastic
16. GrazFeed is for advisors and consultants not farmers
17. Integration of tools into single framework (app) is the end game
18. North – supplement work - methyl donor what is the business case? Need to define
19. Combo projects – future
20. Potential for lifetime performance metrics that include efficiency and carcase specs

LPP Disadvantages Groups of 4 – Discussion groups

Group 1:

Things to improve

- UNE leadership not enthusiastically supported by other partners

- Needed time splits and allocations
- Comms acknowledgement of partners in broader press
- Clearer guidelines needed in some cases
- Greater flexibility for postdocs to ‘gravitate’ to organisations where they ‘fit’ or are supported
- Better through-project debrief and handover when staff turnover
- Contracts have an annual review milestone that could capture above
- Clearer guidelines around applied vs blue sky projects and subsequent deliverables
- MLA take responsibility for coordination of LPP
- Finding commercial partners.

Group 2.

- MDC does not work for CSIRO / smaller universities anymore
- Organise better from the start – adoption plan
- Clear goals and KPIs
- There were no LPP wide communication and information tools, website not known to most

Group 3

- Head agreements need to be organised
- Simplify contracts
- IP and freedom to undertake R&D
- Agreed templates
- Comms and engagement – not too late
- Could do better – next 12 months priority
- LPP workshops rely on traditional reporting too much, need discussion time built in
- Strategic discussions and review – possibility of pivoting
- LPP co-ordination roles – already discussed

Group 4

- Partnerships – collaborate not compete
- Post docs (succession)
- Linkages with others
- Expanded expertise and resources
- MLA – national outcomes – breakdown silos between feedbase -> carcase
- Researchers given free rein

LPP TOP 3 Areas for improvement were

- Adoption Planning
- Contracting with MLA / and inter party legal
- Project Co-ordination

Adoption Planning + Comms

- Connect program leaders to feedback mag/ comms
- Share findings with industry
- MLA press release
- Joining dots – big story
- Keep momentum
- Working towards on farm demos but not PDSs , Producer research sites?

- Collaboration, champions and consultants, focus farms, beefups, meatups, MLA adoption integration into materials – EDGE
- Identify key areas ready for integration –
- Scheme MLA integration – PGS integration
- LPP2 – Adoption pathway focus – needed even without LPP2

LPP Project co-ordination

- Define geographic and subject boundaries
- Lack of a clear, defined objective
- Need to be quicker off the mark
- Blue sky workshop pre-planning
- MLA – control
- Collaborative tools across projects
- CSIRO have sites – need to use more
- Co-ordination
- Regular focus on integration during workshops
- Identify gaps , what , who
- Funding pivots
- Opportunity to value add forage and animals – resources

Contracts/ LEGAL

- Already know where we need to get to
- Umbrella agreements are now in place

LPP - Future Priorities if there was a program

- Real concern that without more support the discoveries made to date will never reach adoption due to lack of ongoing development. Need to get from Horizon 2 to Horizion 1 (ready for market)

Success is:

- NIR work completed with end goal of rapid, accurate of pasture/feed evaluation
- E-Grazor collar and related IT solutions developed and picked up by private sector
- Feeding standards incorporated into electronic SCA 2030.
- Integration of NIR, feeding standards and monitoring technology into unified management tool
- Novel supplement lifts productivity in marginal country

10.2 Product Impact statement (taken from LPP program review final report)

Table H30: Key assumptions for the counterfactual scenario – P.PSH.1000 – novel supplement

Variable	Value	Source
Farm Area (Ha)	500,000	al (2014)
Carrying Capacity	27,955 AE	al (2014)
Weaning rate (%)	56%	al (2014)
Type and number of cattle sold annually	Cows 2+yo: 917 Steers/Heifers 2yo: 8,195 Bulls: 140	n data reported in Hunt et al (2014)
Average sale weights by type of stock sold (kg LW/Hd)	Cows/Heifers 2+yo: 380 Steers/Heifers 1-2yo: 350 Bulls: 600	n data reported in Hunt et al (2014)
Net sale value per Hd by type of cattle sold	Cows 2+yo: $674 Steers/Heifers 2yo: $1,058 Bulls: $1,661	Calculation based on the following assumptions: - 5 year average NLRS real price data utilized for North QLD cows/bulls, heifer and steer live export prices ex Darwin - Freight @ $30/hd for young stock, $40/hd for cows, and $45/hd bulls (Author estimate) - Commission @4% - Other selling costs @ $5/Hd for cows and bulls and$15/hd for other stock
Net cattle sales income ($/Ha)	$19.05	$674+8195*$1058+140*$1,661)/500,000
Bull replacement costs ($/Ha)	$1.68	Calculation based on the following assumptions: - Landed bull purchase cost per Hd $5,000 - Annual bull deaths @ 3% - Bulls purchased = 168 =($5,000*168)/500,000
Animal husbandry costs ($/Ha)	$1.97	Calculation based on the following assumptions - Animal husbandry costs of $35.24/AE (Bowen et al., 2019) - 0.06 AE/Ha (27,955AE/500,000 ha)
Gross Margin ($/Ha)	$15.40	5-$1.68-$1.97
Cost of production ($/kg LW produced)	$1.37	Calculation based on the following assumption:

Variable	Value	Source
		- Overhead and labour costs/Ha of $2.95 (5 yr average ABARES data for west/SW Qld) - ADG of 0.34 kg LW/hd for young stock (Hunt et al. (2014) - Total kg produced/Ha = 4.8 (0.34*365days*19,623 young growing stock p.a.)/500,000 ha +$1.97+$2.95)/4.8
Production /ha/100mm rainfall (kg LW)	1.2	=4.3kg LW per ha/350 mm long term av. Rainfall for Barkly/100

Impact

The benefits of adopting changes based on the expected outputs from project P.PSH.1000 will involve an increase in breeder reproductive rate and increased growth rates of young stock. The types of management interventions that might achieve these gains based on the research for this project have yet to be defined but will likely involve opportunities for improved supplementation of cattle to increase rumen efficiency and improved selection processes for identification of cattle with superior rumen efficiency. According to project researchers there is a high degree of uncertainty regarding timing and extent of adoption around selection for more efficient genotypes and a clearer path to adoption for the novel supplements element of project outputs. Thus, this assessment focusses on impacts associated with the latter as assumptions are more likely to reflect reality.

The scoping study by Hunt et al. (2014) involved analysis of the potential gains to northern beef herd profitability for a range of management interventions, one of which was improving rumen efficiency relative to a base case scenario across a range of northern beef regions. Modelling potential productivity gains due to improvement in rumen function were simulated by reducing the rate at which dry matter digestibility declined each month following pasture senescence. Instead of a 10% decline in digestibility per month, a monthly decay rate of 8% was used and the lower limit on digestibility was lifted by three percentage points from 45% to 48% digestibility. This modelled increase in pasture digestibility resulted in a 21% increase in growth rate of young stock and a 9% increase in calf weaning rate (Hunt et al., 2014). Initial data from project P.PSH.1000 has reported that calf growth rates from cows supplemented with RP methionine have to date been around 20% higher than the control group (project M4), which is consistent with the increase in growth rate modelled by Hunt et al. (2014).

Given that the type of interventions that may deliver the increases in rumen efficiency have yet to be clearly defined, for this analysis it has been assumed that the mechanism involves supplementation with new novel supplements as is being explored by project P.PSH.1000, at an estimated cost of $5-$10 per breeder per year. Once further data is available from the project the implementation costs associated with the recommended practice changes for producers generated from this project can be more accurately costed to updated the assessment of benefit.

The assumptions utilised for estimation of on-farm impact due to adoption of the outputs from this project are provided in Table H31.

Table H31: Key assumptions for impact – P.PSH.1000

Variable	Value	Source
Farm Area (Ha)	500,000	Hunt et al (2014)
Carrying Capacity	32,718 AE	Hunt et al (2014)
Weaning rate (%)	65%	Hunt et al (2014) representing a 9% increase in weaning rate over the base scenario
Type and number of cattle sold annually	Cows 2+yo: 934 Steers/Heifers 2yo: 9,934 Bulls: 143	Based on data reported in Hunt et al. (2014)
Average sale weights by type of stock sold (kg LW/Hd)	Cows 2+yo: 380 Steers/Heifers 2yo: 400 Bulls: 600	Hunt et al. (2014) and project M4 report
Net sale value per Hd by type of cattle sold	Cows 2yo+: $674 Steers/Heifers 2yo: $1,016 Bulls: $1,661	ion based on the following assumptions: - 5 year average NLRS real price data utilized for North QLD cow, heifer and steer slaughter markets - Freight @ $30/hd for young stock, $40/hd for cows, and $45/hd bulls (Author estimate) - Commission @4% - Other selling costs @ $5/Hd for cows and bulls and$15/hd for other stock
Net cattle sales income ($/Ha)	$21.92	$674+9934*$1016+143*$1,661)/500,000
Bull replacement costs ($/Ha)	$1.71	ion based on the following assumptions: - Landed bull purchase cost per Hd $5,000 - Annual bull deaths @ 3% = 1 - Bulls purchased = 171 0*171)/500,000
Animal husbandry costs ($/Ha)	$2.49	ion based on the following assumptions - Animal husbandry costs of $35.24/AE (Bowen et al., 2019) - Novel supplementation for breeders @ $5/Hd (author estimate in consultation with E. Charmley pers. comm.) - 0.7 AE/Ha (32,718AE/500,000 ha)
Gross Margin ($/Ha)	$17.72	2-$1.71-$2.49
Cost of production ($/kg LW produced)	$1.03	ion based on the following assumption: - Overhead and labour costs/Ha of $2.95 (5 yr average ABARES data for west/SW Qld) - ADG of 0.41 kg LW/hd for young stock (Hunt et al. (2014)

Variable	Value	Source
		- Total kg produced/Ha = 6.9 (0.41*365days*23,212 young growing stock p.a.)/500,000 ha +$2.49+$2.95)/6.9
Production /ha/100mm rainfall (kg LW)	2.0	=6.9kg LW per ha/350 mm long term av. Rainfall for Barkly/100

Thus, the estimated net benefits due to producer adoption of practice changes likely to be recommended from this project will be $17.72 subtract the base scenario gross margin per hectare of $15.40 = $2.32 per hectare (15% increase). Based on the estimated cost of production data, the decrease in cost of production per kg LW produced is calculated as 24% due to adoption (($1.37-$1.03)/$1.37). Estimated average increase in beef LW production per ha per 100mm rain is calculated as 43% ((2.0-1.4)/1.4). These calculations are only estimates at this point but once more data is available from the project, more accurate calculations will be able to be made.

Adoption

The target audience for outputs related to methyl supplementation from this project are cattle in northern NSW. It is estimated that the target potential number of cattle for this project output is around 2 million head (E. Charmley pers. comm.). At an estimated average stocking rate of 0.07 head/hectare, this represents approximately 28.5 million hectares. Project P.PSH.1000 involves conducting a survey of producers across northern NSW and south/central Queensland to provide estimates of the extent of nutrient deficiency in cattle in these areas, however this data has yet to be reported. In the interim, estimates provided by Sackett and Holmes (2006) have been utilized to represent the potential target audience for adoption within this total population. Sacket and Holmes noted that while all northern cattle were considered at risk from under-nutrition, only 30% of herds were considered to be actually suffering the effects of under-nutrition.

The pathway to adoption for this project will involve a combination of commercialization of potentially new novel supplements to enhance rumen function, improved/new genetic traits for inclusion in Breedplan and/or phenotypes built into genetic selection tools, and dissemination of information regarding improved cattle management and grazing strategies to producers. It is expected that pastoral companies will play an active role in developing and testing the outcomes of the project and facilitating rapid transfer of promising ideas to industry. It is intended that project outcomes will be disseminated via Beef Up forums, Friday Feedback, Australian Society of Animal Production, Northern Australia Beef Research Update, Beef Australia, and RBRC forums.

Given these types of awareness activities and potential adoption pathways, a conservative adoption rate of 20% of the target of area has been assumed. However, it is noted that if a deficiency area was dominated by large corporates, then the adoption rate could be much higher. More accurate estimates of adoption will be able to be made once the outputs from the project are more clearly defined, along with the adoption pathways and associated extension activities.

In the interim, Table H32 presents the key assumptions utilised for assessment of product adoption.

Table H32: Key assumptions for adoption – P.PSH.1000

Variable	Value	Source
Target area	28.5 million ha	Author estimate in consultation with E. Charmley
Percentage of target area which could benefit from adoption of project outcomes	30%	Author estimate based in information reported in Sackett and Holmes (2006)
Level of adoption among target audience	20%	Author estimate
Estimated area impact (ha)	1.7 mill ha	=28.5 mill*30%*20%
Adoption start year	2025/26	Author estimate based on project delivery timeline
Time to peak adoption	5 years	Author estimate
Dis-adoption rate	5% pa commencing 10 years post initial adoption	Author estimate to account for exits from the industry and substitution with new improved practices over time.

Table H33 provides the estimated number of hectares where management changes are adopted for each year of the analysis period.

Table H33: Estimated total units adopted per year – P.PSH.1000

YEAR	Area (Mill Ha)	YEAR	Area (Mill Ha)	YEAR	Area (Mill Ha)
2025/26	0.171	**2032/33**	1.714	**2039/40**	1.326
2026/27	0.514	**2033/34**	1.714	**2040/41**	1.260
2027/28	1.200	**2034/35**	1.714	**2041/42**	1.197
2028/29	1.543	**2035/36**	1.629	**2042/43**	1.137
2029/30	1.714	**2036/37**	1.547	**2043/44**	1.080
2030/31	1.714	**2037/38**	1.470	**2044/45**	1.026
2031/32	1.714	**2038/39**	1.396		